Full Scale Implementation of Methane Oxidation Bed Technology at Four Landfills in the Thompson-Nicola Regional District – 2016 Results

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EXECUTIVE SUMMARY

This report evaluates the performance of methane oxidation technology applied to four small rural landfills in the Thompson Nicola Regional District (TNRD) of British Columbia, Canada.

The objective of this study is to assess the full implementation of Methane Oxidation Technology in four TNRD landfills at Barriere, Clearwater, Chase and Logan Lake. This is the first full implementation of this technology as an integrated and complimentary add on to the Evapotranspirative cover technology used for the landfill closure. This is also part of the TNRD longer term strategy in dealing with its smaller, older and/or closed landfills in the area. Methane oxidation technology represents a GHG mitigation technology which will improve air quality in the surroundings of the four landfill sites.

In particular, the following sub-objectives were addressed in this report summarizing the results of the 2016 monitoring data:

- Monitoring field test performance by measuring LFG composition, temperature and surface emission at the MOBs at regular intervals.
- Evaluating monitoring results and presenting the results in a final report submitted to TNRD.

Field monitoring of temperatures and regular monitoring of gas composition and surface flux was found to be a robust method of assessing the Methane Oxidation Bed (MOB) performance. Monitoring the MOBs temperature proved to be an excellent tool to assess biological activity, and thus, potential methane oxidation. Temperatures inside the MOB were always higher than air temperatures indicating the presence of biological activity generating heat from the oxidation of methane. Temperature changes also allowed us to assess heterogeneity in the MOB material and the presence of pronounced site effects. We found that methane levels decreased from the bottom of the MOB to the top layers showing methane oxidation activity corroborating the temperature data. Oxygen levels were close to zero in most of the MOB layers except at 20 cm depths (and only occasionally where they were above zero but still very low). The absence of oxygen limits methane oxidation and thus the ability of the MOB to treat methane emissions.

Carbon dioxide levels decreased from the bottom of the MOB to the top layers showing the likely effect of gas dilution with atmospheric air. Nitrogen levels increased from the bottom of the MOB to the top layers showing the likely effect of nitrogen enhancement due to gas dilution with atmospheric air (large nitrogen concentration).

Flux measurements and calculations showed significant methane oxidation at the MOBs with Chase showing highest amounts while Barriere, Clearwater and Logan Lake showed higher % rates of methane removal.

Methane oxidation can lead to significant removal of landfill methane, and thus has the potential to earn GHG credits.

1 INTRODUCTION

This study presents the results of a project undertaken by Abboud Research Consulting Inc. (ARC) and the Thompson-Nicola Regional District (TNRD).

The TNRD is in the process of implementing a new regional solid waste management plan. A major component of this plan was the closure of three smaller landfills leaving two landfills (operated by the TNRD) servicing the region (TNRD, 2008). The two operating Landfills in the TNRD serve 128,473 residents of rural areas including 10 member municipalities (Statistics Canada, 2011a). A municipal landfill operated by the City of Kamloops and located within the City of Kamloops, provides service to residents of Kamloops serving a population of 98,754. (Statistics Canada, 2011b). A third privately operated landfill also serves as a regional landfill.

The TNRD pioneered the use of Methane Oxidation Technology by funding pilot studies to assess the use of the technology at two landfill sites (Barriere and Lower Nicola). The results showed that this technology was successful at treating methane emissions from these landfills (Abboud and Chen, 2010 and Abboud, 2011). The TNRD also started full implementation of the Methane Oxidation Technology in Four landfills starting in 2012 and full design and construction description and initial results were reported in Abboud (2013 and 2014).

Rather than traditional capping and leave behind strategies the TNRD is actively managing the remaining landfill gas emissions from these smaller sites. Traditional capping activities will delay the issue of landfill gas emissions from these sites on to future generations. Also, not dealing with landfill gas at this time will increase the risk of uncontrolled emissions, through cracks or subsurface, now or in the future, which can potentially lead to landfill fires and explosions. By including Methane Oxidation Technology as part of the capping and closure of the smaller landfill sites, the TNRD is looking to actively deal and treat remaining LFG emissions now and during the closure and post-closure period of these landfill sites. It is anticipated that the implementation of

Methane Oxidation Technology will significantly shorten the length and simplify the post closure operation of the TNRD landfill sites. The eventual capital project will be a series of facilities distributed over the five TNRD landfill sites and will improve air quality and mitigate greenhouse gas emissions in the area.

1.1 OBJECTIVE

The objective of this study is to field test Methane Oxidation Technology in four TNRD landfills. This will help the TNRD in dealing with its smaller, older and/or closed landfills in the area. It is based on internal and external project experiences at the TNRD pilot projects at Barriere and Lower Nicola landfills and the Leduc and District Regional Landfill in Alberta.

This study will significantly benefit the TNRD in their plan to close and responsibly manage their older smaller sites, while concentrating on a more regional waste management approach. Methane oxidation technology represents a GHG mitigation technology which will improve air quality in the surroundings of the two landfill sites.

In particular the following sub-objectives will be addressed:

- Monitoring field test performance by measuring LFG composition, temperature and surface emission at the Methane Oxidation beds at regular intervals.
- Evaluating monitoring results with regards to the field performance of the methane oxidation beds.
- Presenting the results in an annual final report submitted to TNRD.

2 MATERIALS AND METHODS

2.1 Methane Oxidation Bed Monitoring

The monitoring started right after the installation of the monitoring equipment, and was conducted several times after the first Methane Oxidation Bed (MOB) establishment in 2012. The regular monitoring events included: assessing the weather condition at the time of sampling, downloading temperature data from the data loggers, taking LFG gas composition measurements and conducting flux measurements using the flux chamber and preparing the gas samples for transport to ARC Edmonton laboratories.

2.1.1 Temperature

At each monitoring event, the temperature data were downloaded to the laptop computer. The daily temperature was compiled from the original downloads to generate the charts on the locations and depths. The data loggers CR1000 (Campbell Sci. Inc.) were used to record temperatures continuously and store an hourly average of each temperature thermocouple.

2.1.2 Gas Composition

Landfill gas composition was measured with the GEM 2000 Gas Analyzer by (LandTec, Colton, California). The concentrations (vol %) of CH_4, CO_2, O_2 and calculates N_2 as (100 – sum of the CH_4, CO_2 and O_2 concentrations) (CES- LandTec, 2005) at 5 depths (20, 55, 90, 125 and 160 cm below the MOB surface) and 4 locations were analyzed and recorded. The average of the four readings of CH_4 concentrations at 160 cm (drainage layer just above the landfill waste) were used as the LFG influx from waste into the MOB and these values were used in the calculation for removal rates.

2.1.3 Flux Measurements

Landfill gas (CH_4 and CO_2) flux measurements were done at 4 separate locations at each MOB and were repeated at 3 separate time periods during the year (spring, summer and fall). The flux measurements were taken using a stainless steel custom built flux chamber (60 x 60 x20 cm). The gas samples were collected from the flux chamber every 5 minutes for a period of 30 minutes. The gas samples were collected by inserting a syringe needle into the septum (installed on the top of the chamber) and drawing 20 ml of the gas samples. The sample in the syringe was transferred to a pre-evacuated sample container (Exetainer 12 ml, Labco Limited, UK). A small battery powered fan was installed to mix the gas and a thermometer also installed for reading the temperature inside the chamber at the time of sampling. The samples were brought back to ARC lab and analyzed for CH_4, CO_2, O_2 and N_2 using a Varian Gas Chromatograph CP-4900 model (Varian, 2009). The gas samples were injected manually into a Varian Molsieve 5A and PoraPlot U Column, where all the permanent gases were separated and analyzed by a Thermal Conductivity Detector. A calibration curve was established for CO_2, O_2, N_2 and CH_4 with RSD of 1.7, 2.3, 2.7, and 1.0 % respectively.

The CH_4 and CO_2 flux were calculated using the following equation:

$Jout_{CH4} = \Delta C.p.V/(\Delta t.A) = (\Delta C/\Delta t).p(V/A)$

Where $\Delta C/\Delta t$ is the slope of gas concentration versus time curve, p is the density of the gas determined from the ideal gas law($g.m^{-3}$), V is the volume of the chamber and A is the surface area covered by the chamber.

The influx of CH_4 was assumed to equal the effluent LFG flux, since theoretically every unit of volume of CH_4 that is oxidized produced an equal volume of CO_2. The equation from (Zeiss, 2002) was used for calculate CH_4 influx.

$J\ in_{CH4}= Cin_{CH4} (Jout_{CH4} + Jout_{CO2})$

Where $J\ in_{CH4}$ is the concentration of methane (L/L) in the landfill.

The methane removal rate (%) is calculated using the equation:

CH_4 removal = $((Jin_{CH4}-Jout_{CH4})/Jin_{CH4}) \times 100$.

3 RESULTS AND DISCUSSIONS

This section will report on the results of the study and any relevant discussions of these results. It will address the methane emissions from the landfill and Methane Oxidation Bed (MOB) surfaces and the monitoring results for temperature and gas composition.

3.1 Temperature Profiles

Temperature is an important parameter in assessing the functioning of any MOB, as it is used as a surrogate for biological activity. The oxidation of methane by microorganisms into CO_2 and biomass is a heat producing reaction and this heat is reflected in increased temperatures. Monitoring the changes in MOB temperature affords us the chance to monitor the microbiological activity in the MOB and thus determine its ability to oxidize methane.

3.1.1 Barriere

The temperature changes in the Barriere MOB were recorded hourly and the daily averages are plotted in Figures 1 and 2.

Figure 1 presents the temperature changes over time as the averages at each of the 4 monitoring locations. The data clearly shows that the MOB temperature is always higher than the air temperature, that the temperatures are highest in the summer and lowest in the winter. Furthermore, the data from the 4 locations show remarkable similarities, which indicate good replication due to the homogeneity of the MOB.

Figure 2 presents the temperature changes over time as the averages at each of the 5 monitoring depths. Again, the data clearly shows that the MOB temperature is always higher than the air temperature, that the temperatures are highest in the summer and lowest in the winter. Furthermore, the data from the 5 depths show different values for the summer months but less different for the winter months. The data from the 5 depths show that the highest variability is in the 20 cm depth as it is closest to the surface while the lowest variability is in the 120 and 160 cm depths as they are close to the almost constant internal landfill temperature.

The temperature data seem to indicate that biological activity is occurring in the MOB and is highest in the summer and lowest in the winter months. We can thus expect to see that the methane removal rates to behave similarly to the temperatures and show highest values in the summer months.

3.1.2 Clearwater

The temperature changes in the Clearwater MOB were recorded hourly and the daily averages are plotted in Figures 3 and 4.
Figure 3 presents the temperature changes over time as the averages at each of the 4 monitoring locations. The data clearly shows that the MOB temperature is always higher than the air temperature, that the temperatures are highest in the summer and lowest in the winter. The data from the 4 locations show two distinct groupings as similarities exist between locations 1 and 2 (1^{st} group) and 3 and 4 (2^{nd} group), which indicate that the MOB has 2 areas, each showing good replication due to the homogeneity of the particular area of the MOB. This anomaly is likely due to the construction of the MOB where a rock sling was used to fill the biofilter with the MOB material leading to a segregation of the heavier biosolids (higher bulk density) from the wood chips (lower bulk density).
Figure 4 presents the temperature changes over time as the averages at each of the 5 monitoring depths. Again, the data clearly shows that the MOB temperature is always higher than the air temperature, that the temperatures are highest in the summer and lowest in the winter. Furthermore, the data from the 5 depths show different values for the summer months but less different for the winter months. Also, the data from the 5 depths show that the highest variability is in the 20 cm depth as it is closest to the surface while the lowest variability is in the 120 and 160 cm depths as they are close to the almost constant internal landfill temperature.

The temperature data seem to indicate that biological activity is occurring in the MOB and is highest in the summer and lowest in the winter months. We can thus expect to see that the methane removal rates to behave similarly to the temperatures and show highest values in the summer months.

3.1.3 Chase

The temperature changes in the Chase MOB were recorded hourly and the daily averages are plotted in Figures 5 and 6.

Figure 5 presents the temperature changes over time as the averages at each of the 4 monitoring locations. The data clearly shows that the MOB temperature is always higher than the air temperature, that the temperatures are highest in the summer and lowest in the winter. The data from the 4 locations show two groupings as similarities exist between locations 1 and 2 (1^{st} group) and 3 and 4 (2^{nd} group), which indicate that the MOB has 2 areas, each showing good replication due to the homogeneity of the particular area of the MOB. The difference between the two groupings, although not large, seems to have arisen after the start of the MOB and is likely due to the addition of new MOB materials after construction was completed or to differential settling of the MOB material.

Figure 6 presents the temperature changes over time as the averages at each of the 5 monitoring depths. Again, the data clearly shows that the MOB temperature is always higher than the air temperature. Furthermore, the data from the 5 depths show that the highest variability is in the 20 cm depth as it is closest to the surface while the lowest variability is in the 120 and 160 cm depths as they are close to the almost constant internal landfill temperature.

The temperature data seem to indicate that biological activity is occurring in the MOB and is highest in the summer and lowest in the winter months. We can thus expect to see that the methane removal rates to behave similarly to the temperatures and show highest values in the summer months.

3.1.4 Logan Lake

The temperature changes in the Logan Lake MOB were recorded hourly and the daily averages are plotted in Figures 7 and 8.

Figure 7 presents the temperature changes over time as the averages at each of the 4 monitoring locations. The data clearly shows that the MOB temperature is always higher than the air temperature, that the temperatures are highest in the summer and lowest in the winter. Furthermore, the data from the 4 locations show remarkable similarities, which indicate good replication due to the homogeneity of the MOB materials.

Figure 8 presents the temperature changes over time as the averages at each of the 5 monitoring depths. Again, the data clearly shows that the MOB temperature is always higher than the air temperature. Furthermore, the data from the 5 depths show that the highest variability is in the 20 cm depth as it is closest to the surface while the lowest variability is in the 120 and 160 cm depths as they are close to the almost constant internal landfill temperature.

The temperature data seem to indicate that biological activity is occurring in the MOB and is highest in the summer and lowest in the winter months. We can thus expect to see that the methane removal rates to behave similarly to the temperatures and show highest values in the summer months.

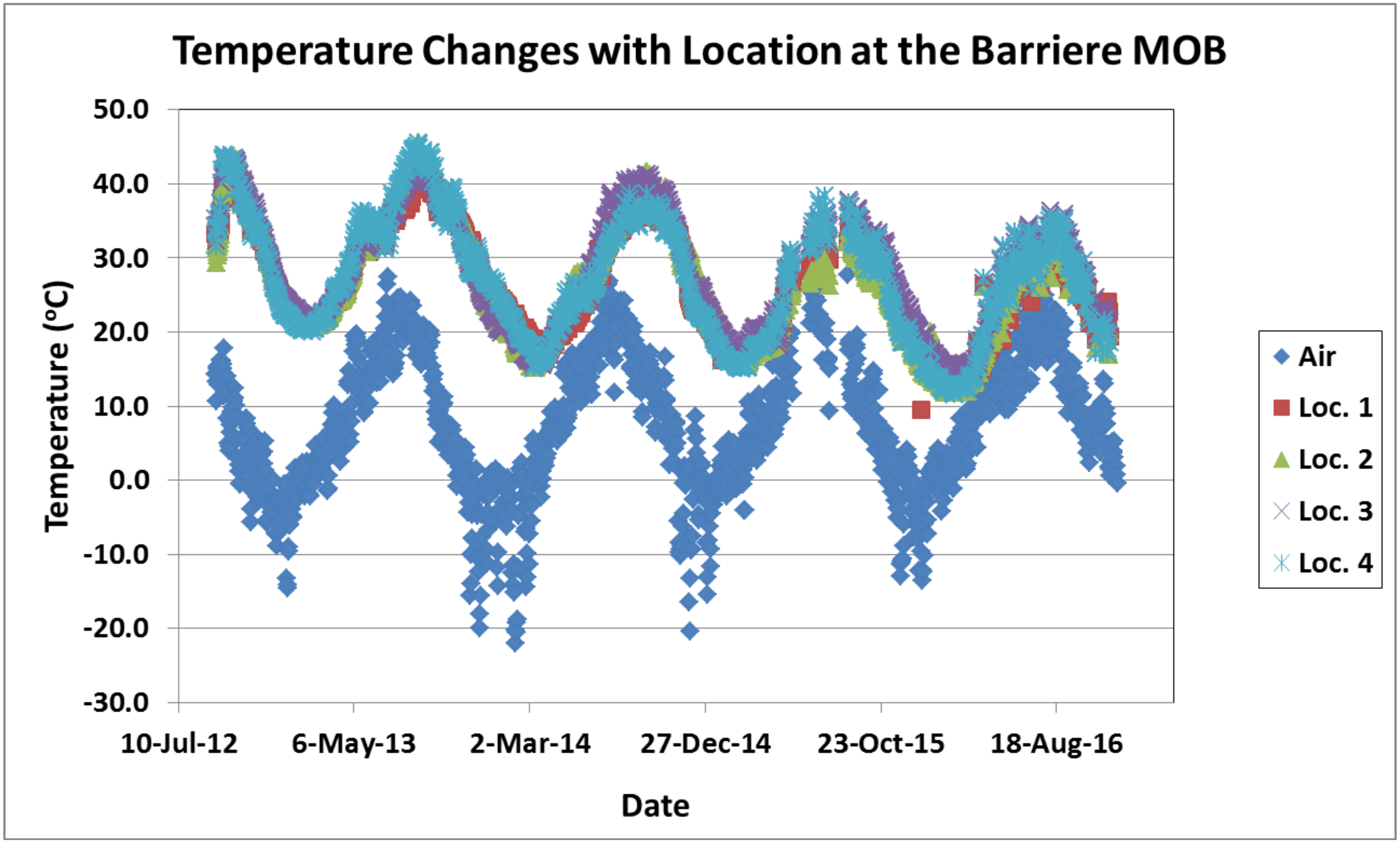

Figure 1. Barriere landfill temperature profile for each measurement location (averaged over 4 MOB depths).

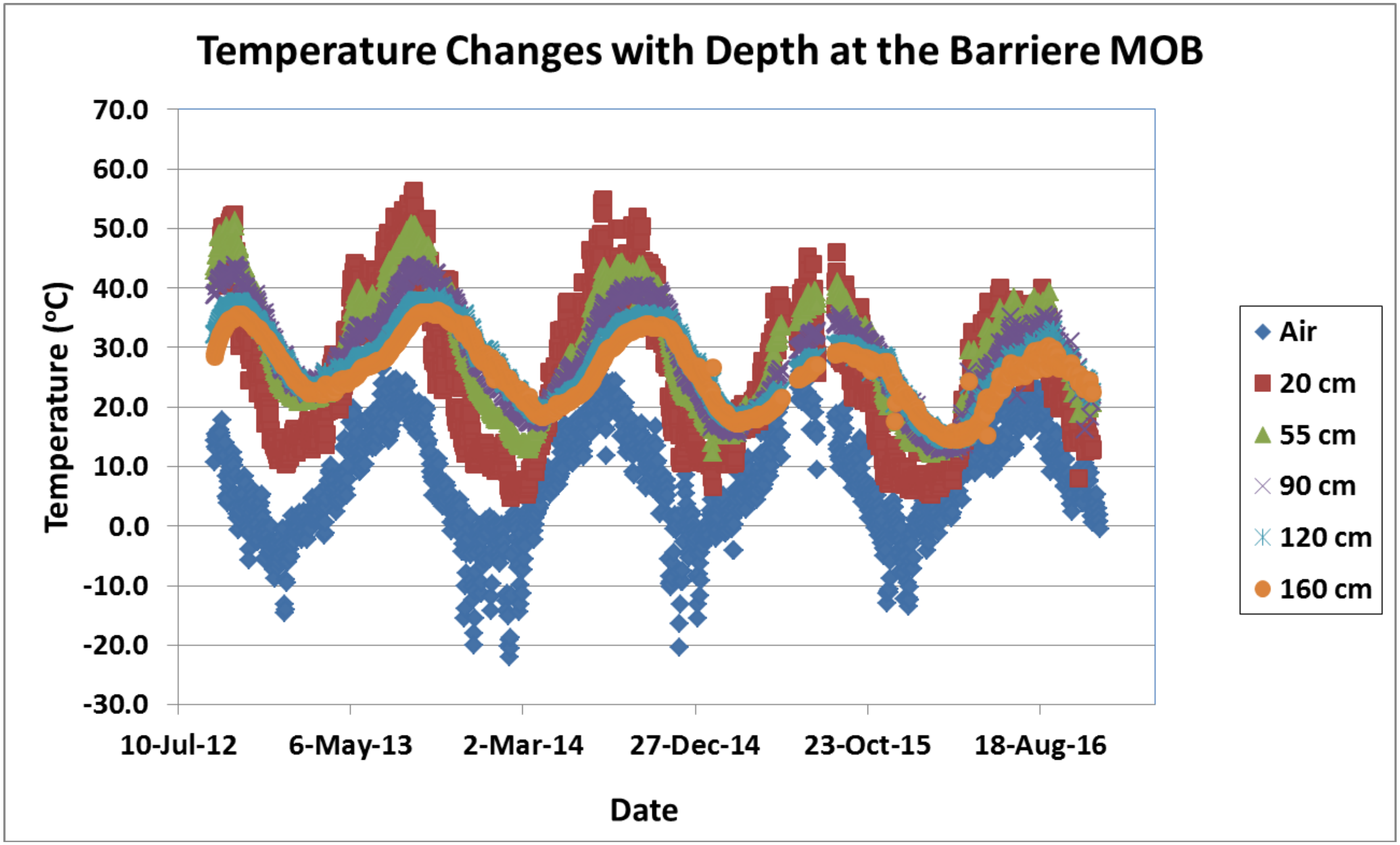

Figure 2. Barriere landfill temperature profile for each measurement depth (averaged over 4 measurement locations).

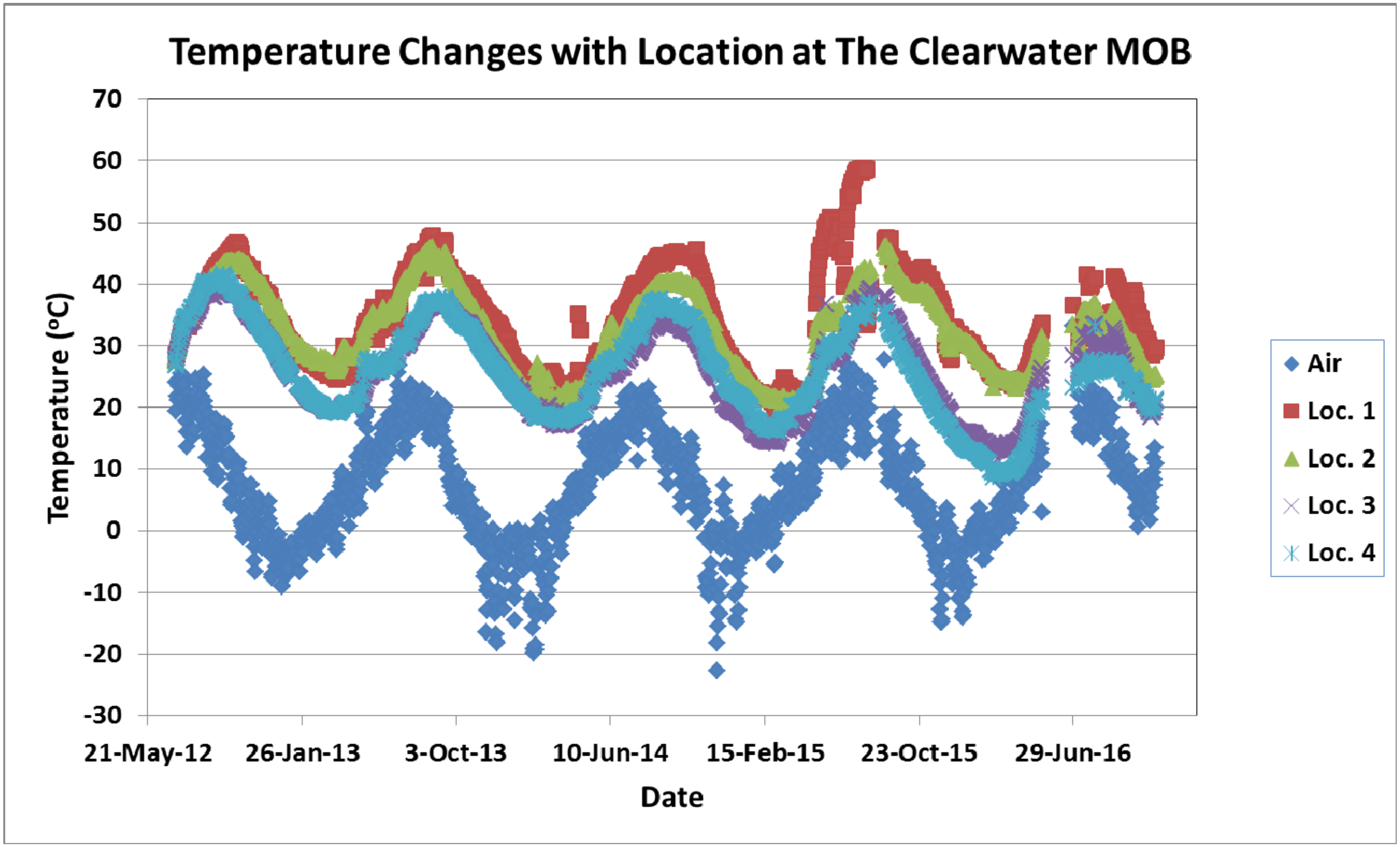

Figure 3. Clearwater landfill temperature profile for each measurement location (averaged over 4 MOB depths).

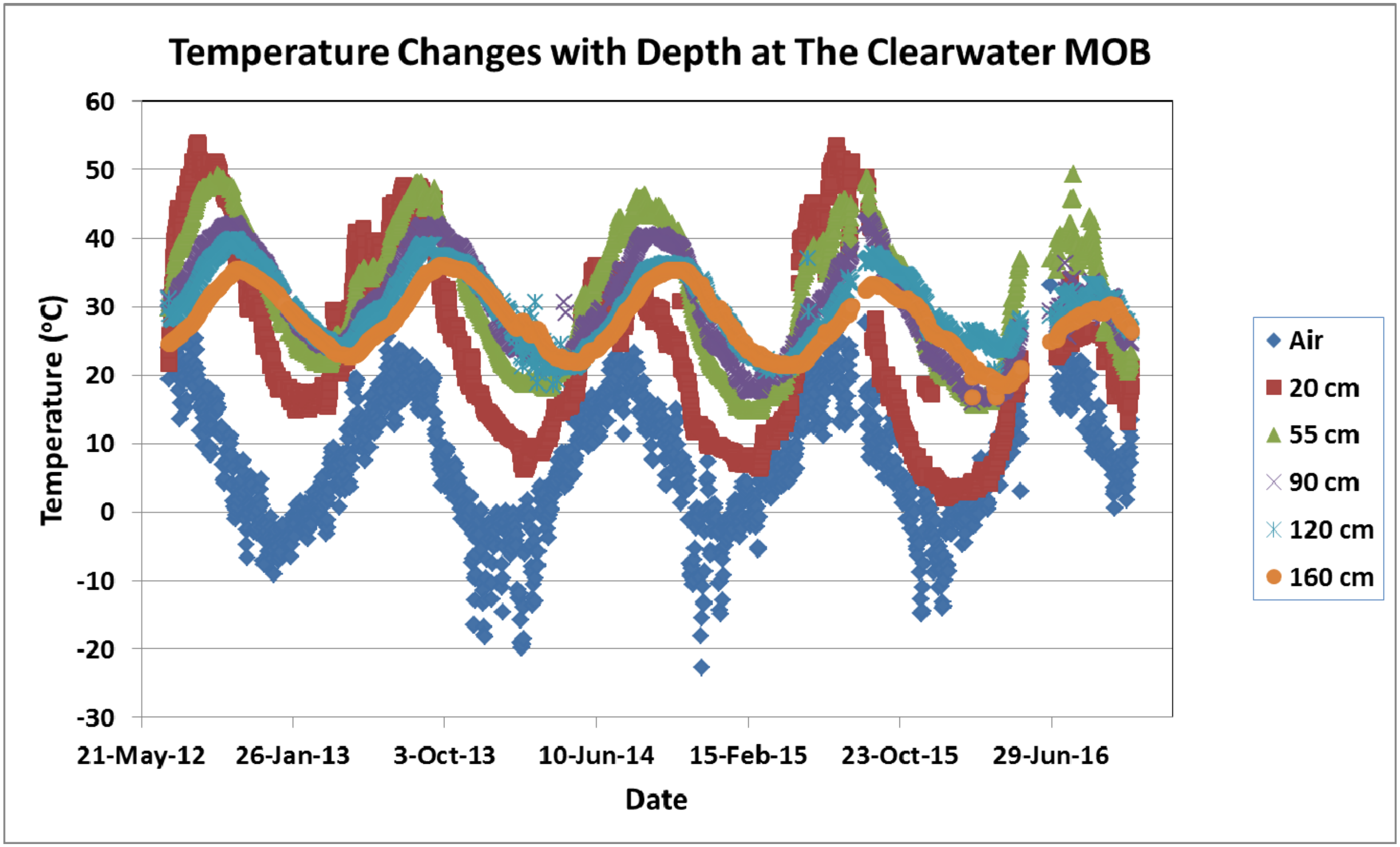

Figure 4. Clearwater landfill temperature profile for each measurement depth (averaged over 4 measurement locations).

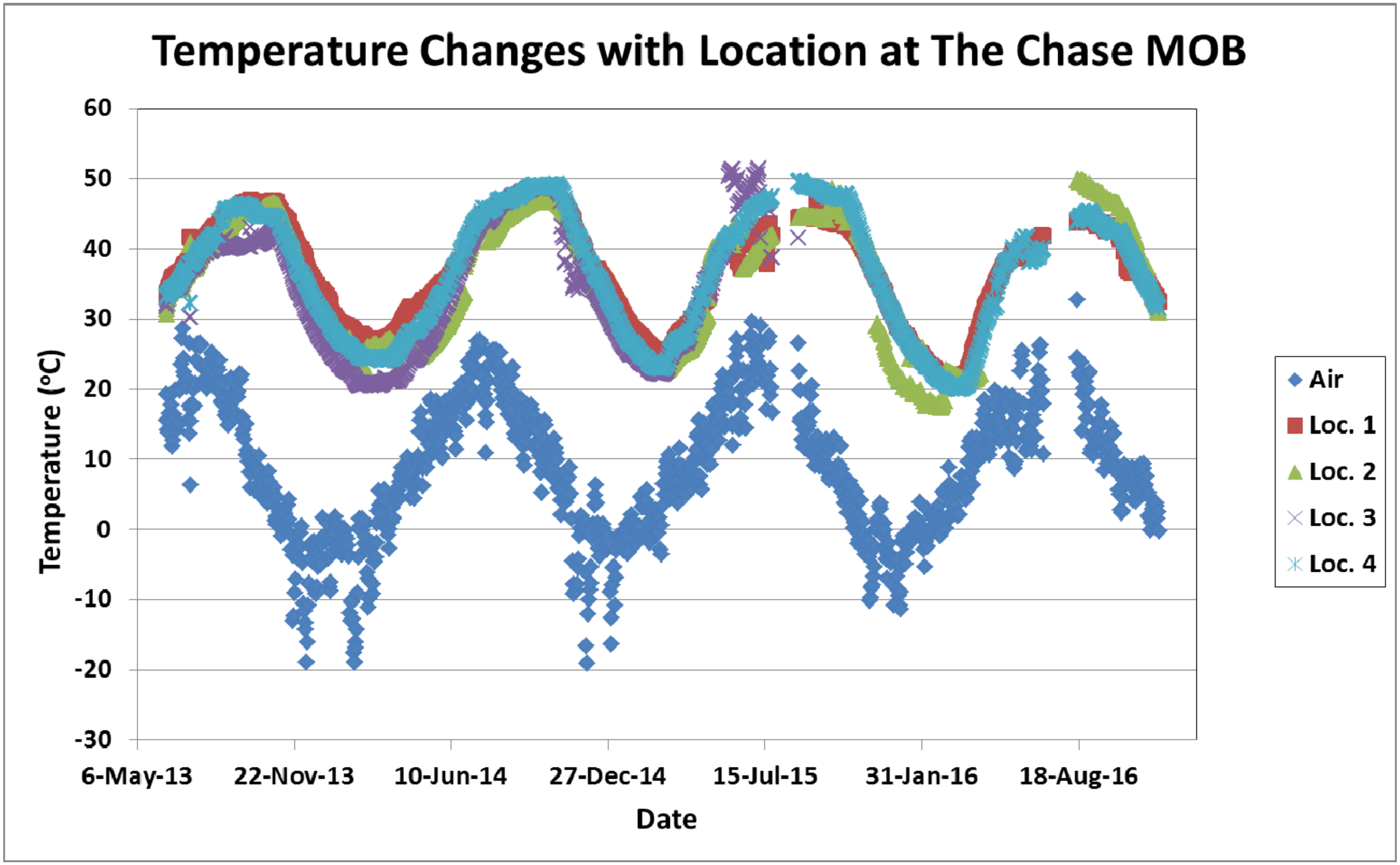

Figure 5. Chase landfill temperature profile for each measurement location (averaged over 4 MOB depths).

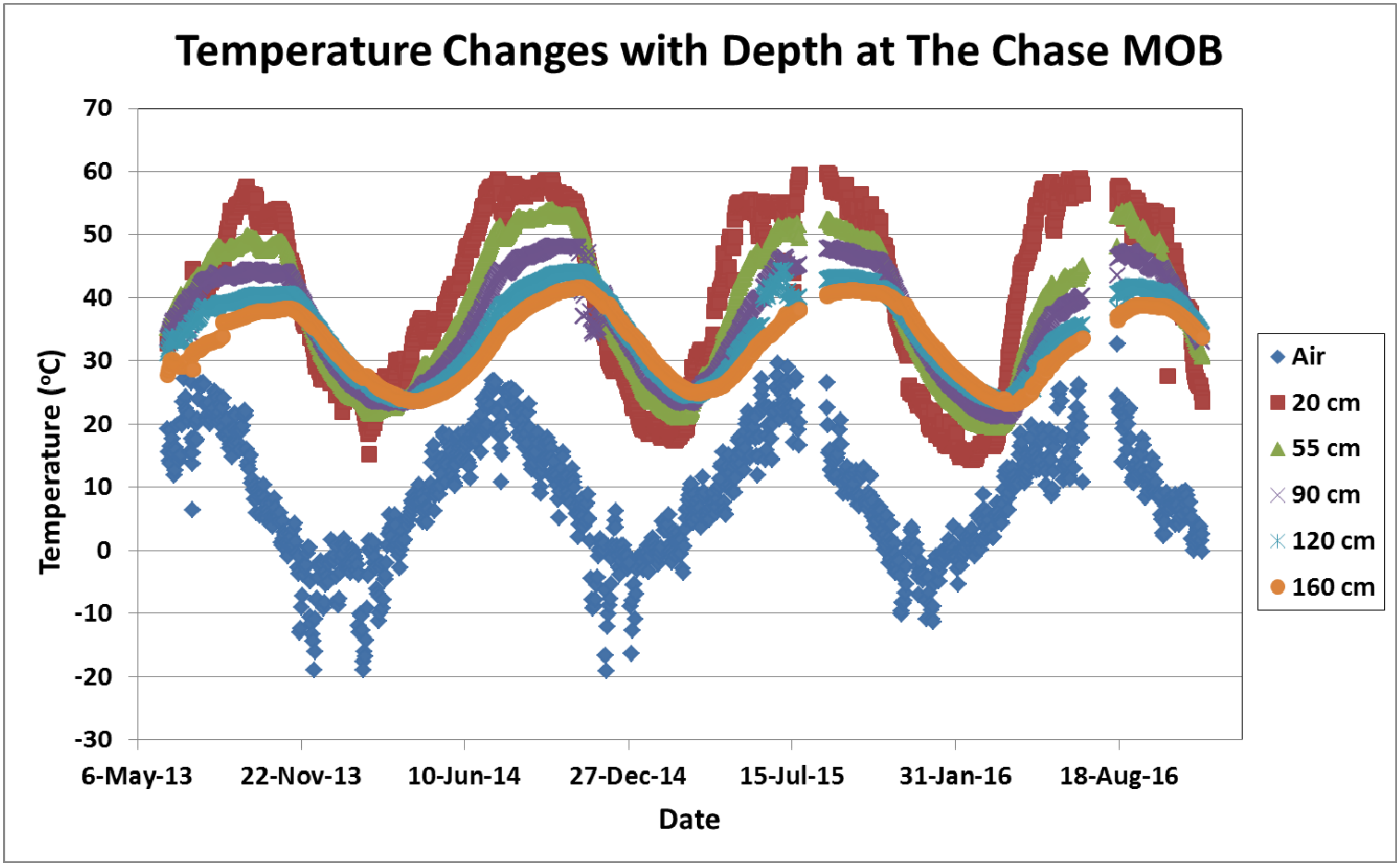

Figure 6. Chase landfill temperature profile for each measurement depth (averaged over 4 measurement locations).

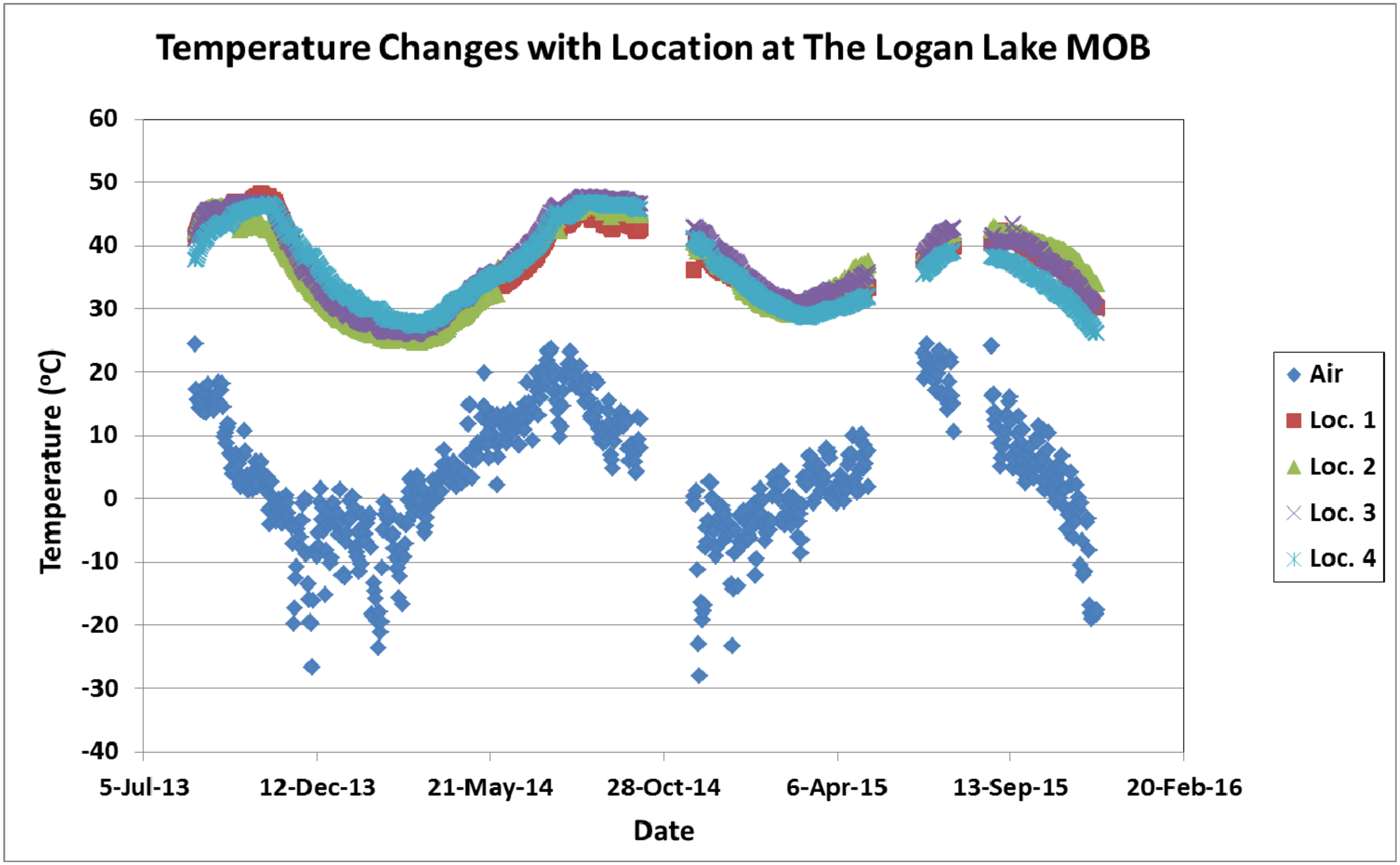

Figure 7. Logan Lake landfill temperature profile for each measurement location (averaged over 4 MOB depths).

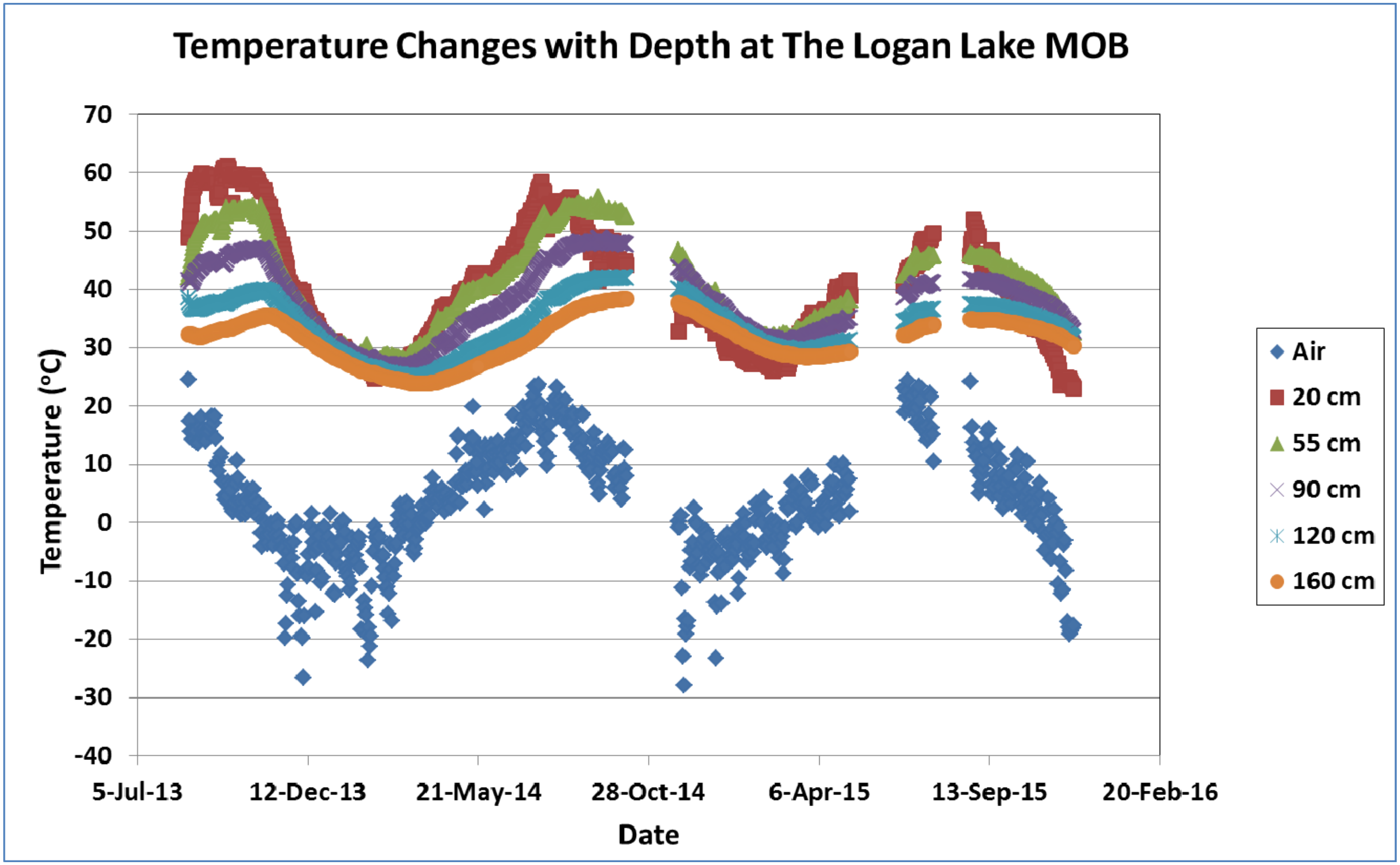

Figure 8. Logan Lake landfill temperature profile for each measurement depth (averaged over 4 measurement locations).

3.2 Gas Composition

Landfill gas consists primarily of CH_4 and CO_2 with traces of other gases. Monitoring the changes in gas composition at different MOB depths allows us to observe changes due to biological activity in the MOB. One expects to have the highest CH_4 concentrations at the drainage layer (160 cm) as it is the same as the landfill CH_4 concentrations (no treatment yet). As the gas moves up it is treated by microbial aerobic degradation, which requires O_2 to move into the MOB from the atmosphere. Thus the monitoring of gas composition with depths allows us to observe the oxidation of CH_4 as it travels up the MOB medium.

Figures 9, 10, 11 and 12 show the changes in gas composition by depth, for the Barriere, Clearwater, Chase and Logan Lake MOBs. The data indicates that the concentration of methane at the landfill surface (160 cm) varies with time which is likely due to variations in weather conditions (temperature and pressure).

3.2.1 Barriere

The gas composition in the Barriere MOB is presented in Figure 9 for the 2016 monitoring events showing the changes by depth for each monitoring period and the changes between monitoring events (seasonal).

Figure 9 shows that the CH_4 and CO_2 concentrations are highest in the lowest depths and decrease as one progresses up through the MOB. The decrease in CH_4 concentrations as it travels up the MOB is due to biological oxidation which reduces the CH_4 concentrations and generates heat (as shown in Figure 2). The decrease in CO_2 concentrations is likely due to the dilution by air as evidenced by the increased N_2 concentrations. O_2 concentration decrease rapidly down the MOB depth and are often near zero, indicating the complete use of O_2 in CH_4 oxidation. We can enhance CH_4 removal by oxidation if we can introduce more O_2 into the MOB, especially to the layers lower than 20 cm.

It is evident from the data that the MOB is capable of removing CH_4 from the landfill gas stream by microbial oxidation, but that ability is limited by the amount of O_2 introduced into the MOB. Thus increasing the O_2 concentrations down the MOB depths will allow for increased CH_4 removal.

3.2.2 Clearwater

The gas composition in the Clearwater MOB is presented in Figure 10 for the 2016 monitoring events showing the changes by depth for each monitoring period and the changes between monitoring events (seasonal).

Figure 10 shows that the CH_4 and CO_2 concentrations are highest in the lowest depths and decrease as one progresses up through the MOB. The decrease in CH_4 concentrations as it travels up the MOB is due to biological oxidation which reduces the CH_4 concentrations and generates heat (as shown in Figure 4). The decrease in CO_2 concentrations is likely due to the dilution by air as evidenced by the increased N_2 concentrations. O_2 concentration decrease rapidly down the MOB depth and are often near zero, indicating the complete use of O_2 in CH_4 oxidation. We can enhance CH_4 removal by oxidation if we can introduce more O_2 into the MOB, especially to the layers lower than 20 cm.

It is evident from the data that the MOB is capable of removing CH_4 from the landfill gas stream by microbial oxidation, but that ability is limited by the amount of O_2 introduced into the MOB. Thus increasing the O_2 concentrations down the MOB depths will allow for increased CH_4 removal.

3.2.3 Chase

The gas composition in the Chase MOB is presented in Figure 11 for the 2016 monitoring events showing the changes by depth for each monitoring period and the changes between monitoring events (seasonal).

Figure 11 shows that the CH_4 and CO_2 concentrations are highest in the lowest depths and decrease as one progresses up through the MOB. The decrease in CH_4 concentrations as it travels up the MOB is due to biological oxidation which reduces the CH_4 concentrations and generates heat (as shown in Figure 6). The decrease in CO_2 concentrations is likely due to the dilution by air as evidenced by the increased N_2 concentrations. O_2 concentration decrease rapidly down the MOB depth and are often near zero, indicating the complete use of O_2 in CH_4 oxidation. We can enhance CH_4

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It is evident from the data that the MOB is capable of removing CH_4 from the landfill gas stream by microbial oxidation, but that ability is limited by the amount of O_2 introduced into the MOB. Thus increasing the O_2 concentrations down the MOB depths will allow for increased CH_4 removal.

3.2.4 Logan Lake

The gas composition in the Logan Lake MOB is presented in Figure 12 for the 2016 monitoring events showing the changes by depth for each monitoring period and the changes between monitoring events (seasonal).

Figure 12 shows that the CH_4 and CO_2 concentrations are highest in the lowest depths and decrease as one progresses up through the MOB. The decrease in CH_4 concentrations as it travels up the MOB is due to biological oxidation which reduces the CH_4 concentrations and generates heat (as shown in Figure 8). The decrease in CO_2 concentrations is likely due to the dilution by air as evidenced by the increased N_2 concentrations. O_2 concentration decrease rapidly down the MOB depth and are often near zero, indicating the complete use of O_2 in CH_4 oxidation. We can enhance CH_4 removal by oxidation if we can introduce more O_2 into the MOB, especially to the layers lower than 20 cm.

It is evident from the data that the MOB is capable of removing CH_4 from the landfill gas stream by microbial oxidation, but that ability is limited by the amount of O_2 introduced into the MOB. Thus increasing the O_2 concentrations down the MOB depths will allow for increased CH_4 removal.

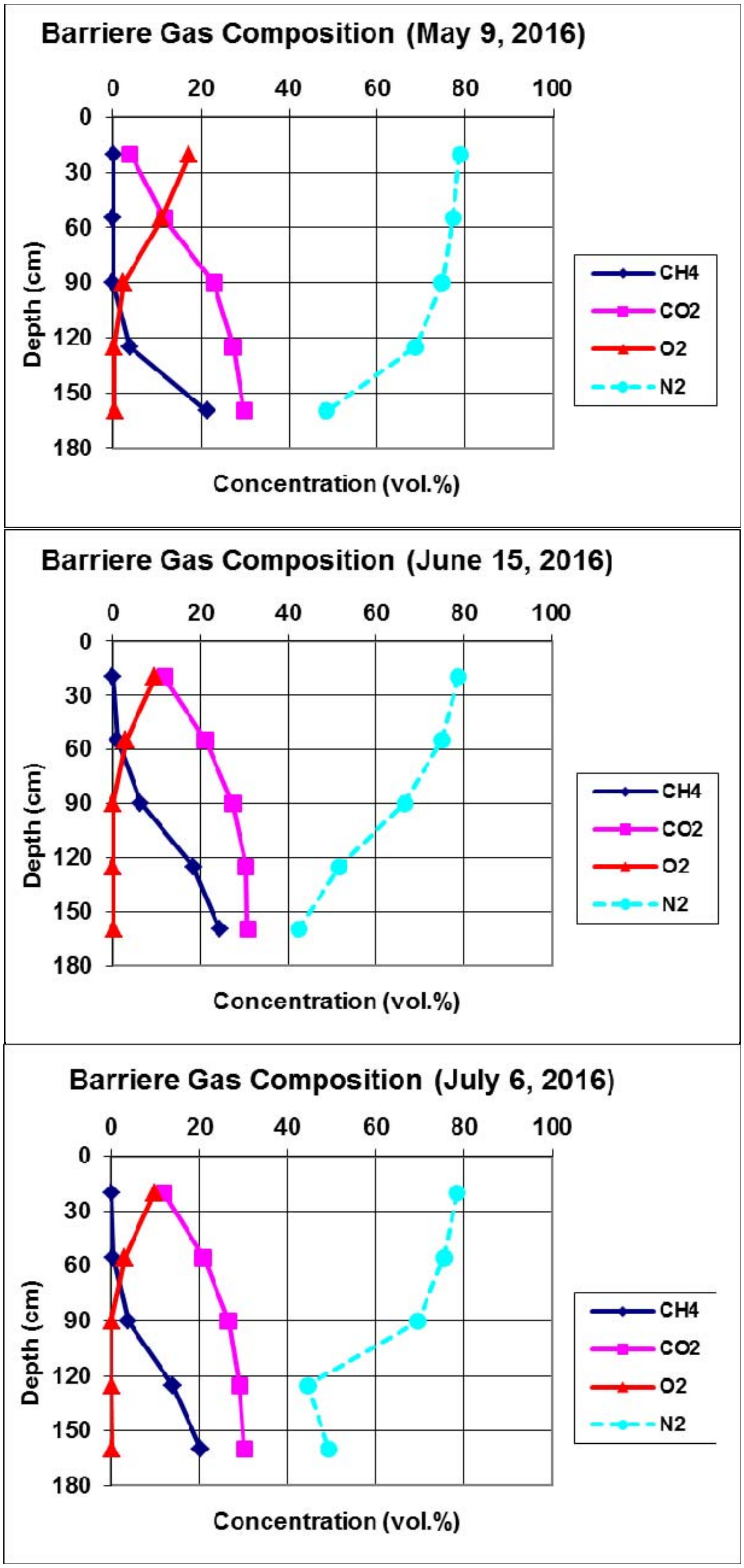

Figure 9. Barriere gas composition at several depths and sampling dates.

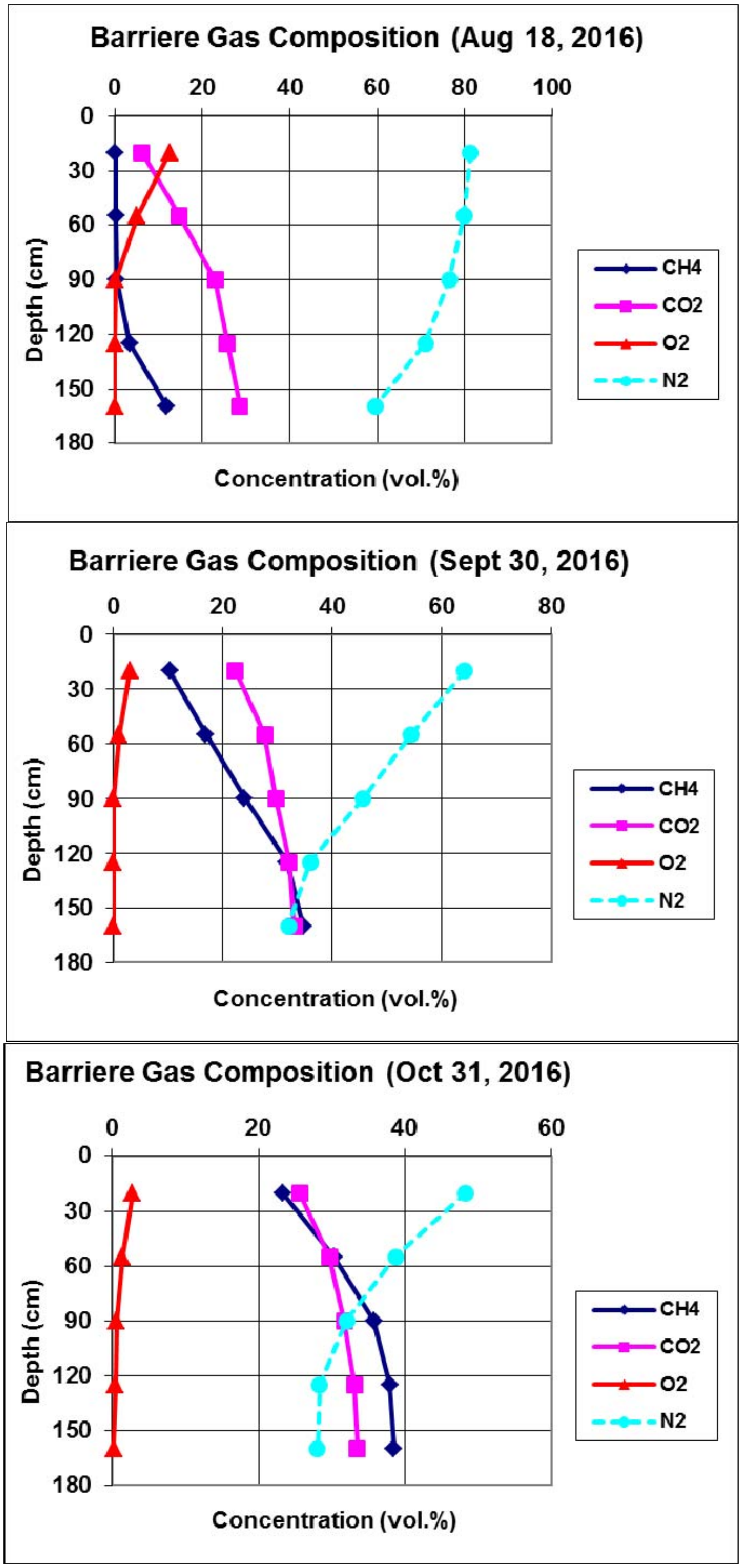

Figure 9 (Continued). Barriere gas composition at several depths and sampling dates.

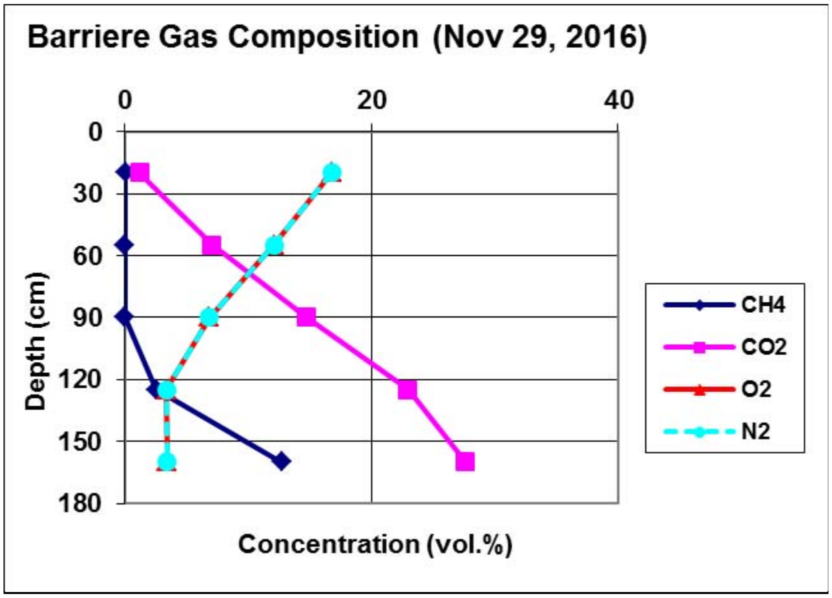

Figure 9 (Continued). Barriere gas composition at several depths and sampling dates.

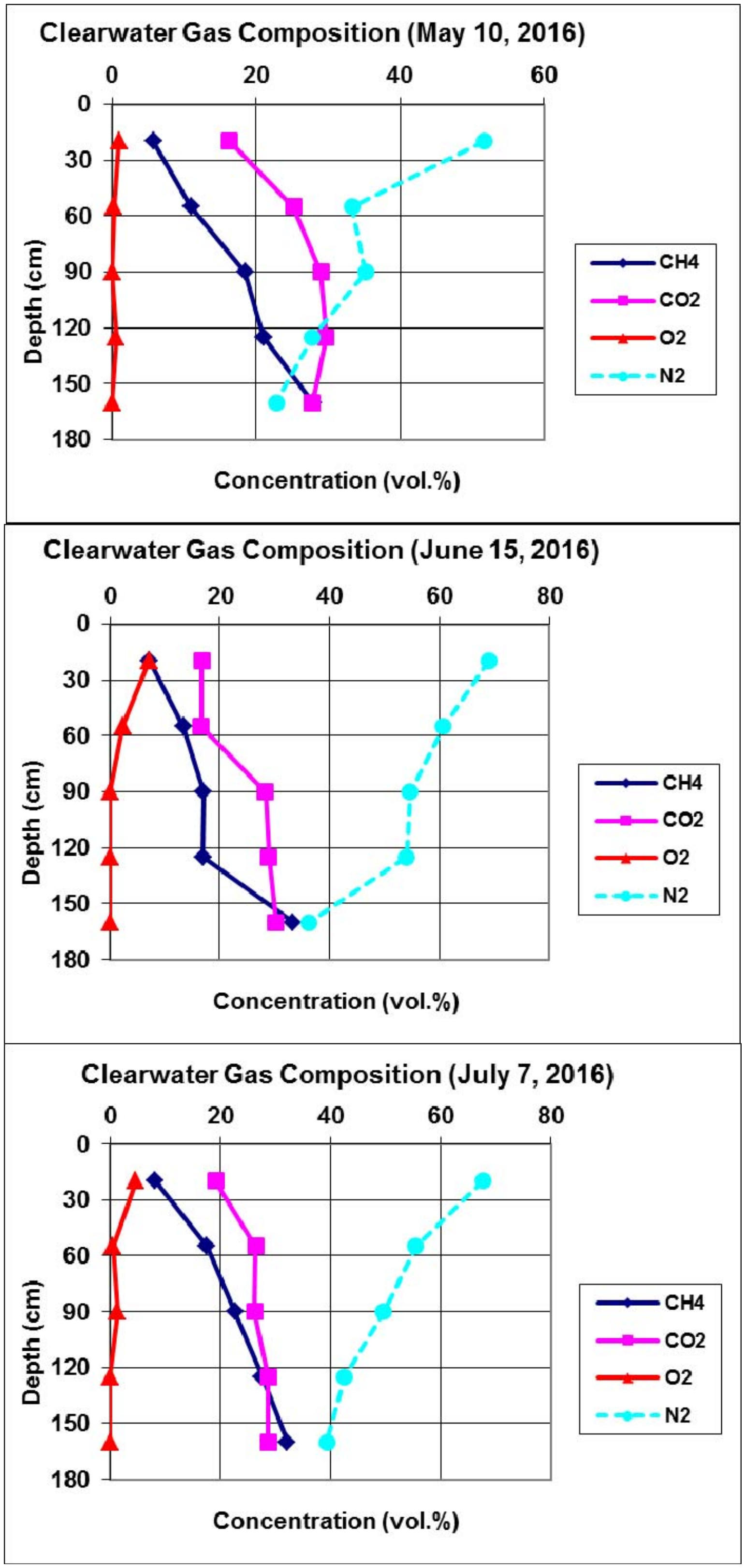

Figure 10. Clearwater gas composition at several depths and sampling dates.

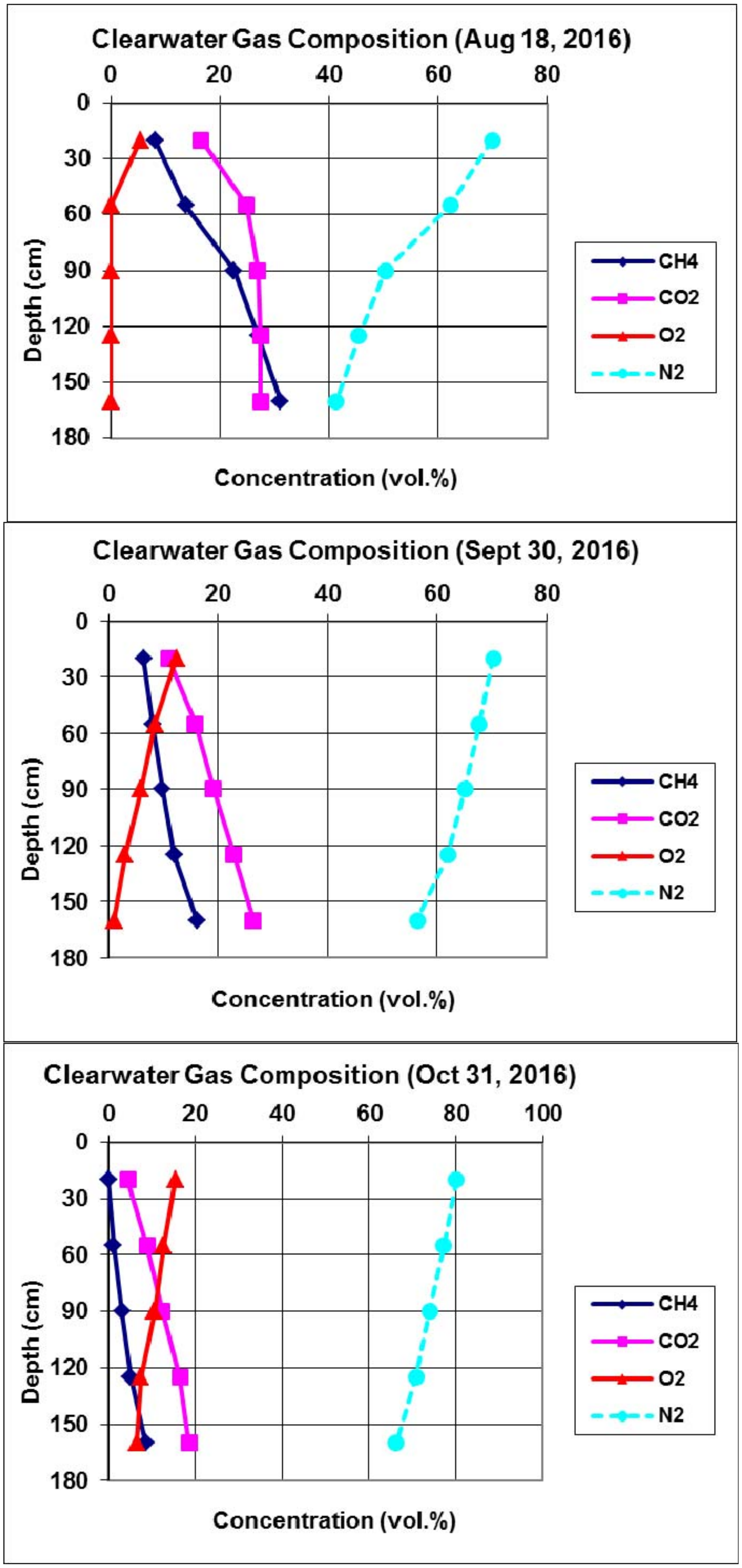

Figure 10 (Continued). Clearwater gas composition at several depths and sampling dates.

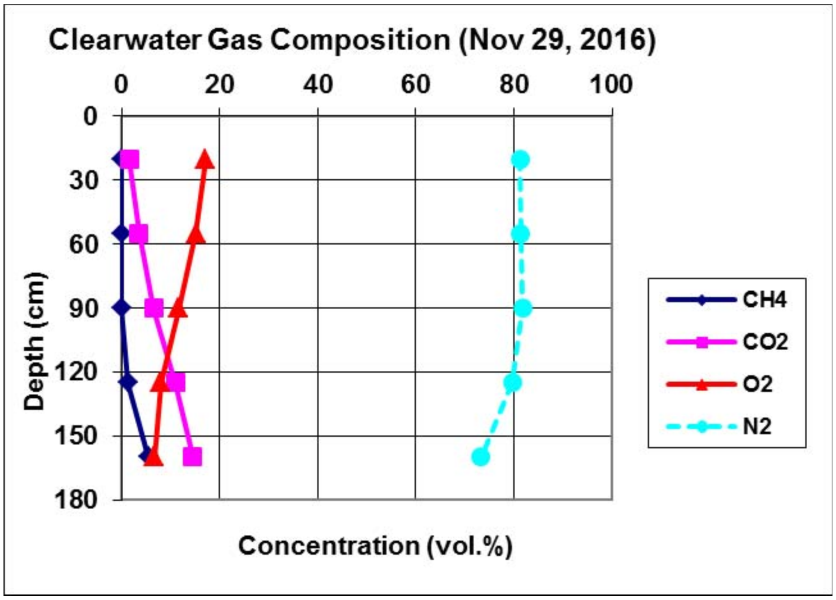

Figure 10 (Continued). Clearwater gas composition at several depths and sampling dates.

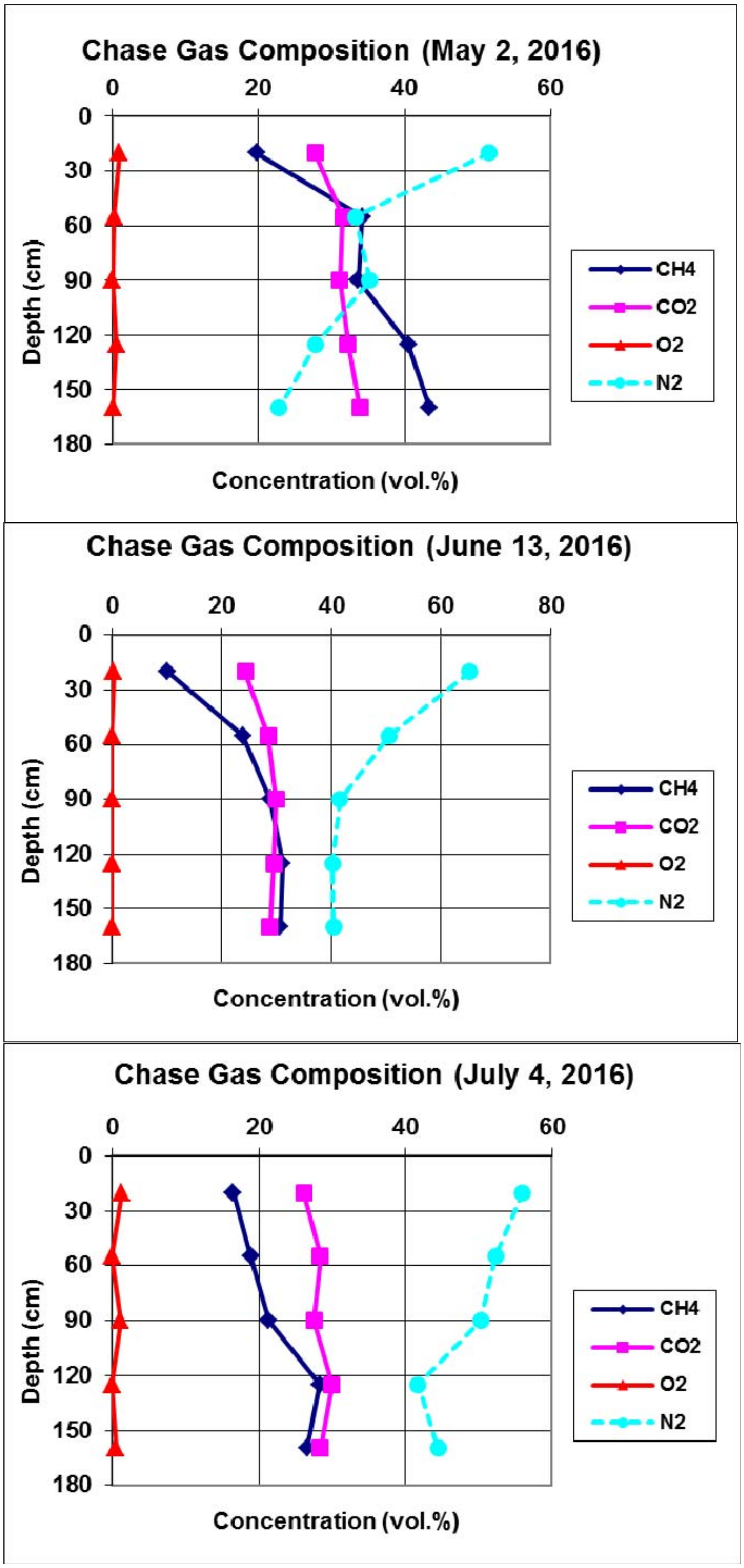

Figure 11. Chase gas composition at several depths and sampling dates.

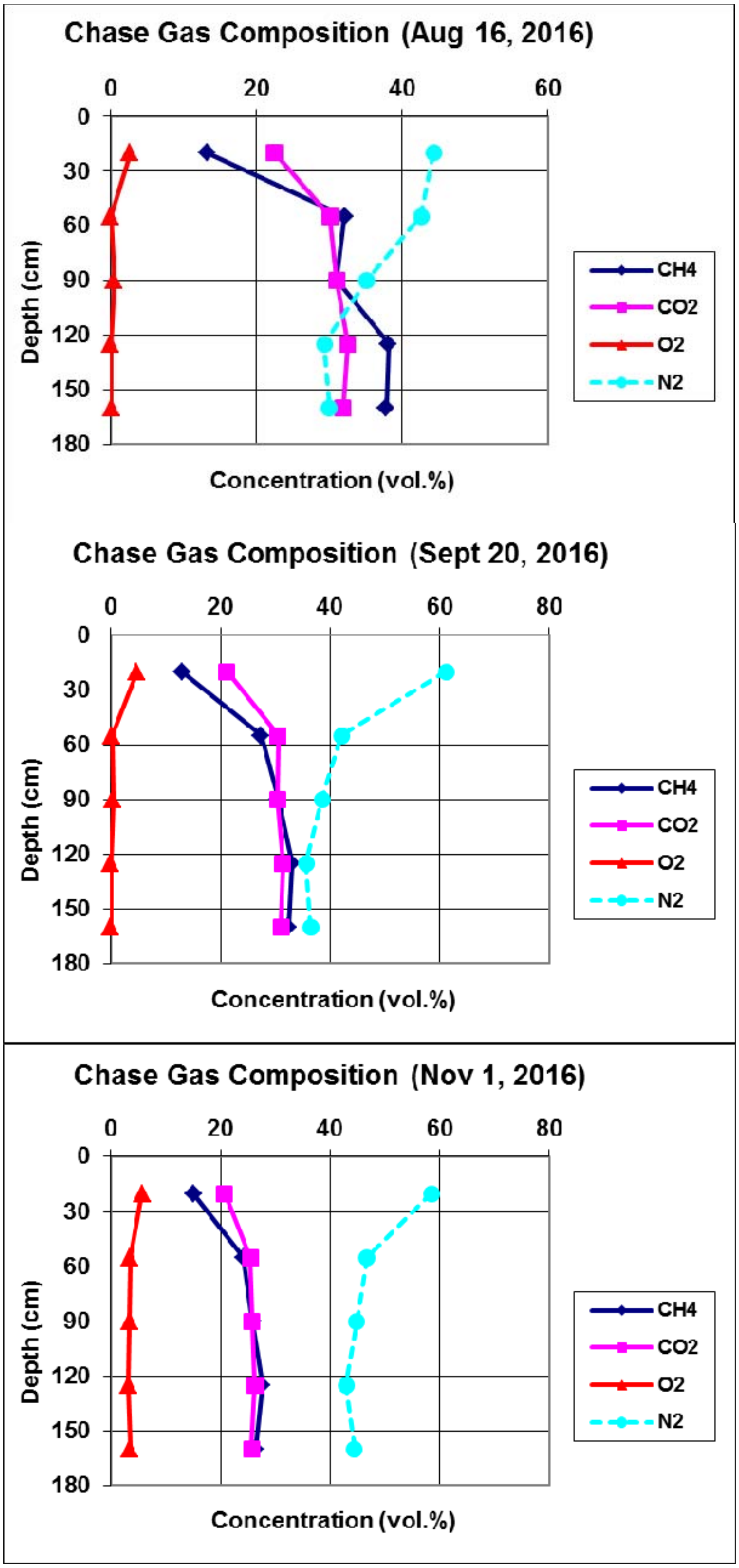

Figure 11 (Continued). Chase gas composition at several depths and sampling dates.

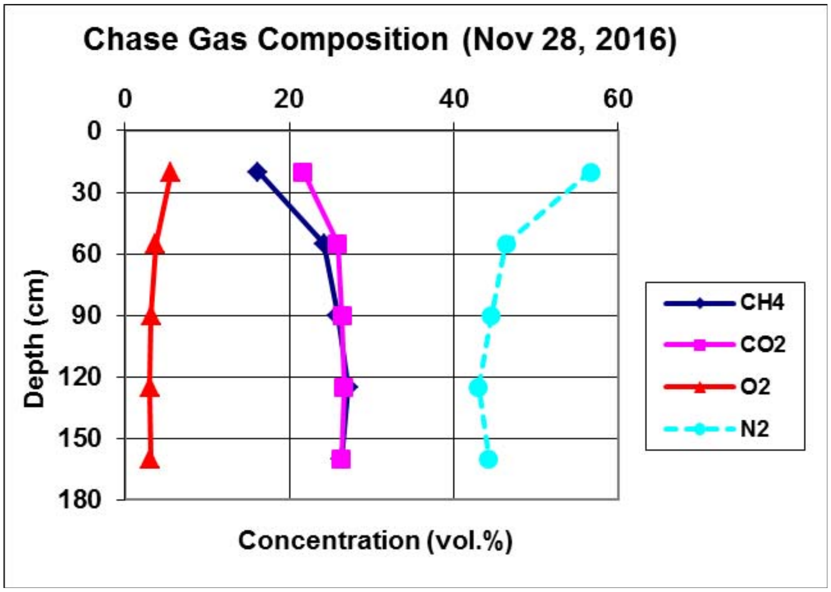

Figure 11 (Continued). Chase gas composition at several depths and sampling dates.

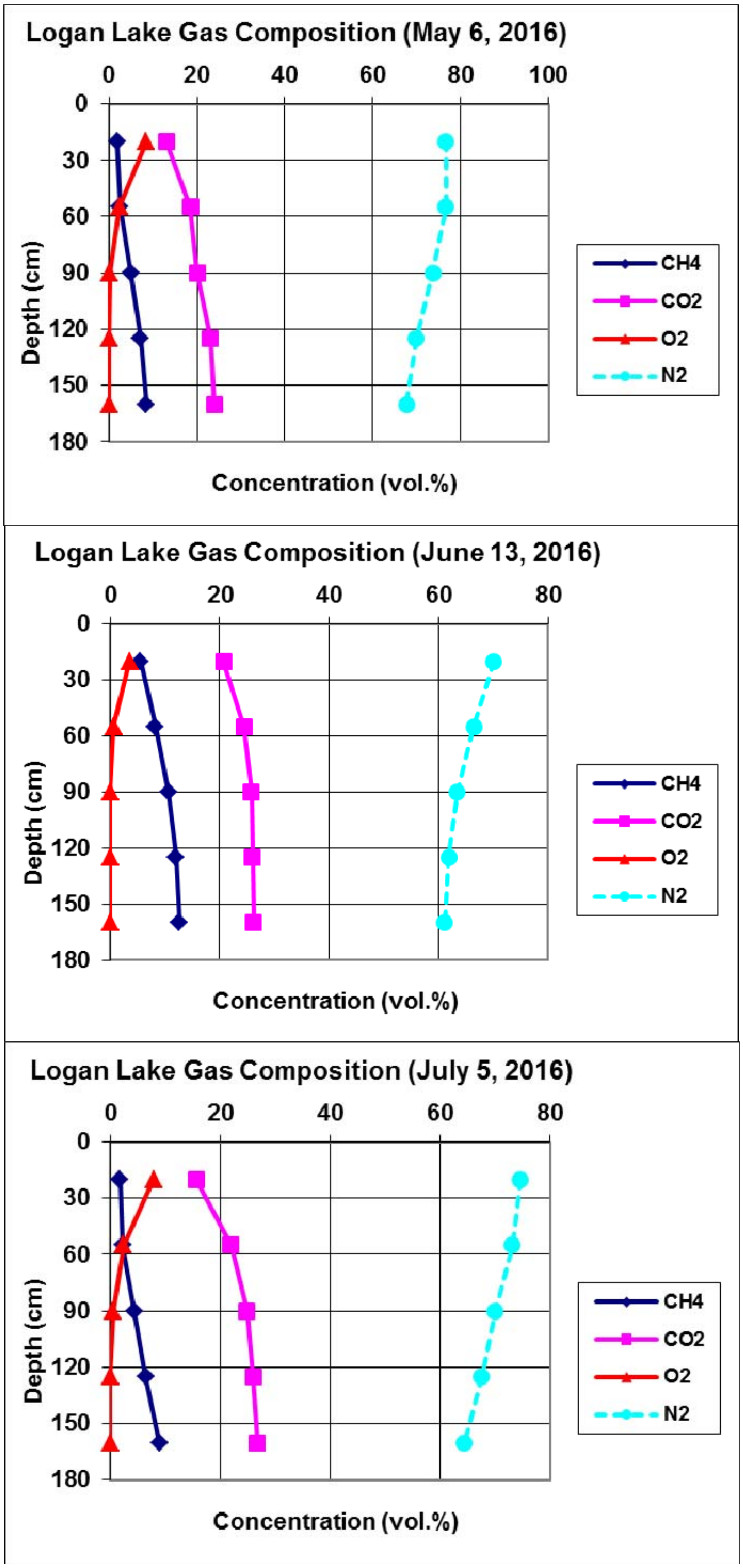

Figure 12. Logan Lake gas composition at several depths and sampling dates.

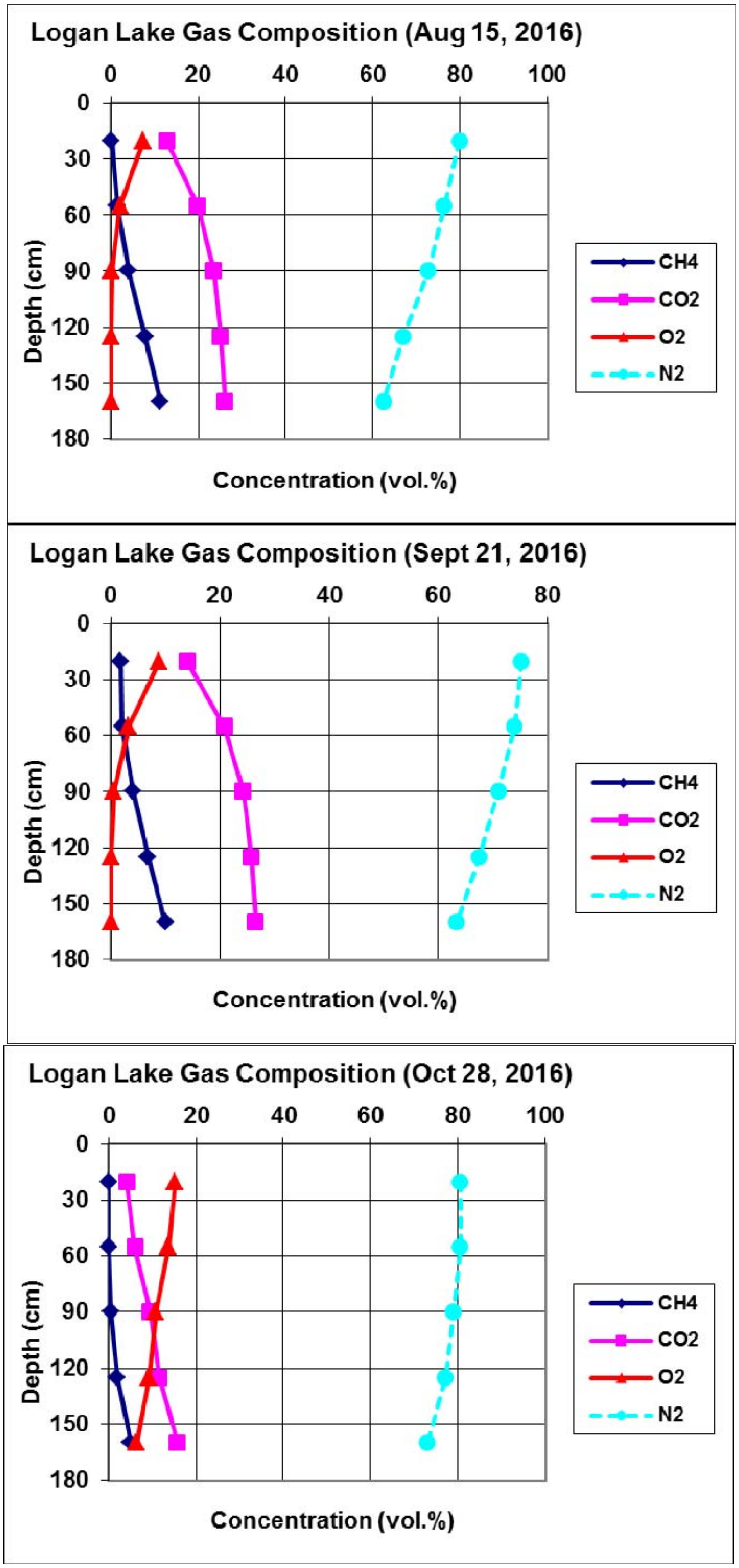

Figure 12 (Continued). Logan Lake gas composition at several depths and sampling dates.

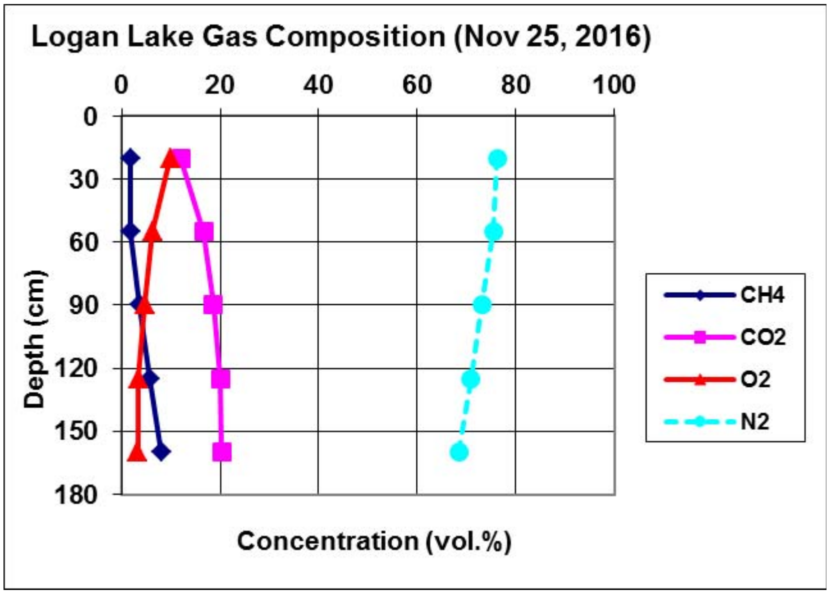

Figure 12 (Continued). Logan Lake gas composition at several depths and sampling dates.

3.3 Flux Measurements

Gas flux measurements are considered as one of the more definitive methods for ascertaining the true gas emissions from landfill and other surfaces. We used our CH_4 and CO_2 surface flux measurements to locate “hot spots” on the landfill surface and thus potential MOB sites, as discussed previously.

Another use of the CH_4 flux measurements is to assess the efficiency of biofiltration technology by calculating the amount of CH_4 removed from the landfill gas stream as it travels through the MOB and into the atmosphere. These measurements can also be used to calculate the amounts of CH_4 oxidized to CO_2 and biomass and thus prevented from entering the atmosphere. This quantity can be used as GHG credit as it is representative of the CH_4 diverted from emission to the atmosphere.

Flux measurements are reported below as means (averages of all measured values at a landfill) and as maximum values (highest measured value at a landfill).

3.3.1 Barriere

The amounts of methane removed by the MOB from the Barriere landfill are shown in Figures 13, 14 and 15 and Table 1 and 2. The data shows highest values in the summer and lower values in the early spring and late fall, confirming the same trend observed with the temperature data. The mean flux values ranged from a low of 4.95 g $CH_4/d/m^2$ in May to a high of 7.56 g $CH_4/d/m^2$ in July. The mean CH_4 removal rates (%) show high efficiencies (100%) for the sampling period (May to October), thus indicating that the MOB was still active during the cold times of the year.

The mean and maximum annual methane removal rates (6.65 and 12.1 g $CH_4/d/m^2$) correspond to reductions in greenhouse gas emissions of 41 and 74 t CO_2 eq./yr respectively; equivalent to 90,225 and 164,221 L of gasoline, 106,021 and 192,972 L of diesel, 95 and 135 barrels of oil or 8 and 15 passenger cars.

3.3.2 Clearwater

The amounts of methane removed by the MOB from the Clearwater landfill are shown in Figures 16, 17 and 18 and Table 1 and 2. The data shows highest values in the fall and summer and lowest values in the early spring, confirming the same trend observed with the temperature data. The mean flux values ranged from a low of 7.68 g $CH_4/d/m^2$ in May to a high of 19.9 g $CH_4/d/m^2$ in July. The mean CH_4 removal rates (%) show high efficiencies (99.8-100%) for the sampling period.
The mean and maximum annual methane removal rates (13.5 and 95.9 g $CH_4/d/m^2$) correspond to reductions in greenhouse gas emissions of 166 and 1,176 t CO_2 eq./yr respectively; equivalent to 367,081 and 2,602,049 L of gasoline, 431,349 and 3,057,611 L of diesel, 386 and 2,734 barrels of oil or 35 and 245 passenger cars.

3.3.3 Chase

The amounts of methane removed by the MOB from the Chase landfill are shown in Figures 19, 20 and 21 and Table 1 and 2. The data shows highest values in the fall months and lowest values in the spring and summer. The mean flux values ranged from a low of 5.1 g $CH_4/d/m^2$ in May to a high of 70 g $CH_4/d/m^2$ in October. The mean CH_4 removal rates (%) show high efficiencies (87.5-91.7%) for the sampling period.
The mean and maximum annual methane removal rates (38.1 and 267 g $CH_4/d/m^2$) correspond to reductions in greenhouse gas emissions of 350 and 2,456 t CO_2 eq./yr respectively; equivalent to 775,637 and 5,435,568 L of gasoline, 911,434 and 6,387,216 L of diesel, 815 and 5,711 barrels of oil or 73 and 512 passenger cars.

3.3.4 Logan Lake

The amounts of methane removed by the MOB from the Logan Lake landfill are shown in Figures 22, 23 and 24 and Table 1 and 2. The data shows highest values in the fall months and lowest values in the spring and summer. The mean flux values ranged from a

low of 5.29 g $CH_4/d/m^2$ in May to a high of 15.5 g $CH_4/d/m^2$ in October. The mean CH_4 removal rates (%) show high efficiencies (100%) for the sampling period.
The mean and maximum annual methane removal rates (10.2 and 37.5 g $CH_4/d/m^2$) correspond to reductions in greenhouse gas emissions of 125 and 460 t CO_2 eq./yr respectively; equivalent to 276,532 and 1,017,897 L of gasoline, 324,947 and 1,196,108 L of diesel, 291 and 1,070 barrels of oil or 26 and 96 passenger cars.

The methane oxidation calculated for all 4 landfill sites (Barriere, Clearwater, Chase and Logan Lake) corresponds to the following mean and maximum annual reductions in greenhouse gas emissions of 682 and 4,166 t CO_2 eq./yr respectively; equivalent to 1,510,289 and 9,219,735 L of gasoline, 1,774,707 and 10,833,907 L of diesel, 1,587 and 9,687 barrels of oil or 142 and 868 passenger cars.

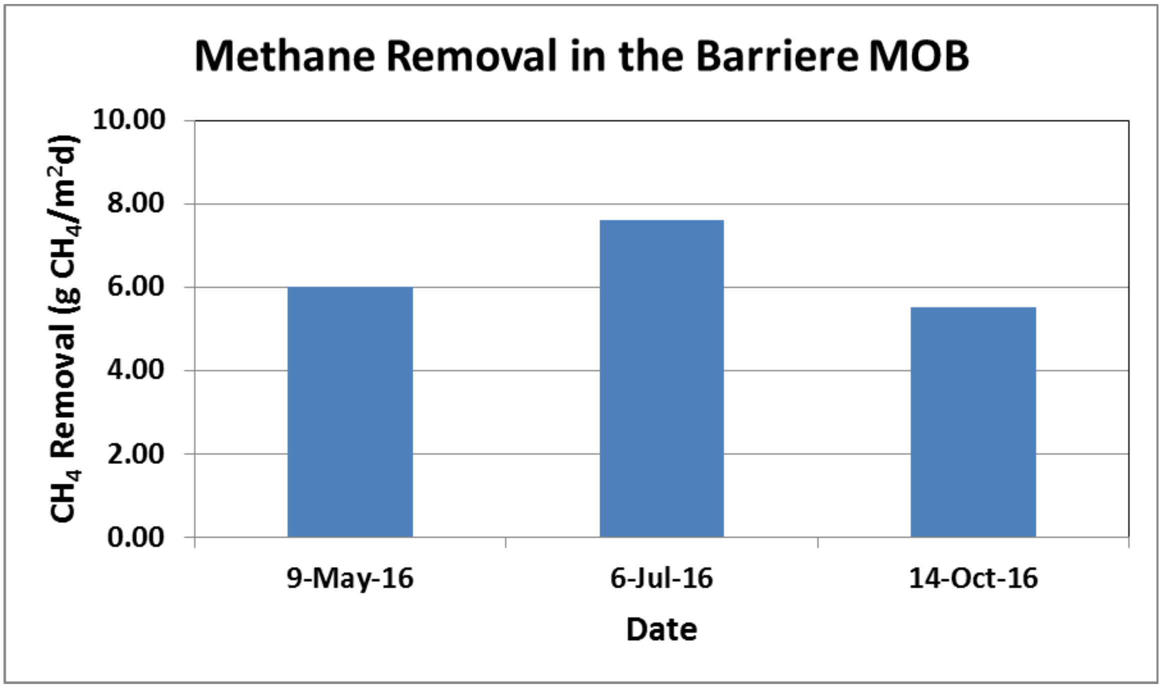

Figure 13. Methane mean removal rates (g/m^{2}d) by the Barriere MOB.

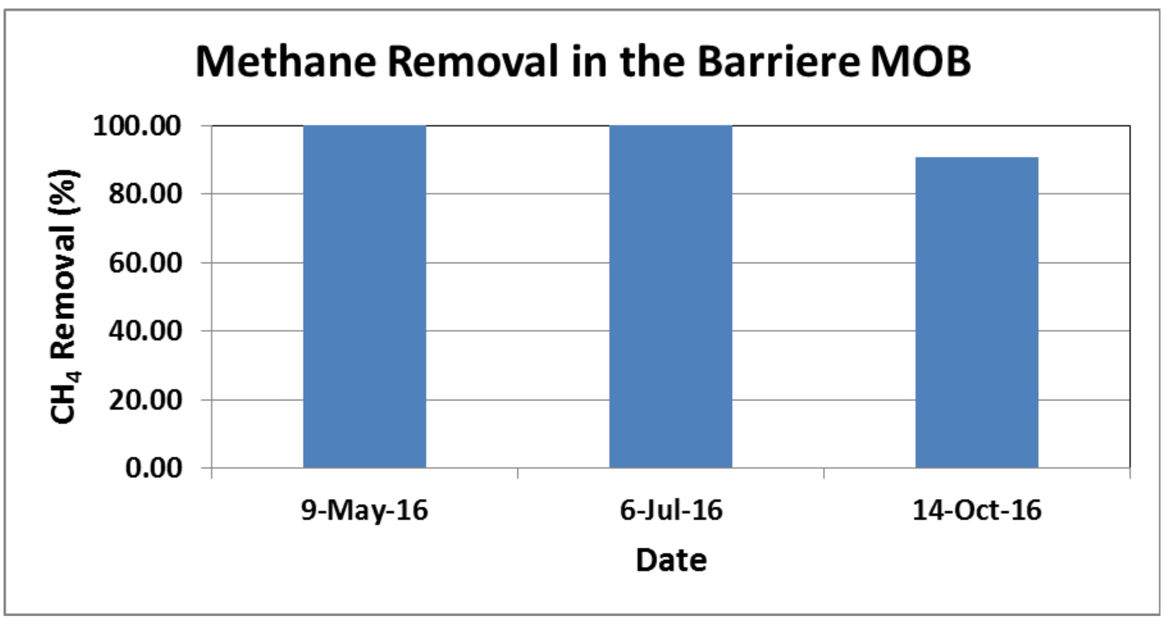

Figure 14. Methane mean removal rates (%) by the Barriere MOB.

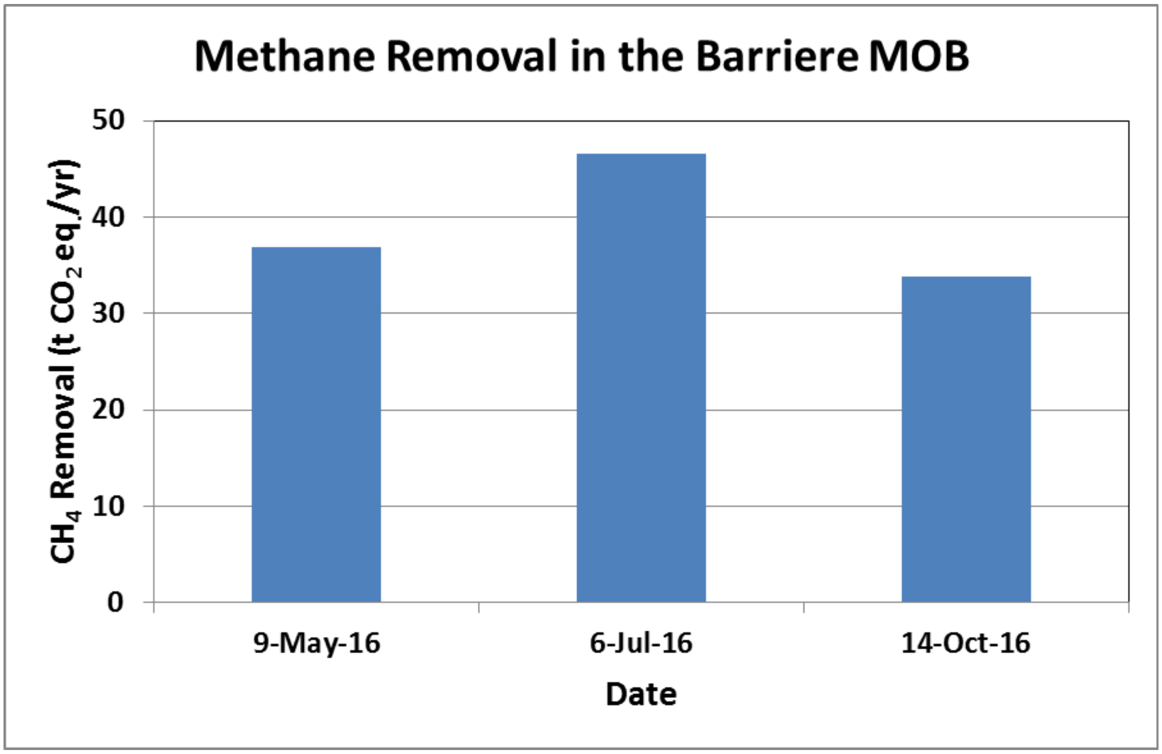

Figure 15. Methane mean removal rates (t CO_2 eq./yr) by the Barriere MOB.

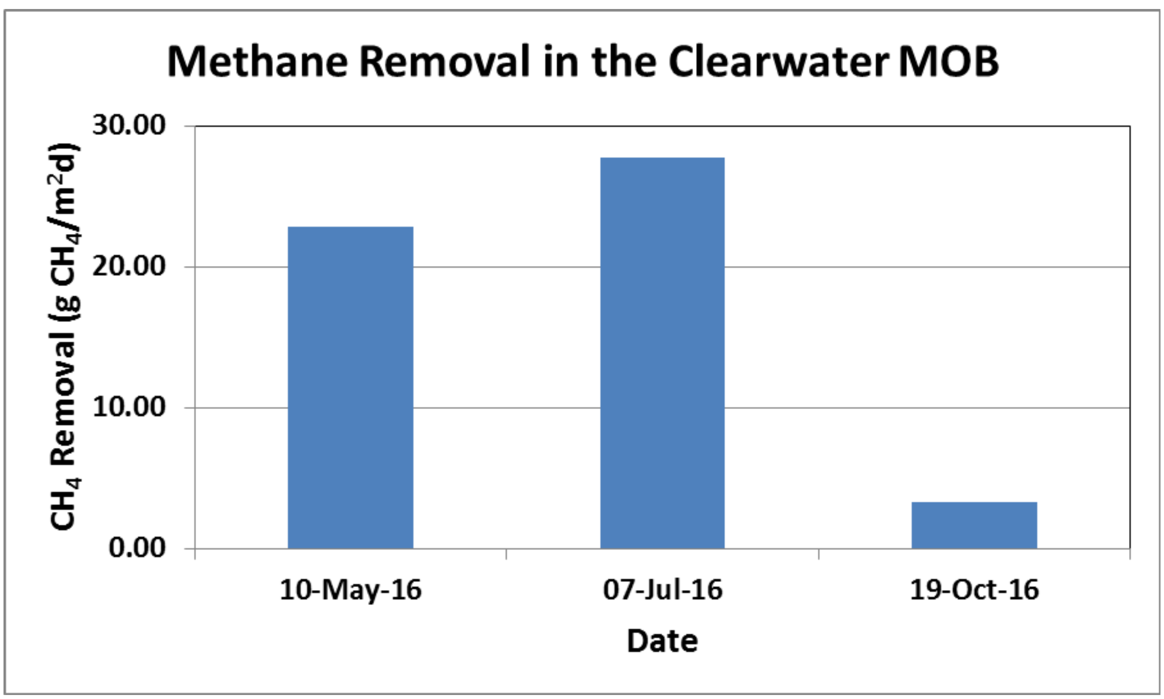

Figure 16. Methane mean removal rates (g/m^2d) by the Clearwater MOB.

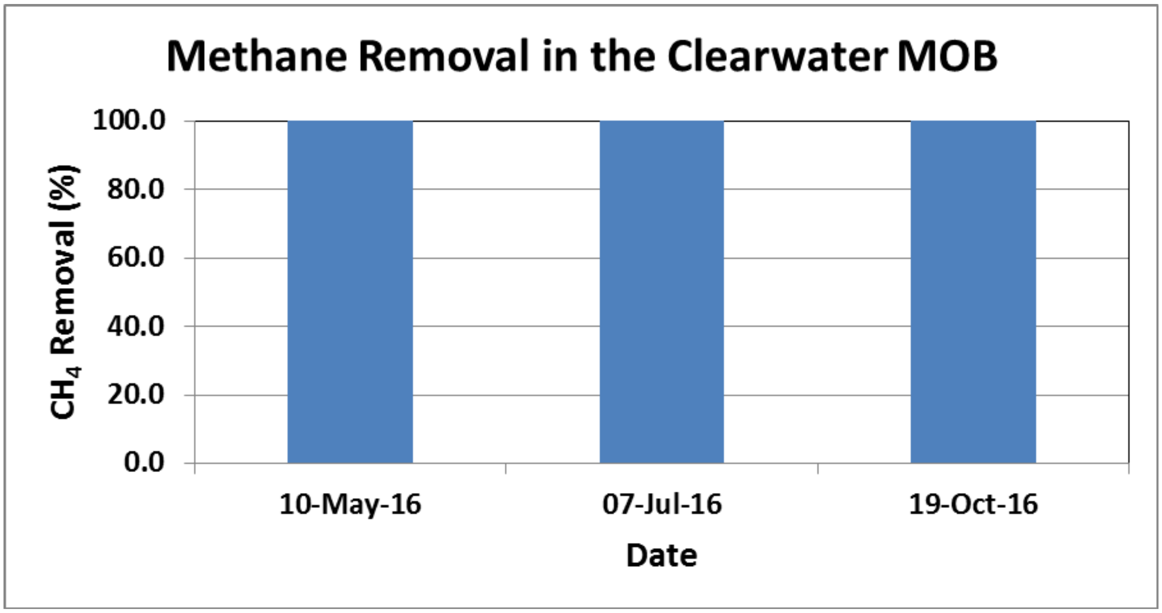

Figure 17. Methane mean removal rates (%) by the Clearwater MOB.

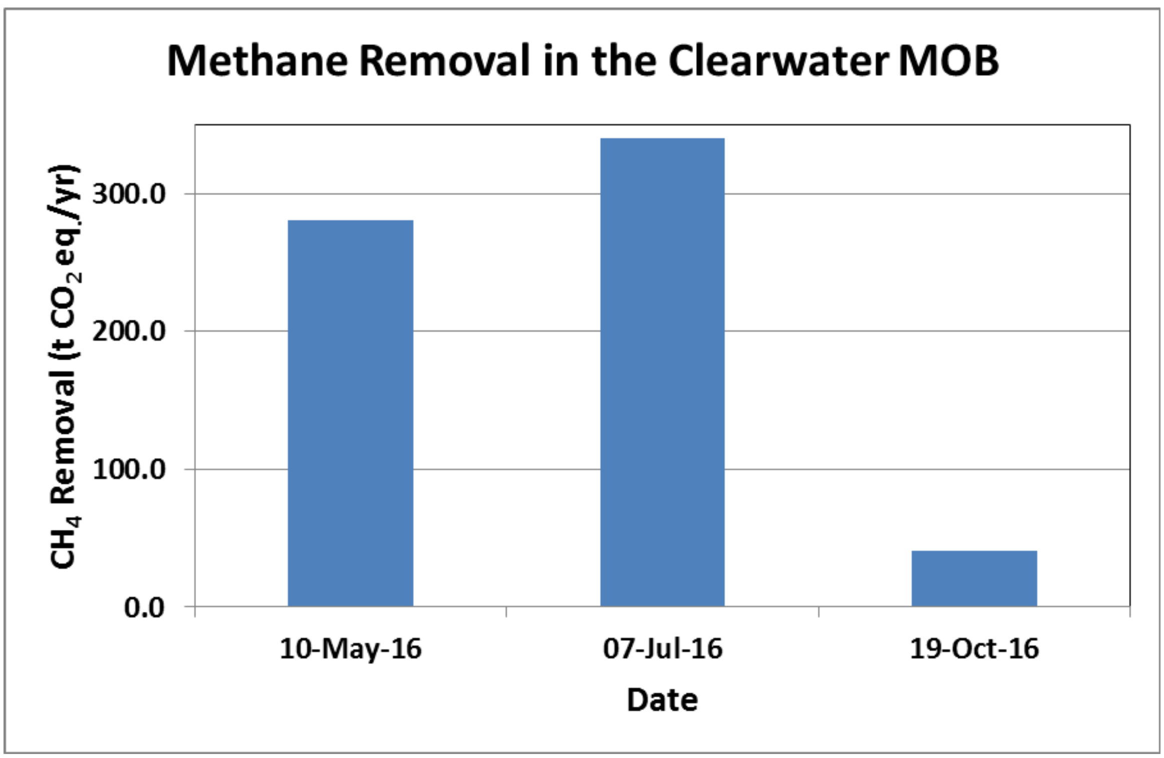

Figure 18. Methane mean removal rates (t CO_2 eq./yr) by the Clearwater MOB.

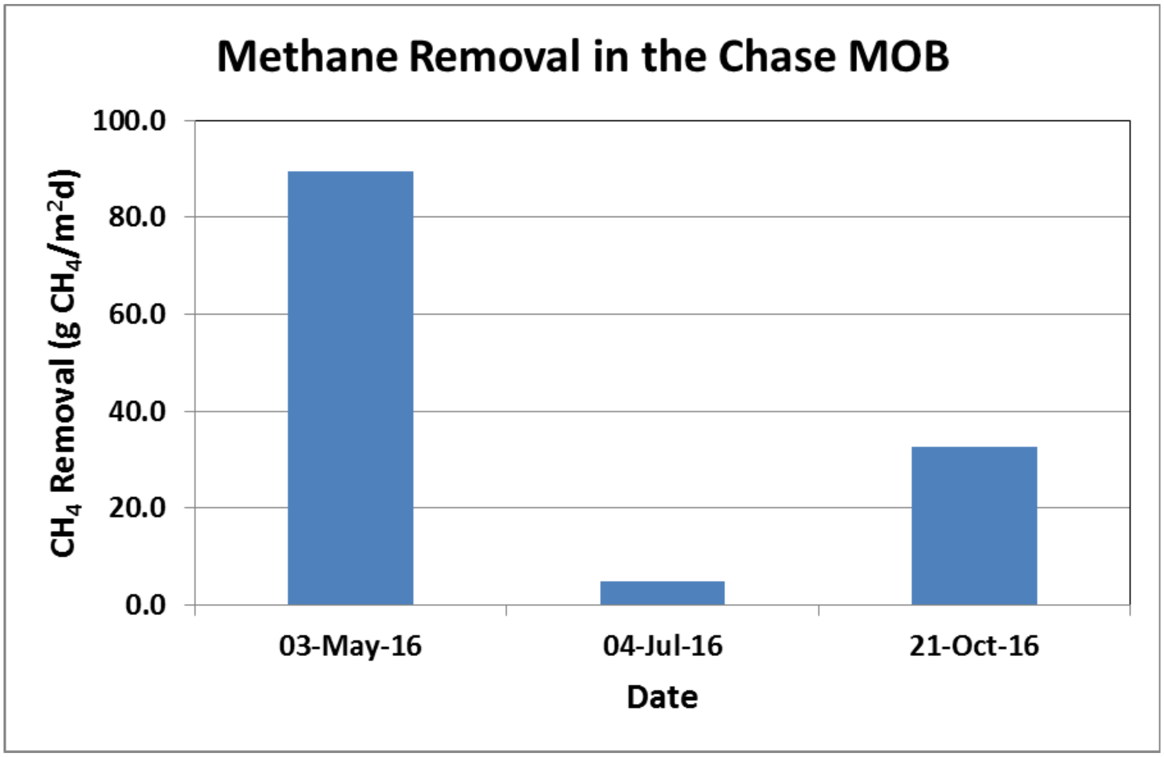

Figure 19. Methane mean removal rates (g/m^2d) by the Chase MOB.

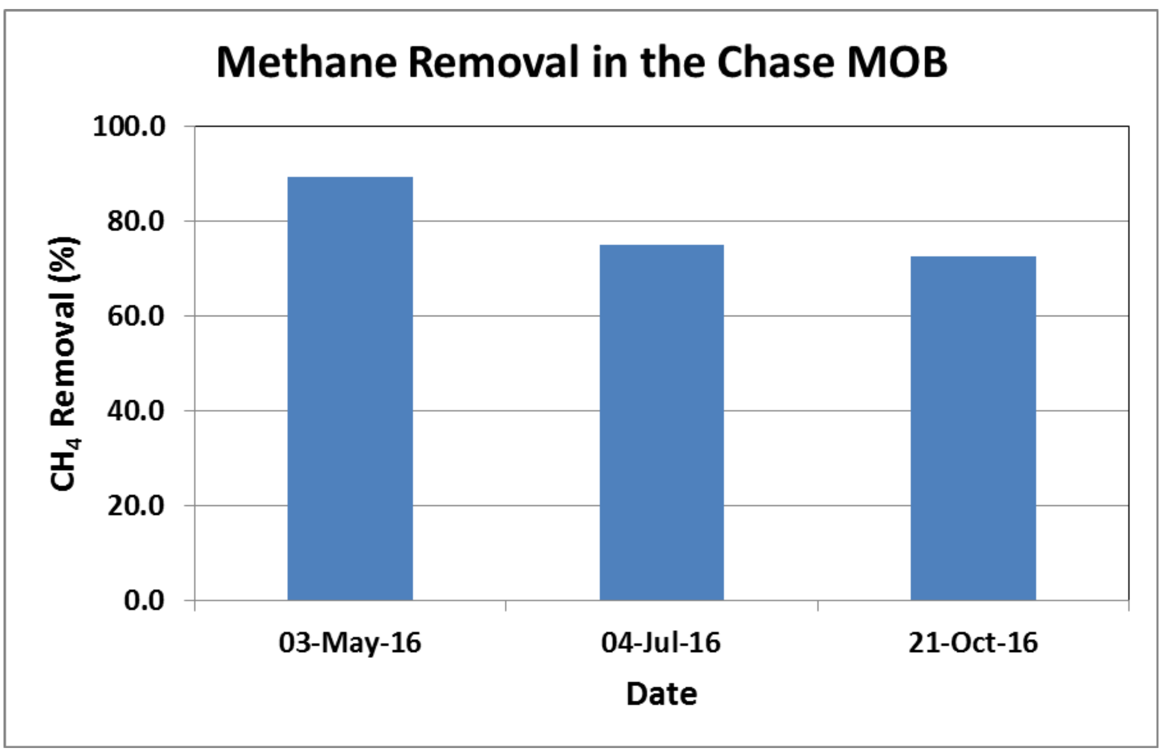

Figure 20. Methane mean removal rates (%) by the Chase MOB.

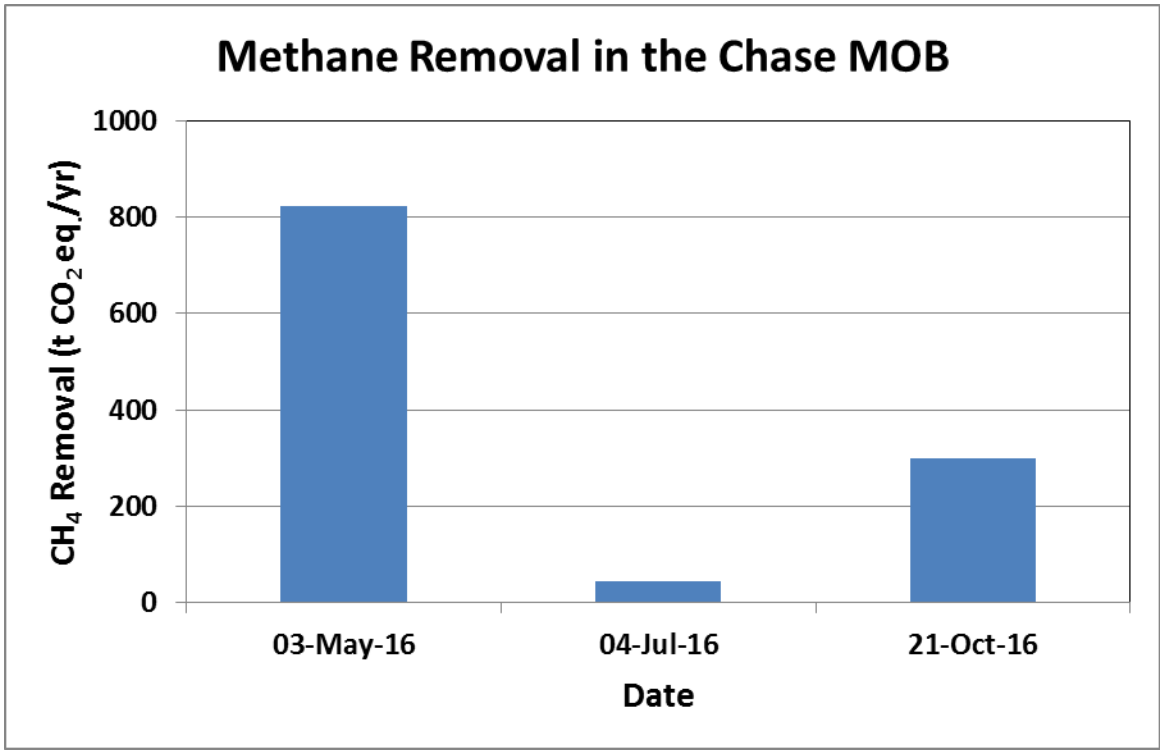

Figure 21. Methane mean removal rates (t CO_2 eq./yr) by the Chase MOB.

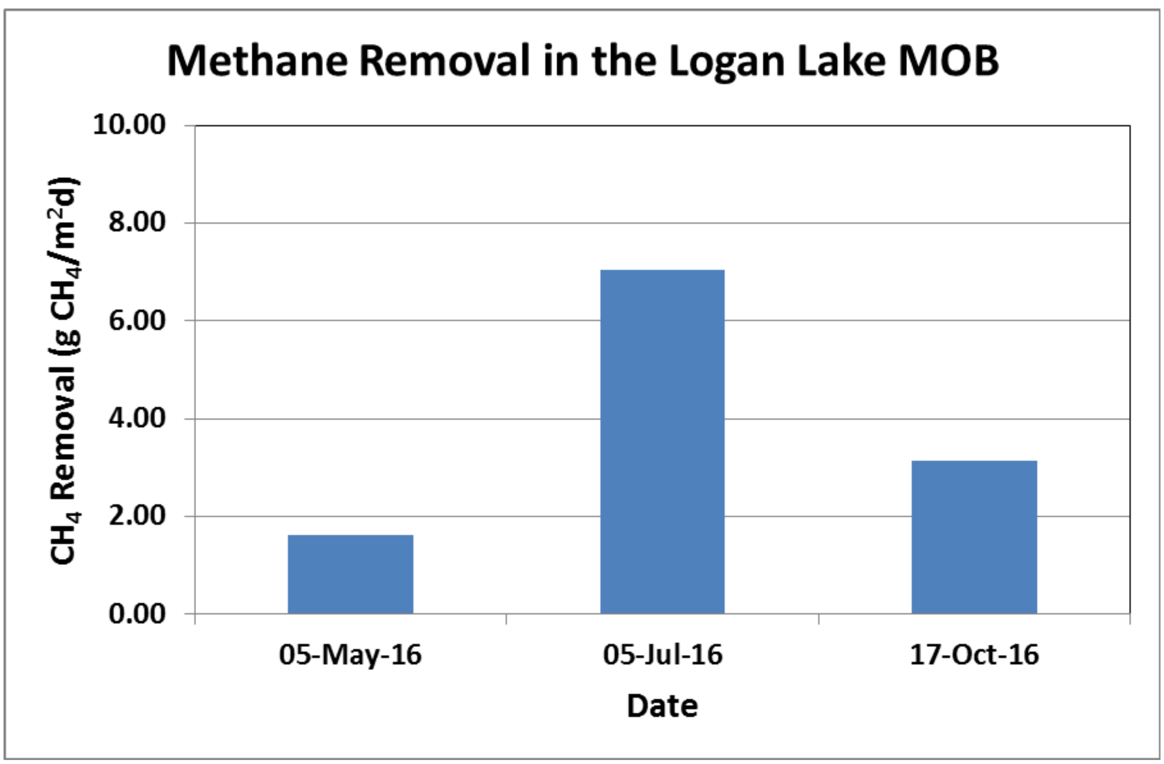

Figure 22. Methane mean removal rates (g/m^2d) by the Logan Lake MOB.

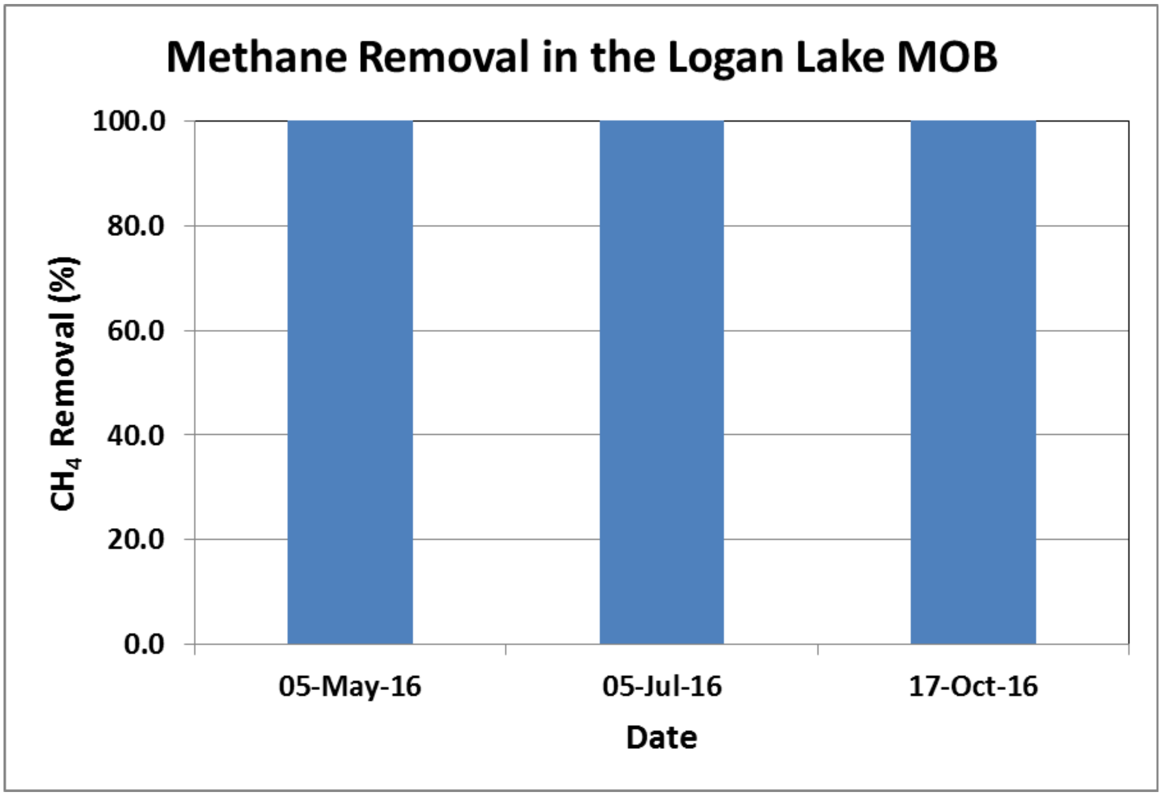

Figure 23. Methane mean removal rates (%) by the Logan Lake MOB.

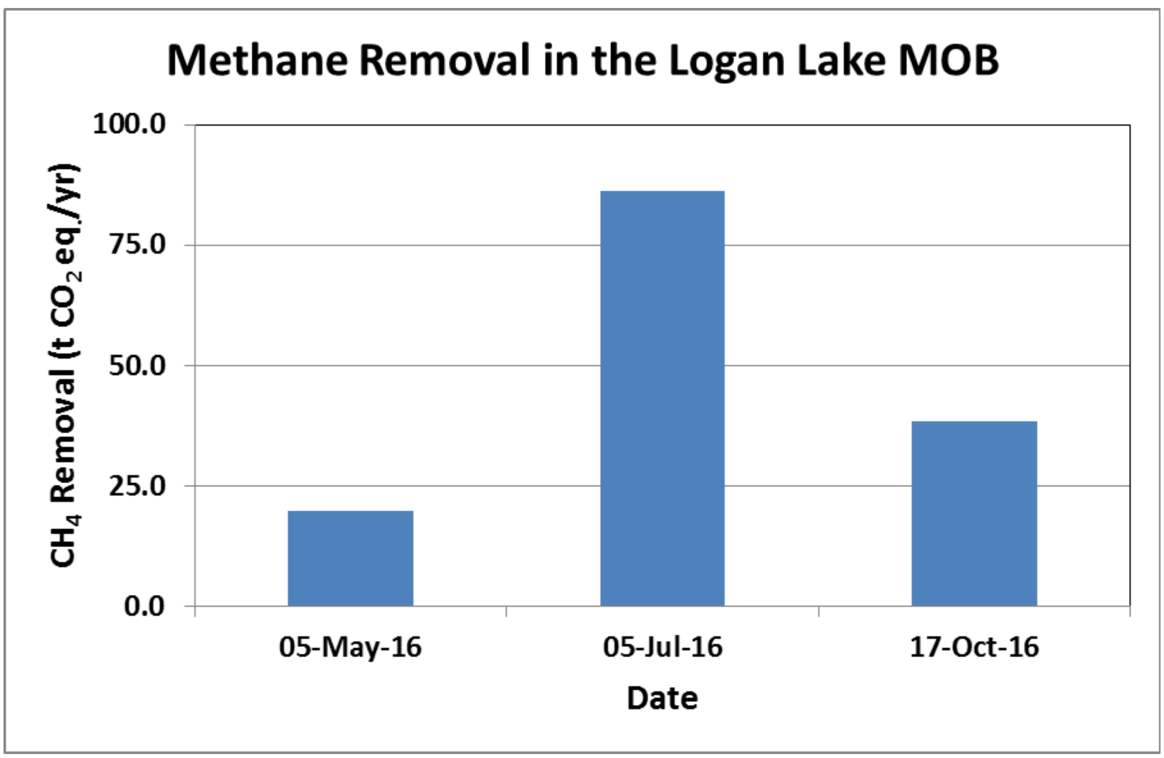

Figure 24. Methane mean removal rates (t CO_2 eq./yr) by the Logan Lake MOB.

Table 1. Annual (2016) GHG Equivalents of Mean Methane Reduced by Oxidation at the TNRD							
Landfill	Mean CH_4 Removal			Gasoline[a]	Diesel[b]	Oil[c]	Pasenger
	(%)	(g CH_4/m2d)	(t CO_2 eq./yr)	(L)		(Barrels)	Cars[d]
Barriere	97	6.38	39	86,557	101,711	91	8
Clearwater	100.0	18.0	220	487,941	573,369	513	46
Chase	78.9	42.3	389	862,052	1,012,978	906	81
Logan Lake	100.0	3.9	48	106,698	125,378	112	10
Total			**697**	**1,543,248**	**1,813,436**	**1,622**	**145**
a. 2.2144 kg CO_2 eq./L gasoline (Carbon Trust (2013))							
b. 2.6008 kg CO_2 eq./L diesel (Carbon Trust (2013))							
c. 0.43 t CO_2 eq./barrel of oil (USEPA (2013))							
d. 4.8 t CO_2 eq./vehicle/yr (USEPA (2013))							

Table 2. Annual (2016) GHG Equivalents of Max. Methane Reduced by Oxidation at the TNRD							
Landfill	Maximum CH_4 Removal			Gasoline[a]	Diesel[b]	Oil[c]	Pasenger
	(%)	(g CH_4/m2d)	(t CO_2 eq./yr)	(L)		(Barrels)	Cars[d]
Barriere	100	11.5	71	156,353	183,728	164	15
Clearwater	100	53.2	652	1,443,244	1,695,924	1,516	136
Chase	100	395	3,633	8,040,010	9,447,638	8,448	757
Logan Lake	100	14.6	179	395,312	464,522	415	37
Total			**4,534**	**10,034,919**	**11,791,812**	**10,544**	**945**
a. 2.2144 kg CO_2 eq./L gasoline (Carbon Trust (2013))							
b. 2.6008 kg CO_2 eq./L diesel (Carbon Trust (2013))							
c. 0.43 t CO_2 eq./barrel of oil (USEPA (2013))							
d. 4.8 t CO_2 eq./vehicle/yr (USEPA (2013))							

4 CONCLUSIONS

The results of this study allow us to make the following conclusions:

- Monitoring the MOB temperature proved to be an excellent tool to assess biological activity and thus potential methane oxidation. Temperature also exposed heterogeneity in the MOB material and pronounced slope effects.
- Temperatures inside the MOB were always higher than air temperatures indicating the presence of biological activity generating heat from the oxidation of methane.
- Methane levels decreased from the bottom of the MOB to the top layers showing methane oxidation activity corroborating the temperature data.
- Oxygen levels were close to zero in most of the MOB layers except at 20 cm depths (and only occasionally where they were above zero but still very low). The absence of oxygen limits methane oxidation and thus the ability of the MOB to treat methane emissions.
- Carbon dioxide levels decreased from the bottom of the MOB to the top layers showing the likely effect of gas dilution with atmospheric air.
- Nitrogen levels increased from the bottom of the MOB to the top layers showing the likely effect of nitrogen enhancement due to gas dilution with atmospheric air (large nitrogen concentration).
- Flux measurements and calculations showed significant methane oxidation at all MOBs.
- Methane oxidation can lead to significant removal of landfill methane, and thus has the potential to earn GHG credits.

5 RECOMMENDATIONS

The results of this study and our experience in conducting it lead us to the following recommendations:

- Regular maintenance of the temperature probes and gas sampling equipment with replacement of defective probes and gas sampling tubes.
- Maintenance of MOBs so that there is no water saturation in the MOBs for an extended period of time.
- Maintenance of clean MOB surfaces by regularly clearing the surface vegetation.
- Regular maintenance (e.g. tilling) of the top MOB layer in order to maximize oxygen levels entering the MOB and to break any channels created by drying and/or plant roots.
- Continue monitoring of the MOBs to explore the long term viability and robustness of the technology and to collect a historic body of data that is beneficial in making the case for carbon credits.
- TNRD should consider extending the implementation of this technology to other landfills (existing or closed).

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