



On the use of multicopters for sampling and analysis of volatile organic compounds in the air by adsorption/thermal desorption GC-MS

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Abstract

We describe a new approach for the determination of volatile organic compounds (VOCs) at precise locations in the air using active sampling on sorbent tubes outfitted to an inexpensive multicopter and analysis by thermal desorption (TD) gas chromatography-mass spectrometry (GC-MS). The aerial sampling method permits for the simultaneous collection of multiple air samples on separate TD tubes concurrently, increasing sample throughput compared to single canister sampling. Furthermore, the method is relatively inexpensive when compared to similar approaches, with overall costs below about \$2000 (U.S. dollars). To demonstrate applicability, we measured VOCs at several heights near anthropogenic sources in the mid-south USA, including a municipal landfill, petroleum refinery, and a coal-fired power plant (CFPP), and within the canopy of a loblolly pine (*Pinus taeda*) forest. Concentrations of benzene, toluene, and xylene (BTX) were higher ($p < 0.05$) downwind of the refinery and CFPP compared to upwind. We observed both a unique mixture of VOCs at each site and higher concentrations of abundant VOCs downwind compared to upwind of the point sources and within versus above the forest canopy. Overall, this feasibility study demonstrates that highly maneuverable multicopters can be used to probe VOC concentrations aloft and thus have great potential to be utilized in unique sampling situations and for vertical profiling.

Keywords Volatile organic compounds · VOC · Multicopter · Petroleum refinery · Coal-fired power plant · Landfill · Forest canopy · Thermal desorption · GC-MS

Introduction

Probing chemical composition aloft is important for determining the sources, distribution, interactions, and fate of airborne pollutants. Volatile organic compounds (VOCs) are emitted to the atmosphere from natural sources, including biogenic emissions from plants and trees (Kesselmeier and Staudt 1999; Kovač-Andrić and Arh 2016), and from anthropogenic sources, including emissions from municipal solid waste

landfills (Chiriac et al. 2009), petroleum refineries (Kalabokas et al. 2001), and coal-fired power plants (CFPPs) (Yan et al. 2016). Inhalation of VOCs, including benzene, toluene, and xylene (BTX), has adverse impacts on human health (Zhou et al. 2011). VOCs are also implicated in the formation of ozone in the lower atmosphere, leading to poor air quality (Ran et al. 2011; Bauri et al. 2015). Thus, there is great interest in quantifying ambient concentrations of VOCs in the lower atmosphere.

Sampling methods for VOCs generally include either whole air sampling or pumping air through a sampling train consisting of a moisture trap, unless targeting water-soluble compounds, and tube(s) containing adsorbents such as Tenax and activated carbon (Demeestere et al. 2007). Passive samplers have also been adapted for low-level monitoring and often consist of radial diffusion tubes containing similar adsorbents (Chiriac et al. 2009). Alternatively, air can be drawn into Tedlar bags or evacuated stainless steel canisters that are subsequently pumped through cryogenic and/or adsorbent traps to pre-concentrate the VOCs and remove water and CO₂ (Yan et al. 2016; Wei et al. 2014). Sorbent-trapped compounds are recovered by either solvent extraction or thermal

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desorption (TD). Analytical methods for VOCs include gas chromatography (GC), for compound separation, followed by on-line mass spectrometry (MS), flame ionization detection (FID), or electron capture detection (ECD) (Demeestere et al. 2007).

Using these methods and ground-based sampling, studies have examined emission characteristics and dispersion around point sources, such as CFPPs (Yan et al. 2016), petroleum refineries (Wei et al. 2014; Cetin et al. 2003), municipal solid waste landfills (Chiriac et al. 2009), and forests (Kesslemeier and Staudt 1999). To sample at greater altitudes, researchers have used airships (Wintel et al. 2013), aircraft (Brown et al. 2013), tethered balloons (Greenberg et al. 1999), and meteorological towers (Ting et al. 2008). More recently, small rotary winged unmanned aerial vehicles (multicopters) have been used in a wide variety of atmospheric studies due in large part to the following advantages they hold over traditional drones: (i) maneuverability (vertical movement and hovering), (ii) low cost (just a few hundred to thousands of US dollars), (iii) lack of engine exhaust (no contamination from exhaust), (iv) capability to land on small spaces (e.g., ships and flat rooftops), and (v) placement of rotors at the periphery (accommodating sensors and sampling devices in the center of the craft) (Chang et al. 2016). In addition, there is potential for integration with real-time displays, data logging, and plume tracking (Villa et al. 2016). Indeed, the adaptation of multicopters for air sampling may facilitate precise vertical and spatial contaminant profiling to identify point sources and gas leaks (Rossi et al. 2014). However, few studies have explored multicopters for sampling of VOCs aloft.

Chang et al. developed a whole air sampling component (WASC) suitable for gaseous compounds, including VOCs, and deployed it on an octo-rotor multicopter (Chang et al. 2016). The configuration consisted of a 2-L stainless steel sampling canister, flow restrictor, valve, and a remote control circuit. The multicopter was also outfitted with sensors for temperature, humidity, pressure, black carbon, and CO₂. The overall cost for the multicopter with the WASC was approximately \$12k in 2016. The system was tested above an exhaust shaft of a roadway tunnel, and it effectively showed the influence of the shaft air on VOCs in the surrounding environment (Chang et al. 2016). In another study, lightweight sensors targeting VOCs themselves were deployed on a hexa-copter (Rossi et al. 2014). Sensor performance was not impaired by airflow during flights. Whereas aerial sampling with canisters and in situ aerial detection with sensors show great promise and are enhancing versatility in aerial studies of VOCs, the former is likely limited to a single sample per flight and the latter needs further development to improve selectivity, sensitivity, and ruggedness.

Here, we take a different approach, re-designing an established ground-based method for VOCs (US EPA Method TO-17) “Determination of VOCs in ambient air using active sampling onto sorbent tubes” (USEPA 1999) for use on-board

multicopters. Our aim was to develop a multicopter sampling method for VOCs aloft, keeping the configuration as simple as possible, overall costs below about \$2000 (U.S. dollars), and payload weight below 1 kg. We have previously showed that a commercially available quadcopter (DJI Phantom III) outfitted with gold-coated quartz cartridges, a pump, and a flow splitter/quad tube holder can be used to probe mercury concentrations aloft (Black et al. 2018). In the present study, we essentially used the same setup except we replaced the mercury traps with four VOC TD tubes. To test applicability, we sampled upwind and downwind of different point sources, including a petroleum refinery, CFPP, and a municipal solid waste landfill, as well within the canopy of a loblolly pine (*Pinus taeda*) forest. The tubes were sealed in the field and later analyzed by TD-GC-MS. We observed a unique mixture of VOCs at each site and measured higher concentrations of certain VOCs downwind compared to upwind, demonstrating that the method can characterize emissions from a variety of point sources. This short communication describes our method, presents preliminary results, and discusses modifications that would benefit future research. Whereas we report field results, full characterization of the VOC sources and their emission fluxes is beyond the scope of this feasibility study.

Materials and methods

Modification of the multicopter for VOC sampling

We modified a popular recreational quadcopter (Phantom III Professional, DJI Inc.) for sampling VOCs (Fig. 1). Briefly, the multicopter camera was removed and the chassis outfitted with an air pump (AirLite, SKC Inc.), an acrylic quad tube holder/flow splitter, and TD tubes. The setup was similar to prior work for aerial sampling of gaseous mercury (Black et al. 2018), except that the mercury traps were replaced with stainless steel TD tubes packed with a combination of Tenax® TA, Carbograph™ 1TD and Carboxen™ 1003 sorbents (Universal tubes, Markes International, part number: C3-AAXX-5266). This sorbent combination quantitatively retains many VOCs and thus is routinely used with US EPA Method TO-17. The total weight of the payload was 580 g, about half the weight of the quadcopter without its camera (1100 g) and almost one-tenth the weight of the payload used in other studies (Chang et al. 2016). We used an inexpensive lightweight pump but other, more sophisticated pumps that permit timed or intermittent sampling, record volume, or have other features may also be used, though multicopters with additional rotors may be needed for additional carrying capacity.

The sorbent tubes were pre-conditioned and blanked to ensure that the sorbent is cleaned of any residual VOCs. The TD tubes were connected to the quad tube holder with a small (~

2 cm) portion of tygon tubing, with the tube being fully inserted until in contact with the flow splitter/tube holder. For our early work at the CFPP, we used protective covers outfitted with 0.2 μm PTFE syringe filters (see Fig. 1) in part because of the increased potential for airborne particulates. At the other sites, we pulled air directly through the TD tubes. At these later sites, we are measuring total concentrations as particles retained in the tubes and are subject to the thermal desorption process. No portion of the air sampling apparatus was heated during sampling. The sampling equipment was secured to the multicopter using zip ties. The air sampling inlet was within 25 cm of the GPS module of the multicopter drone. Recent research has used computational fluid dynamic simulations to improve understanding of the complex flow interactions of multicopters. Air velocity modeling for the Phantom III quadcopter suggests that the air sampling volume above the active rotors extends upward only about 1 m (Yoon et al. 2017; Diaz and Yoon 2018). Thus, the bulk of the air parcel being sampled is relatively close to the true UAV position/height. The air pump was turned on immediately before takeoff and was shut off immediately after landing. Because the pump was manually turned on and off at ground level, VOCs were collected during UAV transit to the desired sampling height. However, this was < 5% of the total sample collection time, which averaged 16 min (limited by battery charge). Adding a pump that can be remotely turned on and off would allow sampling from only the desired height and location. The pump flow rate was set to 100 ml min⁻¹, resulting in ~ 1.6 L air passing through the sorbent tubes. The flow rate was checked before and after sampling trips using a calibrated rotameter. Tubes were sealed with Teflon end-caps immediately after sampling and shipped next day to Markes International's laboratory in California for analysis.

Sampling and site descriptions

We collected a total of 40 field samples near point sources in the mid-south USA: 12 at a municipal solid waste landfill, 12 near a petroleum refinery, 8 near the CFPP, and 8 in a loblolly

pine forest (Fig. 2). One tube was used as a travel blank with each field campaign. To avoid interference with aircraft, sampling was restricted to > 8 km from the nearest airport and to heights of < 120 m. Upwind and downwind samples were collected within about an hour of each other.

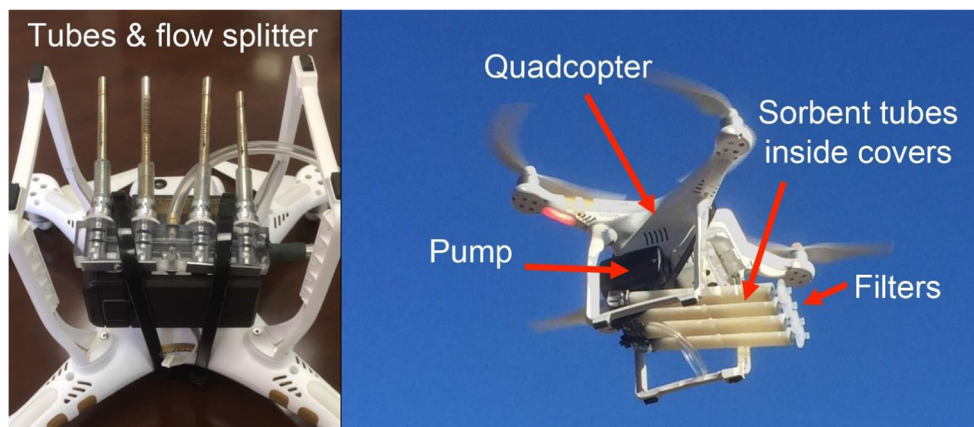
Three Rivers Landfill, located in Pontotoc, MS, is an active municipal solid waste landfill that began operation in 1994. At the landfill, four samples were collected upwind and eight downwind, all at a height of 30 m. We sampled < 250 m downwind of the site on private land (34.299726 N, - 89.056689 W) on 10 December 2017. The landfill occupies about 81,000 m² of land, has a depth of ~ 30 m, and is about one-third full with an estimated capacity of ~ 13 million metric tons. Wind was out of the SSE at ~ 4–10 km/h.

The Valero petroleum refinery is located near downtown Memphis, TN, a city with a population of about ~ 650,000. The refinery has a capacity of ~ 195,000 barrels per day and is a major supplier of jet fuel to the FedEx Corporation hub in Memphis. At the refinery, four samples were collected upwind at a height of 46 m and eight downwind (four each at 46- and 76-m heights). Upwind samples were collected ~ 3 km southwest near T.O. Fuller State Park (35.068225 N, - 90.118496 W) and downwind ~ 250 m north at Martin Luther King Park (35.089112 N, - 90.085740 W) on 10 December 2016. Wind was out of the SE at ~ 8–12 km/h.

The Red Hills Plant is a 440-MW facility located in Ackerman, MS. The Red Hills facility uses lignite coal mine adjacent to the site. At the CFPP, the number of samples was equally split between upwind and downwind locations, and sampling occurred at 76 m. For the Red Hills Plant, upwind samples were collected ~ 5 km northwest near Jeff Busby State Park (33.412487 N, - 89.260724 W) and downwind samples < 1 km south on private land (33.371829 N, - 89.218192 W) on 3 February 2017. Wind was out of the NNW at ~ 10–16 km/h.

The loblolly pine forested site was located outside the Oxford, MS city limits (34.380296 N, - 89.600048 W). Loblolly pine is the primary commercial pine species of the

Fig. 1 Quadcopter outfitted with sampling equipment. Underneath view showing pump, acrylic quad tube holder, and four thermal desorption tubes (VOC traps) without protective tube covers (left) and view showing the quadcopter in the air



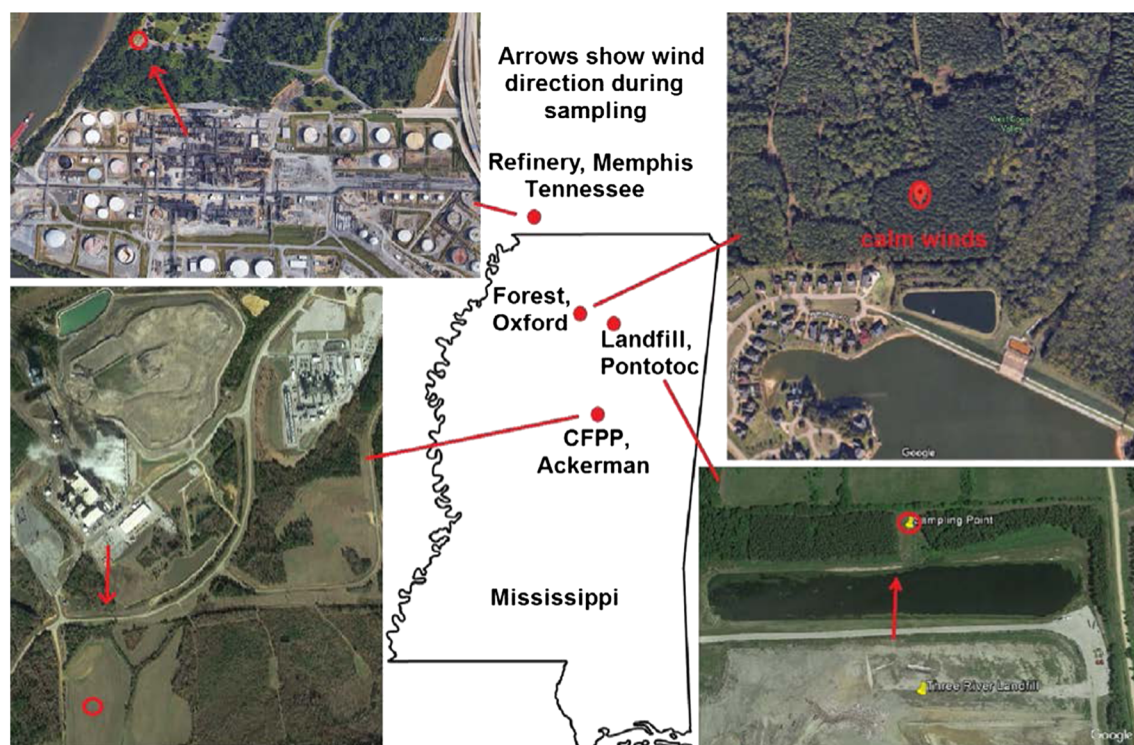


Fig. 2 Map showing the general layout of the study area, as well as the specific sampling sites downwind of the refinery, CFPP, and municipal solid waste landfill

southeastern USA because it is adaptable to a variety of sites and is among the fastest growing pines; it is extensively cultivated in Mississippi for pulpwood and lumber. The forest provides an example for sampling more biogenic VOCs, sampling in a relatively confined space (between trees in the forest canopy), as well as providing a type of control to compare to the industrial sites. At the forest, we sampled within and above the canopy at 20 and 26 m, respectively. We collected samples on 9 April 2017, while hovering the multicopter at a height of 20 m within the forest canopy and at 26 m just above the canopy. There was less than 6 km/h wind speed during sampling.

Determination of VOCs by thermal desorption GC-MS

VOCs collected on the sorbent traps were determined by thermal desorption GC-MS following US EPA TO-17 (USEPA 1999). The analytical system used for this study comprised a Markes TD100-xr thermal desorber, coupled to a GC-MS (Thermo Trace-1310 GC and Thermo ISQ MS). Operating parameters are given in Table 1. Briefly, the sorbent tubes were heated in a flow of helium carrier gas, transferring the analytes to an electrically cooled, air toxic focusing trap (Markes International) inside the TD100-xr. Once the process of transferring vapors from the sample/sorbent tube to the focusing trap was completed, the trap was purged with dry carrier gas in the sampling direction to remove residual water.

The flow of carrier gas was then reversed and the trap heated rapidly. At this point, the retained organics were desorbed into the carrier gas stream and transferred/injected onto the GC analytical column.

BTX are routinely monitored to provide an indication of VOC concentrations as a whole in ambient air and to quickly assess VOC emissions from a range of sources (Rad et al. 2014; Bauri et al. 2015). For our early work (CFPP, petroleum refinery, and forest canopy), we only calibrate using BTX compounds. Concentrations were obtained by dividing the amount of analyte (in ng) determined on the TD tube by the volume of air (in L) that passed through the tube. The resultant concentration in nanograms per liter is equivalent to micrograms per cubic meter reported herein. For other compounds, we used the benzene calibration and thus report their concentrations as benzene equivalents, meaning the concentration of benzene that would yield an equivalent signal.

For the later work at the landfill site, we calibrated the TD-GC-MS using a much wider range of VOCs. Specifically, we used a Markes Calibration Solution Loading Rig (CSLR) to prepare five standards ranging from 0.1 to 15 ng from a mix of 23 VOCs (JMHV VOC mix; Supelco, Bellefonte, PA, USA). The CSLR consists of an injection port with a controlled carrier gas supply and sorbent tube connection. The liquid VOC standards were slowly injected and vaporized in a 100 ml min^{-1} flow of high purity helium, allowing the analytes to reach the sorbent bed in the vapor phase. All calibration

Table 1 Thermal desorption GC-MS instrumental parameters

Thermal desorption unit (Markes International TD100-xr)

Cold trap low = 20 °C	Pre-purge = 1 min	Pre-purge = 20 mL min ⁻¹	Desorb = 280 °C
Desorb = 5 min	Desorb = 50 mL min ⁻¹	Purge = 1 min	Purge = 50 mL min ⁻¹
Trap high = 320 °C for 3 min	Outlet/split ratio = 9:1	Trap heating rate = 100 °C s ⁻¹	TD flow path = 180 °C
Tubes: “Universal” (Tenax, Carbograph 1TD, and Carboxen 1003)		Focusing trap: air toxic analyzer gas trap	
Gas chromatography (Thermo Trace 1310)			
Carrier gas: helium	Column: Agilent DB-VRX 60 m × 0.25 mm × 1.40 μm	Mode: constant flow at 1.2 mL min ⁻¹	
Temp. program = 40 °C (2 min), 10 °C min ⁻¹ to 220 °C (10 min)			
Mass spectrometry (Thermo ISQ)			
Source: EI	Full scan = <i>m/z</i> 35–300	Source temp. = 250 °C	Transfer line = 250 °C

tubes were run with the same TD method parameters as the samples. Peak areas were divided by amounts for the standards to provide relative response factors.

Data analysis

Average concentrations for individual VOCs for upwind and downwind samples were compared using a two-sample *t* test assuming unequal variance and one-tailed distributions. Differences were deemed significant at the $p < 0.05$ level.

Results and discussion

Using the quadcopter for sampling and thermal desorption GC-MS for analysis, we determined VOC concentrations upwind and downwind of a petroleum refinery, CFPP, and a municipal solid waste landfill and within and above a forest canopy. A comparison of upwind and downwind VOC concentrations is shown in Fig. 3, and the most abundant compounds detected at each site are listed in Table 2. VOC concentrations were generally higher downwind compared to

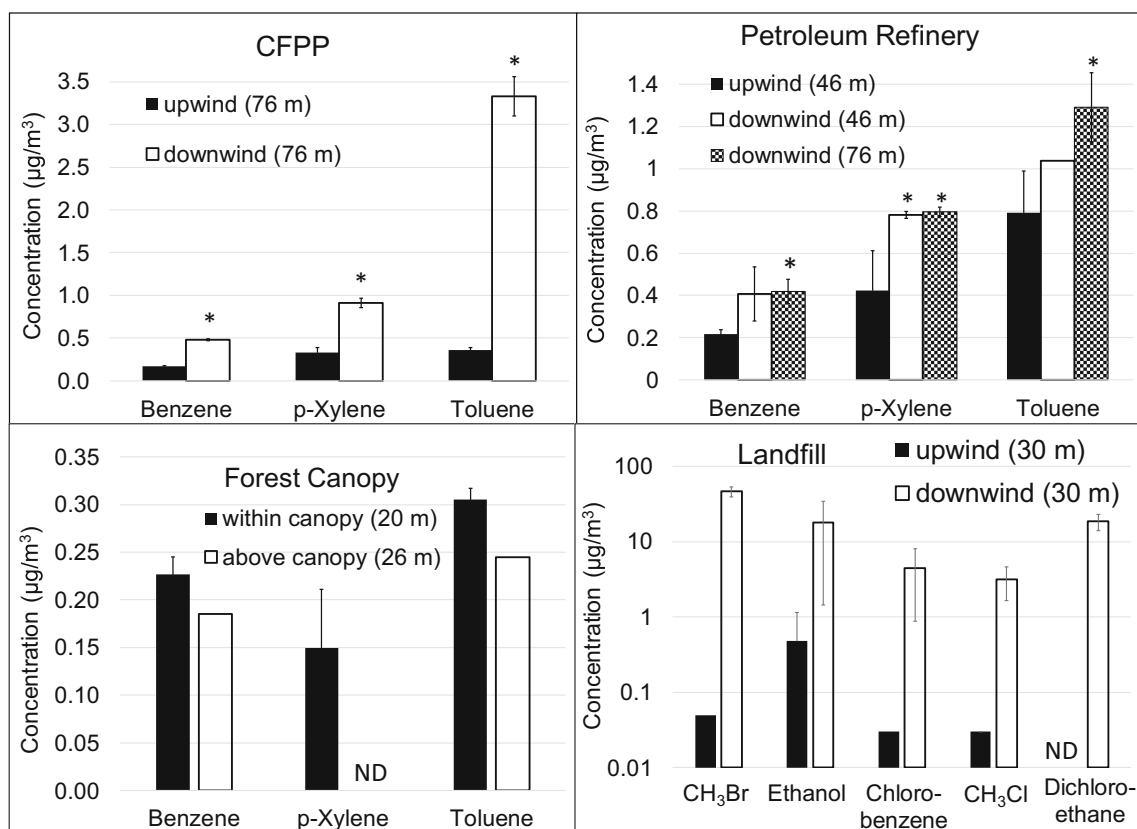


Fig. 3 Concentrations of VOCs upwind and downwind of a CFPP, petroleum refinery, a 1-day municipal solid waste landfill and at two heights in a loblolly pine forest. Downwind concentrations designated

with an asterisk are statistically higher than upwind concentrations ($p < 0.05$). ND = not detected. Detection of several compounds upwind of the landfill was sporadic and thus the group was not treated statistically

Table 2 Concentrations (mean and range in $\mu\text{g}/\text{m}^3$) of the most abundant VOCs detected at each sampling site

Refinery ^a	CFPP ^a				Forest canopy ^a				Landfill			
	Compound	Upwind	Downwind	Compound	Upwind	Downwind	Compound	Above	Within	Compound	Upwind	Downwind
Propene		1.3 (ND–2.8)	7.8 (ND–15)	Toluene	1.2 (1.1–1.3)	10.3 (9.8–11)	Freon-12	4.0 (3.9–4.1)	4.4 (3.8–4.9)	Carbon disulfide	0.01 (ND–0.048)	130 (ND–954)
Freon-12		3.8 (3.4–4.0)	3.8 (0–6.4)	<i>o</i> -Xylene	ND	9.1 (8.4–9.5)	Ethanol	1.9 (0.1–3.0)	2.4 (2.1–2.6)	Bromomethane	ND	23 (ND–52)
Toluene		1.6 (1.3–2.1)	2.3 (2.0–2.9)	1,2,4-Trimethylbenzene	ND	3.6 (2.6–4.3)	Benzene	1.3 (1.2–1.4)	1.6 (1.3–1.7)	Chlorobenzene	ND	20 (5.3–56)
<i>p</i> -Xylene		1.0 (0.5–1.2)	1.8 (1.7–1.8)	Benzene	1.3 (1.2–1.4)	3.3 (3.2–3.4)	Acetone	0.4 (0.1–0.8)	1.7 (1.1–2.2)	Ethanol	0.7 (0–2.3)	19.6 (0.2–152)
1,3-Dimethyl benzene		0.7 (?–?)	2.2 (2.2–2.3)	Freon-12	2.9 (2.8–3.4)	3.1 (3.0–3.2)	1,3-Dimethyl benzene	ND	1.0	Ethyl-chloride	ND	16 (ND–78)
Benzene		1.0 (0.9–1.1)	1.7 (1.5–2.5)	<i>p</i> -Xylene	1.2 (1.0–1.4)	3.0 (2.7–3.2)	<i>o</i> -Xylene	ND	0.94	1,2-Dichloroethane	ND	12 (ND–23)
2-Butanone		0.6 (0.2–1.8)	1.3 (ND–4.7)	Propene	0.4 (0.1–0.8)	2.5 (2.3–2.5)	CFC-113	0.90 (0.83–0.94)	0.89 (0.84–0.93)	1,3-Butadiene	0.01 (ND–0.01)	10.9 (ND–88)
Hexane		0.5 (0.4–0.6)	0.8 (0–1.7)	Ethylbenzene	0.3 (0.3–0.4)	2.2 (1.9–2.4)	Toluene	0.75 (0.71–0.78)	0.94 (0.74–1.1)	Ethenyl acetate	0.05 (ND–0.13)	9.0 (ND–52)
<i>o</i> -Xylene		0.5 (ND–1.9)	0.4 (ND–2)	Benzene, 1-ethyl-4-methyl	ND	1.9 (1.6–2.1)	2-Butanone	0.86 (0.33–2.0)	0.41 (0.32–0.47)	Chloromethane	ND	6.3 (0.6–34.7)
1,2,4-Trimethylbenzene		ND	0.77	Hexane (1.6/0.3)	0.3	1.6	Carbon tetrachloride	0.63 (0.59–0.68)	0.57 (0.53–0.59)	Tetrachloroethylene	0.04 (0.03–0.05)	5.4 (0.8–36)

ND not detected

^a Concentrations are based on benzene and toluene equivalents (see “Determination of VOCs by thermal desorption GC-MS” for details)

upwind. For both the CFPP and refinery, downwind BTX concentrations were higher ($p < 0.05$) compared to upwind (Fig. 3). At the landfill, many compounds measured downwind were not even detected upwind.

VOC patterns varied by site with the type of abundant compounds generally characteristic of their sources: aliphatic and aromatic hydrocarbons elevated near the petroleum refinery and CFPP (Kalabokas et al. 2001; Cetin et al. 2003; Garcia et al. 1992); halogenated- and sulfur-containing hydrocarbons higher at the landfill (Chiriac et al. 2009; Zou et al. 2003); and alcohols, ketones, and aldehydes prevalent in the forest canopy (Isidorov et al. 1985). More specifically, compounds detected downwind of the refinery and CFPP include propene, hexane, 2-butanone, and several derivatives of benzene, whereas ethyl-acetate, ethanol, acetone, 2-butanone, and styrene were measured in the forest canopy. Among the compounds detected downwind of the landfill were carbon disulfide, tetrachloroethylene, chlorobenzene, and halogenated methane species. We also detected dichlorodifluoro-methane (Freon-12) and 1,1,2-trichloro-1,2,2-trifluoroethane (CFC-113), despite their being banned for use as aerosols and refrigerants in 1996 under the Montreal Protocol. Together the upwind/downwind concentration profiles and the characteristic VOC patterns for each site demonstrate that sampling VOCs with sorbent tubes on multicopters followed by analysis using an EPA-approved method (TO-17) can be used to measure ambient levels of airborne VOCs. To fully characterize emissions from point sources requires an independent estimate of emissions, which is beyond the scope of this study.

Reproducibility between individual TD tubes from the same flight was generally less than 30% relative standard deviation (RSD). This level of uncertainty is generally sufficient for evaluating VOC levels near point sources given the relatively large concentration gradients near them. However, a few compounds exhibited a wider concentration range for the same flight. For example, concentrations for carbon disulfide on one flight downwind of the landfill varied between 954 and $78.2 \mu\text{g m}^{-3}$, whereas upwind concentrations were all $< 0.05 \mu\text{g m}^{-3}$. The reason for this variability was not determined, but it did not extend to other compounds collected on the same tubes. Still, this highlights a couple benefits of collecting multiple air samples directly onto individual TD tubes: improved sample throughput, especially compared to collecting a single air sample using a relatively heavy evacuated canister attached to a multicopter, and the capability to better assess measurement uncertainty.

As noted, BTX concentrations downwind of the refinery and CFPP were higher ($p < 0.05$) compared to upwind (Fig. 3). For the refinery, samples were collected at two heights downwind (46 and 76 m), and both were higher in concentration compared to upwind. For benzene and xylene, the concentrations were similar between heights, whereas for toluene, the concentration at 46 m downwind was

intermediate between the upwind and the 76-m downwind. Thus, it appears that downwind dispersal of BTX from these sites is relatively broad as highly reactive species undergo atmospheric and chemical transformations. BTX concentrations in the pine forest ranged from non-detected (for xylene above the canopy) to about $1.4 \mu\text{g m}^{-3}$ for benzene within the canopy. Whereas BTX concentrations were higher within the canopy than above the canopy, the differences were not significant. Others report similar or somewhat higher concentrations of VOCs near petroleum refineries (Kalabokas et al. 2001; Cetin et al. 2003), CFPPs (Garcia et al. 1992), and landfills (Chiriac et al. 2009; Zou et al. 2003); however, it is important to note that our samples were collected offsite on private or public land adjacent to the facilities of interest, rather than close-in on-site or in piped landfill gas.

Conclusions

We describe a new approach for the determination of VOCs in the atmosphere using aerial sampling with a multicopter followed by adsorption/thermal desorption GC-MS analysis. The method permits for the simultaneous collection of replicate air samples on separate TD tubes. This allows for ease of statistical analysis for collected VOCs. Furthermore, the relatively high concentrations found downwind of these point sources in comparison to upwind locations showcase the utility of highly targeted sampling made possible with multicopters. Because the sampling method is portable, it may be particularly useful for evaluating VOC emissions from landscapes and transient sources that are poorly characterized. The relatively low cost of the sampling method ($< \$2000$) should enable aerial VOC sampling for most research groups and commercial laboratories. However, air space and flight restrictions need to be carefully considered before using multicopters. Future work will compare the airborne multicopter sampling platform with a stationary platform (e.g., tower).

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