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Assessment of CO_2 levels prior to injection across the Quest Sequestration Lease Area

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Abstract

The Quest Carbon Capture and Storage (CCS) project in Alberta, Canada, is a fully integrated project, as it involves the capture, transport, injection, storage of CO_2, and a measurement, monitoring and verification (MMV) program. The MMV program has two key objectives: a) to ensure containment and b) to ensure conformance. Prior to the start of CO_2 injection at the end of August 2015, a number of projects were undertaken to gather data from various domains, namely the atmosphere, biosphere, hydrosphere and geosphere, to provide input to the Quest MMV program. The focus of this paper is on monitoring activities undertaken in relation to the atmosphere and biosphere domains. Activities undertaken across the Quest sequestration lease area (SLA) included an eddy covariance system, soil gas probes, soil flux chambers, and walk-over surveys. In conclusion, understanding the spatial and temporal variability of CO_2 levels prior to start of CO_2 injection represents an important activity of a CCS MMV program. It provides technical input to the development of such a program, but also provides knowledge for communication to and awareness of project stakeholders (e.g. landowners) regarding CO_2 levels within the atmosphere and biosphere across a SLA.

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1. Introduction

CO_2 injection started at the Quest Carbon Capture and Storage (CCS) Project in Alberta, Canada, at the end of August 2015. The Quest CCS project is a joint venture between Shell Canada Energy, Chevron Canada Limited, and Marathon Oil Canada Corporation, and is operated by Shell. The CO_2 is captured from the Scotford oil sands bitumen upgrader, located northeast of Edmonton (Fig. 1). Up to 1 Mt of CO_2 per year will be injected into the Basal Cambrian Sandstone (BCS), a saline aquifer located at a depth of about 2 km below ground surface. There are three injection well pads, namely 5-35-59-21W4, 8-19-59-20W4 and 7-11-59-20W4, with injection currently only taking place at the last two pads. Quest is a fully integrated project, as it involves the capture, transport, injection, storage of CO_2, and a measurement, monitoring and verification (MMV) program. The MMV program has two key objectives: a) to ensure containment and b) to ensure conformance. Prior to CO_2 injection, a number of projects were undertaken to provide input to the Quest MMV program with regards to monitoring activities within the atmosphere, biosphere, hydrosphere and geosphere. Further details about the Quest project can be found at the knowledge sharing website [1].

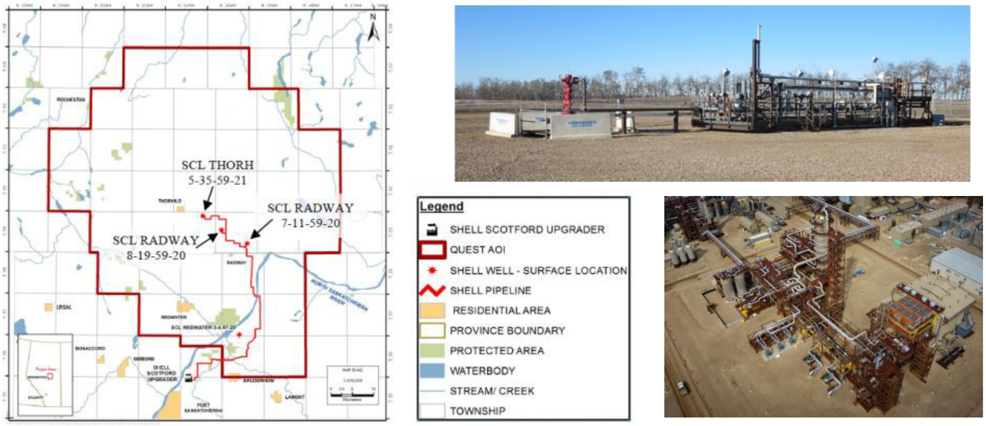

Fig. 1. Map showing the location of the Quest CCS project. Notes: red outline refers to Quest sequestration lease area; light red refers to underground pipeline; SCL THORH 5-35-59-21, SCL RADWAY 8-19-59-20, SCL RADWAY 7-11-59-20 refer to injection wells. Image on top right shows injection well and skid. Image on bottom right shows part of surface capture facility.

1.1. Aim of paper

This paper focuses on pre-start of injection monitoring related to the atmosphere and biosphere. The following objectives will be addressed: a) provide an overview of the various sampling activities undertaken within the Quest sequestration lease area to gather data on CO_2 levels prior to injection, and b) to discuss the findings from these campaigns.

2. Land use in Quest sequestration lease area

The Quest sequestration lease area (SLA), which covers an area of about 3700 km^2 (red outline, Fig. 1), includes a number of different land use types (Table 1). The main land use type is annual crops (~35% of the SLA) followed by broadleaf forest and pasture (each ~23% of the SLA). Other land use types identified within the Quest SLA include coniferous forest, wetland, developed, and water bodies, representing 10, 7, 2, and 1%, respectively. Besides land use type information for the various sampling sites, soil type was also determined.

Table 1. Land use distribution across Quest Sequestration Lease Area and distribution of sampling site locations in 2013.

Land Use	Area (ha)	% of Total Project Area	# of field plots (2013)	% of field plots (2013)
Annual Crops	132,400	35%	5	33%
Broadleaf Forest	86,700	23%	3	20%
Pasture	85,300	23%	3	20%
Coniferous Forest	37,400	10%	2	13%
Wetland	27,000	7%	2	13%
Developed	6,500	2%	0	0%
Water Bodies	4,600	1%	0	0%
Total	380,000	100%	15	100%

3. Sampling sites

Sampling sites, which were identified across the Quest SLA, were selected to ensure data for the main land use types encountered within the SLA (Table 1) were collected with respect to the relative land use distribution. Sampling sites were located both off and on the injection well pads.

3.1. Eddy covariance

An eddy covariance (EC) system was setup on injection pad 8-19-59-20W4 between April 2012 and December 2015. Note that the physical location of the EC system on the pad was changed in July 2014. Initially, the EC system was installed on a mast 2-m above the ground close to a meteorological weather station in the SW corner of the pad. In early July 2014, the system was moved to a tripod in the SE corner of the pad and installed at the 1-m height. This was done in order to ensure that the footprint of the EC measurements lay almost entirely within the injection pad 8-19-59-20W4 area.

3.2. Soil gas probes and soil flux chambers

A number of plots were identified across the SLA to collect soil gas samples outside the injection well pads (referred to as off-well pad). For instance, Table 1 shows the number of plots visited in 2013. In addition, samples were also collected at each injection well pad. Data collection occurred between Q4-2012 and Q2-2015.

3.3. Walk-over surveys

In Q3-2014, walk-over surveys were completed at each of three well pads.

4. Materials and Methods

Key sampling activities included soil surface CO_2 flux measurements and soil gas data collection. Additional sampling activities included collection of eddy covariance (EC) data to assess CO_2 flux at one of the injection pads, as well as in-situ field measurements including soil gas probes, soil flux chambers, and walk-over surveys. The flux footprint of the EC measurements lay almost entirely within the injection pad. Soil gas and surface CO_2 flux measurements were taken both off and on the injection well pad. The walk-over surveys were completed across injection pads. Established and current state-of-the art technologies were used to gather soil gas and soil surface flux data on CO_2 levels (e.g. in-situ field measurements of both compositional and isotopic data on CO_2).

4.1. Eddy covariance

The EC system setup included continuous high-frequency (HF) measurements of the three components of the wind vector and air temperature, CO_2 and H_2O using an infrared gas analyser (IRGA) (model LI-7200, LI-COR, Inc., Lincoln, NE). Meteorological data included air temperature, relative humidity, barometric pressure, wind speed and direction, shortwave (i.e. solar) irradiance, and rainfall. Soil temperature and moisture were also measured.

The same meteorological measurements were continued after the physical relocation of the EC system, except for the addition of three soil heat flux plates. Half-hourly covariances of the sonic air temperature, H_2O and CO_2 mixing ratios with the vertical wind velocity (w) were used to calculate sensible heat (H), latent heat (λE) and CO_2 (F_C) fluxes, respectively. In September 2014, an additional instrument - a four-way net radiometer - was installed to support interpretation of the EC data.

4.2. Soil gas probes and soil flux chambers

In general, soil gas probe and soil flux chamber measurements were undertaken on a quarterly basis with the aim to capture both temporal and spatial variability. Note that sampling was limited at times due to weather conditions (e.g. frozen soil).

On the off-well pad sampling sites, flux chamber measurements were taken at 3 randomly chosen sampling points located within a one hectare of homogeneous soil/vegetation type. These sampling points were repeatedly sampled each season when sampling occurred. Soil surface CO_2 flux measurements were obtained using a field-deployable LI-COR Model 8100A CO_2 flux survey chamber. In the field, the LI-COR chamber was placed upon 20-cm diameter soil collars, which were installed 24 hours before the measurement period. Long grass and other vegetation that may interfere with the closing and sealing of the chamber on the rim of the collar were trimmed using scissors during collar installation. No vegetation, leaf litter or other material was removed from inside the collar unless it interfered with the instrument, i.e., all efforts were made to minimize disturbance to the surface being analyzed. Soil gas samples at the off-well pad sampling sites for laboratory analysis were collected from three depths down to about 2 m below the ground surface, or at a single depth around 1.5 m. A Model 915-0011 ultra-portable field deployable Greenhouse Gas Analyzer (GGA) (Los Gatos Research, California) was used during sample collection to ensure probes were purged of air and that there was no short-circuiting of atmospheric air into the probe post sample collection. Samples were collected in either glass bottles or pre-evacuated SUMMA canisters for off-site laboratory analysis.

At each injection well pad, a number of soil gas probes were installed at a depth of 0.8 to 1 m in a radial fashion around each injection well, along roughly the North, East, South and West directions. In each direction, five soil gas probes were installed at a distance of about 4, 5.5, 7, 10 and 14 m away from the injection well. The collars used for the soil flux chamber measurements at each site were installed in a radial fashion around each injection well at a distance of up to 11.8 m from the injection well. At the injection well pads, chamber flux measurements were collected with either a LI-COR – Picarro or an Eosense (Forerunner) – Picarro system setup. For the latter, a 12-inlet multiplexer was also used.

4.3. Walk-over surveys

For the walk-over survey measurements, a custom built mobile system with off-the-shelf equipment was used. Gas just above the soil surface on each pad was sampled via a tube connected to a survey wheel. The opening of the tube was positioned at about 2 cm above the ground surface. The tube was connected directly to the Picarro analyzer inlet. The system included a GPS unit, as well as an anemometer for measuring wind speed and direction. All data were collected continuously at about 7 second intervals and aligned using Coordinated Universal Time (UTC) with an offset between physical location and gas concentration/isotope ratio to account for the delay between an air sample entering the tube at 2 cm above the ground surface and it reaching the Picarro analyzer.

5. Results and discussion

An extensive and comprehensive dataset has been compiled with regards to soil surface CO_2 flux, ambient air and soil gas CO_2 concentration and isotopic composition across the Quest sequestration lease area. A novel part of this work was real-time field $\delta^{13}C_{CO2}$ measurement and analysis. The various datasets gathered will be compared. Seasonal and spatial differences among the various datasets, covering different key land use and soil types within the Quest sequestration lease area, will also be discussed.

5.1. Eddy covariance

Quality EC measurements have been collected; however, there is some uncertainty in the May 2012 to June 2014 CO_2 flux values for specific parts of the land surface (e.g. pad vs crop). The reason for this is the combination of pad and crop surfaces contributing to the EC system and the proximity of the berms/nearby Aspen trees affected the fluxes for the majority of the wind directions. With regards to the EC measurements taken at the 1-m height on the tripod, data were compromised during the July-August 2014 time period due to the presence of temporary infrastructure on the pad which interfered with the air movement.

Figure 2 shows the time series of CO_2 concentrations and fluxes for the period April 2012 to December 2015. Note that EC measurements taken on the 2-m mast (May 2012 to June 2014) reflect not only the pad footprint, but also contributions from outside the pad area. The results show a very small daytime and night-time F_C of ~0.2 to 0.5 μmol m^{-2} s^{-1} except in June 2015, when concentrations and fluxes far exceeded the normal range observed. In June 2015, an above-ground CO_2 release test was conducted to assess the LightSource technology, which is an atmospheric monitoring system for CO_2 using Boreal Laser Inc. GasFinder open-path gas sensor. Further details about the LightSource technology can be found in the paper by Hirst et al. [2], part of this Energy Procedia's GHGT-13 proceedings issue.

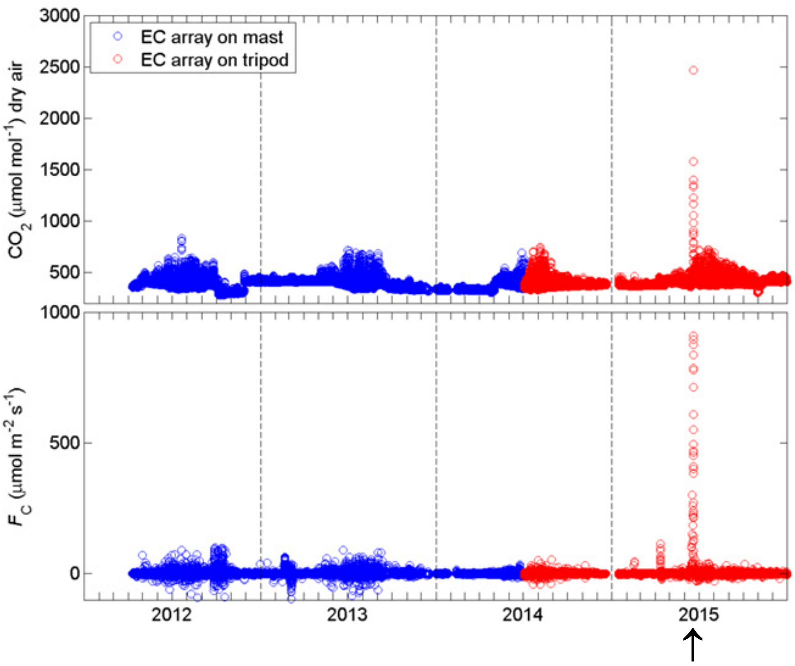

Fig. 2. Time series of half-hourly average CO_2 mixing ratio (top panel) and F_c (bottom panel) from April 10, 2012 to December 31, 2015. Nb: blue points: data collected when EC array was mounted on climate station mast; red points: data collected after EC system was mounted on tripod on July 7, 2014; arrow: CO_2 release test in June 2015.

5.2. Soil flux chamber

Between Q4-2012 and Q4-2014, a comprehensive set of CO_2 flux data off-well pad was established to assess both temporal and spatial variability in soil surface CO_2 flux across the Quest SLA. Flux data were obtained for six different land use types, including annual crop, coniferous forest, deciduous forest, meadow, pasture and wetland. Overall, mean CO_2 fluxes ranged from -0.42 to 24.09 μmol m^{-2} s^{-1} (Fig. 3). Good agreement between repeat analyses at a single collar was observed with the standard deviation being ⩽ 0.6 μmol m^{-2} s^{-1} in 90% of the cases. A seasonal trend, as expected, is clearly visible with highest CO_2 fluxes being measured in summer and lowest in winter (Fig. 3). Note that overall CO_2 fluxes for specific seasons were similar between sampling years. Slight differences may occur between same season for different sampling years to due climatic conditions leading to wetter or drier years, and hence influencing soil biological activity. Differences in soil surface CO_2 fluxes were also observed between land use types (Fig. 4). Meadow, pasture and wetland tended to have higher CO_2 fluxes compared to annual crop or forest (coniferous, deciduous). The relative difference in CO_2 flux magnitude was dependent upon season, with the largest differences being observed in spring and summer. In addition to land use, soil type was also determined at each sampling site. Data were collected from a total of 7 soil types including brunisol, chernozem, gleysol, luvisol, organic, regosol, and solonetz. There is no clear difference in soil surface CO_2 fluxes between soil types, even among the same land use (Fig. 5). During measurement of the off-well pad CO_2 fluxes, $\delta^{13}C_{CO2}$ values were also determined and ranged from -26.7 to -22.6‰, which is consistent with C3 vegetation.

On-well pad soil CO_2 flux values were determined in July 2014 and June 2015, and ranged from -1.3 to 5.0 μmol m^{-2} s^{-1}. On-well pad CO_2 fluxes are significantly less than off-well pad CO_2 fluxes, which can be attributed to the top soil being removed from the pads and "off-pad" sampling sites being vegetated. Mean $\delta^{13}C_{CO2}$ values ranged from -13.4 to 36.5 ‰. In July 2014, soil surface CO_2 flux was determined via both the Picarro and LI-COR systems. Comparing results from both systems indicates that flux derived from the Picarro system was lower compared to flux determined with the LI-COR system, especially at higher flux values (Fig. 6).

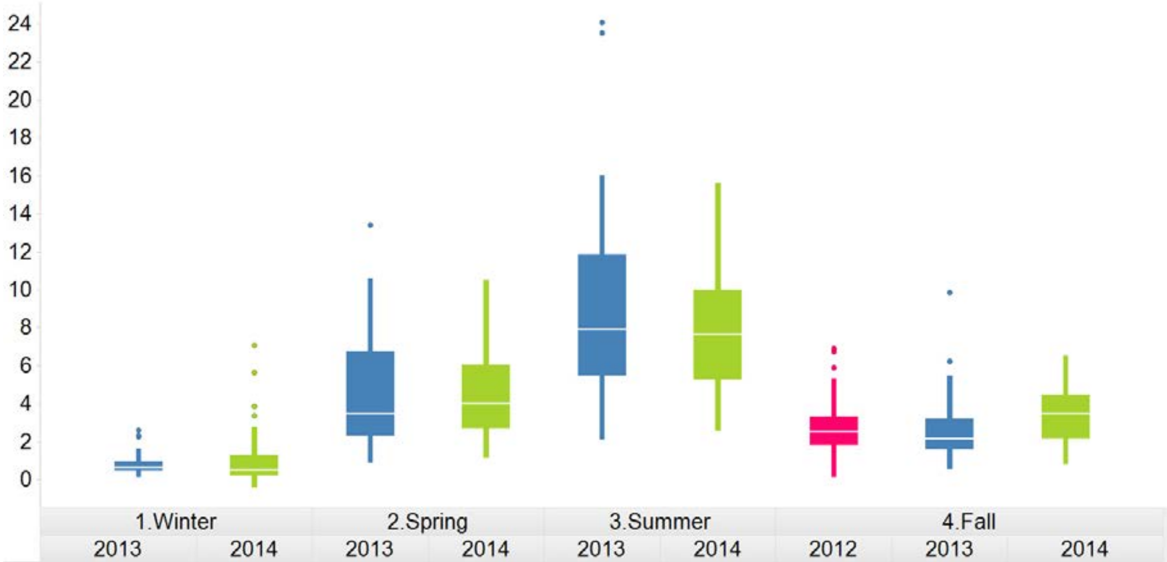

Fig. 3. Box plot of soil surface CO_2 flux (μmol m^{-2} s^{-1}) versus season split by sampling year (2012-rose color; 2013-blue color; 2014-green color) for off-well pad data. Note that this range is based upon the mean CO_2 flux values determined for each sampling point (each soil collar location).

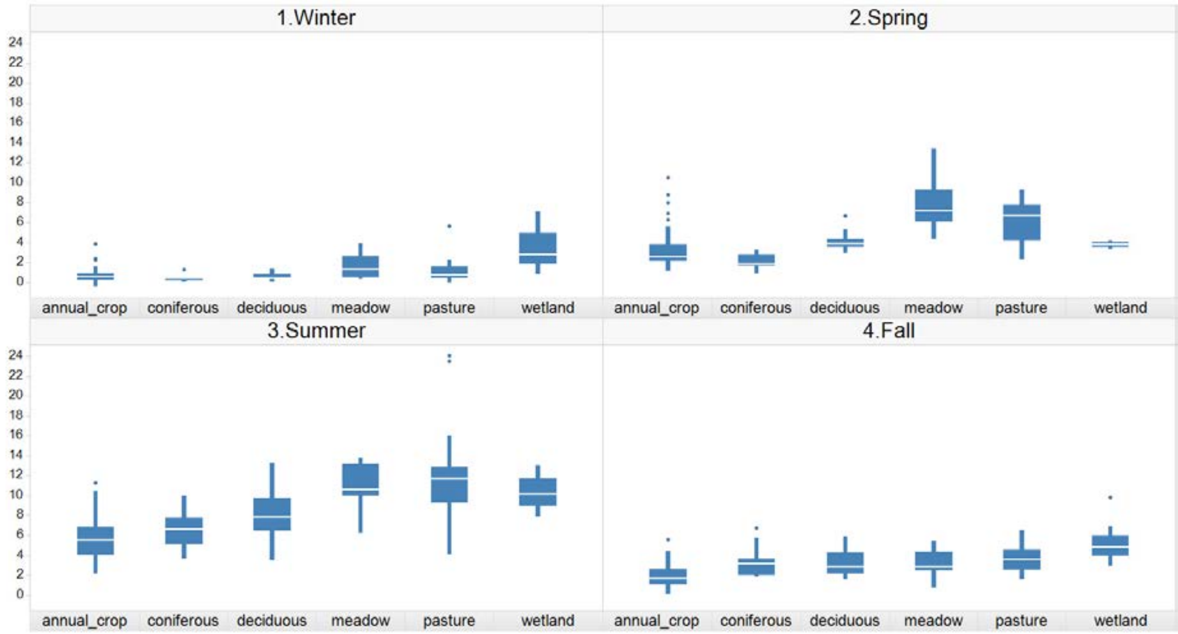

Fig. 4. Box plot of soil surface CO_2 flux ($\mu mol\ m^{-2}\ s^{-1}$) versus land use type split by season for off-well pad data.

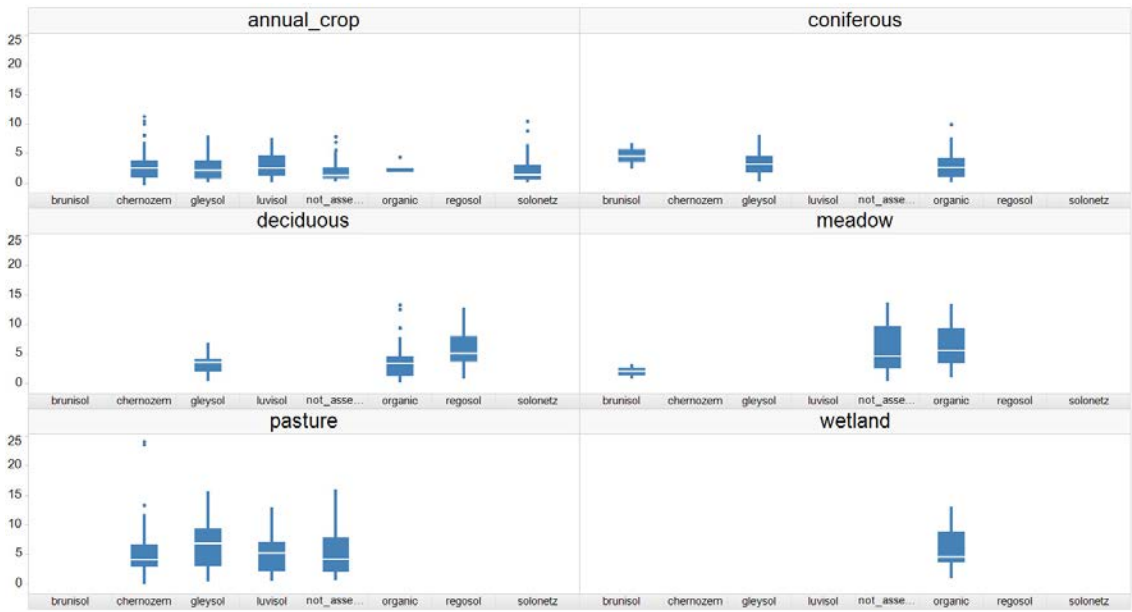

Fig. 5. Box plot of soil surface CO_2 flux ($\mu mol\ m^{-2}\ s^{-1}$) versus soil type split by land use for off-well pad data.

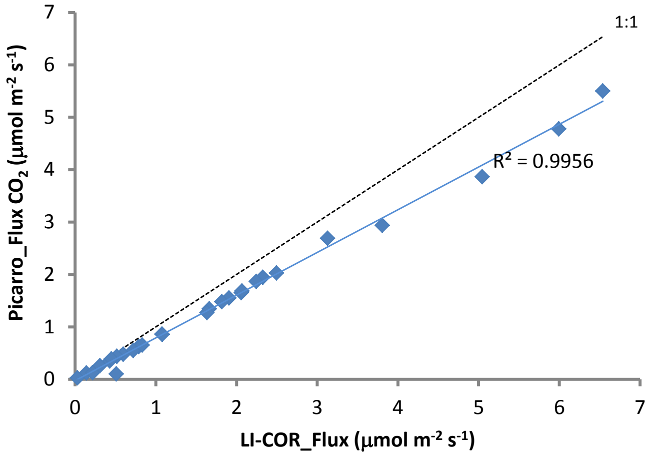

Fig. 6. Cross-plot of soil surface CO_2 flux (μmol m^{-2} s^{-1}) determined using the LI-COR and Picarro system during the July 2014 sampling event at the well pads.

5.3. walk-over survey

The walk-over surveys at all three pads yielded CO_2 concentrations near ambient (367 to 380 ppm) throughout the surveyed area (see example in Fig. 7). As well, there was no consistent pattern observed in the $\delta^{13}C_{CO2}$ values throughout the surveyed area. $\delta^{13}C_{CO2}$ values were similar to expected $\delta^{13}C$ of ambient air.

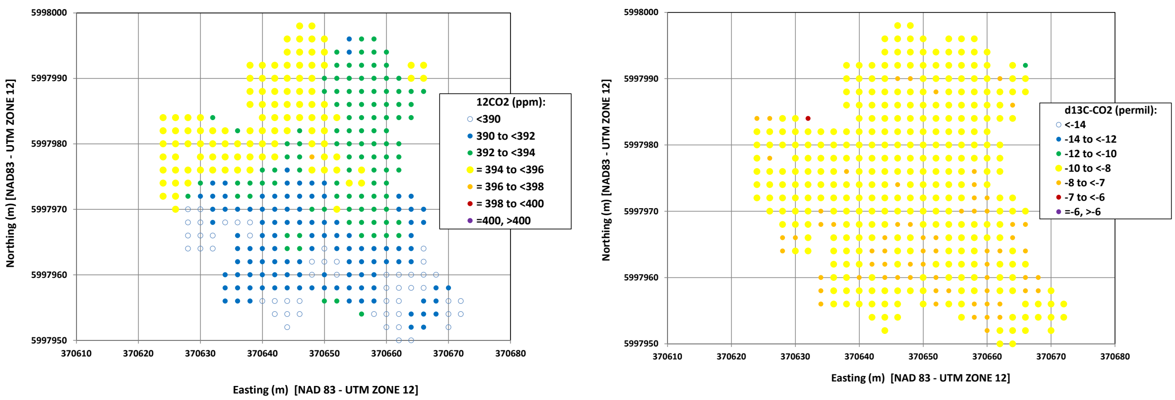

Fig. 7. Spatial plots of air data mapped to regular grid for well pad 8-19-59-20W4 in Q3-2014. Left figure: $^{12}CO_2$ concentration [ppm]; right figure: $\delta^{13}C_{CO2}$ (‰).

5.4. Soil gas probes

Off-well pad soil gas CO_2 concentrations at different depths ranged from around 500 to over 60,000 ppmv. With regards to seasonal changes, soil gas CO_2 concentrations were on average highest in summer and lowest in winter compared to the other seasons (Fig. 8). Spatially, no clear trend was observed in soil gas CO_2 concentration between different land use types; however, soil gas CO_2 concentrations differed among soil types. Luvisol tended to have the highest soil gas CO_2 concentrations (Fig. 9). $\delta^{13}C_{CO2}$ values for off-pad soil gas samples ranged from -29.3 to -10.6 ‰. On a temporal basis, $\delta^{13}C_{CO2}$ values tended to be highest in winter compared to the other seasons (Fig.

10). With regards to land use type, $\delta^{13}C_{CO2}$ values tended to be highest for coniferous compared to the other land use types (Fig. 11); however, no clear difference was observed between soil types.

In June 2015, on-well pad soil gas CO_2 concentrations ranged from 0.5 to 16.9 mole% based on field GC measurements and from 0.6 to 19.1 mole% based on laboratory analysis, with average concentrations of 4.4±3.8 and 4.6±4.4 mole%, respectively. $\delta^{13}C_{CO2}$ values ranged from -26.9 to -21.9 ‰.

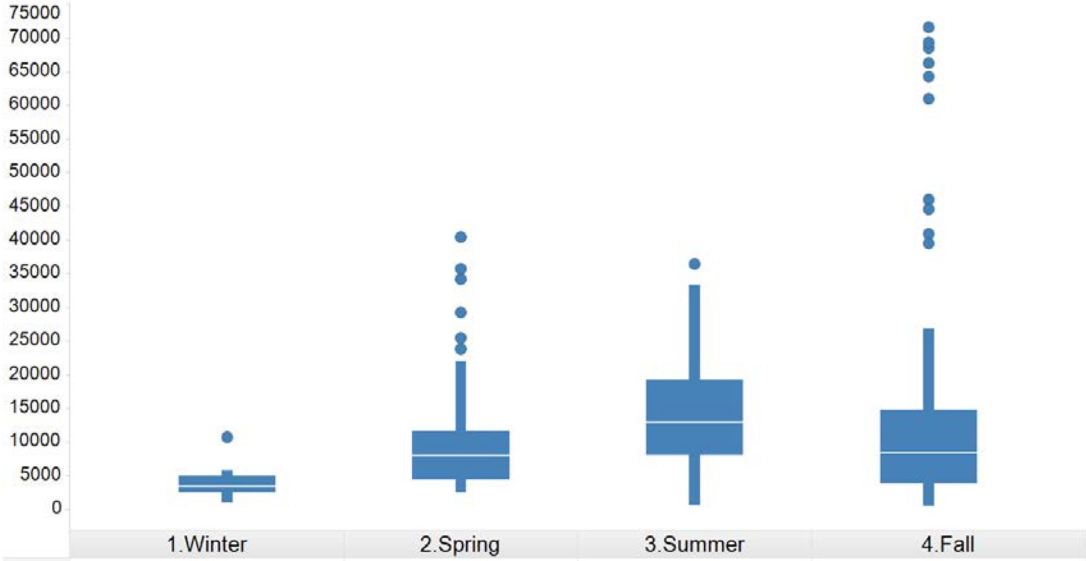

Fig. 8. Box plot of soil gas CO_2 concentration (ppmv) by season for all samples collected off-well pad.

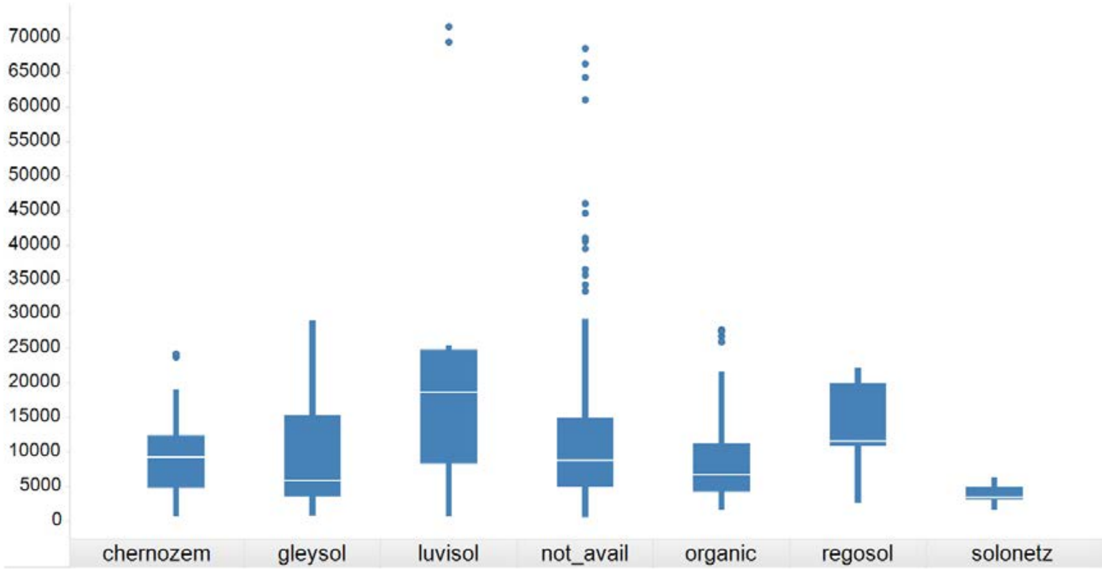

Fig. 9. Box plot of soil gas CO_2 concentration (ppmv) by soil type for all samples collected off-well pad. Note that for some sites, soil type is not available (referred to as not_avail).

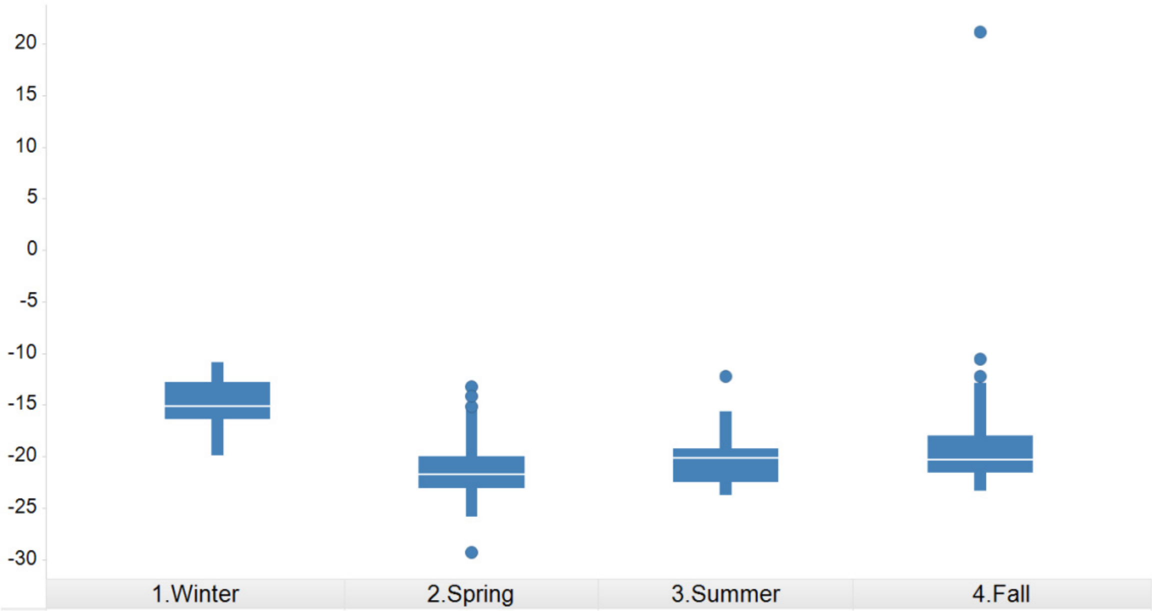

Fig. 10. Box plot of soil gas $\delta^{13}C_{CO2}$ values (‰) by season for all samples collected off-well pad.

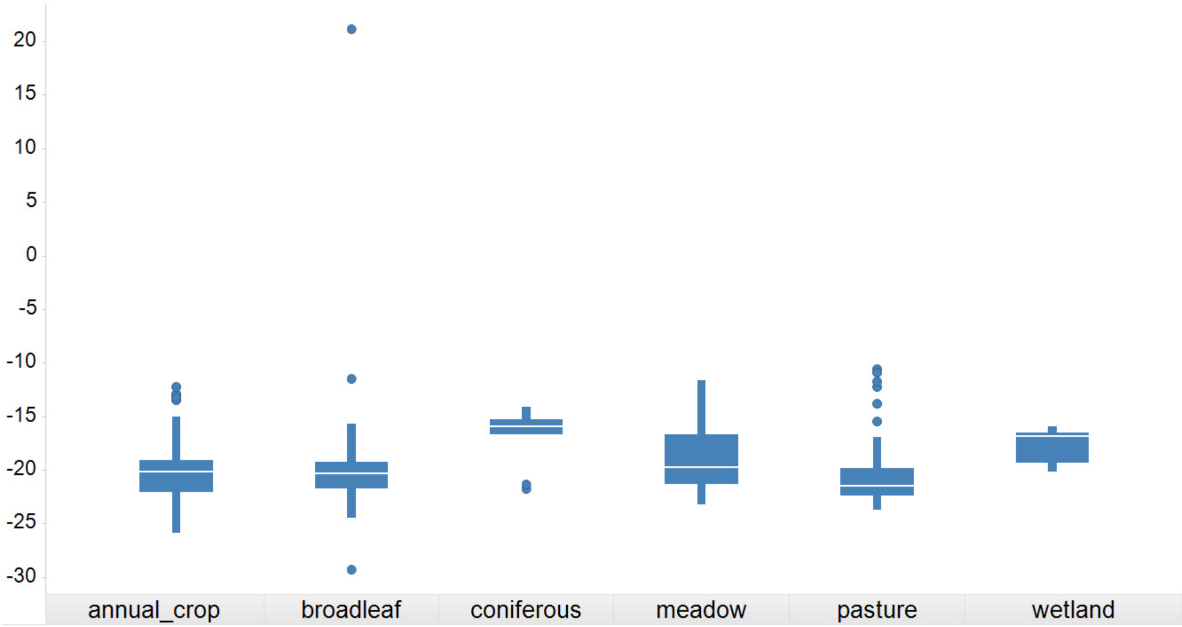

Fig. 11. Box plot of soil gas $\delta^{13}C_{CO2}$ values (‰) by land use type for all samples collected off-well pad.

6. Conclusion

An extensive and comprehensive dataset has been compiled with regards to soil surface CO_2 flux, ambient air and soil gas CO_2 concentration and isotopic composition across the Quest sequestration lease area. Surface CO_2 fluxes ranged from <0.5 μmol m^{-2} s^{-1} on an injection well pad where the top soil has been removed to >20 μmol m^{-2} s^{-1} at off-pad vegetated sampling sites. Understanding the spatial and temporal variability of CO_2 levels prior to start of CO_2 injection represents an important activity of a CCS MMV program. It provides technical input to the development of such a program, but also provides knowledge for communication to and awareness of project stakeholders (e.g. landowners) regarding CO_2 levels within the atmosphere and biosphere across a SLA.

Acknowledgements

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References

[1] Quest Knowledge Sharing, http://www.energy.alberta.ca/CCS/3848.asp (last accessed 23-Sept-2016).

[2] Hirst et al., A new technique for monitoring the atmosphere above onshore carbon storage projects that can estimate the locations and mass emission rates of detected sources, Energy Procedia: this issue, GHGT-13 Proceedings.