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Florida Tower Footprint Experiments

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Abstract

The Florida Footprint experiments were a series of field programs in which perfluorocarbon tracers were released in different configurations centered on a flux tower to generate a data set that can be used to test transport and dispersion models. These models are used to determine the sources of the CO_2 that cause the fluxes measured at eddy covariance towers. Experiments were conducted in a managed slash pine forest,10 km northeast of Gainesville, Florida, in 2002, 2004, and 2006 and in atmospheric conditions that ranged from well mixed, to very stable, including the transition period between convective conditions at midday to stable conditions after sun set. There were a total of 15 experiments. The characteristics of the PFTs, details of sampling and analysis methods, quality control measures, and analytical statistics including confidence limits are presented. Details of the field programs including tracer release rates, tracer source configurations, and configuration of the samplers are discussed. The result of this experiment is a high quality, well documented tracer and meteorological data set that can be used to improve and validate canopy dispersion models.

Introduction

There is a natural cycle in which CO_2 moves between the atmosphere and the ocean and the atmosphere and the terrestrial biosphere. Understanding the dynamics of this cycle is essential to predicting future atmospheric CO_2 levels. Eddy covariance methods are used at AmeriFlux sites to measure the net ecosystem exchange (NEE) of CO_2, H_2O and other parameters in order to understand the movement of CO_2 in terrestrial ecosystems. Generalization of tower based flux measurements requires a detailed knowledge of the footprint, the area responsible for the fluxes measured at the tower. There are also problems with using eddy covariance methods during periods of strong atmospheric stability, particularly during calm nocturnal periods that require further study.

The Florida Footprint experiments were a series of field programs in which perfluorocarbon tracers were released in different configurations centered around a flux tower. The concentrations of these tracers were measured at different levels on the tower. These data will be compared to the meteorological and CO_2 flux data to determine relationships between the tower footprint, the measured fluxes and the meteorological conditions and will be used to improve and validate models used to predict tower footprints.

Experimental Methods

Perfluorocarbon tracers are colorless, odorless cycloalkane compounds that consist of a carbon and fluorine atoms joined by covalent single bonds. The tracers used in the Florida experiments are molecules consisting of five (pentane) or six (hexane) member rings with 1 (methyl), 2 (di-methyl, ethyl) or three (propyl) additional carbon atom structures. These compounds are chemically inert, non-flammable, and have no biological effects. Perfluorocarbon background levels are in the parts per quadrillion (10^{15}) by volume (ppqv) and have grown only slowly over the past 2 decades (Dietz, 1987: Simmonds et al., 2002, Watson et al., 2007). A list of PFTs commonly used as tracers and some of their properties are given in Table 1.

The field experiments were conducted at the Florida AmeriFlux site (29° 45′N, 82° 10′W) in 2002, 2004, and 2006. The site is located 10 km northeast of Gainesville, Florida and is a managed slash pine (*Pinus elliottii* L.) forest in flat terrain. The average canopy height (h) was 11.5 m in 2002 and 13.5 m in 2004 and 2006. The forest understory is characterized by a mixture of gall berries (*Ilex glabra* L.), saw palmettos (*Serenoa repens* L.), Christmas fern (*Polystichum acrostichoides* L.), wax myrtle (*Myrica cerifera* L.), Carolina jasmine (*Gelsemium sempervirens* L.) and eastern bracken ferns (*Pteridium aquilinum* L.). Total foliage area index (FAI) and its vertical profiles were measured by LAI2000 (LiCor, USA). The total maximum FAI was about 2.8 ± 1.0 m^2m^{-2}. Foliage area density in the understory showed two peaks at *z/h* approximately 0.7 and 0.1.

A 96 foot tall walk up tower was used in these experiments. Sonic anemometers were installed on booms extending 3 m from the edge of the tower. Samplers were deployed on scaffold platforms or at the tower base. A sampling tube was run from the sampler inlet to the height on the tower where the measurement was made. The tube was run along the anemometer boom and the end placed near the anemometer head so that air samples were collected at the point where the winds were measured.

Table 1: PFTs commonly used as tracers, acronyms, IUPAC names, chemical formulae, and molecular weights.

Acronym	Chemical Name	Formula	Molecular weight($g\ mol^{-1}$)
PDCB	Perfluorodimethylcyclobutane	C_6F_{12}	300
PMCP	Perfluoromethylcyclopentane	C_6F_{12}	300
PMCH	Perfluoromethylcyclohexane	C_7F_{14}	350
o-PDCH	Perfluoro-1,2-dimethylcyclohexane	C_8F_{16}	400
PECH	Perfluoroethylcyclohexane	C_8F_{16}	400
i-PPCH	Perfluoroisopropylcyclohexane	C_9F_{18}	450
PTCH	Perfluorotrimethylcyclohexane	C_9F_{18}	450

Atmospheric samples of PFTs are collected by passing air through activated charcoal. PFTs as well as other compounds are adsorbed on the charcoal. The larger the volume of air passed through the charcoal, the more material from the atmosphere is collected. Samples used in this study were taken using the Brookhaven Atmospheric Tracer Sampler (BATS). The BATS consists of a base unit containing a pump, timer, and control electronics, and a lid containing. 22 or 23, 1/8 inch o.d. stainless steel tubes packed with Ambersorb[®] (Rhom and Hass, Philadelphia, PA). The lid also contains a multi-port valve that places the active sampling tube in the sample stream. The nominal pumping rate is 50 ml min^{-1}. Samples were collected on BATS for 30 minutes concentrating the material in approximately 1.5 liters of air on each tube.

Analysis of the BATS Lids was performed using gas chromatography with an electron capture detector (ECD).

The quantity of PFT available for analysis is determined by the volume of air that is sampled. The ECD has the sensitivity to quantify background levels of PFT if the material in 1.5 liters of ambient air is collected. However, in ambient air samples, there are many other compounds, including SF_6, nitrogen oxides, and chlorofluorocarbons (CFCs) such as Freon[®], present in higher quantities than the PFTs that can potentially interfere with PFT detection.

The first step in the analytical process is desorption of the sample from the collection tube by ballistically heating the tube to $400^{\circ}C$ driving the concentrated PFTs along with other compounds from the adsorbent into a 1% hydrogen in nitrogen carrier gas stream. The sample passes through an oxidizing catalyst and dryer and is concentrated on a trap packed with Florisil® (Supelco, Inc., Bellefonte, PA) adsorbent. The focusing trap is heated, desorbing the sample into the carrier gas flow and onto a carbon layer open tubular (CLOT) precut column where it undergoes chromatographic separation. Flow from this column can be directed through a vent to the atmosphere or through a heated palladium reducing catalyst onto a second trap packed with Florisil®. By switching the sample stream between the vent and the trap, the eluting PFTs can be directed onto the trap while interfering compounds are vented. The Pd catalyst combined with the 1% H_2 in the carrier gas reduces the compounds that co-elute with the PFTs to forms that are not detected by the ECD. After the PFTs have been collected on the trap, the precut column is back-flushed sweeping any compounds still on the column out the vent and preparing it for the next desorption cycle. The sample on the trap is desorbed and collected compounds transferred to the main column, which is the same composition as the precut column. The PFTs are separated on the main column and delivered to the detector. The ECD signal is recorded using data acquisition software that integrates peaks and records the raw and processed data. Analysis of each sample takes approximately 15 minutes.

Calibration of the gas chromatograph is accomplished using standards introduced into the analytical system in sample tubes. The tubes are loaded by injecting measured quantities of a standard mixture, determined using volumetric syringes, into a stream of ultra high purity (UHP) N_2 flowing through the tube. Standards are run with each set of samples which allows variations in instrument performance to be quickly identified and corrected.

The Limit of Detection (LOD) is three times noise and the Limit of Quantitation (LOQ) is 10 times noise. The confidence limits at the limit of quantitation are ± 20% (Taylor, 1987). The standard deviation of injections of the smallest volume calibration level, 2μL, was used as the noise value used to determine the LOD and LOQ for the analysis method (Table 2). These values represent the uncertainty in an individual measurement using this analytical method.

Table 2: LOD and LOQ from standards based on the standard deviation of 2 μL standard for GC 2. The values are in units of ppqv

	PDCB	PMCP	PMCH	ocPDCH	iPPCH	PTCH	ptPDCH
Standard deviation	0.88	1.46	1.83	1.03	1.70	2.65	1.21
LOD	3	5	6	3	6	9	4
LOQ	10	15	18	10	17	26	12

The sample volume is determined by using the perfluorocarbon, ptPDCH as an internal standard (Draxler et al., 1991). Since this compound is not released as a tracer, the

background level can be determined and the amount of ptPDCH in an individual sample used to determine the actual volume of air that passed through the adsorbent bed. The average quantity of ptPDCH per liter of ambient air was determined from the average of background samples:

$$\overline{[ptPDCH]}_b = \frac{1}{N} \sum_{i=1}^{M} \sum_{j=1}^{Q} \left\{ \frac{PDCH_{i,j}}{\left[\frac{(F_i 30)}{1000} \right]} \right\}$$

where :

$\overline{[ptPDCH]}_b \equiv$ the average concentration of ptPDCH, in fL/L or ppqv

$PDCH_{i,j} \equiv$ the quantity of ptPDCH in sample j of sampler i, in fL

$F_i \equiv$ the sampler flow rate of sampler i, measured in the laboratory, in ml min^{-1}

$M \equiv$ Number of samplers used in the average

$Q \equiv$ Number of samples collected by the sampler

$N \equiv$ the total number of samples $= (M)(Q)$

30 is the sampling time in minutes

the factor of 1000 converts the volume to liters

This factor and the quantity of ptPDCH measured in each sample are then used to calculate the volume of air passed through the adsorbent bed for each sample.

$$V_k = \frac{ptPDCH_k}{\overline{[ptPDCH]}_b}$$

where :

$V_k \equiv$ the volume of sample k

$ptPDCH_k \equiv$ the quantity of ptPDCH in sample k, in fL

$\overline{[ptPDCH]}_b \equiv$ the background concentration of ptPDCH determined from BATS samplers

The reported tracer concentrations are calculated from three quantities. The quantity of tracer in a sample is calculated using the calibration standard data. This is converted into concentration using the background concentration of the reference tracer ptPDCH to determine the sample volume. The background concentration of the tracers is then subtracted. The error in the reported values must be calculated by propagating the errors in all three of these quantities.

The error in the sample volume is determined from the error in the measurement of ptPDCH in the sample and the error in the background concentration of ptPDCH. The error in the background concentration is the standard deviation of the mean. The error in

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the sample volume is calculated from the error in the quantity of ptPDCH measured in the sample and the error in the background concentration of ptPDCH according to the following definitions and equations:

$V \equiv$ the calculated sample volume

$ptPDCH_m \equiv$ the quantity of PFT determined from the analysis uncorrected for sample volume (in fL)

$[ptPDCH]_b \equiv$ the background concentration of ptPDCH (in fL/L)

$\delta V \equiv$ the error in the calculated sample volume

$\delta ptPDCH_m \equiv$ the error in the measured ptPDCH

$\delta[ptPDCH]_b \equiv$ the error in the background concentration of ptPDCH

$$V = \frac{ptPDCH_m}{[ptPDCH]_b}$$

$$\delta V = \sqrt{\left[\frac{\partial z}{\partial ptPDCH_m}\delta ptPDCH_m\right]^2 + \left[\frac{\partial z}{\partial[ptPDCH]_b}\delta[ptPDCH]_b\right]^2}$$

$$\delta V = \sqrt{\left[\frac{1}{[ptPDCH]_b}\delta ptPDCH_m\right]^2 + \left[\frac{ptPDCH_m}{[ptPDCH]_b^2}\delta[ptPDCH]_b\right]^2} \equiv$$

The error in the sample volume and typical values for BATS samplers used to calculate this value are given in Table 14.

Table 3: Error in BATS volume correction determined from uncertainties in background [ptPDCH] and ptPDCH measured in sample in ppqv.

BATS	ptPDCH$_m$	δptPDCH$_m$	$[ptPDCH]_b$	$\delta[ptPDCH]_b$	δV
(ppqv)	10.50	1.00	7.12	0.07	0.14

This quantity is then used with the error in the measured quantity of PFT to calculate the error in the background corrected PFT concentration. The relationships for this calculation are given by the following definitions and equations:

$[PFT] \equiv$ the concentration of PFT in ppqv

$x \equiv$ the quantity of PFT determined from the analysis uncorrected for sample volume (in fL)

$V \equiv$ the volume of the sample determined by the measurement of ptPDCH (in L)

$b \equiv$ the background correction

$\delta x, \delta[PFT], \delta V, \delta b \equiv$ the errors in these values

$$[PFT] = \frac{x}{V} - b$$

$$\delta[PFT] = \sqrt{\left[\frac{\partial y}{\partial x}\delta x\right]^2 + \left[\frac{\partial y}{\partial V}\delta V\right]^2 + \left[\frac{\partial y}{\partial b}\delta b\right]^2}$$

$$\delta[PFT] = \sqrt{\left[\frac{1}{V}\delta x\right]^2 + \left[\frac{x}{V^2}\delta V\right]^2 + \delta b^2}$$

Table 4: Uncertainty in the PFT concentration from BATS samples as a function of measured PFT concentration.

concentration (ppqv)	Error (σ) (ppqv)	relative error (%)	95% confidence (2σ) limit (ppqv)
10	2.5	25	5
20	2.7	14	6
40	3.5	9	7
80	5.5	7	11
100	6.7	7	14
1000	62	6	124

2002 Experiments

The 2002 Florida field experiments were conducted in the late winter and early spring (Table 2). Six experiments were conducted in the middle of the day (Table 5) and were designed to measure diffusion under the forest canopy in well mixed conditions.

The tracers were released in gas phase from cylinders of nitrogen containing PFT at the ppm level connected to release lines constructed of 3/8-inch outside diameter polyethylene tubing. The release lines were fitted with a critical orifice, constructed of PEEK precision tubing, in the line at 20 inch intervals. This spacing created an effective line source. The critical orifice resulted in a uniform flow of approximately 1.75 mL/min per orifice with a negligible pressure drop along the line. The line was suspended from poles located every 25 ft in concentric arcs. The arcs were centered on the flux tower at radii of 10.75 m, 21.5 m, 43 m. There were three release heights on each arc (Table 3). The sources at the 0.5 and 0.85 fraction of the canopy height (h) at each radius were on arcs that covered 203 degrees, from due North (0°) to 203° (Figure 1) The sources at the

lowest level, 0.08h, at each radius covered 360° (Figure 2).The canopy height was nominally 12 m.

Table 5: Test number, dates and start and end time for the Florida 2002 tracer field experiments.

Test #	Date	Start Time	End Time
1	5-Feb	11:00	14:30
2	9-Feb	10:30	14:00
3	14-Feb	11:00	14:30
4	22-Feb	10:30	14:00
5	1-Mar	11:00	14:30
6	6-Mar	11:00	14:30

Table 6: Source heights. y is vertical height. Canopy height (h) is 12 m.

y (m)	y/h
0.91	0.08
6.40	0.51
10.06	0.85

Table 7: Radii (distance from the flux tower) and beginning and ending heading for the source arcs at the 0.51 h and 0.85 h heights.

radius (m)	beginning heading	ending heading	arc length (m)
10.75	0	203	38.09
21.5	0	203	76.17
43	0	203	152.35

Six PFTs were released in each test. In tests 1, 2, and 6 the tracers were released from the 10.75 and 21.5 m arcs. In tests 3 - 5 they were released from the 21.5 and 43 m arcs. Release rates and locations for each trace are given in Tables 10-12.

PFT samples were collected on the tower using programmable BAT samplers. The programmable samplers were located at seven heights on the tower (Table 3). Samples were collected for ½ hour periods from 10:30 or 11:00 until 14:00 or 14:30. The sampler for the 0.4 h level failed in tests 1, 2, and 3 and the sampler at 2.0 h failed during tests 1, 4, 5, and 6. No data were collected at these heights during these tests.

Table 8: Radii (distance from the flux tower) and beginning and ending heading for the source arcs at the 0.08 h heights.

radius (m)	beginning heading	ending heading	arc length (m)
10.75	0	360	67.54
21.5	0	360	135.09
43	0	360	270.18

Table 9: Location of PFT samplers on the flux tower. Canopy height was 12 m.

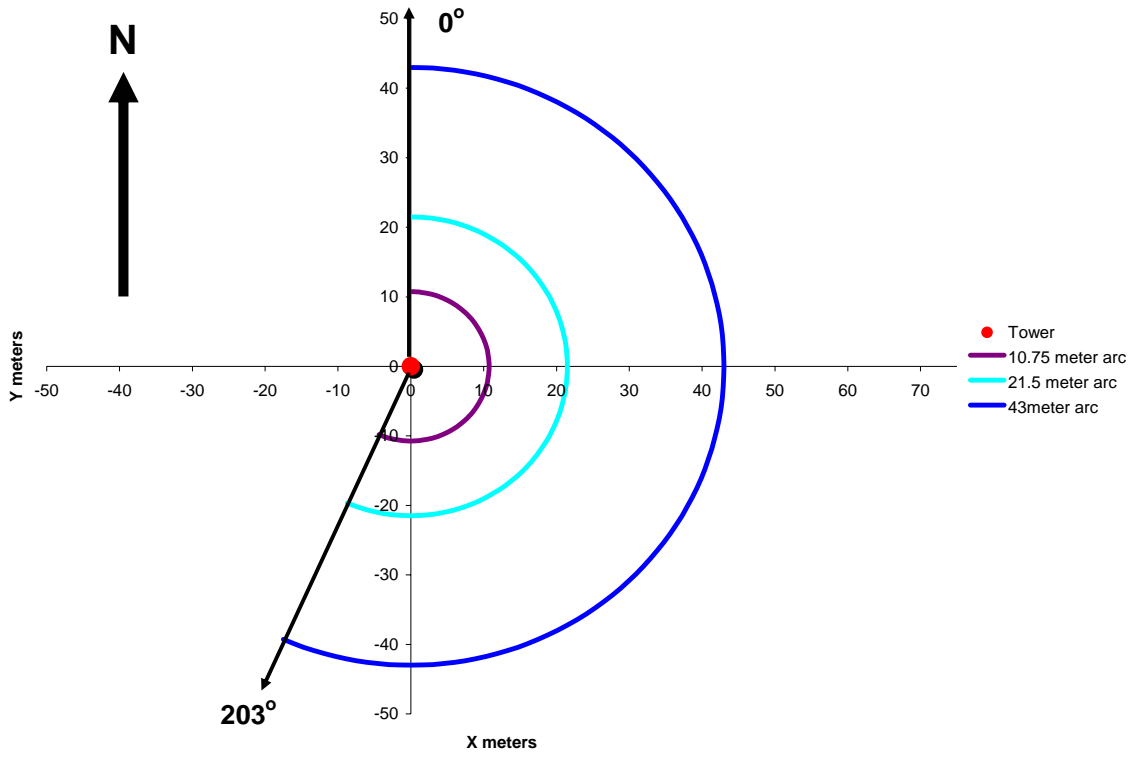| Fraction of canopy height	Elevation (m)
0.1	1.2
0.25	3
0.4	4.8
0.55	6.6
0.7	8.4
0.85	10.2
1	12
1.4	16.8
2.0	24

Figure 1: Source layout for the 0.51h and 0.85h release levels. Canopy height (h) is 12m.
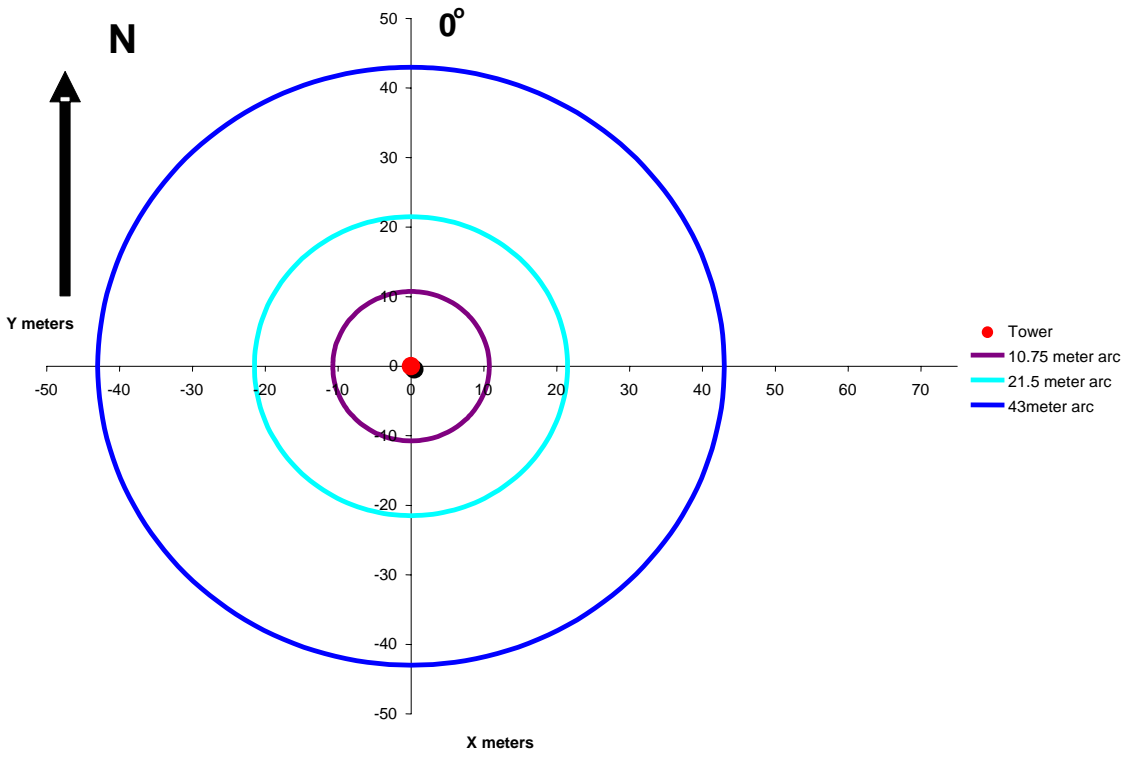
Figure 2: Source layout for the 0.08h. Canopy height (h) is 12m.

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Table 10: Tracer release rates for tests 1 and 2.

Arc	Source Height (m)	Source Height (fraction h)	PFT	Arc Length (m)	Source Strength (nL min^{-1})	Source Strength ($\text{nL min}^{-1}\text{m}^{-1}$)
10.75	0.9	0.08	PTCH	68	523	8
10.75	6.4	0.51	iPPCH	38	369	10
10.75	10.1	0.85	PECH	38	1333	35
21.5	0.9	0.08	PMCP	135	2025	15
21.5	6.4	0.51	PMCH	76	1017	13
21.5	10.1	0.85	ocPDCH	76	199	3
43	0.9	0.08		270		
43	6.4	0.51		152		
43	10.1	0.85		152		

Table 11: Tracer release rates for tests 3 - 5.

Arc (m)	Source Height (m)	Source Height (fraction h)	PFT	Arc Length (m)	Source Strength (nL min^{-1})	Source Strength ($\text{nL min}^{-1}\text{m}^{-1}$)
10.75	0.9	0.08		68		
10.75	6.4	0.51		38		
10.75	10.1	0.85		38		
21.5	0.9	0.08	PTCH	135	1495	11
21.5	6.4	0.51	iPPCH	76	1363	18
21.5	10.1	0.85	PECH	76	3465	45
43	0.9	0.08	PMCP	270	6649	25
43	6.4	0.51	PMCH	152	3499	23
43	10.1	0.85	ocPDCH	152	453	3

Table 12: Tracer release rates for Test 6.

Arc (m)	Source Height (m)	Source Height (fraction h)	PFT	Arc Length (m)	Source Strength (nL min^{-1})	Source Strength (nL min^{-1}m^{-1})
10.75	0.9	0.08	PTCH	68	674	10
10.75	6.4	0.51	iPPCH	38	577	15
10.75	10.1	0.85	PECH	38	1440	38
21.5	0.9	0.08	PMCP	135	5940	44
21.5	6.4	0.51	PMCH	76	1955	26
21.5	10.1	0.85	ocPDCH	76	258	3
43	0.9	0.08		270		
43	6.4	0.51		152		
43	10.1	0.85		152		

2004 Experiments

The purpose of the 2004 experiments was to measure transport and dispersion beneath the forest canopy in three stability classes; well mixed, experiments 2, 6, and 7; the transition between well mixed and stable, experiments 1; and 4, and under stable to moderately stable conditions, experiments 3 and 5 (Table 13).

Table 13: Experiment Number, dates, and start and end times.

Experiment	Date	Start Time	End Time
1	4/28/2004	12:00	17:00
2	4/29/2004	9:00	14:00
3	5/12/2004	18:30	0:00
4	5/14/2004	11:30	16:30
5	5/14/2004	19:00	0:30
6	5/15/2004	9:00	14:30
7	6/30/2004	9:30	13:00

The tracers in this study were released using permeation sources. These sources are small vials containing liquid PFT that are sealed with permeable membranes. Vials are filled with approximately 5cc (8.5g) of tracer. The membranes allow PFT vapor to diffuse into the environment at rates of micrograms per minute. The lower molecular weight, more volatile PFTs have the fastest permeation rates. These sources are passive. They require no power. They have been used in indoor building transport and infiltration studies and atmospheric dispersion experiments on meter to kilometer scales. The rate at which the PFT permeates the membrane is dependent on area and thickness of the membrane, and vapor pressure of the PFT which makes the release rate temperature dependent. The temperature dependence is given by:

$$S = S_0 \exp\left[\frac{-\Delta H_{eff}}{R}\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]$$

where:

$S \equiv$ permeation rate at temperature T

$S_0 \equiv$ permeation rate at reference temperature T_0

$\Delta H_{eff} \equiv$ effective enthalpy of permeation

$R \equiv$ Molar gas constant

$\Delta H_{eff}/R$ is an effective enthalpy of permeation

The value of $\Delta H_{eff}/R$ is determined empirically by measuring the release rate as a function of temperature. Release rate is determined gravimetrically using a precision balance to weigh a sample of sources stored at a series of controlled temperatures (Dietz et al., 1986). The constants used in the calculation of release rates are given in Table 14.

Temperature data used to calculate the release rates (Table 16) were collected from 4 battery powered temperature loggers located with the sources and from the meteorological instruments on the tower. Temperatures were averaged over the test period.

Table 14: Data used in calculation of the passive source release rates.

PFT	$\Delta H_{eff}/R$	Rate at 21.5^o C (nL/min)
PDCB	3400	36
PMCH	3400	26.2
ocPDCH	3557	621
PECH	3557	1406
iPPCH	3557	817
PTCH	3557	507

The tracer release was designed to provide a maximum signal from the tracer at the tower of at least 5 times the background level. This was accomplished using permeation sources located on 3, 180° arcs centered on the tower. The arcs had radii of 50, 125, and 300 meters and ran from headings of 45° to 225°. The sources were located every 4° along these arcs (Figure 1). Two different PFTs were located at each point at levels of 0.10 and 0.85 of the canopy height or approximately 1.3 and 11.5 meters above the forest floor. The 4° spacing was chosen to give uniform concentration at short distance downwind of the arc creating an effective line source. A simple Gaussian plume model (Smith, 1968) was used to determine the distance downwind of the point sources (x) where the point sources became an effective line source. Results for each arc are given in Table 15.
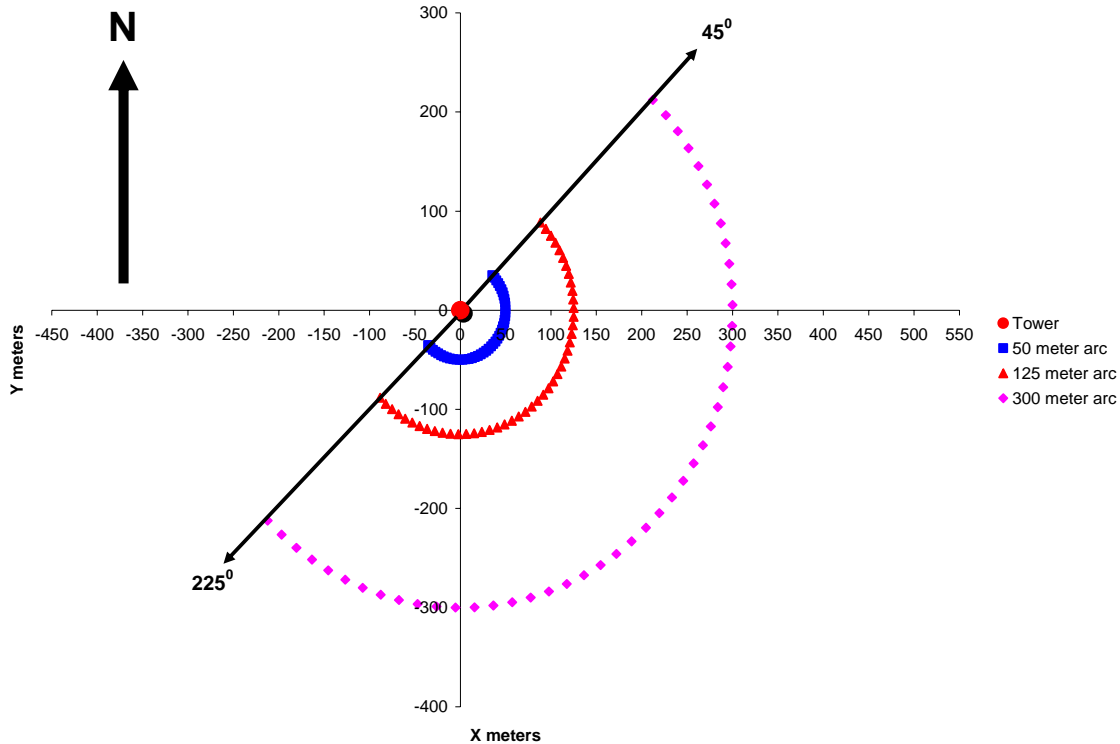
Figure 3: Release configuration showing 50, 125, and 300 meter arcs and location of the sources. The tower is located at the origin.

Table 15: Results of Gaussian plume model using neutral stability conditions. Source separation, crosswind diffusion parameter (σ_y), downwind distance from point sources and fraction of radius where effective line source occurs.

Arc Radius (r) (m)	Source Separation(d) (m)	Crosswind Diffusion, σ_y (m)	Downwind Distance (x) (m)	Fraction of radius x/r
50	3.5	2.1	11.5	0.23
125	8.7	5.2	36	0.288
300	21	12.6	111	0.37

Seven experiments were conducted. The experiment number, date and start and end times are given in Table 13. The arc, release height, PFT, temperature, and release rates for each experiment are given in Table 16. The heights where the sonic anemometers and PFT samplers were located on the flux tower are given in Table 17.

Table 16: Arc, Release height, PFT, temperature, and release rates for each experi

Experiment	Arc	Height	PFT	Mean Temperature (^{o}C)	Release Rate (nL min^{-1})	Release Rate (nL min^{-1} m^{-1})
1	50	0.10	PMCH	30.7	37	21
		0.85	PDCB	30.7	51	15
	125	0.10	iPPCH	30.7	1177	135
		0.85	PTCH	30.7	730	84
	300	0.10	ocPDCH	30.7	894	43
		0.85	PECH	30.7	2025	97
2	50	0.10	PMCH	27.5	33	19
		0.85	PDCB	27.5	45	13
	125	0.10	iPPCH	27.5	1039	119
		0.85	PTCH	27.5	645	74
	300	0.10	ocPDCH	27.5	789	38
		0.85	PECH	27.5	1787	85

Experiment	Arc	Height	PFT	Mean Temperature (^oC)	Release Rate (nL min^{-1})	Release Rate (nL min^{-1} m^{-1})
3	50	0.10	PMCH	22.9	28	16
		0.85	PDCB	22.9	38	11
	125	0.10	iPPCH	22.9	865	99
		0.85	PTCH	22.9	537	61
	300	0.10	ocPDCH	22.9	657	31
		0.85	PECH	22.9	1489	71
4	50	0.10	PMCH	28.7	34	20
		0.85	PDCB	28.7	47	14
	125	0.10	iPPCH	28.7	1090	125
		0.85	PTCH	28.7	676	77
	300	0.10	ocPDCH	28.7	828	40
		0.85	PECH	28.7	1875	90
5	50	0.10	PMCH	27.5	33	19
		0.85	PDCB	27.5	45	13
	125	0.10	iPPCH	27.5	1039	119
		0.85	PTCH	27.5	645	74
	300	0.10	ocPDCH	27.5	789	38
		0.85	PECH	27.5	1787	85
6	50	0.10	PMCH	26.7	32	18
		0.85	PDCB	26.7	44	13
	125	0.10	iPPCH	26.7	1007	115
		0.85	PTCH	26.7	154	18
	300	0.10	ocPDCH	26.7	766	37
		0.85	PECH	26.7	1733	83

Experiment	Arc	Height	PFT	Mean Temperature (^{o}C)	Release Rate (nL min^{-1})	Release Rate (nL min^{-1} m^{-1})
7	50	0.10	PMCH	29.9	36	21
		0.85	PDCB	29.9	50	14
	125	0.10	iPPCH	29.9	1142	131
		0.85	PTCH	29.9	708	81
	300	0.10	ocPDCH	29.9	868	41
		0.85	PECH	29.9	1965	94

Table 17: Tower locations of sonic anemometers and BATS samplers.

Fraction of Canopy Height	Height (m)	Number of Anemometers	Anemometers Type	BATS Samplers
2.13	28.80	2	RM Young	PFT sampler
1.91	25.76	1	RM Young	
1.71	23.04	1	RM Young	
1.57	21.18	2	RM Young	
1.43	19.33	1	Cambell	PFT sampler
1.29	17.44	1	RM Young	
1.16	15.61	1	RM Young	PFT sampler
1.03	13.86	1	Cambell	PFT sampler
0.89	11.95	1	Cambell	PFT sampler
0.75	10.12	1	RM Young	PFT sampler
0.62	8.34	1	Cambell	PFT sampler
0.48	6.46	1	Cambell	PFT sampler
0.35	4.67	1	RM Young	PFT sampler
0.21	2.79	1	Cambell	PFT sampler
0.08	1.03	1	Cambell	

2006 Experiments

The Florida 2006 experiments were designed to examine the transport and dispersion in the forest canopy, from sources at the forest floor, at night, under moderately stable to very stable conditions. The experiments were conducted on the nights of June 8th and 9th and 9th and 10th.

The tracers were released in three arcs, 100, 200 and 400 meters from the BNL tower. The sources were placed on the arcs every 4° from 162° to 18° except for the 400 m arc where 3 sources at the northernmost end of the arc were eliminated because of a road (Figure 4). There were 10 sampling heights (Table 18) and 2 duplicate samplers. There were 18 half hour samples collected during each test.

Table 18: PFT sampling locations on the tower for the 2006 experiments.

Fraction of Canopy height	Height (m)
0.07	0.98
0.20	2.76
0.32	4.29
0.48	6.5
0.58	7.86
0.75	10.15
0.89	12.0
1.00	13.5
1.16	15.7
1.29	17.48

Three PFTs were released using passive sources placed at ground level, just above the forest litter layer. PDCB was released on the 40m arc, PMCH on the 200 m arc, and PMCP on the 100m arc. Temperature loggers were placed at two release points on the 200 m arc and two points on the 400 m arc. The passive sources were serum vials with permeable septa. Release rates were calculated using the formulae given in the previous section and the parameters in Table19. The rates are calculated for each half hour

sampling period using the mean of the temperature logger data collected for that period (Tables 20 and 21).
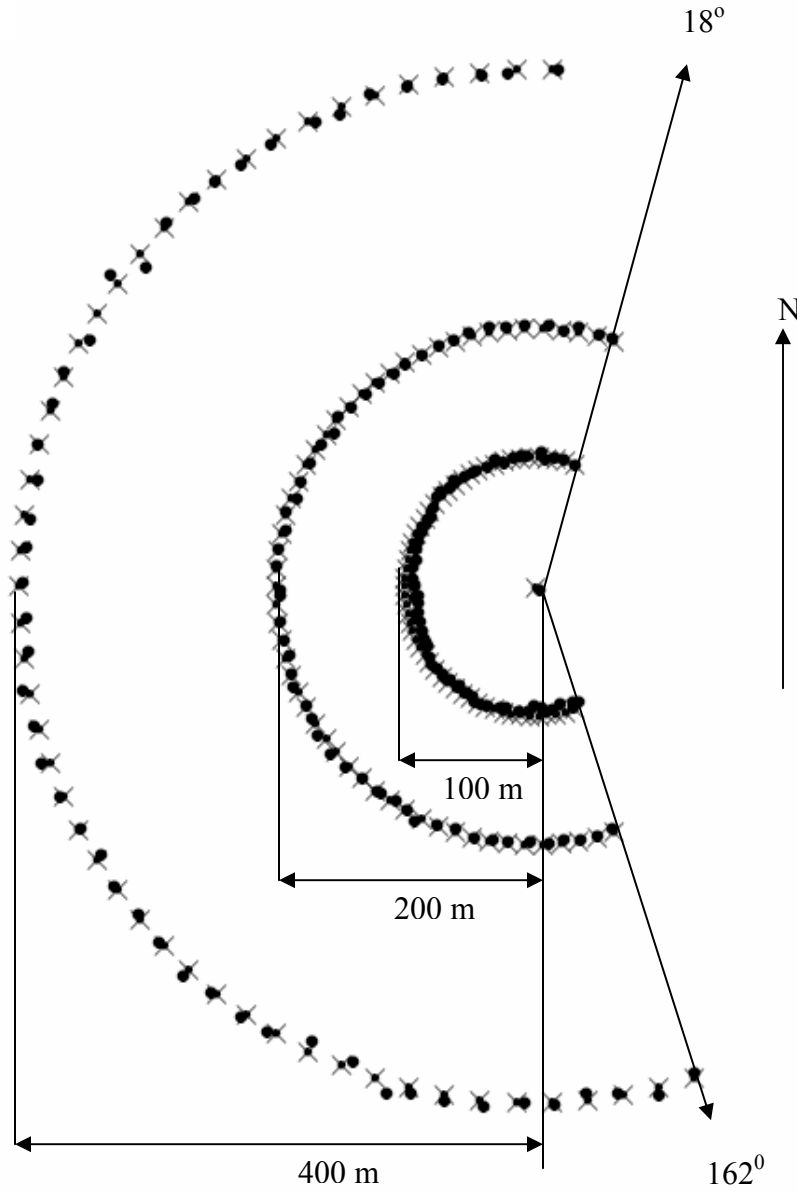
Figure 4: Source layout for the 2006 experiment. Crosses are calculated locations. Dots are the actual locations determined with differential GPS.

Table 19: Parameters for calculation of passive source release rates.

PFT	Δ H/R	Rate at 21.5°C (nL/min)
PDCB	3557	3760
PMCP	3557	4117
PMCH	3557	2554

Table 20: Release data from June 8-9 test.

Sampling Interval Number	Sampling Interval Midpoint Time	Mean Temperature (°C)	PMCP 100 m Arc Release Rate (nL min^{-1}m^{-1})	PMCH 200 m Arc Release Rate (nL min^{-1}m^{-1})	PDCB 400 m Arc Release Rate (nL min^{-1}m^{-1})
1	19:15	30.5	1768	548	397
2	19:45	29.2	1677	520	398
3	20:15	26.2	1496	464	355
4	20:45	24.0	1367	424	324
5	21:15	22.4	1283	398	305
6	21:45	21.1	1214	377	288
7	22:15	19.7	1148	356	272
8	22:45	18.7	1100	341	261
9	23:15	17.8	1062	329	252
10	23:45	17.1	1027	319	244
11	0:15	16.6	1006	312	239
12	0:45	16.2	989	307	235
13	1:15	15.6	967	300	230
14	1:45	15.3	952	295	226
15	2:15	14.8	934	290	222
16	2:45	14.5	921	286	219
17	3:15	14.4	915	284	217
18	3:45	14.0	902	280	214

Table 21: Release data from June 9-10 test.

Sampling Interval Number	Sampling Interval Midpoint Time	Temperature (^{o}C)	PMCP 100 m Arc Release Rate (nL min^{-1}m^{-1})	PMCH 200 m Arc Release Rate (nL min^{-1}m^{-1})	PDCB 400 m Arc Release Rate (nL min^{-1}m^{-1})
1	19:15	31.7	1851	574	415
2	19:45	31.0	1801	559	428
3	20:15	29.2	1679	521	398
4	20:45	27.6	1579	490	375
5	21:15	26.6	1517	471	360
6	21:45	25.6	1460	453	347
7	22:15	25.4	1444	448	343
8	22:45	22.8	1304	404	309
9	23:15	24.0	1366	424	324
10	23:45	23.4	1333	413	316
11	0:15	22.8	1301	403	309
12	0:45	22.3	1279	397	303
13	1:15	21.9	1256	390	298
14	1:45	22.5	1290	400	306
15	2:15	23.3	1329	412	315
16	2:45	23.3	1329	412	315
17	3:15	22.0	1263	392	300
18	3:45	21.3	1225	380	291

The background measurements were made about 3 km upwind of the site (Table 22).

Table 22: Background measurement statistics determined from samples taken in rural Florida. The values are in units of ppqv. N is the number of samples

	PDCB	PMCP	PMCH	ocPDCH	iPPCH	PTCH	ptPDCH
mean	2.7	8	8	1	0	0	7.7
stdev	0.4	0.6	0.9	0.4	0.2	0.2	0.8
sdom	0.07	0.09	0.14	0.07	0.03	0.03	0.1
N	36	36	36	36	36	36	36

Results of the duplicate samplers are given in Figure 5. They show excellent agreement between the samples collected and analyzed from two separate samplers.
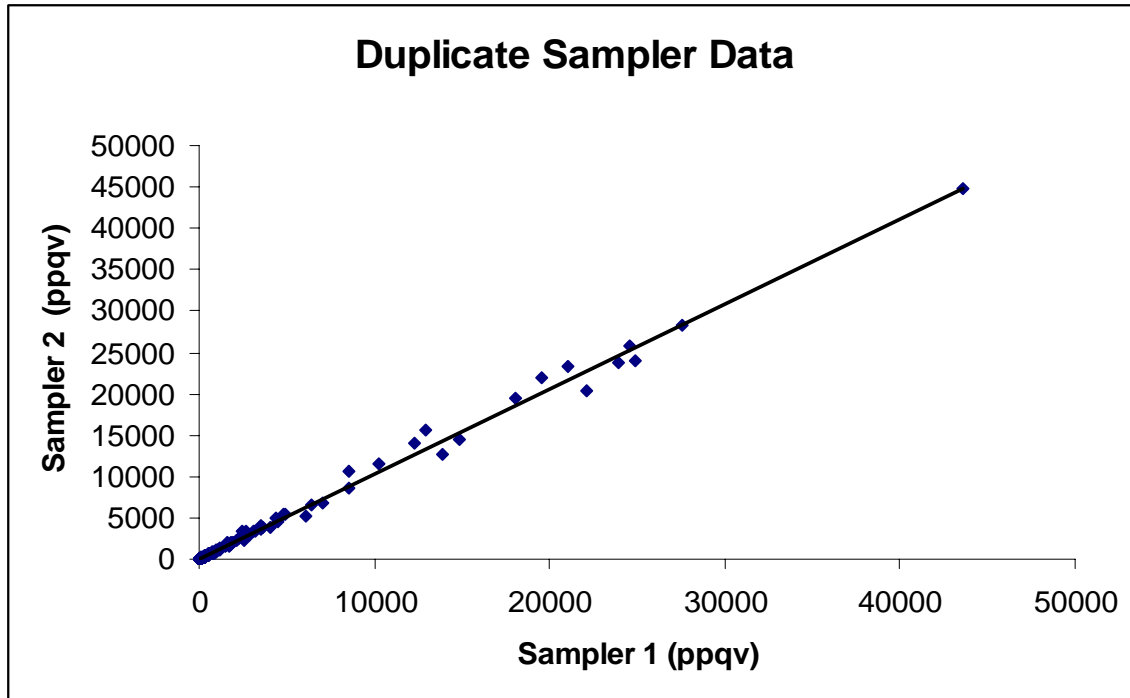
Figure 5: Correlation plot of data from duplicate samplers. Linear fit is: y = 1.03x + 42 with r^2 = 0.995.

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