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Journal
Atmospheric Environment, 35(36)

ISSN
1352-2310

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Publication Date
2001-12-01

DOI
10.1016/S1352-2310(01)00429-0

PERGAMON

Atmospheric Environment 35 (2001) 6465–6477

ATMOSPHERIC ENVIRONMENT

www.elsevier.com/locate/atmosenv

A land use database and examples of biogenic isoprene emission estimates for the state of Texas, USA

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Received 9 January 2001; accepted 15 August 2001

Abstract

Using data from a variety of sources, land use and vegetation in Texas were mapped with a spatial resolution of approximately 1 km. Over 600 classifications were used to characterize the land use and land cover throughout the state and field surveys were performed to assign leaf biomass densities, by species, to the land cover classifications. The total leaf biomass densities associated with these land use classifications ranged from 0 to 556 g/m^2, with the highest assigned total and oak leaf biomass densities located in central and eastern Texas. The land cover data were used as input to a biogenic emissions model, GLOBEIS2. Estimates of biogenic emissions of isoprene based on GLOBEIS2 and the new land cover data showed significant differences when compared to biogenic isoprene emissions estimated using previous land cover data and emission estimation procedures. For example, for one typical domain in eastern Texas, total daily isoprene emissions increased by 38% with the new modeling tools. These results may ultimately affect the way in which ozone and other photochemical pollutants are modeled and evaluated in the state of Texas.

Keywords: Biogenic emissions; Texas; Land cover; Isoprene

1. Introduction

The state of Texas has several urban areas that fail to meet the National Ambient Air Quality Standards for ozone, including the Houston/Galveston, Beaumont/Port Arthur and Dallas/Ft. Worth metropolitan areas. Numerous other urban areas within the state are considered 'near non-attainment' regions and have come close to exceeding, or have recently exceeded, the standards. Further, both photochemical modeling and ambient observations indicate that elevated atmospheric ozone concentrations are not limited to the urban areas, but also extend throughout the eastern half of the State of Texas, including rural areas (for more information, refer to http://www. tnrcc. state. tx. us).

Much of Eastern and Central Texas contains significant amounts of vegetation and forests. This vegetation may be the source of substantial emissions of biogenic volatile organic compounds (BVOCs), which, when mixed with nitrogen oxides from anthropogenic sources, can lead to ozone formation in rural areas (e.g. Fehsenfeld et al., 1992; Guenther et al., 2000).

To accurately model ozone formation throughout Texas, reasonable BVOC emission estimations are

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1352-2310/01/$ - see front matter
PII: S1352-2310(01)00429-0

required. The biogenic emission estimates depend on many factors, primarily the types of vegetation species located throughout the region, as well as the densities of these species. This paper will present a composite land use database that includes a mapping of groundcover for the state of Texas. The database also includes a description of the vegetation species distributions and densities for each land use classification that describe the landcover. These data have been acquired from several projects in smaller regions throughout the state and extrapolated to remaining areas of the state. The new landcover database has been used in conjunction with GLObal Biogenic Emissions and Interactions System version 2 (GLOBEIS2). Daily isoprene emission estimates calculated with the new Texas land use data and GLOBEIS2 are presented, and are shown to be substantially different than the emission estimates derived from previous landcover databases.

2. Methodology

Previously available land use data used to predict biogenic emissions in Texas have been found to contain inaccurate information about the distribution of vegetation in much of the state (Wiedinmyer et al., 2000). Therefore, it has been a goal of the state of Texas to create more accurate land use mappings for the purpose of estimating reasonable BVOC emissions inventories for photochemical models. With this goal in mind, a composite land use and vegetation database of Texas was created. These data were compiled from a collection of smaller study databases for study regions throughout central and eastern Texas, and extrapolated to the western half of the state. The information for all areas within Texas was normalized and joined with the use of geographical information systems (GIS) to create one comprehensive map and database. The resulting landcover database was used to estimate biogenic emissions throughout Texas using GLOBEIS2. The following sections provide data on the land use and landcover inventory, the merging of landcover data, and the biogenic emission modeling.

2.1. Land use inventory: Eastern and Central Texas

Land use and vegetation databases were created for several study regions throughout Central and Eastern Texas, as shown in Fig. 1. Wiedinmyer et al. (2000) discuss in detail the specific methodologies applied to create these land use inventories. Only a brief summary is presented here.

The first task for each region was to make a mapping of the land cover with a spatial resolution of approximately 1 km. This process included the identification and evaluation of digital databases (see Wiedinmyer et al., 2000). The rural areas in each study region were assigned land use classifications determined by the Texas Parks and Wildlife Department (TP&WD). The TP&WD has compiled a mapping of the vegetation communities specific to the state from satellite imagery and studies at the ground level. This dataset was determined to be the most specific for the region of study and the most applicable for the estimates of biogenic emissions.

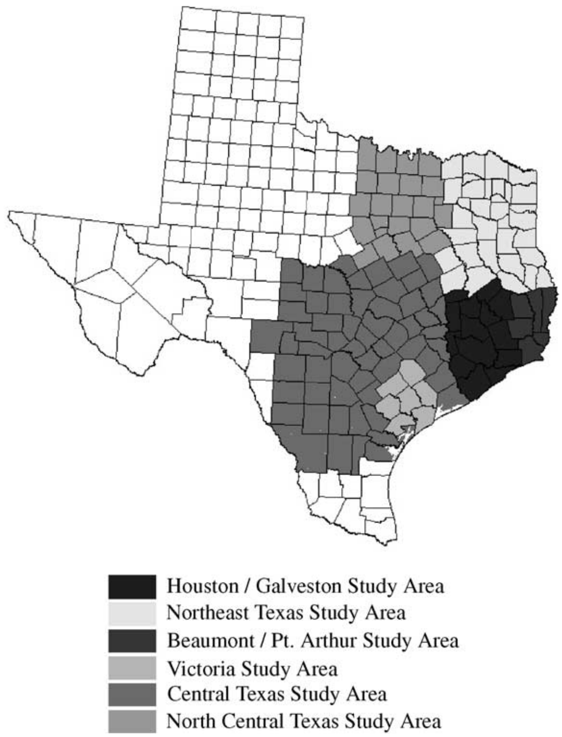

Fig. 1. Regional project domains in Eastern and Central Texas.

Specific land use categories were desired to achieve better resolution in the urban areas. Urban land use maps were obtained from available datasets provided by both public and private organizations. If no more recent urban land use data were available, the USGS Land Use and Land Cover (LULC) database was applied to provide spatially resolved urban land use classifications. For instance, no recent land use data were available for the city of San Antonio. Therefore, the urban land use classifications of the USGS LULC were applied to describe this urban area. Table 1 presents a summary of land use and vegetation data that were applied to the Eastern and Central Texas study areas. Additional details are available in Wiedinmyer (1999).

The next step in the process of creating a land use database applicable for estimating biogenic emissions was to determine species distributions and leaf biomass densities to be associated with each land use

Table 1
Land use and vegetation data used to create a composite Texas land use and land cover database

Coverage	Source	Scale	Last update
USGS Land Use Land Cover	USGS http://edcwww.cr.usgs.gov/glis/hyper/guide/1_250_lulc	300 m	1974–76
Texas Parks and Wildlife Department Database	TP and WD ftp://204.64.181.202/pub/GIS/vegetation/http://www.tpwd.state.tx.us/frames/admin/veg/	30 m	1984
USGS Land Cover Characteristics (LCC)	USGS http://edcwww.cr.usgs.gov/landdaac/glcc/na_int.html	1 km	1993
USDA National Resources Inventory (NRI)	Texas headQuarters, Temple, TX Mikki Yoder http://www.tx.nrcs.usda.gov/nri/nri.html	County	1996
USDA-National Agricultural Statistics Service (NASS)	USDA http://www.usda.gov/nass/nassinfo/nassinfo.html	County	1996
Texas Agricultural Statistics Service (TASS)	Headquarters in Austin, Texas http://www.io.com/~tass/	County	1996
City of Austin Land Use Database	City of Austin http://www.ci.austin.tx.us/landuse/	Derived from 30 m	1990
Turner, Collie, and Braden Inc. Land Use Data for Houston	Turner, Collie and Braden, Inc. Houston, Texas	Derived from 30 m	1992
City of Victoria Department of Planning Land Use	City of Victoria Department of Planning	Parcel level	1995
North Central Council of Governments (NCTCOG) Land Use Land Cover	NCTCOG	Derived from 30 m	1990

classification. This information was collected during a series of field studies that took place throughout Central and Eastern Texas between 1997 and 99. Wiedinmyer et al. (2000) provides detailed information about the survey methodology. In rural land use classifications, survey transects of areas from 1000 to 2000 m^2 in representative vegetation were inspected. These areas were divided into 100 m^2 plots, and information on the species and trunk diameter of all trees with diameters greater than 4 cm in these plots was collected. Land cover classifications with the highest tree density or those with the highest density of *Quercus* (Oak) trees took priority for these field surveys, since these classifications are expected to emit the most biogenic emissions. Fig. 2 shows the locations of the field surveys performed in forested areas, and Table 2 summarizes these survey classifications. Urban land use classifications in Dallas/Ft. Worth, Houston/Galveston, Beaumont/Pt. Arthur, Austin and Victoria were surveyed by automobile, and tree size and species distribution data were collected.

The information collected during the field surveys was used to calculate the biomass density (g leaf mass/m^2 ground area) for each species in each land use classification, following the empirical relationships suggested by Geron et al. (1994). For those land use classifications in which no surveys were performed, species lists and densities were determined from the information gathered in surrounding land use classifications, from visual observations made in the field and from qualitative descriptions provided for each land use classification by the TP&WD.

The TP&WD provided only one land use classification denoted as "Cropland. " Additionally, the TP&WD vegetation database contained a land use classification labeled "Other [Grasslands]". Visual observations made in the field indicated that these areas contained not only grasslands and croplands, but also rangeland and clusters of forest. To provide better descriptions of the land use in these areas, the TP&WD landcover assignments for "Cropland" and "Other" classifications were refined using USGS data for each county. USGS Land Cover Characteristics (LCC) data with the North America Seasonal Land Cover Regions Legend were digitally laid over areas designated as "Cropland" or "Other" by the TP&WD database. The USGS LCC data are based on 1-km AVHRR data spanning April 1992 through March 1993, and therefore have 1-km nominal spatial resolution. The North America Seasonal Land Cover Regions Legend uses 202 land use classifications. For the TP&WD polygons with areas of greater than 1 km^2 and only the "Cropland" or "Other" designations, the LCC data provided more information about the plant communities in these areas and better spatial resolution. The many USGS LCC classifications assigned were simplified and grouped

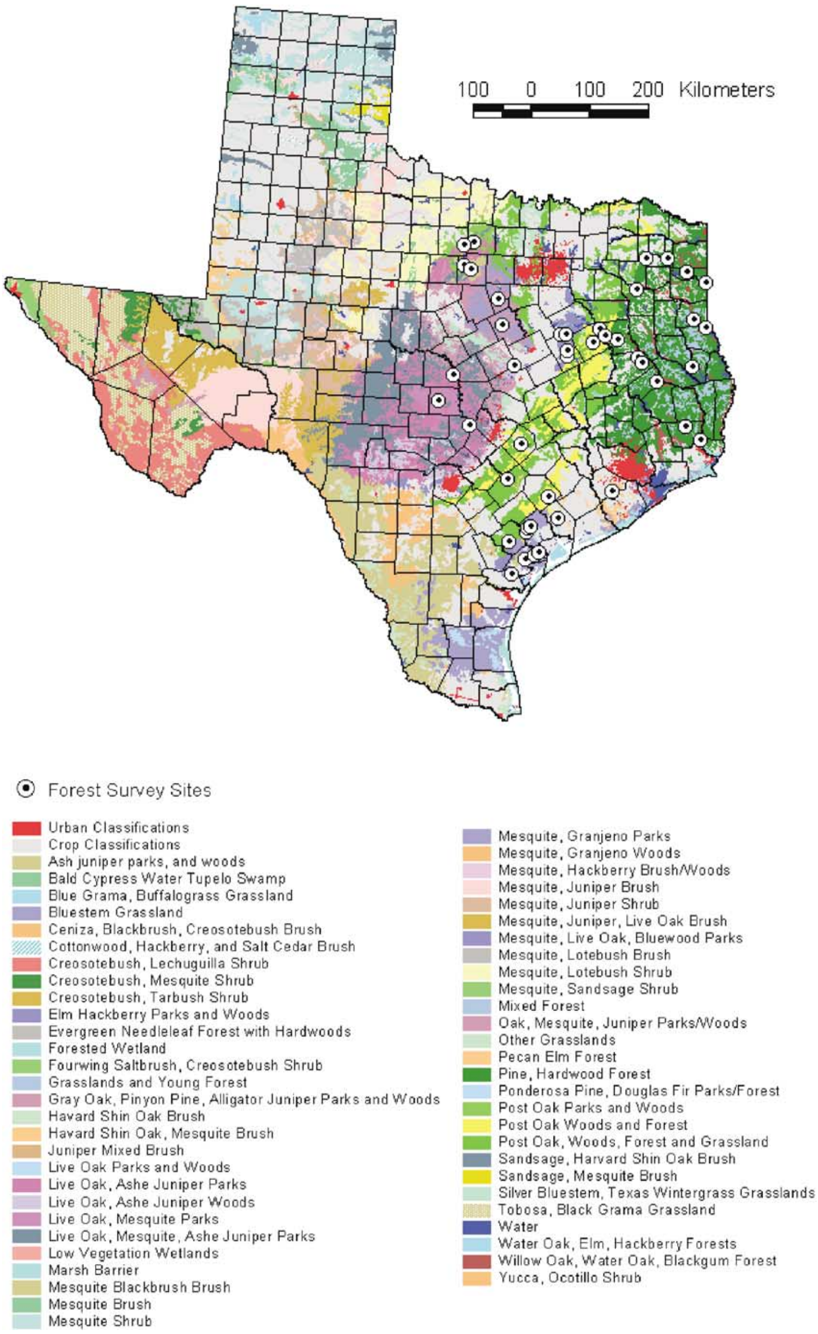

Fig. 2. Map of all rural land use classifications assigned to the state of Texas. The locations of the field survey sites performed in forested areas between 1997 and 99 are shown.

into six general categories by county. The resulting classifications assigned in the areas designated as cropland were 'Cropland with Grassland', 'Cropland with Woodlands', 'Cropland with Wetlands', 'Cropland with Deciduous Forest', 'LCC Rangeland', and 'LCC Woods', Table 3 shows an example of this methodology for Milam County in Central Texas. The sixth category, 'Cropland with Deciduous Forest', is not shown in Table 3 because it was not assigned in Milam County.

Some areas within the TP&WD crop classifications were designated as wooded areas by the LCC database.

Table 2
Survey information for the major land use classifications assigned to Central and Eastern Texas. Also included is the average Oak area assigned to each of these classifications and the area percent that each of these classes is assigned to the entire state

TP and WD classification	# Of surveys performed	Average Oak coverage (m^2 Oak cover/m^2 ground area)	Percent area assigned in Texas
Pine and Hardwood Forests	19	0.19	6.16
Post Oak Woods and Forests	10	0.40	1.99
Post Oak Woods, Forests and Grasslands	7	0.25	4.79
Oak, Mesquite and Juniper Parks and Woods	6	0.17	6.25
Willow Oak, Water Oak and Blackgum Forests; Water Oak, Elm and Hackberry Forests	4	0.45	0.87
Ash Juniper Parks and Woods	4	0.13	0.15
Marsh Barrier	4	0.00	0.63
Pecan and Elm Forests	3	0.27	0.34
Live Oak and Mesquite Parks	3	0.20	0.56
Bluestem Grassland	3	0.06	1.50
Grassland and Young Forests	3	0.00	1.11
Post Oak Parks and Woods	2	0.61	0.51
Elm and Hackberry Forests	2	0.60	0.40
Bald Cypress and Water Tupelo Swamps	2	0.34	0.03
Live Oak and Ash Juniper Woods	2	0.12	0.89
Mesquite and Blackbrush Brush	2	0.09	4.47
Live Oak and Ash Juniper Parks	2	0.02	2.91
Mesquite, Live Oak and Bluewood Parks	1	0.12	0.29
Silver-Bluestem-Texas Wintergrass Grasslands	0	0.14	0.86
Live Oak Woods and Parks	0	0.07	0.23
Mesquite and Juniper Shrub	0	0.06	0.92
Mesquite, Juniper and Live Oak Brush	0	0.06	0.04
Mesquite and Granjeno Parks	0	0.02	1.47
Mesquite Brush	0	0.00	1.47
Mesquite-Lotebush Brush	0	0.00	1.37
Cenzia, Blackbrush and Creosotebrush Brush	0	0.00	0.59
Cottonwood-Hackberry-Salt cedar Brush/Woods	0	0.00	0.32
Blue Gramma and Buffalograss Grasslands	0	0.00	0.00

In these cases, the "wooded" areas are very small relative to the area of TP&WD forest categories. For these county-level LCC wooded areas, leaf biomass densities and species distributions were assigned to each county LCC "woods" classification using the results of the nearest TP&WD forest classification.

Biomass estimates for the cropland categories were completed using information obtained from the USDA's National Agricultural Statistics Service (NASS) database, county extension agents, and surrounding TP&WD vegetation classifications. Data that included the amount of hay planted and harvested in each county were acquired from the National Resources Inventory (NRI) produced by the USDA Natural Resource Conservation Service (NRCS) and from the Texas Agricultural Statistics Service (TASS) (available on the World Wide Web at http://www.io.com/~tass/). County-level crop area fractions were determined from the NASS and TASS data. The speciated crop areas obtained from these sources were distributed uniformly throughout each of the county-level LCC crop classifications. Any remaining area within the LCC crops with grass, crops with wetlands, or crops with woods classifications was assigned as grasslands, wetlands, or a forest distribution based on the nearby TP&WD forest assignments, respectively. The 'LCC Woods' classification in each county was assigned the species distribution of the nearest TP&WD forest classification. The 'LCC Rangeland' classification was assigned the species distribution of the nearest TP&WD forest classification and a total leaf biomass density associated with a rangeland area.

2.2. Land use inventory: West Texas

A biogenic land cover database was developed for the remaining, primarily western, counties of Texas. Digital maps of land use and vegetation classifications for the western counties were developed using the TP&WD map as the primary dataset. Similar to those classifications located in Central and Eastern Texas, the cropland classification was separated into individual counties

Table 3
Example land use assignments for LCC data within Milam County's TP & WD "Crop" and "Other" areas

Milam County crop/ other LCC categories	Assigned categories
Cropland (Small Grains, Hay, Pasture) with Wetlands	Cropland with Wetlands
Cropland (Cultivated Grasses) with Woodland	Cropland with Woodland
Cropland (Corn, Soybeans, Cotton rice) with Woodland	Cropland with Woodland
Cropland (Corn, Sorghum, Small Grains)/Grassland Mosaic	Cropland with Grassland
Cropland/Grassland	Cropland with Grassland
Cropland (Corn, Cotton, Sorghum, Pasture)/Grassland Mosaic	Cropland with Grassland
Grassland with Cropland (Small Grains, Pasture)	Cropland with Grassland
Grassland with Cropland	Cropland with Grassland
Savanna	LCC Rangeland
Mixed Rangeland (Shrubs and Grasses)	LCC Rangeland
Grassland/Woodland (Oak) Mosaic with Cropland	Cropland with Woodland
Needleleaf Forest (Sitka Spruce, Western Hemlock)	LCC Woods
Evergreen Needleleaf Forest (Longleaf, Slash Pine)	LCC Woods

using *Arc/INFO*. Unique biomass density values were developed and assigned to each county's specific crop distribution. The biomass density data for cropland areas were developed using USDA NASS data, the TASS data, and NRI data from the USDA NRCS. In West and Central Texas, data for acres planted was available for all crops except hay. Hay was reported as acres harvested. Similar "grass-like" crops in this region had a harvested to planted fraction of 0.55. This number was estimated based on information and advice provided by interviewed agriculture extension agents in West Texas. Therefore, the acres of hay planted were estimated from the reported acres of hay harvested by multiplying by two.

Table 4 lists the forest classifications assigned in Western Texas. Since this region of the state does not include many heavily forested areas, and contains few emitting tree species, no field surveys were conducted in western Texas. However, several of the West Texas vegetation classifications have been surveyed as part of other study domains. The results from previous studies in Eastern Texas were applied to the repeated classifications in West Texas. Those classifications for which no field data were available were assigned a species distribution based on vegetation lists provided using detailed TP&WD category descriptions (available on the World Wide Web at http://www. tpwd. state. tx. us/ frames/admin/veg/), data extrapolated from Central

Table 4
Land use classifications assigned in Western Texas

Ashe Juniper Parks and Woods	Mesquite-Hackberry Brush and Woods
Blue Grama-Buffalo Grass Grasslands	Mesquite-Juniper Brush
Bluestem Grasslands	Mesquite-Juniper-Live Oak Brush
Ceniza-Blackbrush-Cresotebush Brush	Mesquite-Juniper Shrub
Cottonwood-Hackberry-Salt Cedar Brush	Mesquite-Lotebush Brush
Creosotebush-Lechuguilla Shrub	Mesquite-Lotebush Shrub
Creosotebush-Mesquite Shrub	Mesquite-Salt Cedar Brush and Woods
Creosotebush-Tarbush Shrub	Mesquite-Sandsage Shrub
Fourwing Saltbush-Creosotebush Shrub	Mesquite Shrub
Gray oak-Pinyon Pine-Alligator Juniper Parks and Woods	Oak-Mesquite-Juniper Parks and Woods
	Other
Harvard Shin Oak Brush	Ponderosa Pine-Douglas Fir Parks and Forests
Harvard Shin oak-Mesquite Brush	Post Oak Parks and Woods
Juniper-Mixed Brush	Sandsage-Harvard Shin Oak Brush
Live Oak Woods and Parks	Sandsage-Mesquite Brush
Live Oak-Ashe Juniper Parks	Silver, Bluestem and Texas Wintergrass Grassland
Live Oak-Ashe Juniper Woods	Tobosa-Black Grama Grasslands
Live Oak-Mesquite-Ashe Juniper Parks	Urban-Abilene
Marsh Barrier	Urban-Amarillo
Mesquite-Blackbush Brush	Urban-El Paso
Mesquite Brush	Urban-Lubbock
Mesquite-Granjeno Parks	West Texas Urban
Mesquite-Granjeno Woods	Yucca-Octillo Shrub

and Eastern Texas studies, and field experience-based judgment.

There were several urban areas described by the TP&WD data for Western Texas. Unique USGS LULC codes and biomass densities were given to the urban areas of El Paso, Lubbock, Abilene, and Amarillo. Remaining urban areas in West Texas were given the same classification ("Urban"). The urban areas in West Texas were assigned species distributions of the vegetation classifications surrounding the urban areas scaled to a total leaf biomass density of 25 g/m^2.

2.3. Merging of land use data

The digital maps containing the land use classifications for each study region in Central and Eastern Texas, and the Western Texas mapping were joined with the use of Arc/Info and and projected in UTM 15 coordinates. One final land cover mapping, containing the data from the databases described above, was created. The LULC data for the domain was gridded to a scale of 0.25 km to remove any slivers of 'no data' produced during the process of joining the study regions together in the GIS. Fig. 2 shows the complete mapping of rural land use classifications assigned to state of Texas. The final digital GIS information is available from the authors.

The urban areas of Dallas/Ft. Worth, Houston/Galveston, Beaumont/Pt. Arthur, Austin, San Antonio and Victoria contain specific land use mappings. For example, Fig. 3 shows a magnified view of Houston, with the detailed land cover assignments.

Each land use classification in the Texas land use mapping was assigned a five-digit code. These codes were assigned to the land use classifications according to the type of land use it described (e.g. cropland, urban and forested). Over 600 land use codes are applied to describe the land cover throughout Texas. These land use codes, the biomass densities assigned to each code and the species distribution for each code is available in Wiedinmyer (1999).

2.4. Biogenic emission modeling

Foliar emissions of VOC were estimated by GLOBEIS2 as

$$\text{Emission} = [\varepsilon][D_p D_f][\gamma_e \gamma_a] \quad (1)$$

where ε is a landscape average emission capacity, D_p is the annual peak foliar density, D_f is the fraction of foliage present at a particular time of year, γ_e is an emission activity factor that accounts for the influence of environmental conditions (light and temperature) and γ_a is an emission activity factor that accounts for leaf age. The main components of GLOBEIS2 include (1) procedures for processing model inputs, (2) a canopy environment model, (3) algorithms for calculating each variable in Eq. (1), and (4) procedures used to summarize emission estimates and generate output in the required format. Landcover characteristics (ε and D_p) are fixed for each model run while D_f and γ_a vary with a monthly time step and γ_e varies with an hourly time step.

GLOBEIS2 uses Microsoft ACCESS as a database manager and embedded Visual Basic code for emission calculation and it contains a number of user-friendly interfaces and error checking modules. It is available at no cost for downloading at http://www.globeis. com. The user is provided with several options for calculating emissions. One set of options enables GLOBEIS2 to duplicate the procedures used by the BEIS2 model, which is also available at no cost for downloading at http://www.epa.gov/ttn/chief/software. html. For all of the modeling discussed in this manuscript, we have used the same genera-level emission factors and foliage characteristics (Leaf area index and foliar density) that are used in BEIS2 (Geron et al., 1994). The landscape average emission factor was based on the landcover characteristics including total foliar density and species composition. Alternative procedures for emission algorithms and canopy environment modeling were also used and are described below.

The GLOBEIS2 input capabilities represent several improvements over BEIS2 methods. An option is the ability to generate user-defined landcover classes with user specified emission factors and foliar densities. The input options are accompanied by data entry tools that facilitate the use of the options. GLOBEIS2 also provides error checking to determine if inputs are consistent.

GLOBEIS2 corrects several minor problems with the BEIS and BEIS2 code dealing with solar angle calculations and specifying canopy extinction coefficients. An error in the BEIS solar angle calculation was traced to an error in the equation given by the original reference (T. Pierce, personal communication). Additional features are the ability to vary foliar density by season (the factor D_f in Eq. (1)) and to estimate the impact of foliage age on isoprene emission (the factor γ_a in Eq. (1)) using the methods described by Guenther et al. (1999, 2000). GLOBEIS2 also allows the user the option of selecting the light and temperature dependence algorithms of Guenther et al. (1999) rather than the Guenther et al. (1993) algorithm that is used by most models (e.g., BEIS2). The Guenther et al. (1999) temperature dependence algorithm adds the capability to account for the influence of the temperature of the past several days as well as the current temperature. The light dependence model of Guenther et al. (1999) recognizes that leaves in the lower potion of the canopy have a lower emission capacity than those near the top. GLOBEIS2 also allows the use of the leaf age algorithm of Guenther et al. (1999) as an option. This algorithm

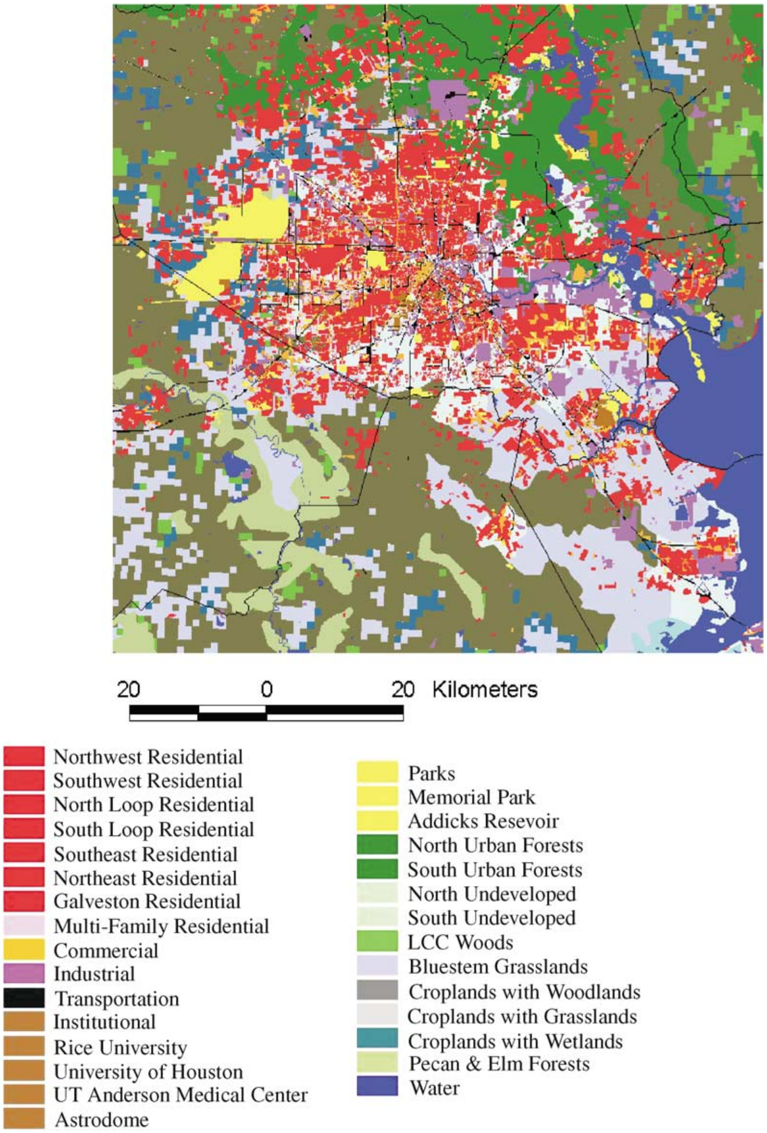

Fig. 3. A magnified view of the land use mapping for the Houston metro area.

assumes that old leaves have a lower emission capacity, and estimates the fraction of young and old leaves present at any given time based on changes in the leaf area index determined from satellite observations.

GLOBEIS2 allowed the option of using the BEIS2 canopy environment model (Geron et al., 1994), along with the ability to change the extinction coefficient used with this model, or the canopy environment model described by Leuning et al. (1995). The Leuning et al. (1995) model is more realistic than the simple model used for BEIS2. The major difference is that that the BEIS2 model overpredicts the amount of sunlight that reaches the lower levels of the canopy. A more realistic result can also be obtained by using the BEIS2 canopy light model with a different extinction coefficient.

A variety of summary reports and output options are available with GLOBEIS2. This includes the ability to specify the chemical composition of VOC categories (e.g., monoterpenes or other VOC) and calculate speciated emissions for individual compounds or for desired categories (e.g., for the VOC categories used for the carbon bond IV chemical mechanism).

The landuse categories assigned by the new land use database for Texas, and their respective tree species and biomass densities, are located in tables within GLOBEIS2. Other land use categories to describe other areas can easily be imported to the program. Emission factors are based on tree genus (and species if data are available), and calculated for each land use category based on the biomass density of each species assigned to each category. These results are used to calculate the biogenic emissions for a given domain area.

3. Results

A digital map of land use and vegetation was compiled for the state of Texas. Over 600 classifications have been assigned to describe the land use and land cover throughout Texas. These are specific to the state and have a resolution of approximately 1 km. A mapping of the land use classifications assigned in Texas and their spatial resolution throughout the state is shown in Fig. 2. The urban areas of Eastern Texas have been assigned digital maps with land use classifications specific for Houston/Galveston, Beaumont/Port Arthur, Dallas/Ft. Worth, Austin, San Antonio and Victoria (for example, see Fig. 3). Each land use classification of the database is allocated a list of tree species and an associated biomass density. The total leaf biomass densities associated with each of these land use classifications ranged from 0 to 556 g/m^2. The classifications with the highest assigned total and oak leaf biomass density are located in Central and Eastern Texas. Therefore, it is from these areas that the highest BVOC emissions would be expected.

The new land use data identify many of the areas within Texas to have more dense forests or higher numbers of emitting species (particularly *Quercus* [Oak]) in places that had previously been assigned little to no vegetation. This is illustrated in Fig. 4, which shows the percent forest and Oak assigned to the state of Texas by

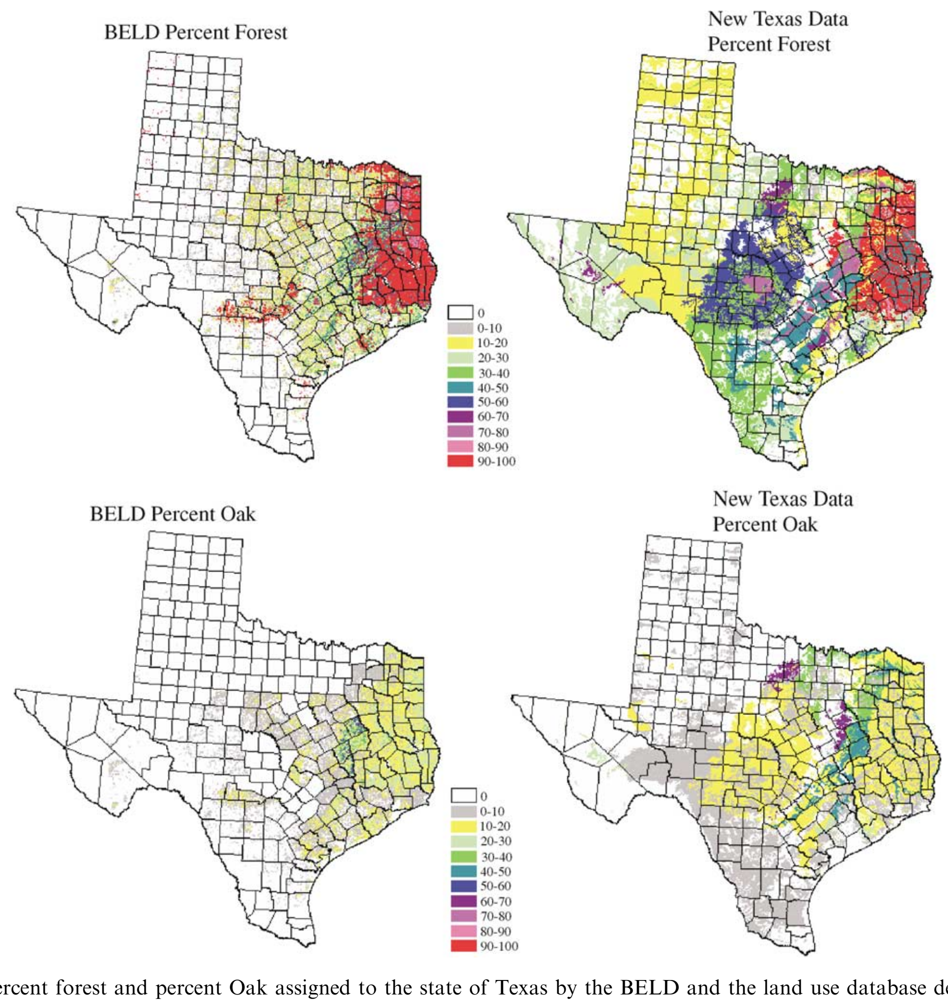

Fig. 4. The percent forest and percent Oak assigned to the state of Texas by the BELD and the land use database described in this paper. The differences in the density assignments can be interpreted as differences in estimated biogenic emissions.

the new land use dataset described in this paper and by Version 3 of the Biogenic Emissions Landuse Database (BELD) (Kinnee et al., 1997). The BELD is a constantly evolving dataset, currently in its third edition, developed by the USEPA, and has been used for prior modeling efforts in Texas. The primary source of data for the BELD in the eastern United States is the US Forest Service's Forest Inventory Analysis (FIA). The FIA data contain extensive information about forest density and species distribution in areas with commercially valuable forest. Since Texas only contains commercially valuable forests in its easternmost counties, the FIA, and therefore, the BELD, are spatially accurate only in Eastern Texas. The BELD contains county- and genus-level vegetation assignments that are not specific for, nor continuous in, Texas.

As Fig. 4 illustrates, there is relatively good agreement between the BELD and the new Texas land use dataset in the eastern part of the state. The continuity of the percent forest assigned by the BELD in the surrounding states to the north and east (specifically, Louisiana) with the new dataset in Eastern Texas is relatively smooth. However, the new land use dataset predicts denser forests with higher concentrations of Oak trees in Central Texas. This directly translates into differences in the amount of BVOC emissions predicted with the two datasets in this region of the state. Therefore, Fig. 4 can be interpreted as the relative spatial and quantitative differences in emissions that biogenic emission models predict with the two datasets.

Statewide, the new Texas land use dataset increased the area assigned as forest in the state by 88% and the Oak area coverage by 110% from the BELD data. Although the BELD provides a 1 km resolution mapping, the vegetation information is still at a county level. Therefore, there is a lack of continuity in the Oak area assigned within the state (Fig. 4). The new land use data eliminates these discontinuities.

The spatially allocated vegetation data were used as inputs to GLOBEIS2. The state of Texas has estimated speciated and total BVOC emissions for several different regional modeling domains and episodes using these tools. These results can be compared to those of past modeling efforts that used different models, emission factors and land use data. For example, Figs. 5 and 6 show the total daily isoprene emissions (tons/day) predicted for a Texas regional model ($16\,km \times 16\,km$ grid cell size) using different land use data and biogenic emission models. Fig. 5 shows the daily total isoprene emissions estimated using Version 2 of the BELD (BELD2) and the Biogenic Emissions Inventory System, version 2 (BEIS2) (Geron et al., 1994) for 10 September 1993. The total daily isoprene emissions estimated for the same modeling domain and day by GLOBEIS2 with the new Texas land use data are illustrated in Fig. 6. The total daily isoprene emissions for the modeling domain is increased by 38% with the new modeling tools, and particular increases in emission estimates occur throughout Central and North-central Texas. These regions have increased emission estimates due to the assignment of Oak trees that are not recognized by the BELD2. Region-wide, the new emission estimates have better spatial resolution because of the improved resolution in the land use data compared to BELD2 (which has county-level vegetation data). The peak isoprene emissions occur between 13:00 and 15:00 local time for both model simulations, but GLOBEIS2 simulates a faster rate of decrease in isoprene emissions after 15:00. This could be the result of improvements in the way that GLOBEIS2 deals with solar angle calculations and specifying canopy extinction coefficients.

In the southeastern region of Texas (see the Houston/Galveston study region in Fig. 1), GLOBEIS2-calculated emissions of total hydrocarbons decreased by 265 tons/day in eight counties in Southeastern Texas, compared to the emissions calculated with the BIOME model (Radian Corporation, 1996), using BEIS2 emission factors. This is a decrease of 18% in total estimated hydrocarbon emissions for a very sensitive region in Texas. This result is consistent with the change in canopy model algorithms between GLOBEIS2 and BIOME. GLOBEIS2 will predict sharp decreases in VOC emissions in areas with dense forest since the new model simulates sunlight penetration of the canopy more accurately than the BIOME model, by more strongly attenuating the light that reaches the lower portions of the forest canopy. The BIOME and BEIS2 models allow too much sunlight to enter the canopy, and thus overestimate emissions from leaves in the lowest layers. Correction of this error leads to significant decreases in emission estimates in areas with plentiful vegetation.

The uncertainties in creating a new land use database can be very large and difficult to quantify. A detailed analysis of the uncertainty associated with the survey methods used to create the Texas land use database is discussed by Wiedinmyer et al. (2000). Unfortunately, a quantitative examination of the assignment of vegetation species density and spatial distribution throughout the state is not possible. However, it is estimated that the methodology of determining vegetation biomass densities (through the selection of field survey sites and the calculation of leaf biomass densities) can lead to a factor of 2 or more uncertainty in the resulting biogenic emission estimation. Other uncertainties in the estimation of the biogenic hydrocarbon emissions are associated with the meteorological data and estimation, the emission factors and the canopy model within GLOBEIS2. Despite the potential for significant uncertainties, the isoprene fluxes predicted based on the new land use data are consistent with field measurements of fluxes in Central Texas (Wiedinmyer et al., 2001). Future

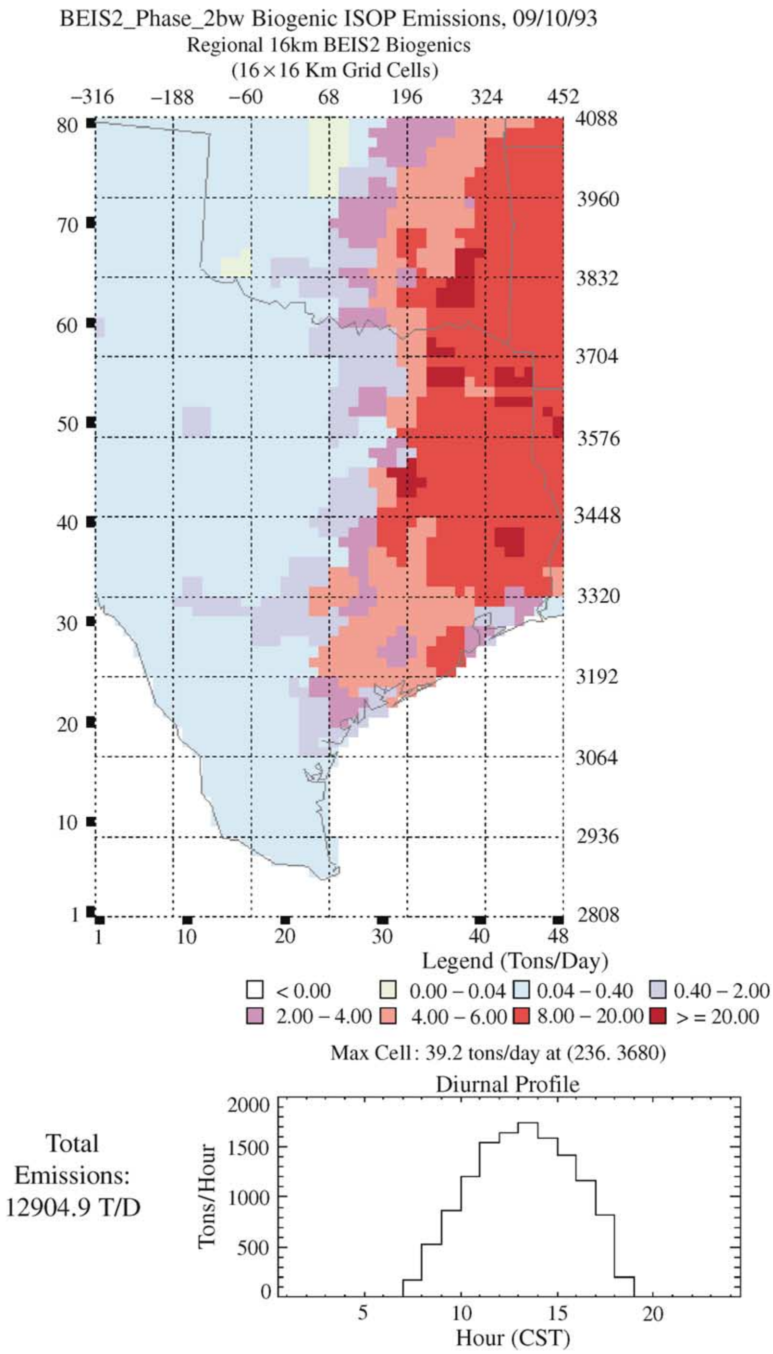

Fig. 5. Daily isoprene emission estimates for a Texas regional modeling domain (16 km × 16 km grid cell size) for 10 September 1993. The estimates presented in this figure were simulated with the BEIS2 model and the BELD2. The diurnal profile of the emissions for the domain is shown.

papers will use aircraft measurements of isoprene concentrations, collected in Texas during the summer of 2000, to evaluate the accuracy of the predicted spatial distribution of isoprene emissions.

4. Conclusions

A new land use database was created for the state of Texas. This dataset includes a mapping of

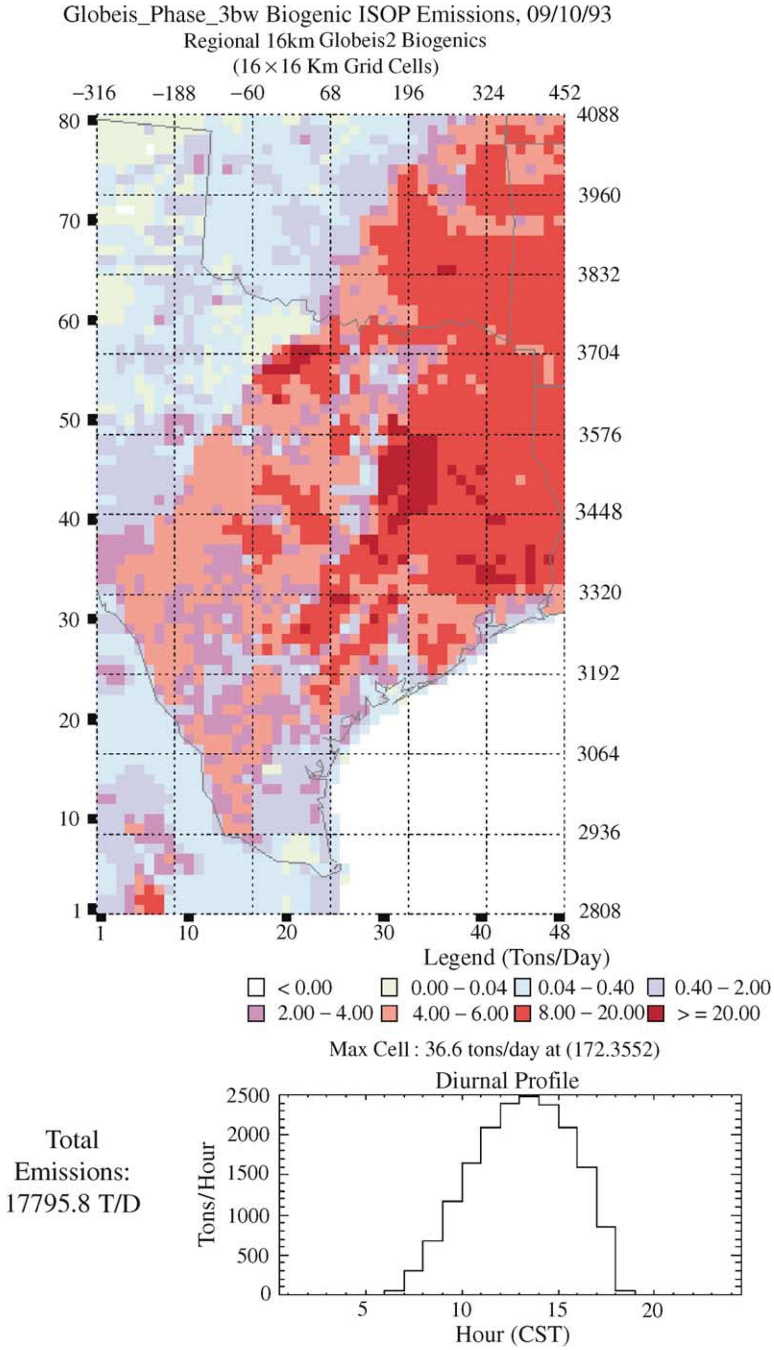

Fig. 6. Daily isoprene emission estimates for a Texas regional modeling domain (16 km × 16 km grid cell size) for 10 September 1993. The estimates presented in this figure were simulated with GLOBEIS2 and the new Texas land use data. The diurnal profile of the emissions for the domain is shown.

classifications assigned to describe the land use and land cover throughout the state. Each classification has been assigned a vegetation species distribution and density. This information has been used to as an input to an improved biogenic emissions model, GLOBEIS2, which was created to calculate more accurate emission estimates. GLOBEIS2 is intended for easy use, including a more accessible way to incorporate area-specific land use data.

The new emission inventories are more accurate, both in magnitude and spatial resolution, when compared to previously calculated emission estimates. The new inventories are used as inputs to photochemical models, which are in turn used to simulate atmospheric chemistry and transport in the region. The results can help improve the understanding of air pollution problems in Texas and promote more useful control strategy options and policy decisions. Field studies conducted to investigate the accuracy of the spatial distribution and magnitude of the new emission estimates have indicated that the new land cover data are more accurate than previously available data.

Acknowledgements

The authors acknowledge field study participants, including Pryanka Bandypadara, Patrick Griffith and Matt Russell. Cindy Murphy provided data management assistance. Ellen Kinnee offered her help and advice regarding the BELD dataset. The authors also thank Chris Geron for his advice and guidance. This work was supported by the Texas Natural Resource Conservation Commission.

References

Fehsenfeld, F., Calvert, J., Fall, R., Goldan, P., Guenther, A., Hewitt, N., Lamb, B., Liu, S., Trainer, M., Westberg, H., Zimmerman, P., 1992. Emissions of volatile organic compounds from vegetation and the implication for atmospheric chemistry. Global Biogeochemical Cycles 6 (4), 389–430.

Geron, C., Guenther, A., Pierce, T., 1994. An improved model for estimating emissions of volatile compounds from forests in the eastern united states. Journal of Geophysical Research 99 (D6), 12773–12791.

Guenther, A., Zimmerman, P., Harley, P., Monson, R., Fall, R., 1993. Isoprene and monoterpene emission rate variability: model evaluations and sensitivity analyses. Journal of Geophysical Research 98 (D7), 12609–12618.

Guenther, A., Archer, S., Greenberg, J., Harley, P., Helmig, D., Klinger, L., Vieling, L., Wildermuth, M., Zimmerman, P., Zitzer, S., 1999. Biogenic hydrocarbon emissions and landcover/climate change in a subtropical savanna. Physics and Chemistry of the Earth B 24 (6), 659–667.

Guenther, A., Geron, C., Pierce, T., Lamb, B., Harley, P., Fall, R., 2000. Natural emissions of non-methane volatile organic compounds, carbon monoxide, and oxides of nitrogen from North America. Atmospheric Environment 34 (12), 2205–2230.

Kinnee, E., Geron, C., Pierce, T., 1997. United States land use inventory for estimating biogenic ozone precursor emissions. Ecological Applications 7 (1), 46–58.

Leuning, R., Kelliher, F., De Pury, D., Schulze, E., 1995. Leaf nitrogen, photosynthesis, conductance and transpiration: scaling from leaves to canopies. Plant, Cell and Environment 18, 1183–1200.

Radian Corporation, 1996. Biogenic sources preferred methods. Emission inventory improvement program document series, Vol. V. Prepared for T. Pierce, Area Sources Committee, Emission Inventory Improvement Program. Download at http://www.epa.gov/ttn/chief/eiip/techreport/volume05/index. html.

Wiedinmyer, C., 1999. Biogenic hydrocarbons in Texas: source characterization and chemistry. Ph.D. Dissertation, Department of Chemical Engineering, University of Texas, Austin, Texas.

Wiedinmyer, C., Strange, I.W., Estes, M., Yarwood, G., Allen, D., 2000. Biogenic hydrocarbon emission estimates for North Central Texas. Atmospheric Environment 34, 3419–3435.

Wiedinmyer, C., Friedfeld, S., Baugh, W., Greenberg, J., Guenther, A., Fraser, M., Allen, D., 2001. Measurement and analysis of atmospheric concentrations of isoprene and its reaction products in Central Texas. Atmospheric Environment 35, 1001–1013.