

Assessment of volatile organic compound emissions from ecosystems of China

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[1] Isoprene, monoterpene, and other volatile organic compound (VOC) emissions from grasslands, shrublands, forests, and peatlands in China were characterized to estimate their regional magnitudes and to compare these emissions with those from landscapes of North America, Europe, and Africa. Ecological and VOC emission sampling was conducted at 52 sites centered in and around major research stations located in seven different regions of China: Inner Mongolia (temperate), Changbai Mountain (boreal-temperate), Beijing Mountain (temperate), Dinghu Mountain (subtropical), Ailao Mountain (subtropical), Kunming (subtropical), and Xishuangbanna (tropical). Transects were used to sample plant species and growth form composition, leafy (green) biomass, and leaf area in forests representing nearly all the major forest types of China. Leafy biomass was determined using generic algorithms based on tree diameter, canopy structure, and absolute cover. Measurements of VOC emissions were made on 386 of the 541 recorded species using a portable photo-ionization detector method. For 105 species, VOC emissions were also measured using a flow-through leaf cuvette sampling/gas chromatography analysis method. Results indicate that isoprene and monoterpene emissions, as well as leafy biomass, vary systematically along gradients of ecological succession in the same manner found in previous studies in the United States, Canada, and Africa. Applying these results to a regional VOC emissions model, we arrive at a value of 21 Tg C for total annual biogenic VOC emissions from China, compared to 5 Tg C of VOCs released annually from anthropogenic sources there. The isoprene and monoterpene emissions are nearly the same as those reported for Europe, which is comparable in size to China. **INDEX TERMS:** 0315 Atmospheric Composition and Structure: Biosphere/atmosphere interactions; 0322 Atmospheric Composition and Structure: Constituent sources and sinks; 1615 Global Change: Biogeochemical processes (4805); 1851 Hydrology: Plant ecology; **KEYWORDS:** isoprene, succession, Gaia, grasslands, forests, peat bogs

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1. Introduction

[2] Recent work on the ecological and evolutionary relationships of plants that emit (nonmethane) volatile organic compounds (VOCs) has revealed patterns which suggest that biogenic VOCs may play adaptive roles in the

metabolism and development of ecosystems. Isoprene (C_5H_8), for instance, is a highly reactive hydrocarbon emitted in large quantities by a wide variety of plants which can strongly influence concentrations of ozone (O_3), nitrogen oxides (NO_x), and hydroxyl radicals (OH) in the boundary-layer atmosphere over forested continental regions. While phylogenetic studies have revealed no clear evolutionary pattern among the major taxa that links isoprene-emitting plants [Harley *et al.*, 1999], patterns do appear when plants and their emissions are examined in an ecological context. Klinger *et al.* [1994, 1998] have shown that isoprene and monoterpene emissions appear to vary systematically along gradients of ecosystem development (i.e., succession). These and other empirical studies indicate a common spatial-temporal pattern whereby isoprene emissions are seen to be low in early successional grasslands and shrublands, increase to high rates in early to mid-successional deciduous woodlands and "secondary" forests, then decrease to moderate rates in later successional "primary" evergreen forests, and drop to low rates in late

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successional peatlands [Klinger *et al.*, 1998; Guenther *et al.*, 1999a; Helmig *et al.*, 1999b; Isebrands *et al.*, 1999; Schaab *et al.*, 2000; Westberg *et al.*, 2000]. Studies using ecological models to describe VOC emissions during succession show a similar trend [Martin and Guenther, 1995].

[3] Such ecological patterns present opportunities to derive landscape-level VOC fluxes from models parameterized with remotely sensed vegetation data classified according to ecosystem age and/or disturbance regime. The need for a remote-sensing approach is particularly germane as scientists begin to focus on VOC emissions from the species-rich tropics. In rain forests especially, conventional ground-based methods which involve inventorying emissions of each species to characterize landscape-level VOC fluxes are time-consuming and difficult. The utility, however, of a succession-based model for predicting how VOC emissions from terrestrial ecosystems will change with time relies heavily on the degree to which the successional patterns in emissions are global.

[4] In this paper we extend to China the investigation of VOC emissions and ecosystem succession by conducting a species-by-species survey of isoprene and monoterpene emissions and characterizing vegetation composition and structure along successional gradients in boreal, temperate, subtropical, and tropical ecosystems there. Furthermore, we apply our forest and emission inventory data to a regional model to estimate VOC emissions for all of China.

2. Methods

2.1. Study Site Descriptions

[5] Study sites were located in seven regions of China in and around the following research stations: the temperate Inner Mongolia Grassland Ecosystem Research Station, (Inner Mongolia Autonomous Region), the boreal-temperate Changbai Mountain Forest Ecosystem Research Station (Jilin Province), the temperate Beijing Forest Ecosystem Research Station (Beijing Province), the subtropical Dinghu Mountain Forest Ecosystem Research Station (Guangdong Province), the subtropical Ailao Mountain Forest Ecosystem Station (Yunnan Province), the subtropical Kunming Botanical Garden (Yunnan Province), and the tropical Xishuangbanna Tropical Botanical Garden (Yunnan Province). Sampling sites were located in forests that have previously been studied and described by local ecologists. Sampling was conducted during the main growing season at each site. Table 1 lists the vegetation type, sampling period, geographic coordinates, elevation, slope, and aspect for each of the 52 study sites.

2.2. Vegetation Measurements

[6] Vegetation communities at 36 of the sites were identified, gridded, then sampled in 10-m $\times$ 10-m contiguous plots along 50-m to 100-m transects. In each plot all trees were identified, and the tree diameter at breast height (DBH) ($\sim$ 1.5 m from base) and tree height were recorded. All stems 4 cm DBH and 1.5 m tall were counted as trees. Tree layer and understory layer leaf area index (LAI), the ratio of leaf area to ground area, were measured at two central locations in plots using two (above and below canopy) LiCor LAI-2000 instruments. The above-canopy instrument was located at the top of a nearby tower or in a nearby forest clearing.

Visual estimates of absolute cover of growth forms were made, and slope, aspect, and elevation were recorded for each plot. Details of the above methods are described by Helmig *et al.* [1999b].

[7] Leaves of the main plant species occurring in the transects, including cryptogams (mosses and lichens), were collected and photographed against a calibrated white background. In the laboratory, dry weight of each leaf set was obtained by placing leaves in a drying oven for 24 hours at 50°C and weighing on an analytical balance. Digital photos were analyzed using an Interactive Data Language (IDL®) custom leaf area program designed to select adjacent pixels of a similar shade in an image. In each image, the leaf and 25-cm² calibration square pixel areas were determined, giving metric values of (one-sided) leaf area. These data were used to determine the ratio of leaf area (A_L) to leaf biomass (B_L), a parameter used in our emission equations. Species not measured were assigned A_L/B_L values based on the averages of measured species of their respective genus or of their respective growth form.

[8] Tree leaf biomass, expressed as leaf dry weight per unit ground area, was determined using generic algorithms based on DBH and canopy structure. The different algorithms were derived from measured parameters of species typifying the respective forest types of each region. The Geron *et al.* [1994] algorithms were used for the Inner Mongolia, Beijing Mountain, and Changbai Mountain forests, the Tang *et al.* [1998] and Feng *et al.* [1998] algorithms for the Xishuangbanna forests, and the Geron *et al.* [1994] and the Qiu *et al.* [1984] algorithms for the Ailao Mountain forests. Understory leafy biomass was calculated as the product of the A_L/B_L value and the fractional area cover in each plot of leafy biomass for each growth form. (We use the label "leafy" biomass in referring to the leaf-like, green photosynthetic tissue of all plants, including cryptogams which possess no true leaves.) The A_L/B_L values, in cm² per gram dry weight of leafy matter, assigned to the understory growth forms are as follows: graminoids = 121, forbs = 123, deciduous shrubs = 131, evergreen shrubs = 105, lianes = 120, bamboos = 295, ferns = 211, peat mosses = 8, other mosses = 26, and lichens = 150.

2.3. Trace Gas Sampling and Analysis

[9] Emissions of isoprene and other nonmethane VOCs were characterized for 386 of the 541 recorded species using the portable photoionization detector (PID) screening method reported by Klinger *et al.* [1998]. Measurements were taken on several different leaves and/or individual plants of a given species until a consistent result was obtained. On the basis of the semiquantitative results from the PID method, species were assigned emission potentials of high, moderate, or low as per the emission categories of Geron *et al.* [1994]. In addition, 105 species were sampled using the flow-through leaf cuvette method similar to that described by Harley *et al.* [1997] except that the cuvette system was custom-made at the National Center for Atmospheric Research (NCAR) (Boulder, CO). This system recorded flow rates, inlet and outlet air humidity, leaf temperature, and photosynthetically active radiation at 5-second intervals on a Tattletale 5F datalogger (Onset Computer Corp, Pocasset, MA). Cuvette air samples, 500 ml in volume, were collected onto absorbent cartridges using a

Table 1. Location, Sampling Period, Topographic Setting, and Vegetation Type of Study Sites

Vegetation Type ^a	Sampling Period	Latitude	Longitude	Elev. m	Slope, deg	Aspect
<i>Inner Mongolia</i>						
Station area	23 July 2001	43°37.81'N	116°42.30'E	1191	0	-
Mixed grassland*	24 July 2001	43°30.38'N	116°49.39'E	1415	2.5	NNW
<i>Stipa</i> grassland*	24 July 2001	43°32.40'N	116°33.49'E	1174	0	-
Willow shrubland*	25 July 2001	43°09.52'N	116°06.73'E	1296	5	NE
<i>Beijing Mountain</i>						
Station area forest	27 May 1998	40°01'N	115°28'E	1100	n.d. ^b	n.d.
Elm woodland*	26 July 2001	40°21.30'N	116°00.39'E	644	0	-
Pine woodland*	26 July 2001	40°21.11'N	116°00.38'E	695	21	E
Locust woodland*	26 July 2001	40°21.40'N	116°00.43'E	678	15	W
<i>Changbai Mountain</i>						
Alpine tundra	11 Aug. 1998	42°03.27'N	128°03.89'E	~2400	20	W
Birch woodland*	12-25 Aug. 1998	42°03.27'N	128°03.89'E	1980	12	W
Birch/larch forest*	12-25 Aug. 1998	42°03.61'N	128°03.87'E	1863	21	N
Birch/poplar forest*	20-26 Aug. 1998	42°24.26'N	128°05.97'E	700	5	SW
Birch/spruce forest*	11-25 Aug. 1998	42°03.98'N	128°03.90'E	~1700	20	N
Grass/willow shrubland*	20-24 Sept. 1998	42°24.20'N	128°06.35'E	705	0	-
Larch bog forest*	19-25 Aug. 1998	42°08.40'N	128°16.47'E	1200	0	-
Larch/pine forest*	22-25 Aug. 1998	42°11.27'N	128°13.26'E	~1000	0	-
Linden/ash forest*	14-24 Aug. 1998	42°24.18'N	128°06.35'E	705	0	-
Oak/pine forest*	15-26 Aug. 1998	42°24.26'N	128°05.97'E	745	0	-
Pine/linden/fir forest*	24-25 Aug. 1998	42°13.53'N	128°10.65'E	~900	0	-
Pine/spruce forest*	18-25 Aug. 1998	43°08.57'N	128°07.92'E	1190	0	-
<i>Sphagnum</i> /shrub bog*	10-21 Aug. 1998	42°01.83'N	128°25.74'E	1255	0	-
Spruce/fir forest*	12-25 Aug. 1998	42°01.61'N	128°03.85'E	1620	0	-
Spruce/larch forest*	12-25 Aug. 1998	42°04.37'N	128°03.71'E	1640	0	-
Station garden	9-22 Aug. 1998	42°24.26'N	128°05.97'E	705	0	-
<i>Dinghu Mountain</i>						
Station area forest	24-25 May 1998	23°10'N	112°32'E	~400	n.d.	n.d.
<i>Xishuangbanna</i>						
Botanical garden	22 Sept.-2 Nov. 1998	21°55.60'N	101°15.94'E	570	0	-
<i>Castanopsis</i> forest*	24 Sept.-8 Oct. 1998	21°57.66'N	101°12.02'E	820	28	W
Conservation reserve	26 Sept.-2 Nov. 1998	21°55.18'N	101°16.13'E	590	0	-
<i>Cratogeomys</i> moss forest*	2-8 Oct. 1998	21°57.71'N	101°12.24'E	845	10	WNW
Early primary forest*	29 Sept.-7 Oct. 1998	21°55.12'N	101°16.38'E	565	35	NNW
Early secondary forest*	29 Sept.-6 Oct. 1998	21°55.35'N	101°16.23'E	570	10	SE
Elephant reserve	23 Sept. 1998	22°10.60'N	100°31.33'E	750	0	-
<i>Ficus</i> garden	3-13 Aug. 2001	21°55.67'N	101°15.16'E	560	0	-
Mixed plantation	7 Oct.-2 Nov. 1998	21°55.35'N	101°16.23'E	570	0	-
<i>Pometia</i> forest*	24 Sept.-8 Oct. 1998	21°57.67'N	101°12.02'E	805	35	E
Riverside woodland*	7-10 Oct. 1998	21°55.91'N	101°15.29'E	575	10	N
Rubber tree plantation	8-10 Aug. 2001	21°55.44'N	101°16.05'E	570	0	-
Secondary forest*	30 Sept.-7 Oct. 1998	21°55.18'N	101°16.13'E	590	15	W
<i>Shorea</i> forest	22 Sept. 1998	21°57.59'N	101°35.28'E	~700	0	-
<i>Trema</i> grassland	5 Oct. 1998	22°57.95'N	102°26.28'E	910	10	W
<i>Trema</i> woodland*	6 Oct. 1998	21°57.95'N	101°26.28'E	915	25	W
<i>Altai Mountain</i>						
Disturbed mossy forest	29 Oct. 1998	24°19.19'N	100°47.70'E	2325	0	-
Dwarf forest*	16-24 Oct. 1998	24°31.68'N	101°01.84'E	2528	35	WNW
Heath forest*	16-24 Oct. 1998	24°31.68'N	101°01.84'E	2640	25	NW
Late <i>Castanopsis</i> forest*	17 Oct. 1998	24°32.88'N	101°02.45'E	2515	32	NE
Late primary forest*	16-26 Oct. 1998	24°32.56'N	101°01.65'E	2442	15	WNW
<i>Lithocarpus</i> forest/bog*	17-26 Oct. 1998	24°32.24'N	101°10.62'E	2408	9	SSW
Mossy forest*	16-26 Oct. 1998	24°31.68'N	101°01.84'E	2490	20	W
Poplar forest*	17-26 Oct. 1998	24°32.54'N	101°01.63'E	2415	20	S
Poplar woodland*	21-24 Oct. 1998	24°32.72'N	101°01.52'E	2395	23	N
<i>Sphagnum</i> bog*	20-24 Oct. 1998	24°32.81'N	101°01.54'E	2460	2	SW
<i>Kunming</i>						
Botanical garden	5-7 Nov. 1998	25°08.27'N	102°44.32'E	1880	0	-

^a asterisk indicates sites sampled with transects.^b not determined.

large syringe [Helmig *et al.*, 1999a]. Both techniques were applied only on mature, undamaged leaves. All measurements were done around midday on in situ sunlit leaves with air temperatures ranging from 20° to 35°C. The cartridge samples were frozen and brought to NCAR for analysis using gas chromatography mass spectrometry (GC-MS) and atomic emission detection methods for VOCs [Greenberg *et al.*, 1999a].

3. Results and Interpretation

3.1. Distribution and VOC Emissions of Plant Species

[10] Table 2 lists by region the species name, family, growth form, vegetation type, emission potential, and measured emission. High, medium, and low emission potentials were assigned based on measurements in this study and/or emissions reported in the literature [Geron *et al.*, 1994; Guenther *et al.*, 1996; Klinger *et al.*, 1998; Zhang *et al.*, 2000]. For the four species where PID results differed from the leaf cuvette/GC-MS results, the latter results were used to assign emission potentials. Genus-level assignments were based on measured emissions of one or more species within a given genus. Where emission information was not available at the genus level for a given species, emission potentials were treated as missing. Monoterpene emissions for three species measured at Beijing Mountain (*Juglans mandshurica*, *Lespedeza bicolor*, and *Spiraea pubescens*) were found to be unusually high (see Table 2), probably as a result of leaf disturbance during the cuvette sampling. Thus these high values should be considered suspect.

[11] These are the first reported VOC emission measurements for most of the species sampled here. Certain genus- and family-level patterns in isoprene emission seen in Africa [Guenther *et al.*, 1996; Klinger *et al.*, 1998] are apparent in China as well. In China, 12 of the 17 species in the family Moraceae were isoprene emitters, mostly in the genus *Ficus*, a pattern similar to that in Africa. The tendency seen in Africa for species of Caesalpinaceae and Arecaceae to emit isoprene is not as obvious in China. In the family Arecaceae, 5 of 14 species emitted isoprene and in Caesalpinaceae, only 3 species out of 16 were isoprene emitters. One important economic species, the rubber tree *Hevea brasiliensis*, was found to be a strong, light-dependent emitter of monoterpenes. As this tree is planted widely as a monoculture in tropical China, its impact alone on the regional atmospheric chemistry may be significant.

[12] At Changbai Mountain the 56 woody species sampled for biomass and emissions account for over 95% of the forest canopy biomass in the region [Xu *et al.*, 1985; Liu, 1997]. At Xishuangbanna, the 278 woody species sampled for biomass include 80 to 90% of the most abundant forest species in the region according to Cao *et al.* [1996] and Dang and Qian [1997], respectively. The 205 woody species for which VOC emissions were sampled account for between 62 and 83% of the most abundant species in the Xishuangbanna region [Cao *et al.*, 1996; Dang and Qian, 1997]. In the Ailao Mountains, biomass estimates were based on 68 species, including 40 species which constitute between 80 and 95% of the forest biomass [Qian, 1983; Wang, 1983]. Emission estimates were based on 57 species, including 33 species which make up between 75 and 85% of the Ailao forest biomass [Qian, 1983; Wang, 1983; Xie, 1987]. For Inner Mongolia and

Beijing Mountain regions, no comparable forest biomass data could be found. Overall, for those sites where inventory data are available, it appears that our emission results are based on those species that account for the majority of the woody vegetation in the study areas.

[13] Unless determined otherwise, nonwoody canopy taxa were assigned emission potentials of $0.1 \mu\text{g C g}^{-1} \text{hr}^{-1}$ for isoprene and monoterpenes, except for peat (*Sphagnum*) mosses which were assigned an emission potential of $1.0 \mu\text{g C g}^{-1} \text{hr}^{-1}$ for isoprene based on measurements of Hanson *et al.* [1999] and Isebrands *et al.* [1999]. In general, grasses, forbs, ferns, mosses, and lichens are found to emit low or no amounts of isoprene and monoterpenes. However, with only a limited inventory of the herbaceous and cryptogamic species, the actual emissions for this ground vegetation remain poorly characterized. Considering the high biomass of some of these growth forms (e.g., mosses), even a low emission could add significantly to the total emissions.

3.2. Successional Relationships of Vegetation Types

[14] Table 3 summarizes plant abundance and VOC emissions for the various vegetation types in each region according to their successional status. The successional relationships and ecosystem ages are based on previously published studies from China, recorded disturbance histories, tree size distributions, and peat depth and stratigraphy. In the Changbai Mountain region, successional stages from bare ground to spruce-fir forest were pieced together from several published field studies from this region [Barnes *et al.*, 1992; Wu and Han, 1992; Deng *et al.*, 1995; Li *et al.*, 1994; Liu, 1997] as well as field studies in nearby regions containing similar forest types [Li, 1991; Tian *et al.*, 1995]. The ages of the older peatland communities were based on known radiocarbon dates of basal peats at Changbai Mountain sites with peat depths comparable to those measured in this study [Yang and Song, 1992]. Model results of Jiang *et al.* [1999] showing biomass changes over several hundred years of ecosystem development are consistent with the pattern of gradual replacement of deciduous forest by evergreen forest shown here for Changbai Mountain. Species and biomass results of a gap model of forests on Changbai Mountain [Yan and Zhao, 1996], which show the succession of forest types in the sequence poplar/birch $\rightarrow$ oak $\rightarrow$ pine $\rightarrow$ spruce/fir, are also consistent with our findings. Succession at Changbai Mountain is similar to that found in other parts of China, such as in the Gongga Mountain region, western Sichuan Province, where vegetation succession from herbs to deciduous shrubs to deciduous trees to evergreen trees has been documented following glacier retreat [Zhong *et al.*, 1999].

[15] Successional patterns of the vegetation in the Xishuangbanna region follow the classification by Zhang and Cao [1995]. Of the ten vegetation types they report, all but one (monsoon forest over limestone) were included among the sampling sites here. Successional status was determined for the early stages (<100 years) by examining abandoned fields of known age. Later stages of succession were determined from published studies of forest composition and size structure [Dang and Qian, 1997; Su, 1997].

[16] The successional patterns in the subtropical Ailao Mountains are based on previous studies by Wang [1983], Sheng and Xie [1990], and Young *et al.* [1992], as well as on

Table 2. Taxa, Growth Forms, Vegetation Types, Emission Potentials, and Measured Emissions of All Species Sampled in 1998 and 2001

Genus species	Family	Growth Form ^a	Recorded Vegetation Type ^b										Emission Potential ^{c,d}		Measured Emissions ^e	
			gr	sh	dw	df	ef	mf	pf	pe	ex	Isoprene	Terpene	Isoprene	Terpene	
Inner Mongolia																
<i>Agropyron michnoi</i>	Poaceae	grm	✓								L					
<i>Allium tenuissimum</i>	Liliaceae	grm	✓								L					
<i>Anemolpidium chinense</i>	Poaceae	grm	✓								L			0.00	2.86	
<i>Artemisia frigida</i>	Asteraceae	frb	✓								L			0.00	2.17	
<i>A. pubescens</i>	Asteraceae	frb	✓								L					
<i>Aster alpinus</i>	Asteraceae	frb	✓								L					
<i>Astragalus adsurgens</i>	Fabaceae	frb	✓								L					
<i>Betula gmelinii</i>	Betulaceae	dbt	✓								L					
<i>Bupleurum scorzonifolium</i>	Apiaceae	frb	✓								L					
<i>Caragana microphylla</i>	Fabaceae	dbb	✓								L					
<i>Carex korshinskyi</i>	Cyperaceae	grm	✓								M					
<i>Cleistogenes squarrosa</i>	Poaceae	grm	✓								L					
<i>Clematis hexapetala</i>	Ranunculaceae	frb	✓								L					
<i>Coloneaster</i> sp.	Rosaceae	dbb	✓								L					
<i>Cymbaria dahurica</i>	Scrophulariaceae	frb	✓								L					
<i>Dianthus chinensis</i>	Caryophyllaceae	frb	✓								L			0.10	0.59	
<i>Filifolium sibiricum</i>	Asteraceae	frb	✓								L					
<i>Galium verum</i>	Rubiaceae	frb	✓								H					
<i>Haplophyllum dauricum</i>	Rutaceae	frb	✓								L					
<i>Iris dichotoma</i>	Iridaceae	grm	✓								L					
<i>Kochia prostrata</i>	Chenopodiaceae	frb	✓								L					
<i>Koeleria cristata</i>	Poaceae	grm	✓								L					
<i>Leontopodium longifolium</i>	Asteraceae	frb	✓								L					
<i>Leymus chinensis</i>	Poaceae	grm	✓								L					
<i>Ligularia mongolica</i>	Asteraceae	frb	✓								L					
<i>Melilotoides ruthenica</i>	Rosaceae	frb	✓								L					
<i>Oxytropis hirta</i>	Fabaceae	frb	✓								M					
<i>O. myrtillophylla</i>	Fabaceae	frb	✓								L					
<i>Paritnia rupestris</i>	Valerianaceae	frb	✓								L					
<i>Polygonum divaricatum</i>	Polygonaceae	frb	✓								L			0.93	6.06	
<i>Populus davidiana</i>	Salicaceae	dbt	✓								H					
<i>Potentilla tanacetifolia</i>	Salicaceae	frb	✓								L			0.00	5.24	
<i>Salix characta</i>	Salicaceae	dbb	✓								H			23.8	0.83	
<i>S. gordejewii</i>	Salicaceae	dbb	✓								L					
<i>S. rosmarinifolia</i>	Salicaceae	dbt	✓								M			7.21	0.21	
<i>S. sinica</i>	Salicaceae	frb	✓								L					
<i>Salsola collina</i>	Chenopodiaceae	frb	✓								L					
<i>Sanguisorba officinalis</i>	Rosaceae	frb	✓								L					
<i>Saposhnikovia divaricata</i>	Apiaceae	frb	✓								L					
<i>Scabiosa comosa</i>	Dipsacaceae	frb	✓								L					
<i>Scutellaria baicalensis</i>	Lamiaceae	frb	✓								L					
<i>Sedum airoom</i>	Crassulaceae	frb	✓								L					
<i>Serratula centauroides</i>	Asteraceae	frb	✓								L			0.00	1.04	
<i>Stellara chamaejasme</i>	Thymelacaceae	frb	✓								L					
<i>Stipa baicalensis</i>	Poaceae	grm	✓								L					
<i>S. grandis</i>	Poaceae	grm	✓								L			0.00	0.66	
<i>Thalictrum petaloideum</i>	Ranunculaceae	frb	✓								L					
<i>T. squarrosum</i>	Ranunculaceae	frb	✓								L					
<i>Thermopsis lanceolata</i>	Fabaceae	frb	✓								L					
<i>Ulmus pumila</i>	Ulmaceae	dbt	✓								L					
Beijing Mountain																
<i>Acer mono</i>	Aceraceae	dbt	✓								L			0.00	4.95	
<i>Ailanthus altissima</i>	Simarubaceae	dbt	✓								L					
<i>Betula davurica</i>	Betulaceae	dbt	✓								L			0.00	0.36	
<i>Biota orientalis</i>	Cupressaceae	ent	✓								M			0.03	0.63	
<i>Cotinus coggygria</i>	Anacardiaceae	dbt	✓								L					
<i>Juglans mandshurica</i>	Juglandaceae	dbt	✓								L			0.00	3771	
<i>Larix principis-rupprechtii</i>	Pinaceae	dbt	✓								L			7.40	1.41	
<i>Lespedeza bicolor</i>	Papilionaceae	dbt	✓								M			4.20	3236	
<i>Pinus tabulaeformis</i>	Pinaceae	ent	✓								L			0.15	5.71	
<i>Platycladus orientalis</i>	Cupressaceae	ent	✓								L			0.00	61.7	
<i>Populus davidiana</i>	Rosaceae	dbt	✓								H					
<i>Prunus armenica</i> v. <i>ansu</i>	Rosaceae	dbt	✓								L					
<i>Quercus liaotungensis</i>	Fagaceae	dbt	✓								H			98.9	0.10	
<i>Robinia pseudacacia</i>	Papilionaceae	dbt	✓								H			49.8	2.07	
<i>Spiraea pubescens</i>	Rosaceae	dbt	✓								L			0.00	1618	
<i>Ulmus pumila</i>	Ulmaceae	dbt	✓								L					
<i>Ziziphus jujuba</i>	Rhamnaceae	dbt	✓								L					

Table 2. (continued)

Genus species	Family	Growth Form ^a	Recorded Vegetation Type ^b							Emission Potential ^{c,d}			Measured Emissions ^e	
			gr	sh	dw	df	ef	mf	pf	pe	ex	Isoprene	Terpene	
Changbai Mountain														
<i>Abies holophylla</i>	Pinaceae	ent			✓	✓	✓	✓	✓	(L)	(H)			
<i>A. nephrolepis</i>	Pinaceae	ent			✓	✓	✓	✓	✓	L	H			
<i>Acer barbinerve</i>	Aceraceae	dbt						✓	✓	L	M		0.00	0.26
<i>A. mandshuricum</i>	Aceraceae	dbt						✓	✓	(L)	(M)			
<i>A. mono</i>	Aceraceae	dbt			✓	✓	✓	✓	✓	L	M		0.00	0.42
<i>A. pseudo-sieboldianum</i>	Aceraceae	dbt			✓	✓	✓	✓	✓	L	M			
<i>A. tegmentosum</i>	Aceraceae	dbt			✓	✓	✓	✓	✓	(L)	(M)			
<i>A. triflorum</i>	Aceraceae	dbt			✓	✓	✓	✓	✓	L	M			
<i>A. ukurunduense</i>	Aceraceae	dbt			✓	✓	✓	✓	✓	L	M			
<i>Alnus mandshurica</i>	Betulaceae	dbt			✓	✓	✓	✓	✓	L	L			
<i>A. sibirica</i>	Betulaceae	dbt			✓					L	L			
<i>Betula costata</i>	Betulaceae	dbt			✓	✓				L	L		0.00	0.12
<i>B. davurica</i>	Betulaceae	dbt				✓				L	L		0.00	0.91
<i>B. ermanii</i>	Betulaceae	dbt			✓	✓	✓	✓	✓	L	L		0.00	1.40
<i>B. fruticosa</i>	Betulaceae	dbt							✓	L	L		0.00	16.5
<i>B. platyphylla</i>	Betulaceae	dbt			✓	✓	✓	✓	✓	L	L			
<i>Carpinus cordata</i>	Corylaceae	dbt			✓					(L)	[M]			
<i>Chamaedaphne calyculata</i>	Ericaceae	ebs							✓	L	H			
<i>Corylus mandshurica</i>	Corylaceae	dbt			✓	✓				L	L			
<i>Fraxinus mandshurica</i>	Oleaceae	dbt			✓	✓	✓	✓	✓	L	L			
<i>Hylcomium splendens</i>	Juglandaceae	mos				✓	✓	✓	✓	(L)				
<i>Juglans mandshurica</i>	Juglandaceae	dbt			✓	✓	✓	✓	✓	L	H			
<i>Juniperus rigida</i>	Cupressaceae	ent			✓	✓	✓	✓	✓	(L)	[M]			
<i>Larix olgensis</i>	Pinaceae	dnt			✓	✓	✓	✓	✓	L	M		0.00	3.80
<i>Ledum palustre</i>	Ericaceae	ebs				✓	✓	✓	✓	L	H		0.00	31.5
<i>Lonicera chrysantha</i>	Caprifoliaceae	dbt			✓					L	L			
<i>L. edulis</i>	Caprifoliaceae	dbt			✓	✓	✓	✓	✓	L	L			
<i>Maackia amurensis</i>	Papilionaceae	dbt								(L)	(L)			
<i>Padus asiatica</i>	Rosaceae	dbt			✓	✓	✓	✓	✓	H	L		136	0.00
<i>Phellodendron amurense</i>	Rutaceae	dbt			✓					L	L			
<i>Phyllocladus caerulea</i>	Ericaceae	ebs				✓				L	L			
<i>Picea jezoensis</i>	Pinaceae	ent			✓	✓	✓	✓	✓	M	H		7.24	5.17
<i>P. koreana</i>	Pinaceae	ent			✓	✓	✓	✓	✓	M	H		0.00	0.30
<i>Pinus koraiensis</i>	Pinaceae	ent			✓	✓	✓	✓	✓	L	H		0.00	0.26
<i>P. pumila</i>	Pinaceae	ent			✓	✓	✓	✓	✓	(L)	(H)			
<i>P. sylvestrisformis</i>	Pinaceae	ent			✓	✓	✓	✓	✓	L	L			
<i>Populus davidiana</i>	Salicaceae	dbt			✓	✓	✓	✓	✓	L	L			
<i>P. koreana</i>	Salicaceae	dbt			✓	✓	✓	✓	✓	H	L			
<i>P. ussuriensis</i>	Salicaceae	dbt			✓	✓	✓	✓	✓	(H)	(L)			
<i>Potentilla fruticosa</i>	Rosaceae	ebs							✓	L	H			
<i>Quercus mongolica</i>	Fagaceae	dbt			✓	✓	✓	✓	✓	L	L			
<i>Rhododendron chrysanthum</i>	Ericaceae	ebs			✓	✓	✓	✓	✓	H	L			
<i>R. dahurica</i>	Ericaceae	ebs								L	L			
<i>Rosa acicularis</i>	Rosaceae	dbt			✓	✓	✓	✓	✓	(L)	(L)			
<i>Rubus crataegifolius</i>	Rosaceae	dbt			✓					L	L		348	0.00
<i>Salix</i> sp.	Salicaceae	dbt			✓					L	L			
<i>S. matsudana</i>	Salicaceae	dbt	✓							H	L			
<i>S. viminalis</i>	Salicaceae	dbt	✓							H	L			
<i>Smilacina</i> sp.	Liliaceae	frb	✓							H	L			
<i>Sorbus pohuashanensis</i>	Rosaceae	dbt			✓	✓	✓	✓	✓	H	L			
<i>Sphagnum</i> sp.	Sphagnaceae	mos			✓	✓	✓	✓	✓	L	L			
<i>Syringa reticulata</i>	Oleaceae	dbt			✓	✓	✓	✓	✓	[M]	L			
<i>Tilia amurensis</i>	Tiliaceae	dbt			✓	✓	✓	✓	✓	(L)	L			
<i>T. mandshurica</i>	Tiliaceae	dbt		✓	✓	✓	✓	✓	✓	L	L			
<i>Ulmus japonica</i>	Ulmaceae	dbt		✓	✓	✓	✓	✓	✓	L	L			
<i>U. laciniata</i>	Ulmaceae	dbt			✓					L	L			
<i>U. propinqua</i>	Ulmaceae	dbt			✓	✓	✓	✓	✓	(L)	(L)			
<i>U. pumila</i>	Ulmaceae	dbt			✓	✓	✓	✓	✓	L	L			
Unknown grass 1	Poaceae	grm	✓							L	L			
Unknown grass 2	Poaceae	grm	✓							L	L			
<i>Vaccinium uliginosum</i>	Ericaceae	ebs							✓	L	L		0.00	1.13
Dinghu Mountain														
<i>Acacia</i> sp.	Mimosaceae	dbt								L	M		0.38	0.36
<i>A. aculeaeformis</i>	Mimosaceae	dbt			n.d. ^f					L	L		0.00	0.22
<i>A. holosericea</i>	Mimosaceae	dbt			n.d.					L	L		0.00	1.15
<i>A. mangium</i>	Mimosaceae	dbt			n.d.					L	M		0.42	0.66
<i>Alchornea tremiodes</i>	Euphorbiaceae	dbt			n.d.					L	H		0.00	2.70
<i>Bambusa textilis</i>	Poaceae	dbt			n.d.					H	H		454	2.94
<i>Caryota ochlandra</i>	Areaceae	ebt			n.d.					H	M		250	1.49

Table 2. (continued)

Genus species	Family	Growth Form ^a	Recorded Vegetation Type ^b										Emission Potential ^{c,d}			Measured Emissions ^e	
			gr	sh	dw	df	ef	mf	pf	pe	ex	Isoprene	Terpene	Isoprene	Terpene		
<i>Castanopsis fissa</i>	Fagaceae	ebt					n.d.					L	L	0.00	0.19		
<i>C. chinensis</i>	Fagaceae	ebt					n.d.					L	M	0.00	0.70		
<i>Cinnamomum burmani</i>	Lauraceae	ebt					n.d.					H	M	449	1.46		
<i>Cryptocarya concinna</i>	Lauraceae	ebt					n.d.					H	H	95.9	106		
<i>Erythrophileum fordii</i>	Caesalpiniaceae	bt					n.d.					L	M	0.43	1.03		
<i>Ficus microcarpa</i>	Moraceae	ebt					n.d.					L	M	1.41	0.68		
<i>Garcinia oblongifolia</i>	Hypericaceae	ebt					n.d.					L	M	0.47	0.87		
<i>Mallothus paniculatus</i>	Euphorbiaceae	dbt					n.d.					L	M	2.28	1.40		
<i>Ormosia pinnata</i>	Papilionaceae	dbt					n.d.					M	H	20.6	3.98		
<i>Pinus massoniana</i>	Pinaceae	ent					n.d.					L	H	11.9	11.5		
<i>Rhus chinensis</i>	Anacardiaceae	dbt					n.d.					M	H	4.14	4.53		
<i>Schima superba</i>	Theaceae	ebt					n.d.					L	H	0.00	1.19		
<i>Strygium jambos</i>	Myrtaceae	ebt					n.d.					H	L	199	0.15		
<i>Taxodium ascendens</i>	Taxodiaceae	dnt					n.d.					L	H	0.48	3.47		
<i>T. distichum</i>	Taxodiaceae	dnt					n.d.					L	H	0.42	2.96		
<i>Xishuangbanna</i>																	
<i>Acacia</i> sp.	Mimosaceae	bli		✓								M	H				
<i>A. intsia</i>	Mimosaceae	ebt		✓								L	L				
<i>A. spinosa</i>	Mimosaceae	bt										L	L				
<i>Acrocarpus fraxinifolius</i>	Mimosaceae	dbt	✓									L	L				
<i>Aeronychia pedunculata</i>	Rutaceae	ebt				✓											
<i>Actinodaphne henryi</i>	Lauraceae	ebt				✓											
<i>Adenanthera pavonina</i>	Mimosaceae	dbt				✓						M	L	5.21	0.00		
<i>Aesculus lankansensis</i>	Hippocastanaceae	dbt				✓						L	L				
<i>Azelia xylocarpa</i>	Caesalpiniaceae	bt				✓			✓			L	L				
<i>Aglaia abbreviata</i>	Meliaceae	ebt				✓						L	L				
<i>Ailanthus fordii</i>	Simarubaceae	dbt		✓		✓						L	(M)				
<i>Alangium barbatum</i>	Alangiaceae	dbt		✓		✓						L	(L)				
<i>A. chinensis</i>	Alangiaceae	dbt		✓		✓						L	M				
<i>A. kuzii</i>	Alangiaceae	dbt		✓		✓						L	M				
<i>Albizia crasstramea</i>	Mimosaceae	dbt		✓		✓						L	L				
<i>A. lucidior</i>	Mimosaceae	dbt		✓		✓						H	L				
<i>Alchornea davidii</i>	Euphorbiaceae	dbt		✓		✓						[L]	[H]				
<i>Alocasia macrorrhiza</i>	Araceae	frb		✓		✓						L	L				
<i>Alpinia blepharocalyx</i>	Zingiberaceae	frb		✓		✓						L	L				
<i>Alstonia scholaris</i>	Apocynaceae	dbt		✓		✓						L	L				
<i>Annonum villosum</i>	Zingiberaceae	frb		✓		✓						L	L				
<i>Amoora dasyclada</i>	Meliaceae	ebt		✓		✓						L	L				
<i>Amorphophallus virosus</i>	Araceae	frb	✓			✓						L	L				
<i>Aneslea fragrans</i>	Theaceae	dbt				✓						L	L				
<i>Anogeissus acuminata</i>	Combretaceae	bt				✓						L	L				
<i>Anthocephalus chinensis</i>	Rubiaceae	dbt		✓		✓						L	L				
<i>Antiaris toxicaria</i>	Moraceae	dbt		✓		✓						L	L				
<i>Antidesma acidum</i>	Euphorbiaceae	ebt				✓											
<i>A. venosum</i>	Euphorbiaceae	ebt				✓											
<i>Aporosa octandra</i>	Euphorbiaceae	ebt		✓		✓											
<i>A. yunnanensis</i>	Euphorbiaceae	ebt		✓		✓											
<i>Araucaria cunninghamii</i>	Araucariaceae	ent				✓			✓			L	L				
<i>Archontophoenix cunninghamiana</i>	Arecaceae	bt								✓		M	L				
<i>Ardisia</i> sp.	Myrsinaceae	ebt				✓						L	L				
<i>A. tenera</i>	Myrsinaceae	ebt				✓						L	L				
<i>Arenga</i> sp.	Arecaceae	bt										L	L				
<i>A. candata</i>	Arecaceae	ebs										L	L				
<i>Baccaurea ramiflora</i>	Euphorbiaceae	ebt	✓			✓						L	L				
<i>Barringtonia fuscicarpa</i>	Lecythidaceae	ebt				✓						L	L				
<i>B. macrostachya</i>	Lecythidaceae	ebt				✓						L	L				
<i>Bauhinia acuminata</i>	Caesalpiniaceae	bt	✓			✓						H	L				
<i>B. subsessilis</i>	Caesalpiniaceae	bt		✓		✓						H	L				
<i>B. variegata</i>	Caesalpiniaceae	dbt		✓		✓						H	L				
<i>Betischmidia robusta</i>	Lauraceae	ebt				✓											
<i>Bischofia javanica</i>	Euphorbiaceae	dbt		✓		✓											
<i>Bombax ceiba</i>	Bombacaceae	dbt		✓		✓						L	L				
<i>Brassaiopsis glomerulata</i>	Nyssaceae	ebt															
<i>Broussonetia papyrifera</i>	Moraceae	ebt		✓								M	L				
<i>Caesalpinia cucullata</i>	Caesalpiniaceae	bli		✓								L	L				
<i>C. pulcherrima</i>	Caesalpiniaceae	ebs										L	L				
<i>C. sappan</i>	Caesalpiniaceae	ebt				✓			✓			L	L				
<i>Calamus gracilis</i>	Arecaceae	ebt				✓											
<i>Calophyllum polyanthum</i>	Hypericaceae	ebt										L	L				
<i>Camellia kishi</i>	Theaceae	ebt				✓						L	L				

Table 2. (continued)

Genus species	Family	Growth Form ^a	Recorded Vegetation Type ^b										Emission Potential ^{c,d}		
			gr	sh	dw	df	ef	mf	pf	pe	ex	Isoprene	Terpene	Isoprene	Terpene
<i>F. poilanei</i>	Annonaceae	ebt					✓					L	L		
<i>Flemingia macrophylla</i>	Papilionaceae	bli			✓							H	H		
<i>Flueggea virosa</i>	Euphorbiaceae	ebs			✓							H	H	160	0.00
<i>Fokienia hodginsii</i>	Cupressaceae	ent						✓				L	L		
<i>Garcinia bracteata</i>	Hypericaceae	ebt					✓					L	L		
<i>G. cova</i>	Hypericaceae	ebt			✓		✓					L	L	0.00	0.00
<i>G. xanthochymus</i>	Hypericaceae	ebt			✓		✓					M	L	2.96	0.00
<i>G. xanthochymus</i>	Hypericaceae	ebt			✓		✓					L	L		
<i>Girardinia subaequalis</i>	Ulmaceae	ebt					✓								
<i>Glochidion assamica</i>	Euphorbiaceae	dbt			✓		✓					L	L		
<i>Gomphandra tetrandra</i>	Ulmaceae	ebt			✓		✓					L	L		
<i>Gonothalamus griffithii</i>	Ulmaceae	ebt			✓		✓					L	L		
<i>Harpullia cupanioides</i>	Sapindaceae	ebt					✓					L	L		
<i>Hemitelia angustata</i>	Sterculiaceae	bt										L	H	0.17	20.4
<i>Hevea brasiliensis</i>	Euphorbiaceae	dbt										L	L		
<i>Hiptage obrusifolia</i>	Malpighiaceae	dbt			✓							H	H		
<i>Homalium laoticum</i>	Samiaceae	dbt			✓							H	H		
<i>Homonoia riparia</i>	Euphorbiaceae	ebs			✓							(L)	(L)		
<i>Horsfieldia amygdalina</i>	Myristicaceae	ebt			✓							L	L		
<i>H. kingii</i>	Myristicaceae	ebt					✓					L	L		
<i>H. pandurifolia</i>	Myristicaceae	ebt					✓					L	L		
<i>Hypharhe lagenicaulis</i>	Areaceae	ebs					✓					L	L		
<i>Ilex godajam</i>	Aquifoliaceae	ebt			✓			✓				[L]	[L]		
<i>Imperata cylindrica</i>	Poaceae	grm	✓									L	L		
<i>Itea macrophylla</i>	Escalloniaceae	ebt			✓							L	L		
<i>Knema cinerea</i>	Myristicaceae	ebt					✓					(L)	(L)		
<i>K. furfuracea</i>	Myristicaceae	ebt					✓					L	L		
<i>K. globularia</i>	Myristicaceae	ebt					✓					L	L		
<i>Lagerstroemia flos-reginae</i>	Lythraceae	dbt										L	L		
<i>L. intermedia</i>	Lythraceae	dbt			✓							L	L		
<i>L. tomentosa</i>	Lythraceae	dbt			✓							L	L		
<i>Lauroceras undulata</i>	Rosaceae	dbt			✓							L	L		
<i>Leea crispa</i>	Vitaceae	ebt					✓					L	L		
<i>Lindera neocalfiana</i>	Lauraceae	ebt			✓							L	L		
<i>Linociera insignis</i>	Oleaceae	ebt			✓							L	L		
<i>Litchi chinensis</i>	Sapindaceae	dbt					✓					(L)	(L)		
<i>Lithocarpus fomesstratus</i>	Fagaceae	dbt			✓							L	L		
<i>L. truncatus</i>	Fagaceae	dbt					✓					L	L		
<i>Lisea cubeba</i>	Lauraceae	ebt			✓							(L)	(L)		
<i>L. dillenifolia</i>	Lauraceae	ebt			✓							L	L		
<i>L. elongata</i>	Lauraceae	ebt			✓							(L)	(L)		
<i>L. euosma</i>	Lauraceae	ebt			✓							L	L		
<i>L. glutinosa</i>	Lauraceae	dbt			✓							L	L		
<i>L. monopetala</i>	Lauraceae	dbt			✓							L	L		
<i>L. panamonijs</i>	Lauraceae	dbt			✓							L	L		
<i>L. pierrei</i>	Lauraceae	ebt			✓							(L)	(L)		
<i>Livistona saribus</i>	Areaceae	ebt			✓							H	H		
<i>Lycidice rhodolegia</i>	Caesalpiniaceae	bt			✓							L	L		
<i>Macaranga denticulata</i>	Euphorbiaceae	ebt			✓							L	L	0.04	0.07
<i>M. indica</i>	Euphorbiaceae	ebt			✓							L	L		
<i>Machilus tenuipila</i>	Lauraceae	ebt			✓							L	L		
<i>Macropanax chienii</i>	Araliaceae	ebt			✓							L	L		
<i>M. dispermus</i>	Araliaceae	ebt			✓							(L)	(L)		
<i>Mallois barbatus</i>	Euphorbiaceae	ebt			✓							(L)	(L)		
<i>M. macrostachys</i>	Euphorbiaceae	ebt			✓							L	L	0.25	0.14
<i>M. paniculatus</i>	Euphorbiaceae	dbt			✓							L	L		
<i>M. philipinensis</i>	Euphorbiaceae	ebt			✓							L	L		
<i>Mangifera indica</i>	Anacardiaceae	ebt			✓							H	H		
<i>M. sylvatica</i>	Anacardiaceae	ebt			✓							L	L		
<i>Manglietia wangii</i>	Magnoliaceae	ebt			✓							L	L		
<i>Mayodendron igneum</i>	Bignoniaceae	dbt			✓							L	L		
<i>Maytenus hookeri</i>	Celastraceae	ebt			✓							L	L		
<i>Melia azedarach</i>	Meliaceae	dbt			✓							L	L		
<i>M. toosendan</i>	Meliaceae	dbt			✓							L	L		
<i>Meliosma sp.</i>	Sabiaceae	ebt			✓							L	L		
<i>Memecylon polyanthum</i>	Melastomaceae	ebt			✓							L	L		
<i>Metadina trichotoma</i>	Rubiaceae	ebt			✓							H	H	32.6	0.00
<i>Mezettiopsis creaghii</i>	Annonaceae	ebt			✓							L	L	0.00	0.00
<i>Microcos nervosa</i>	Tiliaceae	ebt			✓							L	L	20.8	0.00
<i>Milletia leptobotrya</i>	Papilionaceae	dbt			✓							H	H		
<i>M. pulchra</i>	Papilionaceae	dbt			✓							H	H		

Table 2. (continued)

Genus species	Family	Growth Form ^a	Recorded Vegetation Type ^b											Emission Potential ^{c,d}		Measured Emissions ^e	
			gr	sh	dw	df	ef	mf	pf	pe	ex	Isoprene	Terpene	Isoprene	Terpene		
<i>Mitrephora wangii</i>	Annonaceae	ebt			✓							L					
<i>Morinda angustifolia</i>	Rubiaceae	ebt		✓	✓							L					
<i>Morus macroura</i>	Moraceae	dbt		✓	✓							[L]					
<i>Musa acuminata</i>	Musaceae	ebt		✓	✓							L					
<i>Myrcetia gracilis</i>	Rubiaceae	ebt				✓											
<i>Myristica yunnanensis</i>	Myristicaceae	ebt			✓							H					
<i>Neocinnamomum caudatum</i>	Lauraceae	ebt			✓							L				0.00	
<i>Neonauclea griffithii</i>	Rubiaceae	ebt				✓											
<i>Nephelium chrysseum</i>	Sapindaceae	ebt			✓							L					
<i>Olea rosea</i>	Oleaceae	ebt			✓							L					
<i>Ormosia henryi</i>	Papilionaceae	ebt				✓											
<i>Oroxylum indicum</i>	Bignoniaceae	dbt				✓						L					
<i>Paramichelia baillonii</i>	Magnoliaceae	dbt			✓							L					
<i>Phlogacanthus curviflorus</i>	Acanthaceae	ebt			✓							L					
<i>Phoebe lanceolata</i>	Lauraceae	ebt			✓							L					
<i>P. puwenensis</i>	Lauraceae	dbt			✓							L					
<i>Phoenix roebelinii</i>	Arecaceae	ebt		✓								L					
<i>P. sylvestris</i>	Arecaceae	bt										L					
<i>Phyllanthus emblica</i>	Euphorbiaceae	dbt	✓		✓							(L)					
<i>P. flexuosus</i>	Euphorbiaceae	ebt			✓							L					
<i>Pithecellobium chypearia</i>	Mimosaceae	bt		✓		✓						[L]					
<i>Pittosporopsis</i> sp.	Icacinaceae	ebt			✓							(L)					
<i>P. kerrii</i>	Icacinaceae	ebt			✓							L					
<i>Platanus latifolia</i>	Icacinaceae	ebt			✓							L					
<i>Podocarpus imbricatus</i>	Podocarpaceae	ent			✓							L					
<i>P. macrophylla</i>	Podocarpaceae	ent			✓							L					
<i>P. nagi</i>	Podocarpaceae	ent			✓							L					
<i>P. nerifolius</i>	Podocarpaceae	ent			✓							L					
<i>Poikilospermum lanceolatum</i>	Urticaceae	bli			✓							[L]					
<i>Polyalthia chelensis</i>	Annonaceae	ebt			✓							L					
<i>Polyscias balfouriana</i>	Araliaceae	ebs			✓							L					
<i>Pometia tomentosa</i>	Sapindaceae	ebt			✓							L					
<i>Pouteria grandiflora</i>	Sapotaceae	ebt			✓							L					
<i>Premna flavescens</i>	Verbenaceae	dbt			✓							(L)					
<i>P. fulva</i>	Verbenaceae	dbt			✓							L					
<i>Psidium guajava</i>	Myrtaceae	ebt			✓					✓		L					
<i>Pterocarya tonkinensis</i>	Juglandaceae	dbt			✓							L					
<i>Pterospermum</i> sp.	Sterculiaceae	bt										L					
<i>P. lanceaeifolium</i>	Bignoniaceae	ebt			✓							L					
<i>Radermachera microcalyx</i>	Bignoniaceae	ebt			✓							(L)					
<i>Randia acuminatissima</i>	Rubiaceae	ebt			✓							L					
<i>R. wallichii</i>	Rubiaceae	ebt			✓							(L)					
<i>Rauvolfia verticillata</i>	Apocynaceae	ebt			✓							(L)					
<i>R. vomitoria</i>	Apocynaceae	ebt			✓				✓			L					
<i>Rhus chinensis</i>	Anacardiaceae	dbt		✓								L					
<i>Ricinus communis</i>	Euphorbiaceae	ebt										M					
<i>Sapium baccatum</i>	Euphorbiaceae	ebt				✓						L					
<i>S. eugeniaefolium</i>	Euphorbiaceae	ebt			✓							(L)					
<i>Saraca declinata</i>	Caesalpinaceae	ebt			✓							L					
<i>S. dives</i>	Caesalpinaceae	bt										L					
<i>S. indica</i>	Caesalpinaceae	bt										L					
<i>Schinus molle</i>	Theaceae	ebt	✓		✓							L					
<i>Schizomussaenda dehiscens</i>	Rubiaceae	dbt			✓							L					
<i>Sclerophyllum wallichianum</i>	Santalaceae	ebt			✓							L					
<i>Shorea wangtanshuea</i>	Dipterocarpaceae	dbt			✓							L					
<i>Sindora glabra</i>	Caesalpinaceae	bt				✓						L					
<i>Solanum verbacifolium</i>	Solanaceae	ebt	✓		✓							L					
<i>Spondias pinnata</i>	Anacardiaceae	dbt				✓						L					
<i>Sterculia lanceolata</i>	Sterculiaceae	dbt			✓							H					
<i>Stereospermum colais</i>	Bignoniaceae	dbt				✓						L					
<i>Streblus asper</i>	Moraceae	dbt			✓							H					
<i>Suregada glomerulata</i>	Euphorbiaceae	dbt										L					
<i>Syzygium balsameum</i>	Myrtaceae	ebt			✓							(H)					
<i>S. fluviale</i>	Myrtaceae	ebt			✓							(H)					
<i>S. forrestii</i>	Myrtaceae	ebt			✓							(H)					
<i>S. latifolium</i>	Myrtaceae	ebt	✓									L					
<i>S. oblatum</i>	Myrtaceae	ebt										L					
<i>S. polypetaloidesum</i>	Myrtaceae	ebt										(H)					
<i>Talauma gitingensis</i>	Magnoliaceae	dbt							✓			L					
<i>Tapiscia yunnanensis</i>	Staphyleaceae	dbt										(L)					
<i>Terminalia bellirica</i>	Combretaceae	dbt			✓							L					

Table 2. (continued)

Genus species	Family	Growth Form ^a	Recorded Vegetation Type ^b										Emission Potential ^{c,d}			Measured Emissions ^e	
			gr	sh	dw	df	ef	mf	pf	pe	ex	Isoprene	Terpene	Isoprene	Terpene		
<i>T. myriocarpa</i>	Combretaceae	dbt			✓	✓						L	L	0.02	0.18		
<i>Tetrameles nudiflora</i>	Tetramelaceae	dbt			✓	✓						L	L				
<i>Theobroma cacao</i>	Sterculiaceae	ebt					✓			✓		L	L				
<i>Toona ciliata</i>	Meliaceae	ebt			✓	✓						L	L				
<i>Toxicodendron succedaceum</i>	Anacardiaceae	dbt					✓					L	L	0.00	0.00		
<i>Trema orientalis</i>	Ulmaceae	ebt		✓		✓	✓					L	L				
<i>Trevesia palmata</i>	Araliaceae	ebt				✓	✓					L	L				
<i>Trigonostemon thyrsoides</i>	Euphorbiaceae	ebt				✓	✓					L	L				
Unknown epiphytic moss		mos				✓	✓					M	L				
Unknown grass	Poaceae	grm	✓	✓								L	L				
<i>Urena lobata</i>	Malvaceae	ebs		✓								L	L				
<i>Valica guangxiensis</i>	Dipterocarpaceae	ebt			✓							L	L				
<i>Wallichia caryotoides</i>	Arecaceae	ebt			✓	✓						L	L				
<i>W. densiflora</i>	Arecaceae	ebt			✓	✓						L	L				
<i>Walsura robusta</i>	Meliaceae	ebt			✓							L	L				
<i>Wendlandia tinctoria</i>	Rubiaceae	ebt				✓											
<i>Winchia calophylla</i>	Apocynaceae	ebt			✓							L	L				
<i>Woodfordia fruticosa</i>	Lythraceae	dbt		✓													
<i>Wrightia laevis</i>	Apocynaceae	dbt			✓	✓											
<i>Xanthophyllum siamensis</i>	Xanthophyllaceae	ebt			✓	✓											
<i>Zenia insignis</i>	Caesalpinaceae	dbt			✓	✓			✓			L	L				
Ailao Mountain																	
<i>Acanthopanax evodiaefolius</i>	Araliaceae	bt			✓	✓	✓					L	(L)				
<i>Acer heptalobum</i>	Aceraceae	dbt			✓	✓	✓					L	(M)				
<i>Alnus nepalensis</i>	Benuliaceae	dbt			✓	✓	✓					L	(L)				
<i>Berberis</i> sp.	Berberidaceae	ebs		✓								[M]	[L]				
<i>Betula luminifera</i>	Betulaceae	dbt			✓	✓	✓					L	(L)				
<i>Camellia forrestii</i>	Theaceae	ebt			✓	✓	✓					L	(L)				
<i>Carex</i> sp.	Cyperaceae	grm						✓		✓							
<i>C. nubigena</i>	Cyperaceae	grm						✓		✓							
<i>C. teimogyna</i>	Cyperaceae	grm						✓		✓							
<i>Castanopsis orthocantha</i>	Fagaceae	ebt			✓	✓	✓					L	(L)	0.00	0.00		
<i>C. watti</i>	Fagaceae	ebt			✓	✓	✓					L	(L)				
<i>Cinnamomum pittosporoides</i>	Lauraceae	ebt			✓	✓	✓					L	(M)				
<i>Dichapetalum gelonioides</i>	Dichapetalaceae	bt			✓	✓	✓					L	(L)				
<i>Dichotomanthus tristaniae</i>	Rosaceae	ebs			✓	✓	✓					L	[H]				
<i>Eriobotrya bengalensis</i>	Rosaceae	bt			✓	✓	✓					L	(L)				
<i>Eurya obliquifolia</i>	Theaceae	bt					✓					L	(L)				
<i>Gaultheria forrestii</i>	Ericaceae	ebs					✓					L	(L)				
<i>G. griffithiana</i>	Ericaceae	ebs			✓	✓	✓					L	(L)				
<i>Hartia sinensis</i>	Theaceae	ebt			✓	✓	✓					(M)	(L)				
<i>Hypericum patulum</i>	Hypericaceae	ebs			✓	✓	✓			✓		M	(M)				
<i>H. petiolatum</i>	Hypericaceae	frb							✓	✓		(M)	(M)				
<i>H. uratum</i>	Hypericaceae	frb										(M)	(M)				
<i>Ilex</i> sp.	Aquifoliaceae	ebt			✓	✓	✓					[L]	[L]				
<i>I. corallina</i>	Aquifoliaceae	ebt			✓	✓	✓					[L]	[L]				
<i>I. micrococca</i>	Aquifoliaceae	ebt			✓	✓	✓					[L]	[L]				
<i>I. szechwanensis</i>	Aquifoliaceae	ebt			✓	✓	✓					[L]	[L]				
<i>I. wardii</i>	Aquifoliaceae	ebt			✓	✓	✓					[L]	[L]				
<i>Illicium</i> sp.	Illiciaceae	ebt			✓	✓	✓					(L)	(L)				
<i>I. macranthum</i>	Illiciaceae	ebt			✓	✓	✓					L	(L)				
<i>Impatiens rubro-striata</i>	Balsaminaceae	frb							✓	✓							
<i>Juncus effusus</i>	Juncaceae	grm								✓		L	(L)	0.00	0.00		
<i>J. inflexus</i>	Juncaceae	grm								✓		L	(L)				
<i>J. minimus</i>	Juncaceae	grm								✓		(L)	(L)				
<i>Lithocarpus chintungensis</i>	Fagaceae	ebt			✓	✓	✓					(L)	(L)				
<i>L. hypoviridis</i>	Fagaceae	ebt			✓	✓	✓					(L)	(L)				
<i>L. pachyphyllolides</i>	Fagaceae	ebt			✓	✓	✓					L	(L)				
<i>L. xyllocarpa</i>	Fagaceae	ebt			✓	✓	✓					(L)	(L)				
<i>L. yunnanensis</i>	Fagaceae	ebt			✓	✓	✓					L	(L)				
<i>Litsea elongata</i>	Lauraceae	ebt			✓	✓	✓					L	(L)				
<i>Lyonia ovalifolia</i>	Ericaceae	ebt			✓	✓	✓					L	(L)				
<i>Machilus viridis</i>	Lauraceae	ebt			✓	✓	✓					L	(L)				
<i>Mahonia converta</i>	Berberidaceae	ebs										M	(L)				
<i>Manglietia insignis</i>	Magnoliaceae	ebt			✓	✓	✓					L	(L)				
<i>Neolitsea homilantha</i>	Lauraceae	ebt			✓	✓	✓					L	(L)	0.00	0.00		
<i>N. polycarpa</i>	Lauraceae	ebt			✓	✓	✓					L	(L)				
<i>Oenanthe dielsii</i> v. <i>stenophylla</i>	Apiaceae	frb			✓	✓	✓										
<i>Pinus armandi</i>	Pinaceae	ent			✓	✓	✓					L	(L)	H	H		
<i>P. yunnanensis</i>	Pinaceae	ent			✓	✓	✓					L	(L)	H	H		

Table 2. (continued)

Genus species	Family	Growth Form ^a	Recorded Vegetation Type ^b							Emission Potential ^{c,d}		Measured Emissions ^e	
			gr	sh	dw	df	ef	mf	pf	pe	ex	Isoprene	Terpene
<i>Poa khasiana</i>	Poaceae	grm										(L)	
<i>Populus bonatii</i>	Salicaceae	dbt			✓					✓		(L)	
<i>Potentilla griffithii</i>	Rosaceae	frb				✓						L	
<i>Primula deflexa</i>	Primulaceae	frb								✓		(L)	
<i>Prunus cerasoides</i>	Rosaceae	dbt				✓						[L]	
<i>P. maximowiczii</i>	Rosaceae	dbt				✓						[L]	
<i>Pteridium revolutum</i>	Pteridiaceae	frn			✓							L	
<i>Rhododendron decorum</i>	Ericaceae	ebt				✓						(L)	
<i>R. delavayi</i>	Ericaceae	ebt			✓	✓						L	
<i>R. irroratum</i>	Ericaceae	ebt			✓	✓						L	0.00
<i>R. leptothrium</i>	Ericaceae	ebt			✓	✓						L	
<i>Rosa longicauspis</i>	Rosaceae	dbt	✓									(L)	
<i>Salix</i> sp.	Salicaceae	dbt			✓							H	
<i>Schefflera delavayi</i>	Araliaceae	ebt			✓							L	
<i>S. hypoleuca</i>	Araliaceae	ebt			✓							(L)	
<i>S. shweliensis</i>	Araliaceae	ebt			✓							(L)	
<i>Schima argentea</i>	Theaceae	ebt			✓							(L)	
<i>S. noronhae</i>	Theaceae	ebt			✓							(L)	
<i>Senecio scandens</i>	Asteraceae	frb			✓							(L)	
<i>Sinurundinaria nitida</i>	Poaceae	dbt				✓						L	
<i>Skimmia arborescens</i>	Rutaceae	ebt										(L)	
<i>Smilax lebrunii</i>	Smilacaceae	bli										(L)	
<i>Sorbus ferruginea</i>	Rosaceae	dbt	✓									[M]	
<i>Sphagnum junghuhnianum</i>	Sphagnaceae	mos				✓						L	0.00
<i>Spiraea japonica</i>	Rosaceae	dbt										(L)	5.28
<i>Stachys kouyangensis</i>	Labiaceae	frb											
<i>Stranvaesia davidiana</i>	Rosaceae	bt			✓							[L]	
<i>Syrax perkinsiae</i>	Syraceae	ebt										(L)	
<i>Sweria bimaculata</i>	Gentianaceae	frb											
<i>Symplocos anomala</i>	Symplocaceae	ebt				✓						(L)	
<i>S. botryantha</i>	Symplocaceae	ebt				✓						(L)	
<i>S. dryophila</i>	Symplocaceae	ebt				✓						(L)	
<i>S. poilanei</i>	Symplocaceae	ebt				✓						(L)	
<i>Tapiscia yunnanensis</i>	Staphyleaceae	dbt				✓						L	
<i>Ternstroemia gymnanthera</i>	Theaceae	ebt			✓	✓						L	
<i>Vaccinium dulcoulxii</i>	Ericaceae	ebt			✓	✓						L	0.00
<i>Viburnum cylindricum</i>	Caprifoliaceae	ebt			✓	✓						[L]	
<i>V. foetidum</i>	Caprifoliaceae	ebs			✓	✓						[L]	
<i>Kunning</i>													
<i>Acanthopanax evodiaefolius</i>	Araliaceae	bt			✓							L	0.00
<i>Alangium kuzii</i>	Alangiaceae	dbt			✓							L	0.00
<i>Annestea fragrans</i>	Theaceae	dbt			✓							L	0.00
<i>Broussonetia papyrifera</i>	Moraceae	ebt			✓							M	6.16
<i>Celtis tetrandra</i>	Ulmaceae	ebt			✓							L	0.00
<i>Dichotomanthus tristanciaecarpa</i>	Rosaceae	ebs			✓							L	0.00
<i>Dolichandrone stipulata</i>	Bignoniaceae	dbt			✓							L	0.00
<i>Illicium macranthum</i>	Illiciaceae	ebt			✓							L	0.00
<i>Mahonia converta</i>	Berberidaceae	ebs			✓							M	4.63
<i>Melia toosanden</i>	Meliaceae	dbt			✓							L	0.00
<i>Pinus armandi</i>	Pinaceae	ent			✓							L	0.00
<i>P. yunnanensis</i>	Pinaceae	ent			✓							L	0.39
<i>Podocarpus imbricatus</i>	Podocarpaceae	ent			✓							L	0.17
<i>Schima wallichii</i>	Theaceae	ebt			✓							L	0.00
<i>Shorea wangtianshuea</i>	Dipterocarpaceae	dbt			✓							L	0.00
<i>Symplocos dryophila</i>	Symplocaceae	ebt			✓							L	0.00
<i>Terminalia bellirica</i>	Combretaceae	dbt			✓							L	0.00

^a dbt, deciduous broadleaved shrub; ebs, evergreen broadleaved shrub; bli, broadleaved tree; bt, broadleaved tree; dbt, deciduous broadleaved tree; ebt, evergreen broadleaved tree; dnt, deciduous needleleaved tree; ent, evergreen needleleaved tree; grm, graminoid; frb, forb; mos, moss.

^b gr, grassland; sh, shrubland; dw, deciduous woodland; df, deciduous forest; ef, evergreen forest; mf, moss forest; pf, peat forest; pe, peatland; ex, exotic.

^c isoprene emission potentials ($\mu\text{g C g}^{-1} \text{ hr}^{-1}$): H = 70, M = 14, L = 0.1; terpene emission potentials ($\mu\text{g C g}^{-1} \text{ hr}^{-1}$): H = 3.0, M = 0.6, L = 0.1.

^d parentheses indicate genus-based assignments; brackets indicate literature-based assignments.

^e units: $\mu\text{g C g}^{-1} \text{ hr}^{-1}$; 2001 measurements in italics.

^f not determined.

observed forest structure, peat depth, and gross peat stratigraphy. The successional patterns shown here, to about 500 years, are consistent with successions described from other subtropical forests of China [Ming, 1987; Zhou *et al.*, 1999; Chau and Marafa, 1999; An *et al.*, 2001]. Wang [1983]

further proposes that, in this region, succession occurs from peatland to *Populus* forest, although no data in support of this pathway are presented. In our study we found unambiguous evidence that, in the absence of large-scale disturbance, peatlands are replacing the *Lithocarpus* forest in the region,

Table 3. Means ($\pm$ S. E.) of Leafy Biomass, Leaf Area Index, and Emission Potentials According to Vegetation Type and Ecosystem Age Class

Veg Type ^a	N	Plots	Age Class, years	Ecosystem	g m ⁻²	Forbs	g m ⁻²	Shrubs	g m ⁻²	Trees	g m ⁻²	Deciduous	g m ⁻²	Evergreen	g m ⁻²	Ferns	g m ⁻²	Cryptogams	g m ⁻²	Total	g m ⁻²	Leaf Area Index	mg C m ⁻² hr ⁻¹	Standardized Isoprene Flux	mg C m ⁻² hr ⁻¹	Standardized Terpene Flux	µg C m ⁻² hr ⁻¹
gr	10	10	1-10		78 ± 4	23 ± 5	36 ± 6	0	0	0	0	0	0	0	0	0	0	25 ± 16	110 ± 30	1.2 ± 0.1	0.2 ± 0.2	0.8 ± 0.3	2 ± 1	48 ± 11	225 ± 43	785 ± 129	1948 ± 225
sh	10	10	10-25		23 ± 5	11 ± 2	66 ± 4	6 ± 4	0	0	0	0	0	0	0	0	0	76 ± 23	169 ± 25	2.4 ± 0.3	0.8 ± 0.3	4 ± 1	2 ± 1	48 ± 11	225 ± 43	785 ± 129	1948 ± 225
dw	10	10	25-100		9 ± 1	12 ± 2	54 ± 6	277 ± 50	63 ± 14	254 ± 43	0.1 ± <0.1	0	0	0	0	0	0	92 ± 31	498 ± 49	4.7 ± 0.1	1.7 ± 0.7	4 ± 1	2 ± 1	48 ± 11	225 ± 43	785 ± 129	1948 ± 225
df	11	11	100-200		5 ± 1	13 ± 2	45 ± 5	277 ± 50	63 ± 14	254 ± 43	0.1 ± <0.1	0	0	0	0	0	0	92 ± 31	498 ± 49	4.7 ± 0.1	1.7 ± 0.7	4 ± 1	2 ± 1	48 ± 11	225 ± 43	785 ± 129	1948 ± 225
ef	15	15	200-300		7 ± 2	17 ± 1	38 ± 5	100 ± 14	645 ± 76	23 ± 8	0	0	0	0	0	0	0	285 ± 13	1022 ± 69	5.7 ± 0.2	3.1 ± 0.5	1.1 ± 0.5	48 ± 11	225 ± 43	785 ± 129	1948 ± 225	1948 ± 225
mf	27	27	300-500		6 ± 1	12 ± 1	44 ± 5	68 ± 15	23 ± 8	0	0	0	0	0	0	0	0	541 ± 48	712 ± 41	2.7 ± 0.1	0.4 ± 0.1	0.5 ± 0.1	47 ± 20	102 ± 27	102 ± 27	102 ± 27	102 ± 27
pf	10	10	500-1000		10 ± 3	8 ± 1	44 ± 5	68 ± 15	23 ± 8	0	0	0	0	0	0	0	0	541 ± 48	712 ± 41	2.7 ± 0.1	0.4 ± 0.1	0.5 ± 0.1	47 ± 20	102 ± 27	102 ± 27	102 ± 27	102 ± 27
pe	5	5	1000+		4 ± 0.3	2 ± 1	15 ± 5	0	0	0	0	0	0	0	0	0	0	738 ± 58	902 ± 61	2.9 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	47 ± 20	102 ± 27	102 ± 27	102 ± 27	102 ± 27
gr	6	6	1-10		27 ± 5	23 ± 8	36 ± 6	0	0	0	0	0	0	0	0	0	0	25 ± 16	110 ± 30	1.2 ± 0.1	0.2 ± 0.2	0.8 ± 0.3	2 ± 1	48 ± 11	225 ± 43	785 ± 129	1948 ± 225
sh	13	13	10-25		9 ± 1	11 ± 2	66 ± 4	6 ± 4	0	0	0	0	0	0	0	0	0	76 ± 23	169 ± 25	2.4 ± 0.3	0.8 ± 0.3	4 ± 1	2 ± 1	48 ± 11	225 ± 43	785 ± 129	1948 ± 225
dw	18	18	25-100		10 ± 2	12 ± 2	54 ± 6	277 ± 50	63 ± 14	254 ± 43	0.1 ± <0.1	0	0	0	0	0	0	92 ± 31	498 ± 49	4.7 ± 0.1	1.7 ± 0.7	4 ± 1	2 ± 1	48 ± 11	225 ± 43	785 ± 129	1948 ± 225
df	11	11	100-200		5 ± 1	13 ± 2	45 ± 5	277 ± 50	63 ± 14	254 ± 43	0.1 ± <0.1	0	0	0	0	0	0	92 ± 31	498 ± 49	4.7 ± 0.1	1.7 ± 0.7	4 ± 1	2 ± 1	48 ± 11	225 ± 43	785 ± 129	1948 ± 225
ef	15	15	200-300		7 ± 2	17 ± 1	38 ± 5	100 ± 14	645 ± 76	23 ± 8	0	0	0	0	0	0	0	285 ± 13	1022 ± 69	5.7 ± 0.2	3.1 ± 0.5	1.1 ± 0.5	48 ± 11	225 ± 43	785 ± 129	1948 ± 225	1948 ± 225
mf	27	27	300-500		6 ± 1	12 ± 1	44 ± 5	68 ± 15	23 ± 8	0	0	0	0	0	0	0	0	541 ± 48	712 ± 41	2.7 ± 0.1	0.4 ± 0.1	0.5 ± 0.1	47 ± 20	102 ± 27	102 ± 27	102 ± 27	102 ± 27
pf	10	10	500-1000		10 ± 3	8 ± 1	44 ± 5	68 ± 15	23 ± 8	0	0	0	0	0	0	0	0	541 ± 48	712 ± 41	2.7 ± 0.1	0.4 ± 0.1	0.5 ± 0.1	47 ± 20	102 ± 27	102 ± 27	102 ± 27	102 ± 27
pe	5	5	1000+		4 ± 0.3	2 ± 1	15 ± 5	0	0	0	0	0	0	0	0	0	0	738 ± 58	902 ± 61	2.9 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	47 ± 20	102 ± 27	102 ± 27	102 ± 27	102 ± 27
gr	1	1	1-2		48	5	0	0	0	0	0	0	0	0	0	0	0	52	152 ± 31	2.7 ± 0.6	<0.1	<0.1	1	<0.1 ± <0.1	1	<0.1 ± <0.1	<0.1 ± <0.1
sh	3	3	2-10		13 ± 4	21 ± 10	69 ± 3	13 ± 7	33 ± 22	2 ± 2	0.1 ± <0.1	0.1 ± <0.1	0.1 ± <0.1	0.1 ± <0.1	0.1 ± <0.1	0.1 ± <0.1	1 ± 1	152 ± 31	2.7 ± 0.6	2.7 ± 0.6	0.3 ± 0.3	<0.1	1	<0.1 ± <0.1	1	<0.1 ± <0.1	<0.1 ± <0.1
dw	8	8	10-20		6 ± 2	7 ± 2	67 ± 15	446 ± 93	147 ± 39	3 ± 2	8 ± 4	679 ± 102	5.2 ± 0.2	4.9 ± 0.2	2.1 ± 0.2	1.5 ± 0.6	7.2 ± 5.5	461 ± 90	2.7 ± 0.6	2.7 ± 0.6	0.3 ± 0.3	<0.1	1	<0.1 ± <0.1	1	<0.1 ± <0.1	<0.1 ± <0.1
df	10	10	20-100		6 ± 2	9 ± 2	60 ± 7	446 ± 93	147 ± 39	3 ± 2	8 ± 4	679 ± 102	5.2 ± 0.2	4.9 ± 0.2	2.1 ± 0.2	1.5 ± 0.6	7.2 ± 5.5	461 ± 90	2.7 ± 0.6	2.7 ± 0.6	0.3 ± 0.3	<0.1	1	<0.1 ± <0.1	1	<0.1 ± <0.1	<0.1 ± <0.1
ef	33	33	100-300		1 ± 0.2	7 ± 1	58 ± 3	51 ± 14	435 ± 39	9 ± 2	22 ± 3	582 ± 44	4.9 ± 0.2	4.9 ± 0.2	2.1 ± 0.2	1.5 ± 0.6	7.2 ± 5.5	461 ± 90	2.7 ± 0.6	2.7 ± 0.6	0.3 ± 0.3	<0.1	1	<0.1 ± <0.1	1	<0.1 ± <0.1	<0.1 ± <0.1
mf	7	7	300+		0.3 ± 0.1	4 ± 0.3	35 ± 2	54 ± 25	96 ± 30	2 ± 1	167 ± 12	358 ± 47	2.1 ± 0.2	2.1 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2
df	9	9	100-200		8 ± 4	6 ± 2	39 ± 7	60 ± 25	79 ± 21	7 ± 3	111 ± 23	311 ± 22	4.0 ± 0.3	4.0 ± 0.3	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2
ef	10	10	200-300		9 ± 3	5 ± 1	30 ± 4	28 ± 14	215 ± 42	8 ± 2	87 ± 21	381 ± 51	4.3 ± 0.1	4.3 ± 0.1	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2
mf	36	36	300-500		4 ± 1	30 ± 4	30 ± 4	3 ± 2	286 ± 37	5 ± 1	128 ± 10	460 ± 35	4.3 ± 0.1	4.3 ± 0.1	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2
pf	6	6	500-1000		2 ± 6	4 ± 1	30 ± 4	3 ± 2	286 ± 37	5 ± 1	128 ± 10	460 ± 35	4.3 ± 0.1	4.3 ± 0.1	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2	2.4 ± 0.2
pe	5	5	1000+		1 ± 3	2 ± 3	2 ± 1	0	0	0.1 ± <0.1	817 ± 98	873 ± 94	2.4 ± 0.2	2.4 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2

^aVegetation type: gr, grassland; sh, shrubland; dw, deciduous woodland; df, deciduous forest; ef, evergreen forest; mf, moss forest; pf, peat forest; pe, peatland.

and we found no evidence of succession from peatland to *Populus* forest. This evidence can be seen in the oldest (500-1000 years) *Lithocarpus* forests (the so-called "dwarf forests") where we find peatland plants, particularly *Sphagnum* mosses, colonizing the forest floor. Also, in the dwarf forests along the margins of peatlands, the peat bog vegetation is overgrowing forest plants and soils. Here there is an abundance of dead and dying trees, with logs and stumps buried under the peat. Measured peat depths in these bogs range from 205 to 404 cm, which suggests that the oldest parts of these peatlands are several thousands of years in age.

[17] The successional patterns described here for China are consistent with successional studies elsewhere that show, in the absence of disturbance, pathways of ecosystem development going from evergreen forest to peat forest to peatland [Klinger *et al.*, 1990; Klinger, 1996a, 1996b; Klinger and Short, 1996]. However, other studies suggest different successional pathways and relationships among the ecosystem types described here, thus leaving the matter open to further investigation.

3.3. Leafy Biomass, Leaf Area, and VOC Emissions

[18] Mean values of leafy biomass, leaf area, and VOC emissions according to successional status of plots in each of the study areas are also listed in Table 3. The biomass values reported here are generally consistent with values reported from comparable sites in China. Measured leafy biomass of *Stipa*-dominated grasslands in northern China is reported by Gao and Yu [1998] as 153 g (leaf dry weight) per m⁻² (ground area) compared to 109 g m⁻² determined in this study. At Changbai Mountain, Xu *et al.* [1985] reported canopy leafy biomass values of 262 and 269 g m⁻² for two deciduous forest types, and 240 and 326 g m⁻² for two evergreen forest types, compared to canopy leafy biomass for deciduous forests of 340 g m⁻² and for evergreen forests of 353 g m⁻² measured here. Cao *et al.* [1995] reported cryptogam biomass of 400 to 558 g m⁻² for moss forests and 534 g m⁻² for a peatland compared to values of 351 and 480 g m⁻² measured here, respectively. Shao *et al.* [1992] found an herb (graminoid + forb) leafy biomass of 42.2 g m⁻² in deciduous forest compared to 17.5 g m⁻² found here. Tree leaf biomass reported for a Xishuangbanna primary rain forest is 791 g m⁻² [Dang *et al.*, 1997] compared to tree leaf biomass of primary rain forest found here to be 486 g m⁻². Estimates of leafy biomass for subtropical broad-leaved evergreen forest, similar to Ailao Mountain forests, range from 128 [Chen *et al.*, 1993] to 346 g m⁻² [Qiu *et al.*, 1984], compared to 243 g m⁻² reported here. At Ailao Mountain, Qiu *et al.* [1984] reported moss forest canopy leafy biomass of 346 g m⁻² compared to 289 g m⁻² here.

[19] The only comparable measurements of LAI found in the literature are for the Changbai Mountain region, reported as 6.9 for deciduous forest and 4.7 for evergreen forest [Xu *et al.*, 1985], compared to values found here of 4.7 and 5.2, respectively. There are no known measurements of VOC emissions for comparable forests in China.

[20] Figure 1a shows the mean values of total leafy biomass for each plot according to successional stage. The trend in group means shows that leafy biomass of plants increases sigmoidally with ecosystem age, consistent with Odum's [1971] principles of ecosystem development. While the curve in Figure 1a shows leafy biomass continuing to increase

during succession, Table 3 indicates that the leafy biomass in later successional stages is composed largely of cryptogams.

[21] Calculated isoprene and monoterpene emissions for each plot according to successional stage are shown in Figures 1b and 1c. Isoprene values were adjusted for leaf area index and standardized for a sun zenith angle of 57 degrees, an above-canopy PAR of 1500 $\mu\text{moles m}^{-2} \text{s}^{-1}$, and a leaf temperature of 30°C. The curve of isoprene mean group values indicates that isoprene emissions are highest in the early successional forest stages (3–4 mg C m⁻² hr⁻¹) and drop to lower levels in the late successional forests and peatlands (0.1–2 mg C m⁻² hr⁻¹). The group means for monoterpene emissions indicate highest monoterpene emissions (~2 mg C m⁻² hr⁻¹) in the late successional moss forests and declining somewhat in the peatland stages. These patterns are very similar to those found in previous successional studies of VOC emissions in Africa [Klinger *et al.*, 1998], in North America [Guenther *et al.*, 1999a; Helmig *et al.*, 1999b], and in Europe [Schaab *et al.*, 2000].

3.4. VOC Emission Estimates for China

[22] VOC emissions for all of China were computed using the model of Guenther *et al.* [1995], parameterized and modified for China in the following ways. The percentage of forest types by province was calculated from forest inventory results reported by Wu [1997]. From this inventory we utilized data on two forest classifications to arrive at province-level forest composition and cover (Table 4). One data set provided province-level areas for the following categories: coniferous forest, broadleaved forest, bamboo forest, economic forest, total forest, and total area. A second data set gave provincial presence-absence and nationwide percentage cover for 15 forest types: *Quercus*, *Betula*, *Populus*, *Larix*, *Picea*, *Abies*, *Cunninghamia lanceolata*, *Pinus massoniana*, *P. tabulaeformis*, *P. yunnanensis*, mixed conifer, mixed broadleaf, broadleaf, sclerophyll, and other. These latter forest types were condensed to 12 by combining the three *Pinus* types to a single *Pinus* type and combining the *Abies* and *Cunninghamia lanceolata* types to a single fir type. The first data set provided area-weighted indices for these 12 forest types according to the percentage composition of "conifer," "broadleaf," or "other" ("bamboo" + "economic") forest cover. Characterizations of species composition, leafy biomass density, and emissions data collected at the Changbai, Xishuangbanna, and Ailao locations in areas representative of nearly all these forest types were then applied to the values in Table 4. The results (Table 5) show the canopy leafy biomass, isoprene emission factors, monoterpene emission factors, and emission factors of other volatile organic compounds (OVOCs) calculated from *N* samples (plots) in each forest type, except sclerophyll forest. OVOC emission factors were based on a value of 1.5 $\mu\text{g C g}^{-1} \text{hr}^{-1}$ assigned for all canopy species [Geron *et al.*, 1994]. These results were then used to weight, proportional to the magnitude of leafy biomass and emission rates, the forest emission factors for each province in the regional VOC emissions model of Guenther *et al.* [1999b]. Inputs of temperature and light in the Guenther model are based on monthly average values from a 0.5° × 0.5° gridded meteorological database.

[23] Model results of VOC annual emissions from forested areas of China by province are given in Table 6. These

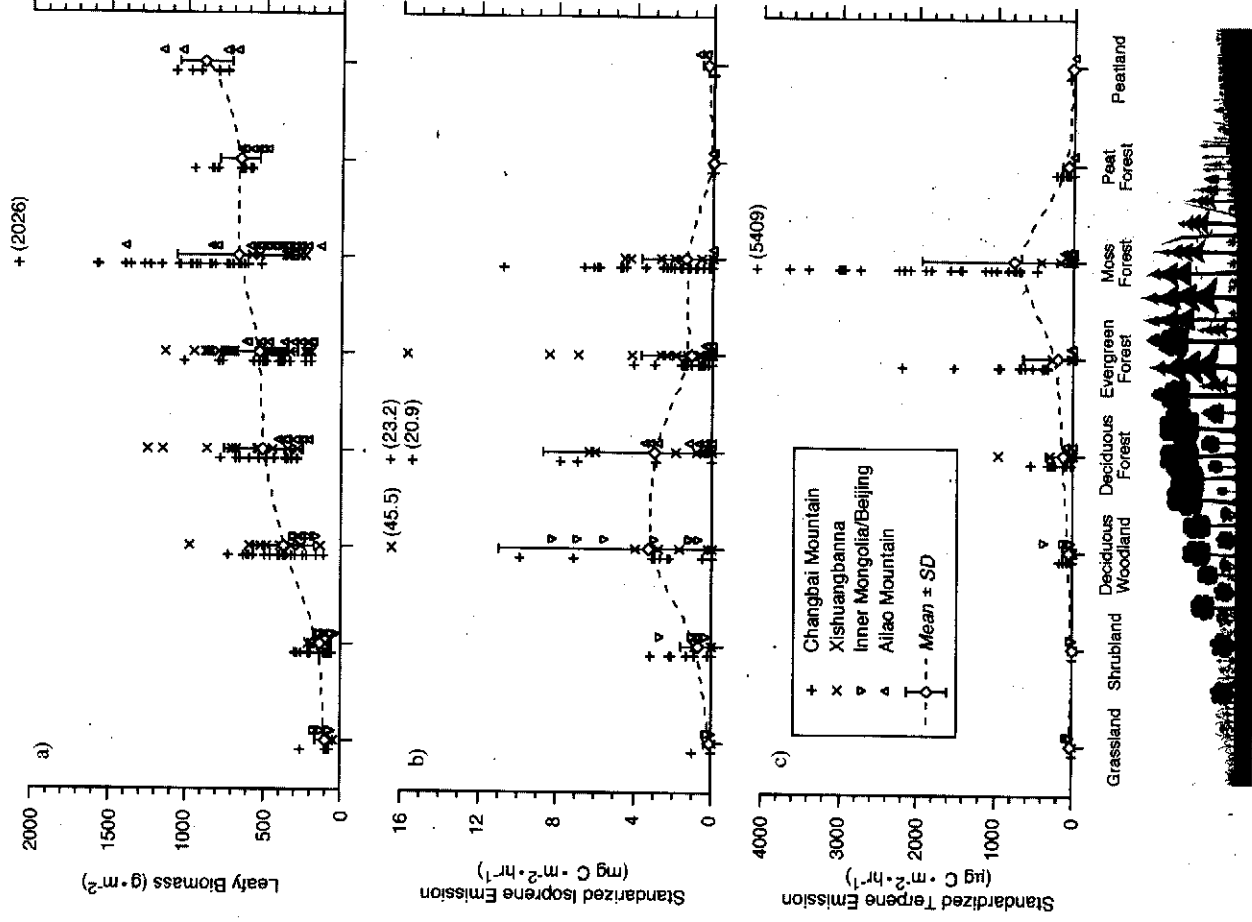


Figure 1. Individual plot means and group means ($\pm$ S. D.) of (a) total leafgreen biomass, (b) standardized isoprene emissions, and (c) standardized monoterpene emissions for all plots grouped according to successional stage.

results give annual VOC emissions for China (except Taiwan) of 4.1 Tg C as isoprene, 3.5 Tg C as monoterpenes, and 13 Tg C as OVOCs. The isoprene emissions found in this study are substantially lower than the value of 15.0 Tg C yr^{-1} of isoprene obtained using the Guenther *et al.* [1995] model (Table 7). This discrepancy is mainly due to the differences in model input values for the forest cover and isoprene emission factors, which Guenther *et al.* [1995] obtained from data sets that contained little or no information specific to China on forest species composition or VOC emissions. The isoprene + monoterpene annual emissions of 7.6 Tg C found here are similar to the isoprene + monoterpene annual emissions of 8.3 Tg C calculated for China

by Bai *et al.* [1995] using an extrapolation method based on branch measurements of VOC emissions from 15 representative tree species. The annual biogenic VOC emissions are considerably higher than the annual anthropogenic VOC emissions reported for China to be 5.3 Tg C [Piccot *et al.*, 1992], although we expect that the relative amounts of anthropogenic and biogenic emissions vary widely from region to region in China.

[24] Figures 2a, 2b, and 2c show the distribution across China of modeled July noonday emission rates of isoprene, monoterpenes, and OVOCs, respectively. These figures reveal marked differences in distributions and rates of VOC emissions compared to those shown by Guenther *et*

Table 4. Percentage of Forested Area of the 12 Forest Types Used in the Emission Estimates Listed by Province

Province	Forested Area, km ²	Forest Type											
		Betula	Broadleaf	Fir	Larix	Mixed Broadleaf	Mixed Needleleaf	Other ^a	Picea	Pinus	Populus	Quercus	Sclerophyll
Anhui	22561	0	4.8	18.3	0	0	0	27.2	0	23.0	5.9	14.0	6.8
Beijing	2671	9.2	0	0	9.3	0	0	45.5	0	7.0	6.0	15.9	7.1
Fujian	61484	0	8.4	23.2	0	0	0	23.9	0	29.1	0	15.3	0
Gansu	19486	12.0	4.7	4.6	8.1	8.0	4.2	10.5	5.3	4.4	6.7	23.0	8.6
Guangdong	65431	0	7.6	19.1	0	9.0	11.0	18.7	0	25.4	0	0	9.2
Guangxi	60217	0	6.0	13.5	0	0	0	20.4	0	26.7	7.3	17.5	8.5
Guizhou	26028	6.5	2.5	14.5	0	4.4	7.1	15.7	0	28.5	3.7	12.5	4.7
Hainan	10663	0	26.0	0.8	0	29.0	0	43.2	0	1.0	0	0	0
Hebei	24806	8.7	3.4	0	5.4	5.9	3.1	38.5	3.8	3.2	4.9	16.8	6.2
Heilongjiang	161620	12.1	4.7	7.8	12.6	8.1	7.2	0.3	8.7	0	6.8	23.2	8.6
Henan	17527	0	0	4.6	4.6	0	0	25.2	0	8.7	13.5	28.2	15.1
Hubei	39522	7.9	3.6	14.1	10.2	0	0	15.7	0	23.4	4.8	14.3	5.9
Hunan	69490	0	1.7	16.7	0	0	0	39.9	0	32.0	2.1	5.1	2.5
Inner Mongolia	140657	12.9	6.0	0	14.1	0	0	6.2	10.5	9.4	7.9	23.4	9.7
Jiangsu	4122	0	3.4	14.9	0	0	0	44.3	0	18.7	4.1	9.8	4.7
Jiangxi	67277	0	3.0	24.3	0	4.1	0	25.0	0	30.4	0	8.9	4.3
Jilin	63469	14.5	5.6	5.0	8.0	9.7	4.6	0.7	5.6	0	8.1	27.8	10.4
Liaoning	39186	9.2	3.6	3.7	6.4	6.2	3.3	30.8	4.2	3.5	5.1	17.6	6.6
Ningxia	1020	15.3	7.1	0	6.0	0	0	18.4	0	4.6	9.4	27.7	11.5
Qinghai	2501	15.7	0	14.9	24.0	0	0	1.4	16.6	14.2	13.3	0	0
Shaanxi	12700	10.9	5.0	0	14.9	0	0	13.6	11.1	9.9	6.7	19.7	8.2
Shandong	16288	0	0	0	9.7	0	0	60.6	0	7.3	5.3	11.1	6.0
Shanghai	147	0	0	0	0	0	19.7	78.9	0	0	0	0	1.4
Shanxi	49735	15.7	7.2	4.8	3.4	0	0	12.9	0	6.3	9.6	28.4	11.8
Sichuan	115318	5.8	2.7	16.7	12.5	0	0	10.3	5.8	28.0	3.5	10.5	4.3
Taiwan	19695							(data not available)					
Tianjing	858	0	7.4	0	0	0	0	46.7	0	4.8	9.0	21.6	10.5
Tibet	71699	0	0	24.6	0	9.5	0	0	26.5	23.9	0	15.4	0
Xinjiang	13056	11.4	7.2	16.7	24.4	0	0	4.3	18.1	0	8.4	0	9.4
Yunnan	94042	8.9	3.4	18.5	12.2	5.9	0	8.5	7.4	6.7	5.0	17.0	6.3
Zhejiang	43759	0	1.3	26.1	0	0	0	32.4	0	32.8	1.6	3.9	1.9
Total	1337035	8.5	3.6	11.3	8.4	5.8	2.1	10.5	3.9	18.9	5.0	15.9	6.2

^a mainly economic and bamboo forest areas.

al. [1995]. Our results differ mostly with respect to isoprene emissions, which here are highest mainly in the temperate woodland savannas and forests of central and northeastern China. *Guenther et al.* [1995] report the highest isoprene emissions occurring in the subtropical and tropical forests of southeast China, at overall rates several times higher than we find here. Overall monoterpene and OVOC emissions for China are shown here to be near or slightly lower than those reported by *Guenther et al.* [1995], with the highest emissions coming similarly from the subtropical forests of

southeast China. Our results, however, show monoterpene and OVOC emissions to be relatively high in the temperate and boreal forest areas of central and northeast China compared to the results of *Guenther et al.* [1995].

4. Discussion

4.1. VOC Emissions and Ecosystem Succession

[25]. The above results extend to China the occurrence of a successional pattern in VOC emissions where the highest

Table 5. Assigned Biomass and Emission Factors for China Forest Types

Forest Type	N Plots ^a	Canopy Leafy Biomass, g m ⁻²	Emission Factors		
			Isoprene, $\mu\text{g C m}^{-2} \text{ hr}^{-1}$	Terpene, $\mu\text{g C m}^{-2} \text{ hr}^{-1}$	OVOC, $\mu\text{g C m}^{-2} \text{ hr}^{-1}$
<i>Betula</i>	9	259	1960	24.6	388
Broadleaved	108	426	2990	36.4	639
Fir	7	430	3160	1040	644
<i>Larix</i>	16	174	221	188	261
Mixed Broadleaved	20	274	725	68.3	411
Mixed Needleleaved	11	440	2310	831	660
Other ^b	-	350	1860	52.3	525
<i>Picea</i>	19	792	9530	2220	1190
<i>Pinus</i>	11	448	1300	870	672
<i>Populus</i>	11	266	5980	270	399
<i>Quercus</i>	4	423	23600	202	634
Sclerophyll	0	n.m. ^c	n.m.	n.m.	n.m.

^a number of plots used in calculation of assigned factors.^b average of broadleaved and mixed broadleaved forest types.^c not measured.

Table 6. Forest Area, Leafy Biomass, and Estimated Annual VOC Emissions by Province

Province	Total Area, km ²	Forest Area, km ²	Tree Leaf Biomass of Forest Areas, g m ⁻²	Isoprene Emissions, 10 ⁹ g C yr ⁻¹	Monoterpene Emissions, 10 ⁹ g C yr ⁻¹	OVOC ^a Emissions, 10 ⁹ g C yr ⁻¹
Anhui	138165	22561	372	92.5	82.7	359
Beijing	17821	2671	314	13.9	7.80	26.3
Fujian	121500	61484	414	140	205	366
Gansu	449734	19486	338	167	119	482
Guangdong	177901	65431	367	103	159	596
Guangxi	237600	60217	368	195	129	709
Guizhou	176471	26028	378	80.5	70.5	370
Hainan	34104	10663	349	16.8	12.0	124
Hebei	185879	24806	339	99.2	50.9	321
Heilongjiang	454608	161620	346	328	257	517
Henan	167000	17527	310	97.7	50.3	403
Hubei	185862	39522	347	139	132	435
Hunan	211835	69490	389	113	159	505
Jiangsu	102600	4122	370	21.2	16.0	216
Jiangxi	166723	67277	390	116	201	447
Jilin	188869	63469	329	152	51.7	235
Liaoning	145739	39186	342	89.7	33.1 ^c	221
Inner Mongolia	1158402	140657	350	528	344	1518
Ningxia	66400	1020	307	28.3	12.9	96.3
Qinghai	721514	2501	381	56.5	53.1	346
Shaanxi	156623	12700	357	204	157	396
Shandong	152221	16288	323	38.9	27.8	345
Shanghai	5956	147	363	0.02	0.02	0.27
Shanxi	205977	49735	317	86.4	81.0	253
Sichuan	566079	115318	381	245	351	786
Taiwan	35760	19695	n.a. ^b	n.a.	n.a.	n.a.
Tianjing	11493	858	332	2.59	1.42	22.2
Xinjiang	1647000	13056	356	398	197	1487
Tibet	1228436	71699	514	61.1	92.7	424
Yunnan	382644	94042	359	382	288	746
Zhejiang	101800	43759	399	62.6	120	257
All China	9602716	1337035	360	4057	3462	13010

^a OVOC, other volatile organic compound.^b data not available.

isoprene emissions occur in pioneer and early secondary forests, and the highest monoterpene emissions occur in late secondary and primary forests [cf. Li and Klinger, 2001]. Lower isoprene and monoterpene emissions are found in early successional grasslands and late successional peatlands. We suggest that the systematic patterns in the VOC emissions found here in the forests and peatlands of China and elsewhere [Klinger *et al.*, 1994, 1998; Guenther *et al.*, 1999a; Helmig *et al.*, 1999b; Isebrands *et al.*, 1999; Schaab *et al.*, 2000; Westberg *et al.*, 2000] are indicative of deterministic, self-organizing behavior in ecosystems, consistent with theories and concepts in systems ecology, complexity, and Gaia theory [Lovelock, 1995]. The validity of this view, as applied to the ecosystems of China, is backed by several Chinese ecologists [Han, 1992; Chang, 2000]. From a systems perspective, the successional patterns in isoprene found here point toward a possible func-

tional role of isoprene at the ecosystem level. As postulated by Klinger *et al.* [1998], isoprene may enhance the formation of available nitrogen (N) in the canopy atmosphere, thus promoting the assimilation of N into an N-limited early successional forest ecosystem.

4.2. VOC Emissions From China

[26] Refining the magnitudes and distributions of biogenic VOC emissions in China is important in order to better understand potential feedbacks of these emissions on the vegetation via ozone. Ozone levels are found to be high in several urban and nonurban areas of China and may be affecting crop yields [Chameides *et al.*, 1999; Shao *et al.*, 2000]. Models indicate that biogenic VOCs significantly affect ozone production in these regions [Luo *et al.*, 2000; Shao *et al.*, 2000] and may even be limiting for ozone production in the rural areas of northern China. Our results

Table 7. Comparison of Regional and Global VOC Emission Estimates

Region	Area, 10 ⁶ km ²	Isoprene Emissions, Tg C yr ⁻¹	Monoterpene Emissions, Tg C yr ⁻¹	OVOC Emissions, Tg C yr ⁻¹	Area Average Isoprene Emiss., g C m ⁻² yr ⁻¹	References
China	9.6	4.1	3.5	13	0.43	This study
China	9.6	15.0	4.3	9.1	1.56	Guenther <i>et al.</i> [1995]
Europe	9.9	4.6	3.9	5.0	0.46	Simpson <i>et al.</i> [1999]
North America	24.7	29.3	21.0	33.6	1.19	Guenther <i>et al.</i> [2000]
Central Africa	4.54	35.4	-	-	7.80	Guenther <i>et al.</i> [1999b]
Central South America	14.2	108	12	-	7.61	Greenberg <i>et al.</i> [1999b]
Global (Land)	146.8	503	127	517	3.43	Guenther <i>et al.</i> [1995]

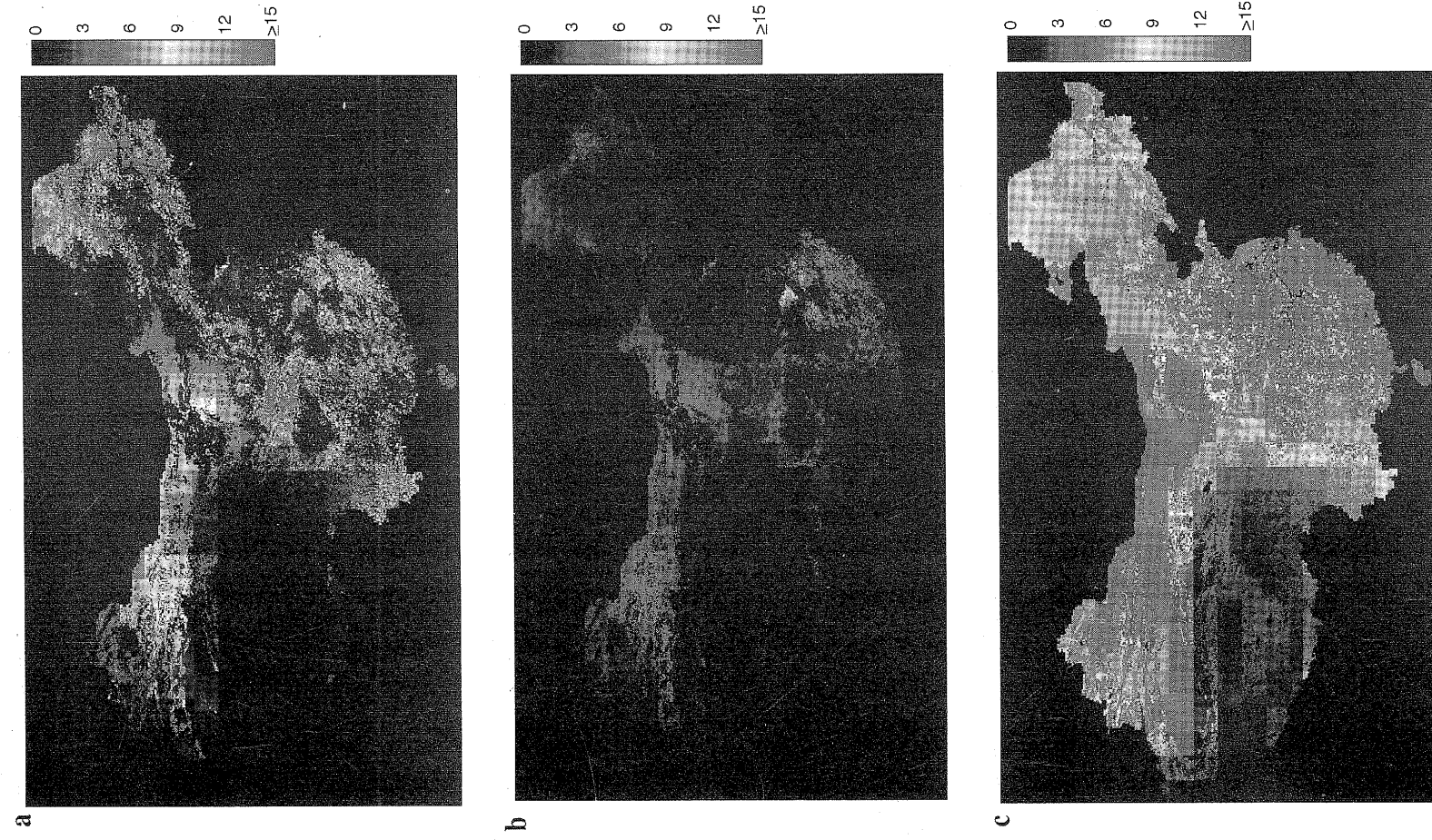


Figure 2. Modeled average July noonday emissions ($\text{mg C m}^{-2} \text{ d}^{-1}$) for China of (a) isoprene, (b) monoterpenes, and (c) other volatile organic compounds.

give higher-than-previous estimates of isoprene emission for northern China, and hence greater potential for ozone production there.

[27] Comparing our VOC emission estimates for China with estimates for Europe, central Africa, central South America, and North America (Table 7), we find that China and Europe are quite similar with respect to isoprene and monoterpene emissions. Our OVOC emission estimates for China, however, are considerably higher than those for Europe, reflecting the large extent of grasslands in China. North America, central Africa, and central South America exhibit higher isoprene emissions on a per-area basis than do China and Europe, suggesting that early successional forest cover is relatively high in the former regions. Discrepancies between our VOC emission results and those of Guenther *et al.* [1995] for China (Table 7), as in the fourfold difference in isoprene emissions discussed in section 3.3, highlight the importance of conducting field studies in regions that are poorly characterized with respect to forest cover and VOC emissions.

4.3. Uncertainties

[28] The major uncertainties of these findings arise from observational errors in plot measurements and from inaccuracies of key assumptions used in the extrapolation. Uncertainty in the VOC emission potential assigned for a given species can occur from species misidentification, from inaccurate determinations of VOC emission, and from an unrealized discrepancy between assigned versus actual emission potentials. Such a discrepancy can result from assigning unmeasured species of a given genus the same emission potential as the measured species. Error from misidentification is likely quite low as botanical experts were employed for all identifications. The frequency of incorrect assessment of emission potentials (i.e., determining the emission potential of a plant is high when it is actually moderate), based on comparing PID screening results with leaf cuvette method, is about 10% [Klinger *et al.*, 1998]. It is possible that some plants identified as isoprene emitters with the PID may instead be emitting monoterpenes or methyl butenol in a light-dependent manner. *Hevea brasiliensis* (rubber tree), for example, exhibits light-dependent VOC emissions which, when sampled using the leaf cuvette/GC-MS method, are found to be mainly monoterpenes. However, in other plants with light-dependent monoterpene emissions, the values tend to be low [Kesselmeier *et al.*, 1996]. Methyl butenol emissions have been found only in the *Pinus* species of North America. Because the pines here were found to have low or no isoprene emissions, it appears that methyl butenol is not contributing to any overestimate in isoprene emissions. Uncertainty of assigned versus actual emission potentials, based on the degree to which species' emission potentials were derived from genus assignments versus actual measurements, is estimated at 10% for Changbai Mountain, 20% for Ailao Mountain, and 25% for Xishuangbanna. As discussed in section 3.2, there is an added uncertainty (10%) in the emission potentials of the nonwoody vegetation.

[29] Uncertainties in the determination of vegetation abundance (LAI and leafy biomass) arise from both error in measurement and error in the forest algorithms. The

optical sensing methods employed for LAI are accurate to about 20% for the range of LAIs found in this study. The forest algorithms are not reported with uncertainty levels, so their error, based on comparing our leafy biomass results with other studies in China (see section 3.2), is estimated to be 20% for trees and 50% for understory vegetation (mainly as an underestimation).

[30] The VOC emission estimates for China rely largely on the accuracy of the national forest inventory data [Wu, 1997], on the degree to which our plots are representative of a given forest type, and on the validity of model assumptions. All of our study sites were located with the assistance of local scientists in typical forest types in and around ecological research stations of the Chinese Academy of Sciences. An uncertainty factor of about three has been associated with regional model estimates of biogenic VOC emission rates, but this uncertainty is not based on a quantitative evaluation. The error associated with emissions predicted for a specific landscape can be evaluated using above-canopy eddy flux measurements [e.g., Guenther and Hills, 1998], but there is currently no method for evaluating or even constraining these flux estimates. The uncertainties associated with specific model procedures can be evaluated for particular circumstances, such as a quantitative test of the response of isoprene emission to changes in temperature, but it is not possible to assign rigorous uncertainty estimates to the regional results because of the limited data. A factor of three is probably a reasonable estimate of the uncertainty associated with annual total VOC estimates for China, but predictions for specific times, locales, and compounds can be much more uncertain.

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