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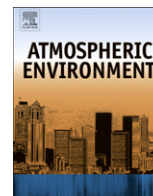
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A biogenic volatile organic compound emission inventory for Hong Kong

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ABSTRACT

Biogenic volatile organic compounds (BVOCs) in the atmosphere react to form ozone and secondary organic aerosols, which deteriorate air quality, affect human health, and indirectly influence global climate changes. The present study aims to provide a preliminary assessment of BVOC emissions in Hong Kong (HKSAR). Thirteen local tree species were measured for their isoprene emission potential. Tree distribution was estimated for country park areas based on field survey data. Plant emission data obtained from measurements and the literature, tree distribution estimation data, land use information, and meteorological data were combined to estimate annual BVOC emissions of 8.6×10^9 gC for Hong Kong. Isoprene, monoterpenes, and other VOCs contributed about 30%, 40%, and 30% of the estimated total annual emissions, respectively. Although hundreds of plant species are found in Hong Kong country parks, the model results indicate that only 10 tree species contribute about 76% of total annual VOC emissions. Prominent seasonal and diurnal variations in emissions were also predicted by the model. The present study lays a solid foundation for future local research, and results can be applied for studying BVOC emissions in nearby southern China and Asian regions that share similar climate and plant distributions.

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1. Introduction

Air pollution is drawing more attention than ever before from the Government as well as the general public of Hong Kong, as various negative impacts of poor air quality have been recognized, ranging from increased incidents of pulmonary diseases in the population, to its adverse effects on economy and tourism. Volatile organic compounds (VOCs) play an important role in air pollution in Hong Kong. VOC emissions from anthropogenic sources (AVOCs), such as power plant and road traffic have been well studied (e.g., Guo et al., 2007). However, little is known about VOC emissions from biogenic sources in Hong Kong.

Vegetation is the primary source of biogenic volatile organic compounds (BVOCs) which include terpenoids (e.g., isoprene and monoterpenes), hexenal family compounds (hexenals, hexenols, and hexenyl esters), methanol, and acetone (Guenther et al., 2000). In the presence of sunlight and nitrogen oxides (NO_x), reaction of VOCs contributes to the formation of ozone (O_3) (Atkinson, 2000; Fuentes et al., 2000). The impact of BVOC on O_3 formation becomes more prominent in summer, when both photochemical activity and BVOC emissions reach the peak.

Tropospheric O_3 is a greenhouse gas. In addition, through its chemical impact on hydroxyl radical (OH), it modifies the lifetimes of other greenhouse gases, such as methane (CH_4) (IPCC, 2001). Hence, climate change is indirectly promoted by BVOC emissions. O_3 also adversely affects public health. Exposure to ozone reduces pulmonary function, causes cough and chest tightness (Abelsohn et al., 2002), and exacerbates asthma (Watson and Sheppard, 2005). Local studies show significant association between O_3 and hospital admission due to respiratory diseases (Wong et al., 1999; Lee et al., 2006). Studies also suggest that elevated O_3 concentration would lead to increase in total, cardiovascular and respiratory mortality (Zhang et al., 2006; Zeller et al., 2006; Bell et al., 2007).

Photooxidation of isoprene (Claeys et al., 2004) and monoterpenes (Hoffmann et al., 1997; Kavouras et al., 1998) also contributes to the formation of secondary organic aerosol (SOA). Atmospheric aerosols play a critical role in climate change by modifying the radiative balance of the atmosphere by scattering or absorbing solar radiation (IPCC, 2001). It is estimated that organics contribute ~20–50% of total fine aerosol mass on a global scale and as high as 90% in tropical forested areas (Andreae and Crutzen, 1997; Kanakidou et al., 2005) where biomass burning and biogenic sources dominate.

Biogenic VOCs are typically more reactive than AVOCs (Abelson, 1988), and their reactivity has been estimated to be two to three times that of their counterparts from gasoline combustion (Carter, 1994).

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Therefore, they can adversely affect air quality, even when emitted at lower rates than AVOCs. Furthermore, they represent background emissions that should not be considered for any emission control measures. Hence, any VOC emission control policy will be in vain if most of the VOC emissions in a region are from biogenic sources. The role of BVOCs in the environment and air quality highlight the need for accurately characterizing BVOC emissions in Hong Kong.

Hong Kong (The Hong Kong Special Administrative Region of the People's Republic of China, HKSAR) (22°17'N, 114°08'E) is one of the two special administrative regions (SARs) of the People's Republic of China (PRC). It is on the southeastern coast of China, facing the South China Sea in the south, and bordering Guangdong Province in the north. Hong Kong's climate is subtropical, it is cool and dry in winter, hot, humid and rainy from spring through summer, and is warm, sunny, and dry in autumn.

Although Hong Kong is a relatively small region (1108 km²; Planning Department, Hong Kong, 2005) and is densely populated (7,041,000) (2005 estimate), vegetative areas, i.e., woodland and shrubland, account for a high proportion (40%) of the total Hong Kong areas (447 km²; Planning Department, 2005). Its flora is highly diverse, with 3164 native and introduced vegetation species and varieties (Hong Kong Herbarium, 2004). Vegetation is predominantly tropical (Dudgeon and Corlett, 2004).

The aim of the present study is to develop a capacity for investigating and understanding of BVOC emissions in Hong Kong. Isoprene emission rates of 13 Hong Kong tree species were measured. A BVOC emission inventory was established, and spatial and temporal distributions of BVOC emissions in Hong Kong were estimated.

2. Methodology

2.1. Measurement of isoprene emissions from 13 Hong Kong tree species

Isoprene emission rates of 13 tree species were measured by a static enclosure measurement approach. A branch of one seedling of each species being investigated was enclosed in a glass chamber at a temperature of 30 °C and light intensity 1000 μmol m⁻² s⁻¹ for 1 h. Light was supplied by two white light sources at left and right sides of the glass chamber. The enclosure system was housed in a growth chamber (Conviron, ND, USA) for temperature control, and variation of temperature was maintained not exceeding 1 °C throughout the experiments. Humidity in the glass chamber could not be controlled. Therefore, enclosure period was limited to 1 h to reduce humidity change. Temperature inside the chamber was monitored by a temperature probe, while light intensity was measured by a photometer. Measurements were repeated with the same branch of the seedling to reduce sample-to-sample variability. Isoprene emissions were sampled by solid-phase micro-extraction sampler (SPME) equipped with carboxen/polydimethylsiloxane (CAR/PDMS) fiber (Supelco, MO, USA) (Deng et al., 2004) for 10 min, and transferred to a HP 5890 gas chromatograph with flame ionization detector (GC-FID) (Hewlett-Packard Inc., Avondale, PA, USA). The VOCs on the SPME fiber were desorbed at the GC injection port for 5 min at 250 °C, and VOCs were separated on a DB-5MS (30 m length, 0.25 mm i.d.) capillary column (Agilent, CA, USA). The initial temperature of the GC oven was held at 30 °C for 3 min, then programmed to increase to 125 °C at 4 °C min⁻¹ and then to 250 °C at 10 °C min⁻¹. The final temperature (250 °C) was held for 10 min. Nitrogen was used as carrier gas at a flow rate of 2.1 ml min⁻¹ with a 1:7 split ratio.

Calibration of the SPME-GC-FID system was conducted before the analysis using a standard gas mixture (Scientific and Technical Gases Limited, Staffordshire, UK), which consisted of isoprene and four other terpenoid species at 1 ppm.

Isoprene detection by GC-FID was confirmed by GC-MS analysis. BVOCs emitted from *Eucalyptus robusta* were analyzed by a HP6890 gas chromatograph with mass spectrometry detector (GC-MS) (Hewlett-Packard Inc., Avondale, PA, USA). The same column and program for controlling oven temperature in GC-FID analysis was used in the GC-MS analysis. Measurements taken from a blank enclosure system demonstrated that the glass chamber was not releasing any hydrocarbons.

2.2. Construction of a BVOC emission model for Hong Kong

The Hong Kong land area (1100 km²) was divided into grid cells of area 0.01 km² using the ESRI ARCMAP GIS program. Hong Kong areas were divided into two major categories: country park areas and non-country park areas, which account for 37% and 63% of the total Hong Kong area (Planning Department, Hong Kong, 2005), respectively. Different land cover approaches were used to characterize vegetation in the two categories.

Land cover of country park areas were represented in term of their tree distribution, which was estimated based on two sets of field survey data. The first set of data was provided by the HKSAR Sustainable Development Unit (SDU) which composed of 137 records of visits to areas in various country parks. The second set of field surveys was conducted by the survey team of the Department of Botany, The University of Hong Kong (Botany, HKU). The survey team made 65 visits to the country park areas that had not been visited by SDU. As a result, a complete set of site visit data covering all Hong Kong country parks was generated by combining the records from these two sources. Tree distributions in country parks were estimated by extrapolating site visit data, assuming even tree distribution within the area of each of the country park.

Due to limited information on tree cover and speciation, and the lack of clear boundaries of vegetative areas in non-country park areas, a quantitative tree distribution estimate could not be performed for these areas. Land covers of non-country park areas were instead described in terms of 16 different land use types based on data provided by HKSAR Planning Department (2004).

BVOC emission factors were assigned to country park areas according to the contribution of each tree species to the total tree cover of the area. Standard emission factors of isoprene, total monoterpene (TMT) and other volatile organic compounds (OVOCs) were assigned to 148 Hong Kong tree species. Thirteen tree species, for which isoprene emission rates were measured in this study, were assigned the measured values compiled in Table 1. For monoterpene emission rates of the 13 species, and isoprene and monoterpene emission rates of all other species, measurement values reported in the literature (listed under Table 4) were assigned by the taxonomic approach (Benjamin et al., 1996; Karlik et al., 2002) as follows: for species with reported emission rate measurements, the individual or mean (if there were more than one measurement reported) emission rate for the species was assigned. If no measurements were reported for a species, but emission rates of other species within the same genus were reported, the mean value for that genus was assigned to the unmeasured species. If no measurement was reported for any of the species within the genus, but measurements for other species within the family were reported, then the mean emission rate for the family was assigned to the species. Finally, for species with no measurement reported for any species within a family, it was not assigned with an emission rate. As the emission rates of other VOCs (OVOCs) of plants are highly uncertain and pending further investigations, the value of 1.5 μg C g⁻¹ h⁻¹, recommended by Guenther et al. (1994), was assigned to all plant species.

BVOC emission factors for non-country park areas were assigned based on land use types of the areas. The 16 land use types

Table 1
Isoprene emission rates of 13 Hong Kong tree species

Genus_species	Family	Mean emission rate ($\mu\text{g C g}^{-1} \text{h}^{-1}$)	Literature value ($\mu\text{g C g}^{-1} \text{h}^{-1}$)	Reference
<i>Acacia confusa</i>	Mimosaceae	UD	0.17	Baker et al. (2005)
<i>Bauhinia variegata</i> var. <i>candida</i>	Caesalpiniaceae	20±2.4	70	Klinger et al. (2002)
<i>Castanopsis fissa</i>	Fagaceae	UD	0	Klinger et al. (2002)
<i>Cinnamomum burmannii</i>	Lauraceae	2.5±0.1	0	Baker et al. (2005)
<i>Cinnamomum camphora</i>	Lauraceae	UD	0	Baker et al. (2005)
<i>Cyclobalanopsis edithiae</i>	Fagaceae	UD	N/A	N/A
<i>Eucalyptus citriodora</i>	Myrtaceae	6.4±1.1	48.9±5.4	He et al. (2000)
<i>Eucalyptus robusta</i>	Myrtaceae	10±1.1	44±12.5	He et al. (2000)
<i>Eucalyptus torelliana</i>	Myrtaceae	4.2±0.6	N/A	N/A
<i>Ficus hispida</i>	Moraceae	3.3±0.7	29.9	Klinger et al. (2002)
<i>Ficus microcarpa</i>	Moraceae	UD	1.41	Klinger et al. (2002)
<i>Mallotus paniculatus</i>	Euphorbiaceae	UD	2.28	Klinger et al. (2002)
<i>Macaranga tanarius</i>	Euphorbiaceae	UD	0	Baker et al. (2005)

All measurements were conducted at $1000 \mu\text{mol m}^{-2} \text{s}^{-1}$ and 30°C . Emission rates are expressed as mean±standard deviation of three replicates. UD: undetected. N/A: no literature value available for comparison/not applicable.

were assigned the emission factors of similar categories available in the GloBEIS program (<http://www.globeis.com/>).

Vegetation leaf mass density (LMD; horizontal canopy coverage in unit $\text{g dry weight m}^{-2}$) and leaf area index (LAI; the ratio of square meters of a projected leaf area to square meters of ground area) were used as model inputs. Literature values (Geron et al., 1994) were adopted to provide the best estimation of LMD and LAI of each Hong Kong tree species as more specific data were not available. For LMD, the values were $1500 \text{ g (dry weight) m}^{-2}$ for genera of *Abies*, *Picea*, *Tsuga*, and *Pseudotsuga*, 700 g m^{-2} for genera of *Pinus* and other coniferous, and 375 g m^{-2} for deciduous stands. These values were established using published data that were determined by destructive sampling or leaf fall collection from fully stocked stands. LAI values were assumed to be equal to 3 for pine stands, 5 for deciduous stands, and 7 for *Abies*, *Picea*, and *Pseudotsuga* stands. Geron et al. (1994) compared these values with those reported by other researchers and reported good agreement.

Hourly sun irradiation data and temperature data recorded from 1 August 2004 to 31 July 2005 were provided by the Hong Kong Observatory and were used to estimate the PAR and temperature inputs required for estimating emissions. Due to the substantial computation resources required for estimating hourly emissions for a year, monthly averaged values of diurnal hourly profiles of sun irradiation and temperature were used for the simulation.

The algorithms, including canopy environment model, of Guenther et al. (1999) were used to estimate isoprene, TMT, and OVOC emissions for sun and shade leaves at each canopy depth. Isoprene emissions were estimated as

$$\text{Emission rate (mg C m}^{-2} \text{ h}^{-1}) = \epsilon D \gamma_T \gamma_p,$$

where ϵ is the isoprene emission capacity of plant [$\mu\text{g C g (leaf dry weight)}^{-1} \text{ h}^{-1}$] at 30°C and 1000 PAR , D is the foliar density [$\text{g (leaf dry weight) m}^{-2}$ (ground)], which is calculated as the product of LAI and LMD (g m^{-2} ground), γ_T is the coefficient accounting for the influence of temperature on emissions, γ_p is the coefficient accounting for the influence of light intensity on emissions.

The influence of light intensity on isoprene emissions (γ_p) was calculated as

$$\gamma_p = \frac{\alpha C_L Q}{(1 + \alpha^2 Q^2)^{0.5}},$$

where $\alpha = 0.001 + 0.00085 \text{ LAI}$, $C_L = 1.42 \exp(-0.3 \text{ LAI})$, and Q is equal to the current light intensity (PAR).

The influence of temperature on isoprene emissions (γ_T) was calculated as

$$\gamma_T = \frac{E_{\text{opt}} C_{T_2} \exp(C_{T_1} x)}{C_{T_2} - C_{T_1} \{1 - \exp(C_{T_2} x)\}},$$

where $x = [(1/T_{\text{opt}}) - (1/T)]/R$, E_{opt} ($=1.9$) is the maximum normalized emission capacity, T_{opt} ($=312.5 \text{ K}$) is the temperature at which E_{opt} occur, T is the current temperature (K), R is the gas constant ($=0.00831$), and empirical coefficients C_{T_1} ($=95$) and C_{T_2} ($=230$) represent energy of activation and deactivation, respectively.

TMT and OVOCs emissions were calculated by

$$\text{Emission rate (mg C m}^{-2} \text{ h}^{-1}) = \epsilon D \gamma_T,$$

where ϵ is the TMT or OVOC emission capacity of plant [$\mu\text{g C g (leaf dry weight)}^{-1} \text{ h}^{-1}$] at 30°C and 1000 PAR , D is the foliar density [$\text{g (leaf dry weight) m}^{-2}$ (ground)], and γ_T is the coefficient that represents the effect of temperature on emissions, which is calculated by

$$\gamma_T = \exp[\beta(T - T_s)],$$

where β is an empirical coefficient which is set as 0.09 K^{-1} , T is the current temperature (K), and T_s is the standard temperature (303 K).

3. Results

Isoprene emission rates of 13 common Hong Kong tree species were measured and the results are presented in Table 1. Six tree species were found to be isoprene emitters, while seven tree species exhibited no detectable emissions of isoprene. *Bauhinia variegata* var. *candida* is the species which exhibited the highest isoprene emissions ($20 \mu\text{g C g}^{-1} \text{ h}^{-1}$). Literature values are also presented in Table 1, and measurement values are generally comparable to literature values. Variations may due to the use of different measurement methods, and/or different environmental conditions which plants subjected to before experiments. Isoprene emission measurement data of the 13 species were used to assign emission factors for the model simulation described below.

The total BVOC emissions in Hong Kong from 1 August 2004 to 31 July 2005 were estimated to be $8.6 \times 10^9 \text{ g C}$. Isoprene contributed 30% ($2.6 \times 10^9 \text{ g C}$), monoterpenes account for 40% ($3.4 \times 10^9 \text{ g C}$), OVOCs account for 30% ($2.6 \times 10^9 \text{ g C}$) of the total BVOC emissions, respectively. Monthly BVOC emissions varied by about a factor of four and are illustrated in Fig. 1. Estimated BVOC emissions were highest in July due to high temperature and strong sun irradiation; and lowest in February as a result of relatively low temperature and weak sun light. Seasonal totals varied by more than a factor of 3

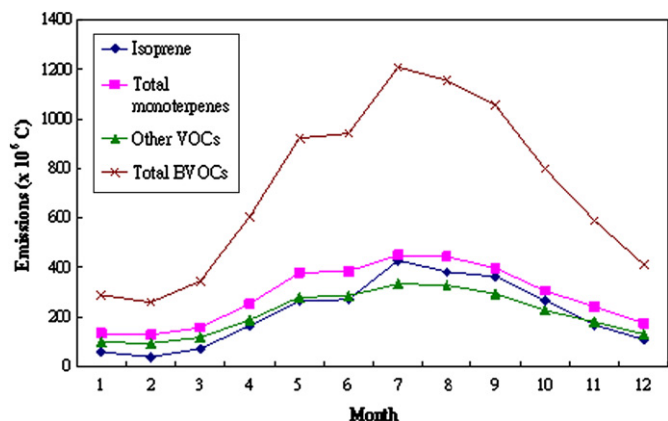


Fig. 1. Monthly BVOC emissions estimated for Hong Kong.

with 3.3×10^9 gC in summer (June–August) and 9.6×10^8 gC in winter (December–February).

BVOC emissions were estimated to have significant diurnal variations. Diurnal variations in BVOC emissions in February and July are shown in Fig. 2 for comparison. Hourly emission values shown are monthly averaged values. Though magnitudes of emissions are different, emission patterns are similar for the 2 months. Isoprene emission estimates, which were affected by both light and temperature, occurred only in daytime. TMT and OVOCs emissions were estimated to be temperature dependent but independent of light. Therefore, emissions of these compounds were estimated to occur throughout the day at steady rates.

Spatial distribution of total BVOC, isoprene, TMT and OVOCs are shown in Fig. 3. Most BVOC emissions are contributed by country

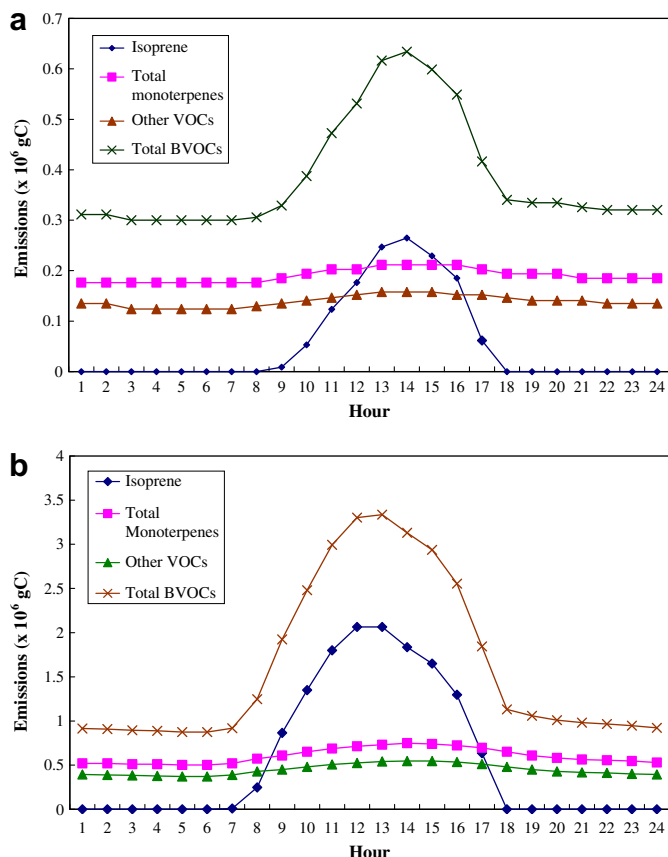


Fig. 2. Diurnal variation in estimated BVOC emissions: (a) February; (b) July.

park areas, where vegetation densities are higher than most of the non-country park areas.

4. Discussion

4.1. Comparison between VOC emissions from anthropogenic and biogenic sources in Hong Kong

The annual total AVOC emissions in Hong Kong in 2004 were estimated to be 41900 metric tons (Environmental Protection Department, 2007a). The sources of AVOC emissions include public electricity generation, road transport, navigation, civil aviation, other fuel combustion (industrial, commercial, domestic, and off road transport) and non-combustion sources (mainly consisting of consumer products, paint and printing). The annual total BVOC emissions were estimated to be 11000 metric tons (8.6×10^9 gC) in this study. AVOCs and BVOCs, therefore, account for 79% and 21% of the total annual VOC load in Hong Kong, respectively.

AVOC emission sources dominate over biogenic sources as a result of high population and automobile traffic in Hong Kong. It is expected that the amount of AVOC emissions will be reduced gradually in the future by the implementation of more regulations (Environmental Protection Department, 2007b) on limiting AVOC emissions in Hong Kong. BVOCs represent background emissions that are not being considered for emission control measures. Furthermore, the higher reactivity of BVOC species than their anthropogenic counterparts (Atkinson, 2000) implies their higher potential in deteriorating air quality. Biogenic sources are, therefore, playing an increasingly important role in Hong Kong air quality.

4.2. Comparison of BVOC emission estimates for Hong Kong with emission estimates for other regions

BVOC emission estimates for Hong Kong, Beijing, China and Global land areas are compared in Tables 2 and 3. The area averaged BVOC emissions in Hong Kong were estimated to be higher than that for Beijing and China, and comparable to global average estimates. The proportions of isoprene, monoterpene and OVOCs in the total BVOC emissions also vary between different regions.

Since vegetation coverage in Beijing (7%; Wang et al., 2003) is much lower than that in Hong Kong, Hong Kong is expected to have a higher average area BVOC emissions than Beijing. The higher averaged area BVOC emissions of Hong Kong than China is expected due to the much lower forest cover fraction, ~14%, for China (Klinger et al., 2002). In addition, the average temperature and solar radiation is much higher for Hong Kong than for China.

The above comparisons show that even though Hong Kong is a small region, its high proportion of vegetative cover and subtropical climate have the potential to contribute a significant amount of BVOC to the global VOC budget. The local flora is highly diverse and dominated by tropical species for which BVOC emissions have not been well studied. However, Table 4 shows that only 10 tree species contribute about 76% of the total estimated BVOC emissions from Hong Kong. An improved characterization of BVOC emissions from Hong Kong plant species will improve estimates of BVOC emissions from southern China and other regions with similar climate and plant species.

4.3. Uncertainties and areas of potential improvement

This study was designed to provide an initial estimate of Hong Kong BVOC emissions that could be used to determine the importance of biogenic emissions in this region. The results indicate that these emissions are important and that additional efforts are

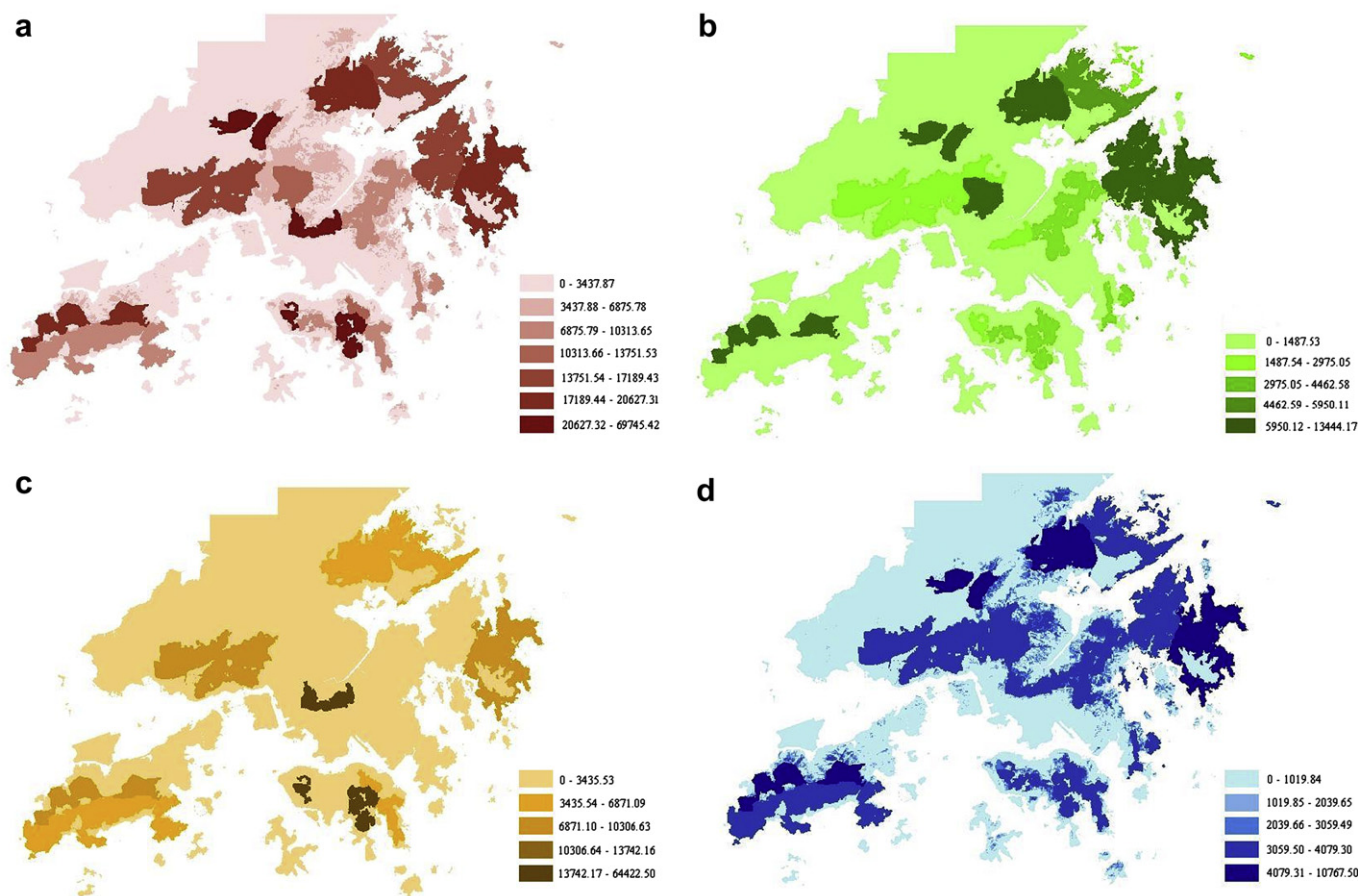


Fig. 3. Spatial distribution of: (a) total BVOC emissions ($\text{mgCm}^{-2}\text{year}^{-1}$) in Hong Kong; (b) isoprene emissions ($\text{mgCm}^{-2}\text{year}^{-1}$) in Hong Kong; (c) TMT emissions ($\text{mgCm}^{-2}\text{year}^{-1}$) in Hong Kong; (d) OVOC emissions ($\text{mgCm}^{-2}\text{year}^{-1}$) in Hong Kong.

required to reduce the large uncertainties associated with these preliminary estimates. These uncertainties are discussed in this section and future research priorities are recommended.

The static enclosure used for this initial screening study may not be suitable for accurately characterizing some BVOC emissions and their response to environmental and physiological driving variables. This is because the physiology of plants and their BVOC emissions may be affected by carbon dioxide reduction, water vapor condensation and thermal stress in the enclosure. All enclosures have some disturbances associated with the measurement and above-canopy measurements are desirable for evaluating emission estimates and investigating long-term variations.

The major components of the biogenic emission modeling approach used in this study are land cover distributions, emission factors, weather variables and the algorithms relating emissions to weather. Previous investigators have found that each of these components can make a significant contribution to the total uncertainty associated with these emissions (e.g., Hanna et al., 2005;

Guenther et al., 2000, 2006). These studies indicate that biogenic emission estimates are generally within 50% when plant species composition is characterized and emission factor measurements are available for the dominant species in a region. Uncertainties are as high as a factor of 5 or more when these data are not available. This study has provided both plant species composition data and emission factor measurements for Hong Kong although additional improvements could be made with more accurate emission factors and vegetation distribution data. The emission factor estimates for non-country parks are only rough estimates and the extrapolation of field survey data to estimate tree distribution in country parks may not accurately characterize tree coverage. LAI and LMD values used were adopted from literature estimates of mostly temperate tree species and may not adequately represent local vegetation. The assignment of emission factors based on taxonomic relationship is a straightforward approach to account for the lack of emission rate data for some species but it can lead to large uncertainties when dominant species are assigned emission rates based on very few

Table 2
BVOC emission estimates for Beijing, China, Global and Hong Kong

Country/region	Area ($\times 10^6 \text{ km}^2$)	Total BVOC emissions (gCyear^{-1})	Area average BVOC emissions ($\text{gCkm}^{-1}\text{year}^{-1}$)	References
Hong Kong	1.1×10^{-3}	8.6×10^9	7.8×10^6	This study
Beijing	1.8×10^{-2}	1.6×10^{10}	8.9×10^5	Wang et al. (2003)
China	9.6	2.1×10^{13}	2.2×10^6	Klinger et al. (2002)
Global (land)	146.8	1.1×10^{15}	7.5×10^6	Guenther et al. (1995)

Table 3
Percentage of BVOC species in total BVOC emissions

Country/region	Isoprene (%)	Total monoterpenes (%)	Other VOCs (%)	Reference
Hong Kong	30	40	30	This study
Beijing	48	22	30	Wang et al. (2003)
China	20	17	63	Klinger et al. (2002)
Global (land)	44	11	45	Guenther et al. (1995)

Table 4
Ten tree species contributing to most of the total BVOC emissions in Hong Kong

Tree species	Family	Distribution (%) ^a	Contribution to the total BVOC emissions (%)	Isoprene emission rate ($\mu\text{g C g}^{-1} \text{h}^{-1}$)	Assignment method ^b (references) ^c	Monoterpene emission rate ($\mu\text{g C g}^{-1} \text{h}^{-1}$) (references) ^c	Assignment method ^b (references) ^c	OVOC emission rate ($\mu\text{g C g}^{-1} \text{h}^{-1}$) ^d
<i>Gordonia axillaris</i>	Theaceae	3.9	25	0.09	F	52.5	F	1.5
<i>Baeckea frutescens</i>	Myrtaceae	13	22	22.1	F	0.78	F	1.5
<i>Schima superba</i>	Theaceae	0.7	9	0	S (Klinger et al., 2002)	119	S (Klinger et al., 2002)	1.5
<i>Cinnamomum parthenoxylon</i>	Lauraceae	3.2	6.4	88.1	G	0.66	G	1.5
<i>Lophostemon confertus</i>	Myrtaceae	5.3	4	21.8	F	0.78	F	1.5
<i>Syzygium jambos</i>	Myrtaceae	0.6	2.4	199	S (Klinger et al., 2002)	0.15	S (Klinger et al., 2002)	1.5
<i>Cratoxylum cochinchinense</i>	Clusiaceae	1.5	2.2	18.4	S (Klinger et al., 2002)	0	S (Klinger et al., 2002)	1.5
<i>Schefflera heptaphylla</i>	Araliaceae	6.7	2.2	0	S (Baker et al., 2005)	4.58	S (Baker et al., 2005)	1.5
<i>Litsea rotundifolia</i>	Lauraceae	5.8	1.6	0.09	G	0.09	G	1.5
<i>Acacia confusa</i>	Mimosaceae	5.2	1.5	0	*	0.14	S (Baker et al., 2005)	1.5

^a Distribution in country park area, calculated by area coverage/total vegetative area in country parks.

^b Assignment method: method of which the emission rate was assigned to the tree species. Emission rate can be assigned to tree species based on measurement values obtained in this study (*), direct measurement data (S), genus relationship (G), or family relationship (F). Tree species which emission rates were assigned based on genus or family relationship were assigned with the averaged emission rates of species of their genus or family, respectively. All assignment values were calculated from emission rates provided in the following references:

^c References: 1. Plant iso-emission list (2005); 2. Baker et al. (2005); 3. Benjamin et al. (1996); 4. Geron et al. (1994); 5. He et al. (2000); 6. Kesselmeier and Staudt (1999); 7. Klinger et al. (1998); 8. Klinger et al. (2002); 9. Padhy and Varshney (2005); 10. Sun and Leu (2004); 11. Wiedinmyer et al. (2004).

^d Reference: Guenther et al. (1994).

measurements. Since emission rates can vary significantly between closely related species that are within the same genus, and between individuals of the same species on different continents or regions (Kesselmeier and Staudt, 1999; Geron et al., 2001) and also because large uncertainties are associated with emission rates based on one or a few measurements.

This preliminary Hong Kong emission study assumes that monoterpene emissions are a light independent process. However, monoterpene emissions in tropical forests can be dominated by light dependent processes (Rinne et al., 2002; Greenberg et al., 2003), so it is possible that monoterpene emissions of some of the Hong Kong tree species are light dependent. The current emission estimation, in which monoterpene emissions were predicted to occur continuously throughout the day, might overestimate the actual monoterpene emissions in Hong Kong. Additional measurements are needed to determine what fraction of Hong Kong monoterpene and other BVOC emissions are light dependent.

Although the BVOC emission estimates generated in this study have not been validated by independent measurements, the estimates are expected to be generally representative of Hong Kong BVOC emissions. It is anticipated that future enhancements to quality and quantity of BVOC emission rate, leaf mass, density, and tree distribution data will provide more accurate emission estimates. In particular, measurements characterizing the emission rates of the 10 dominant Hong Kong tree species could greatly decrease the total uncertainty associated with these emission estimates. The use of remote sensing methods to characterize leaf area and density and species distributions could also improve emission estimates.

5. Conclusion

The BVOC emissions presented in this paper is an initial attempt to provide a high-resolution inventory of best estimates of BVOC emissions in Hong Kong. Although anthropogenic sources dominate over biogenic sources in the total VOC emissions in Hong Kong, the high reactivity of BVOCs implies their significant potential to affect local air quality. The area average BVOC emissions estimated for Hong Kong are considerably higher than have been estimated for other nearby regions and highlights the need for conducting further research. The results of this study lay a solid foundation for further investigation of Hong Kong BVOC emissions, and also provide information that facilitates studies in nearby southern China, as well as other Asian regions.

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