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SURFACE MONITORING FOR THE SECARB BLACK WARRIOR INJECTION TEST, TUSCALOOSA COUNTY, ALABAMA

M. R. McIntyre, Geological Survey of Alabama
Adam Dayan, University of Alabama
J. C. Pashin, Geological Survey of Alabama
R. A. Esposito, Southern Company
B. R. Strazisar, U.S. Department of Energy, National Energy Technology Laboratory
P. E. Clark, University of Alabama

ABSTRACT

The Black Warrior basin has produced a large quantity of coalbed methane and has the potential for considerable enhanced coalbed methane production. Additionally, as bituminous coal can adsorb approximately twice as much CO_2 as methane at reservoir pressure, the basin has significant potential for CO_2 sequestration. A field test is being conducted and has been designed to test reservoir conditions in the three primary target coal zones. A number of monitoring activities are planned for the site including reservoir pressure monitoring in deep observation wells, fluid and pH monitoring in each coal bed, shallow groundwater quality monitoring, soil gas composition, conservative tracers, and soil CO_2 flux monitoring. A set of soil gas samples was collected and soil flux monitoring was performed at a control site located in Deerlick Creek to provide additional background information on near surface conditions in the region. Preliminary results indicate that a significant volume of CO_2 is found in the soil profile and carbon isotopic data suggests that the CO_2 is of bacterial origin. Soil CO_2 flux data was collected for nine months and indicated a high variability among individual sites and through time. The data show significant seasonal variations, with high flux rates during the warm months associated with high soil activity and low flux rates during the winter months.

INTRODUCTION

The Black Warrior basin (Figure 1) has produced more than 2 Tcf of coalbed methane and the basin is estimated conservatively to have the potential to store 5.9 Tcf of CO_2 in mature reservoirs. Based on this estimate, sequestration of CO_2 would enhance coalbed methane recovery, increasing reserves by more than 20% [1]. A field verification test program of carbon sequestration in coal is being conducted in the Black Warrior Basin under the auspices of the U.S. Department of Energy's Southeastern Regional Carbon Sequestration Partnership (SECARB [2]). The test is a small-scale, short-term test in an area where technical feasibility and commercial applicability are considered to be high. Part of this project is to begin to develop and demonstrate technology to ensure the safe and permanent storage of CO_2 in coal seams.

Deerlick Creek Coal Degasification field (Figure 2) is a mature field, and the geology of the field has been intensely studied (e.g. Wang and others [3]; Pashin and others [4]; Pashin and Groshong [5]; Groshong and others [6]; and Pashin, Jin, and Payton [7]) making it a good field in which to operate. The control site was located at the J.D. Jobson 24-14 #11 well (Permit No. 4001), and while this well cannot be used for the injection test due to circumstances unrelated to geology, the data from this site will provide critical control data on soil gas and soil CO_2 flux in the area. A final test site is now being selected.

The coal of the Black Warrior basin is mainly in the upper Pottsville Formation (Lower Pennsylvanian). The upper Pottsville has been subdivided into regionally mappable coal zones that typically contain multiple coal seams (Figure 3). The principal target beds for coalbed methane production are in the Black Creek, Mary Lee, and Pratt zones. These coal zones are also the primary targets for carbon sequestration.

Project Design

The project focuses on the injection of about 1,000 tons of CO_2 into a mature coalbed methane well and a series of buildup and falloff tests that will be monitored in the injection well and a series of remote observation wells. Before the injection test, one shallow water observation well and three deep observation wells will be drilled (Figures 4 and 5), and the injection well's mechanical integrity will be tested to ensure that the test can be conducted safely. Coal samples from cores in the deep wells will be sent off to have adsorption isotherms for CH_4 and CO_2 run, remaining gas in place analysis, and for proximate, ultimate, and petrographic analysis.

The injection test will begin with a pressure build up test to determine the time required for pressure stabilization of the well and shut-in pressure. The injection of the CO_2 will occur in two stages at each of the three coal zones, beginning with the Black Creek zone, followed by the Mary Lee, and then the Pratt zones. The first stage of the injection consists of a 40-ton slug of CO_2 injected to test the injectivity and help estimate the pressure and rate to inject a larger amount of CO_2. After pressure stabilizes in the coal, 280 tons of CO_2 will be injected to test longer term changes in injectivity and pressure response. Once pressure stabilizes in the Black Creek, the test will be repeated in the Mary Lee coal zone and then the Pratt coal zone [2, 8].

Monitoring Plan

A number of different methods are planned to monitor the injection and ensure the safety and effectiveness of this program. The three deep observation wells will have packers installed to isolate the target coal zones with pressure transducers and, if possible, pH monitors and fluid sampling equipment between the packers within the target injection zones (Figure 5). Pressure will be monitored during the production-buildup and injection-falloff tests. The pressure data will allow for analysis of multi-well interference patterns, permeability anisotropy, and the effect of hydrofractures on fluid transport; it will also allow detection of any cross-communication, if present, between the coal zones and will help determine if leakage is a significant risk associated with enhanced coalbed methane (ECBM) and carbon sequestration. Pressure will also be monitored at the wellhead, in the injection zone, and in the tubing-casing annulus above the packer in the injection well. The shallow observation well is for ground water monitoring and sampling will begin 3 months before injection and continue through site closure. Samples will be taken at least quarterly and will be tested for basic hydrologic and geochemical parameters [8].

Surface soil monitoring activities consist of analysis of soil gas composition and the measurement of soil gas flux. The twenty-one monitoring stations (Figure 4) are arranged in a radial array at 50 m, 100 m, and 150 m from the well. Soil gas samples were taken in February 2007 at the control site and samples will be taken at the test site about 3 months before and 3 months after injection. Samples are taken at a depth of 0, 0.3, 0.6, and 1.0 meters at each station and analyzed for gas composition (N_2, O_2, CO_2, CH_4, and light hydrocarbon concentrations) and isotopic composition of CO_2. Soil CO_2 flux monitoring at the control site began in May 2007 and continued through February 2008. Flux was measured at each of the 21 monitoring stations once a month and weekly measurements were made at two stations. Flux monitoring will begin at the test site at least 3 months before injection and continue until site closure. Shallow ground water and surface monitoring will provide important baseline and post-injection information to be used to evaluate the environmental safety of carbon sequestration and ECBM in the Black Warrior basin [8].

SURFACE MONITORING

Soil Gas

Soil gas samples were taken by inserting the sample tube to the desired depth (starting at 30 cm), then using a syringe to evacuate the air in the tube (approximately 2 volumes of the sampling tube). The syringe was then used to pull a 50 mL sample and the gas injected into a sample pre-evacuated bottle. Two samples were taken at each depth, then the sample tube was pushed to the next depth and sampling was repeated; the surface sample was taken with a syringe in the open air. One sample from each depth was analyzed for the concentrations of nitrogen, argon and oxygen, carbon dioxide, and several light hydrocarbons and the other sample was analyzed for the isotopic composition of CO_2.

The soil gas samples contain an average of 78% nitrogen, 21% oxygen and argon, and less than one percent carbon dioxide (Figure 6). Interestingly, the CO_2 concentration in the soil gases locally exceeds 2 percent; whereas the CO_2 concentration in the coalbed gas produced from the Jobson 24-14 #11 well is only 0.01 percent. The soil gas contains small amounts of hydrocarbons, primarily methane, ethane with some traces of ethylene, n-butane, propane, and propene (Figure 7). The hydrocarbon fraction has a dryness index of about 0.98, which is wetter than the hydrocarbons produced from the Jobson 24-14 #11 well (dryness index = 1.00). The amount of oxygen and argon decreases with depth while CO_2 increases with depth; the nitrogen concentration remains fairly steady. The $\delta^{13}C$ values decrease with depth, which reflects increasing bacterial activity with depth in the soil profile (Figure 8). A few samples deep in the soil profile have $\delta^{13}C$ values similar to the surface sample, which may indicate local communication with the atmosphere.

Soil CO_2 Flux

Soil CO_2 flux was measured using a LI-COR Biosciences LI-8100 soil CO_2 flux analyzer. Raw data were collected in the field, and flux rates were calculated using the software provided with the LI-8100. Two stations were sampled weekly; all 21 stations were sampled monthly. Soil temperature and moisture were also measured at each station.

Soil flux is highly variable between stations and over time. Differences of 7.77 μmols/m^2/s between two sites on the same day have been measured and a difference of 5.13 μmols/m^2/s from one week to the next at one site. While some stations are have consistently below, or above average, average flux rates some vary wildly (Figure 9). There appears to be little correlation between soil temperature or soil moisture and flux rates (Figure 10); however, there does appear to be a seasonal fluctuation (Figures 11, 12 and 13). Seasonal variations are to be expected as there is more soil microbial activity in the warm months than in the winter months. The results of soil flux monitoring demonstrate that significant CO_2 is issuing from the soil profile at the control site, and comparison of pre- and post-injection data at the test site will provide critical information on soil gas emissions and the potential effects of commercial sequestration and ECBM operations.

CONCLUSIONS

A field test is being conducted in the Black Warrior basin that is designed to test reservoir conditions in three Pottsville coal zones. A number of monitoring activities are planned for the site including reservoir pressure monitoring in deep observation wells, fluid and pH monitoring in each coal bed, shallow groundwater quality monitoring, soil gas composition, conservative tracers, and soil CO_2 flux monitoring. A significant quantity of CO_2 is found in the soil naturally and concentrations tend to increase with depth as the CO_2 becomes depleted in ^{13}C; this is consistent with bacterial activity in the soil profile. Less than 1 percent of the soil gas is light hydrocarbons and methane and ethane dominate. The hydrocarbon fraction has a dryness index of about 0.98 and is wetter then the gas produced in the adjacent well; the lower dryness of the soil-gas hydrocarbons suggests that they are locally derived from the soil profile and not the reservoir coal beds. There is a net movement of CO_2 out of the soil year round at the control site between 0.2 μmols/m^2/s and 10.35 μmols/m^2/s. Flux rate exhibits a seasonal variation, with higher rates in the summer and lower rates in the winter.

ACKNOWLEDGEMENTS

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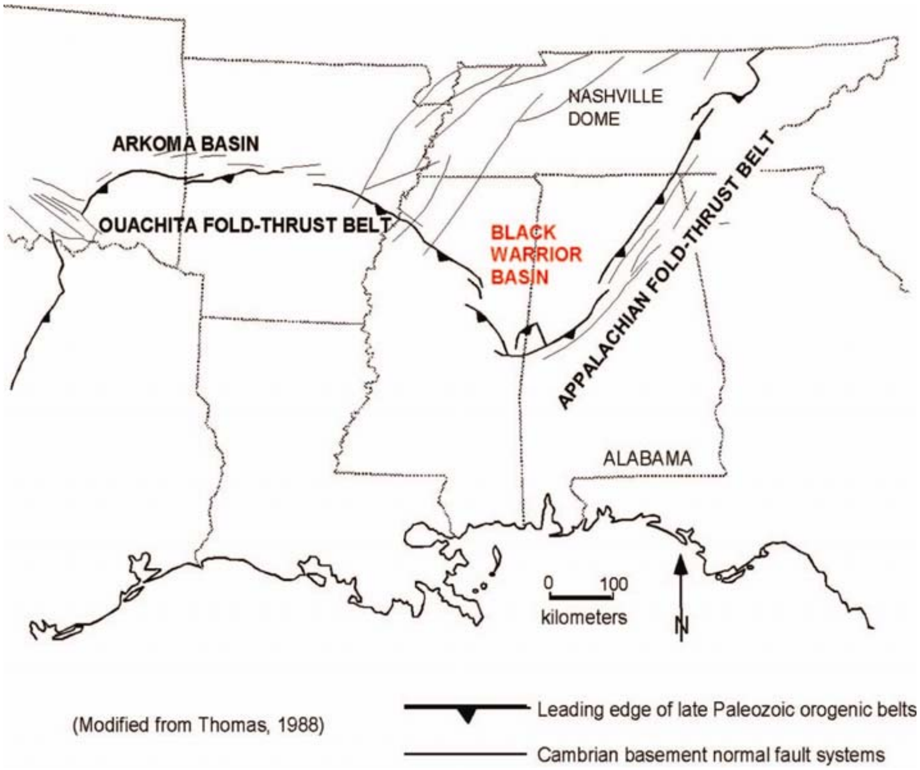


Figure 1. Regional setting and location of the Black Warrior Basin, Alabama.

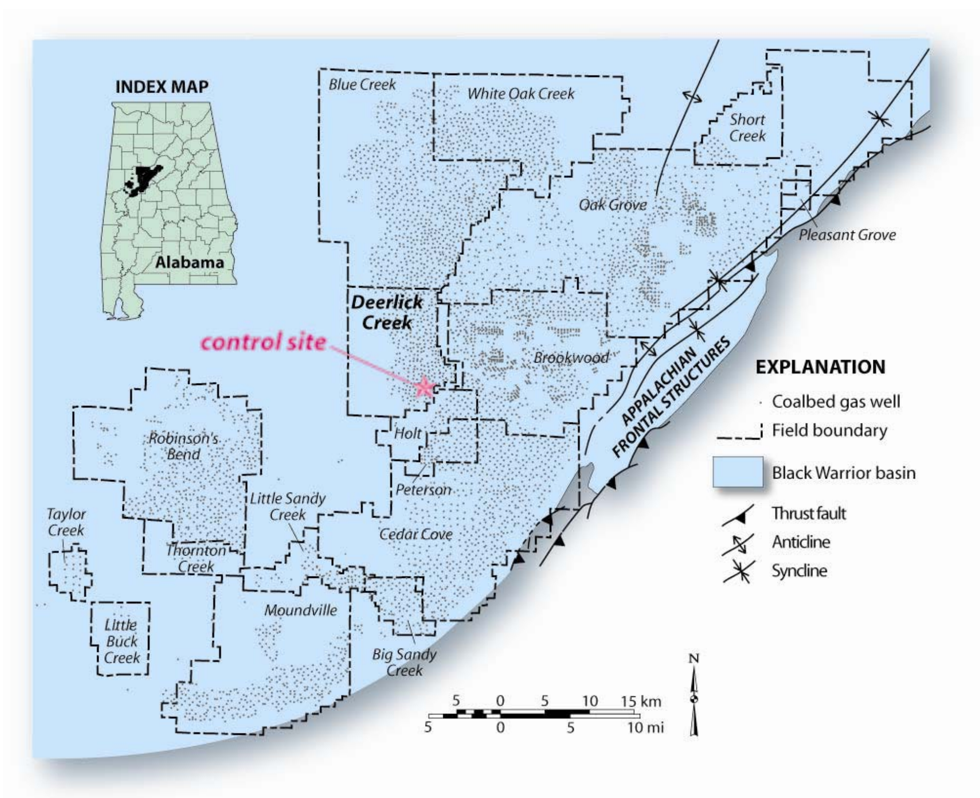


Figure 2. Location of surface monitoring control site.

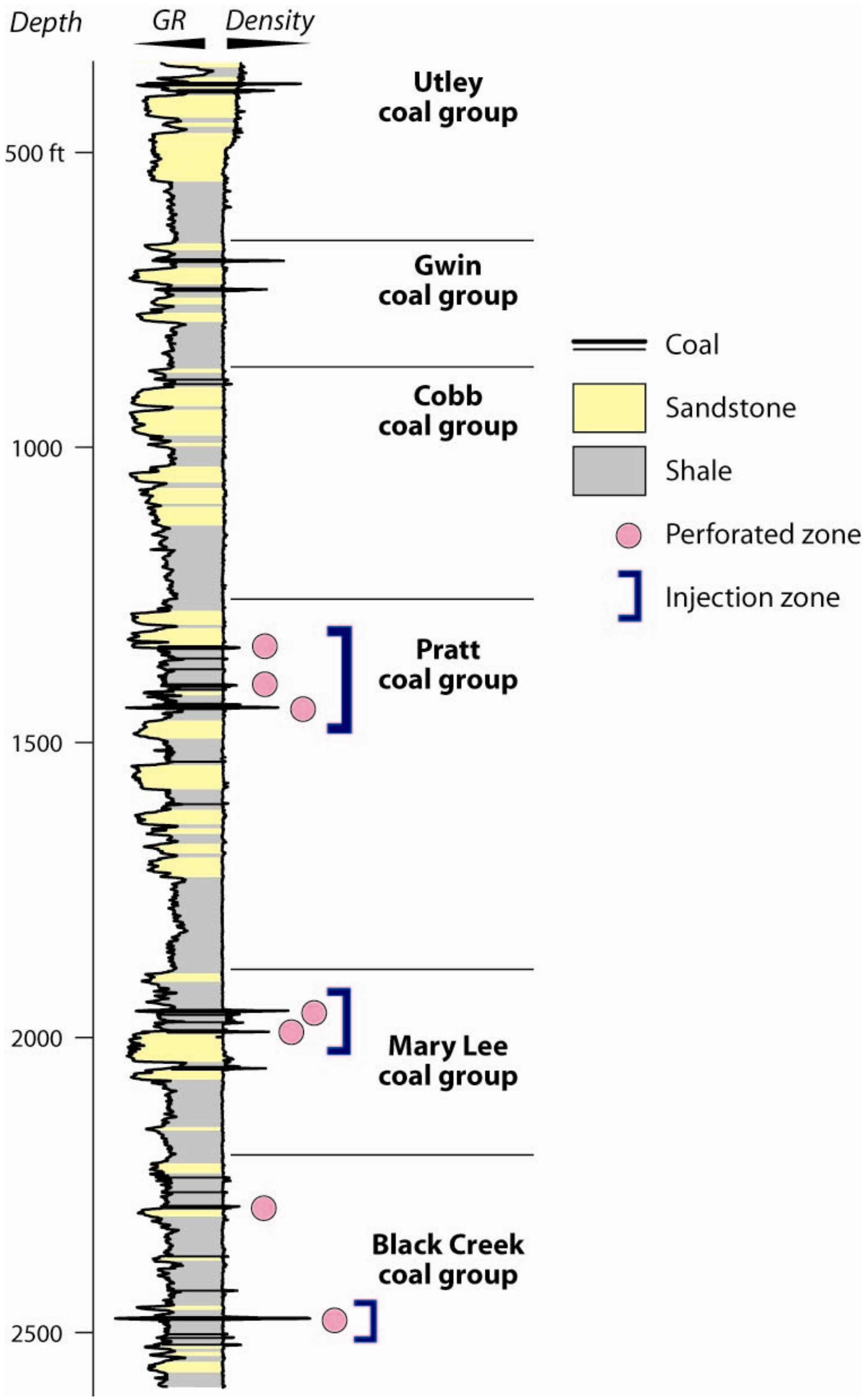


Figure 3. Geophysical well log and stratigraphic section of a well in Deerlick Creek Field.

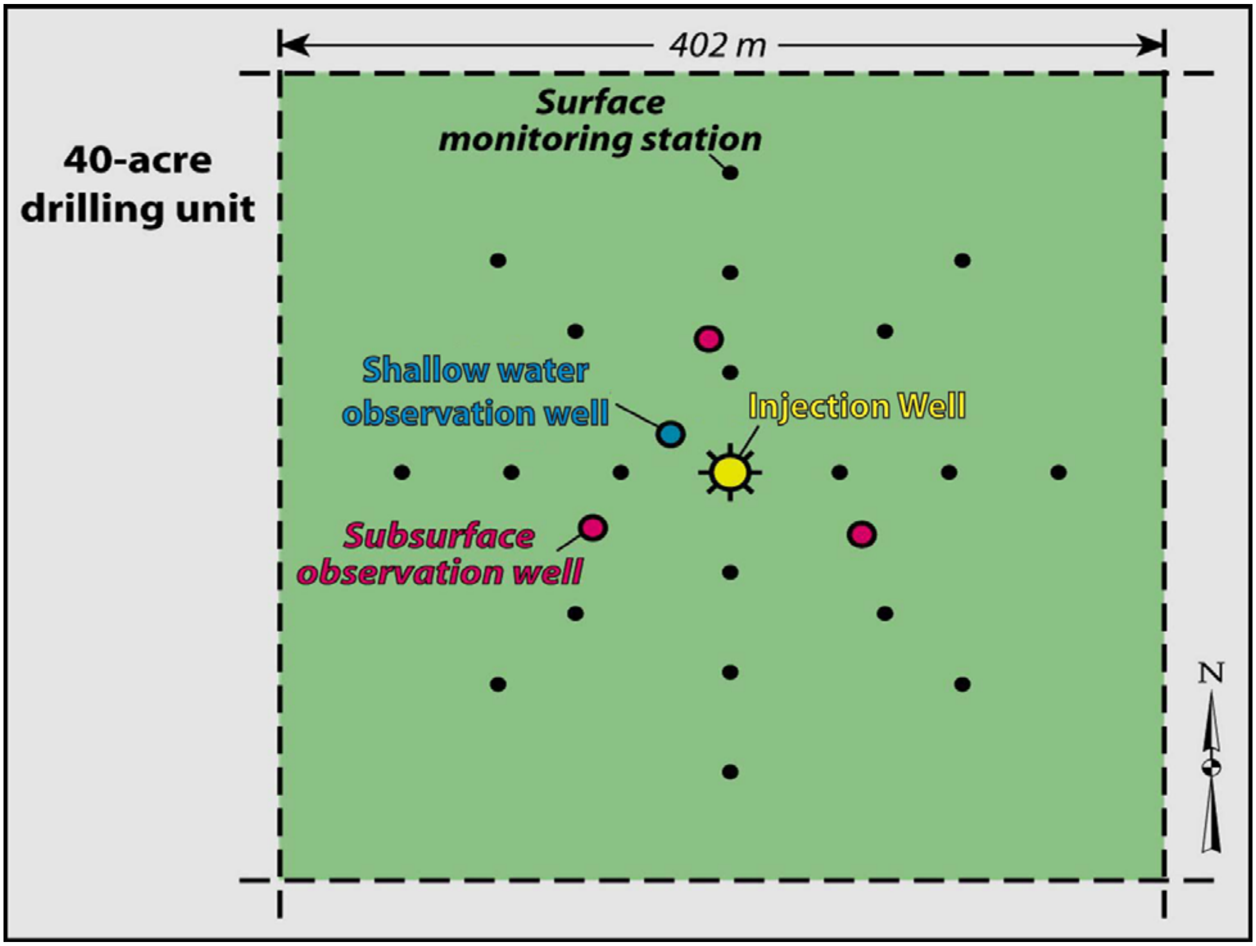


Figure 4. Schematic of the planned locations for wells and surface monitoring stations.

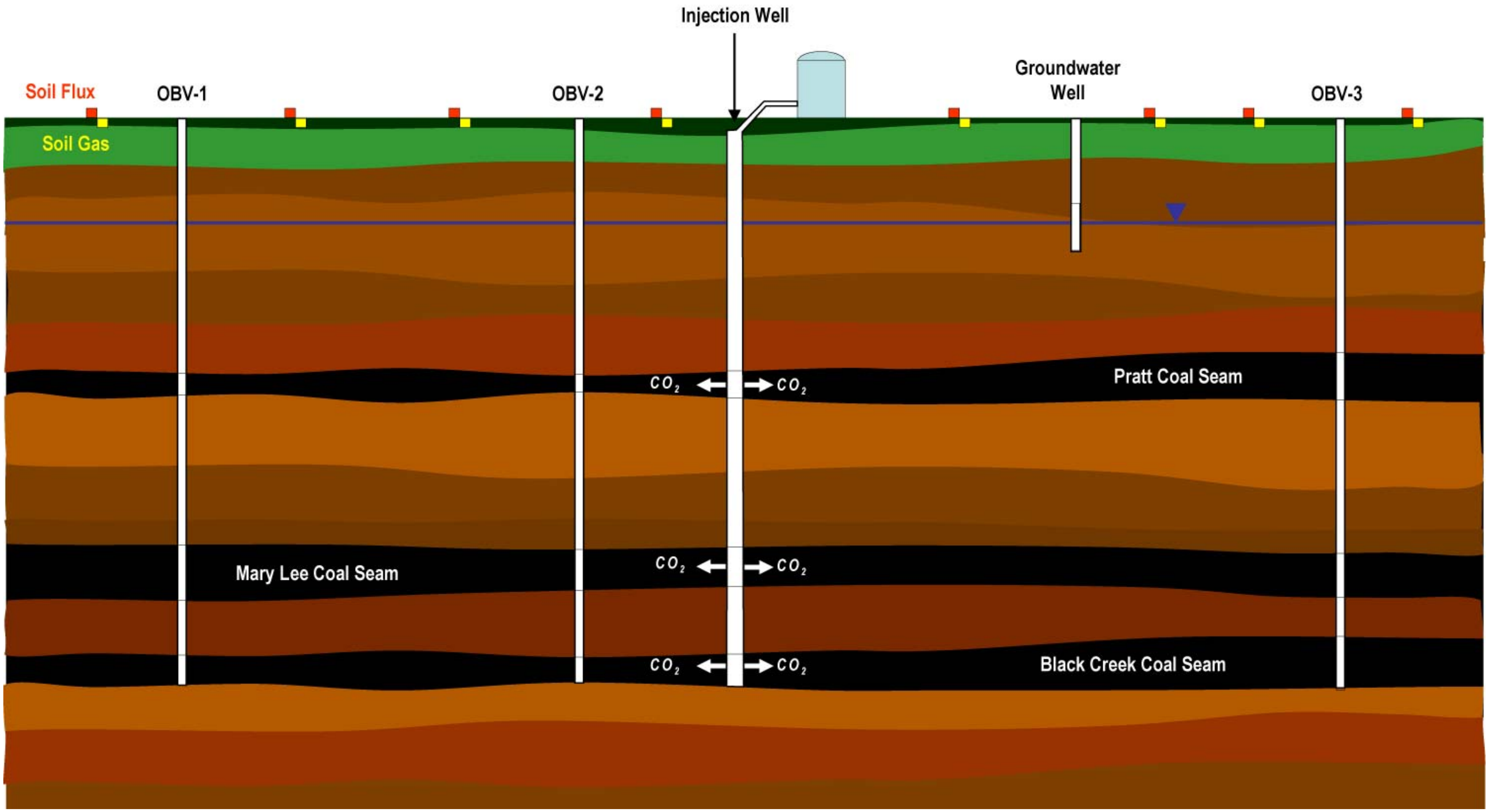


Figure 5. Schematic cross-section showing injection well and observation wells.

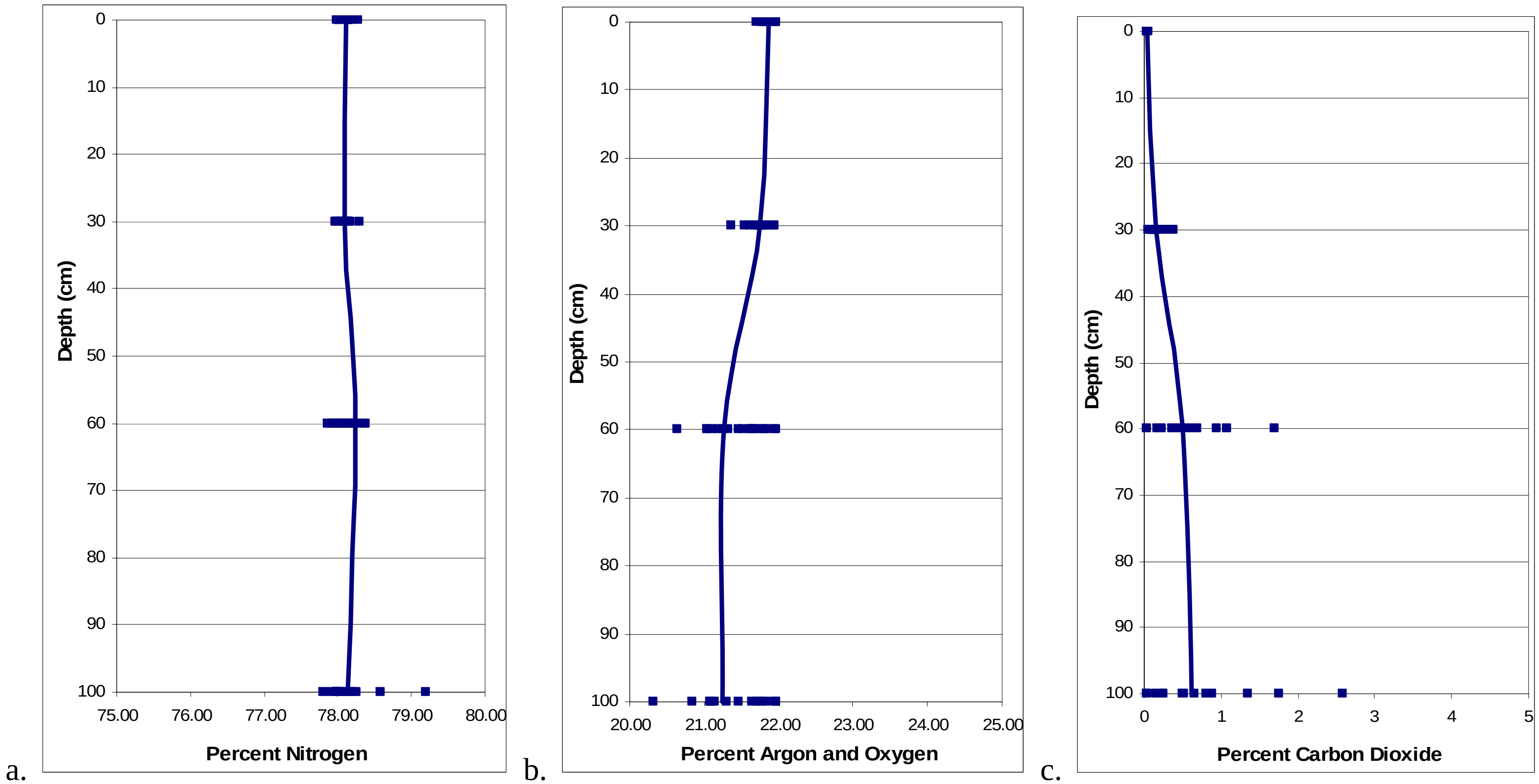


Figure 6. Soil gas composition vs. depth. a. Percent nitrogen. b. Percent argon and oxygen. c. Percent carbon dioxide.

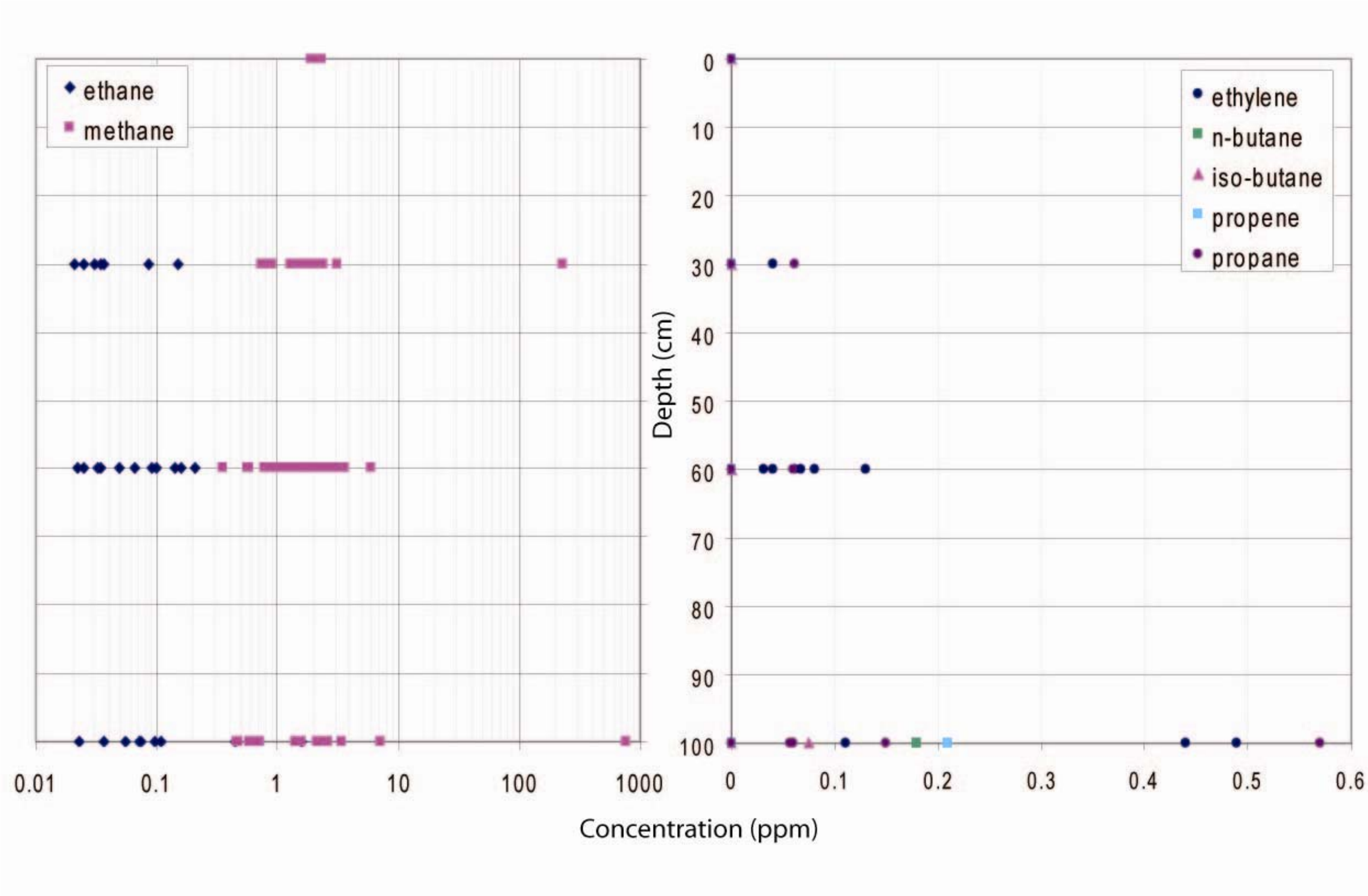


Figure 7. Concentration of light hydrocarbons in the soil gas.

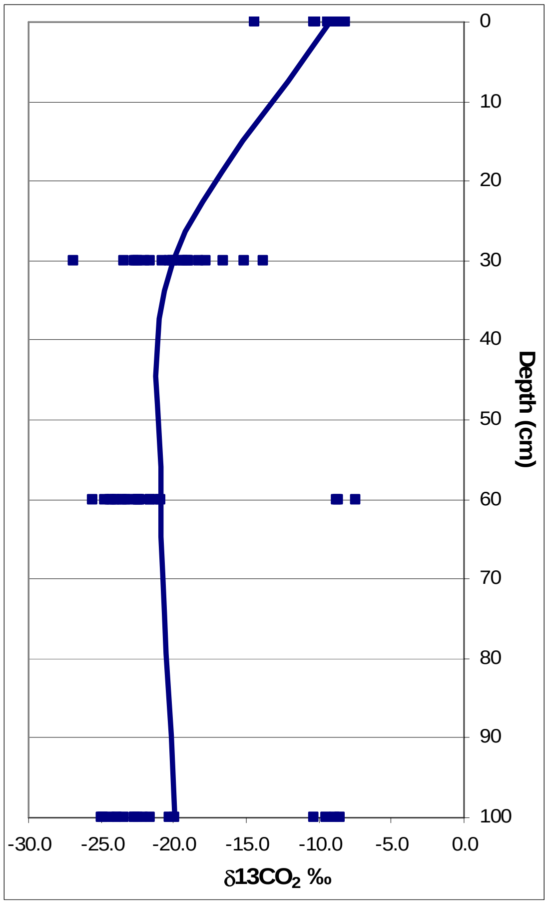


Figure 8. $\delta^{13}C$ vs. depth.

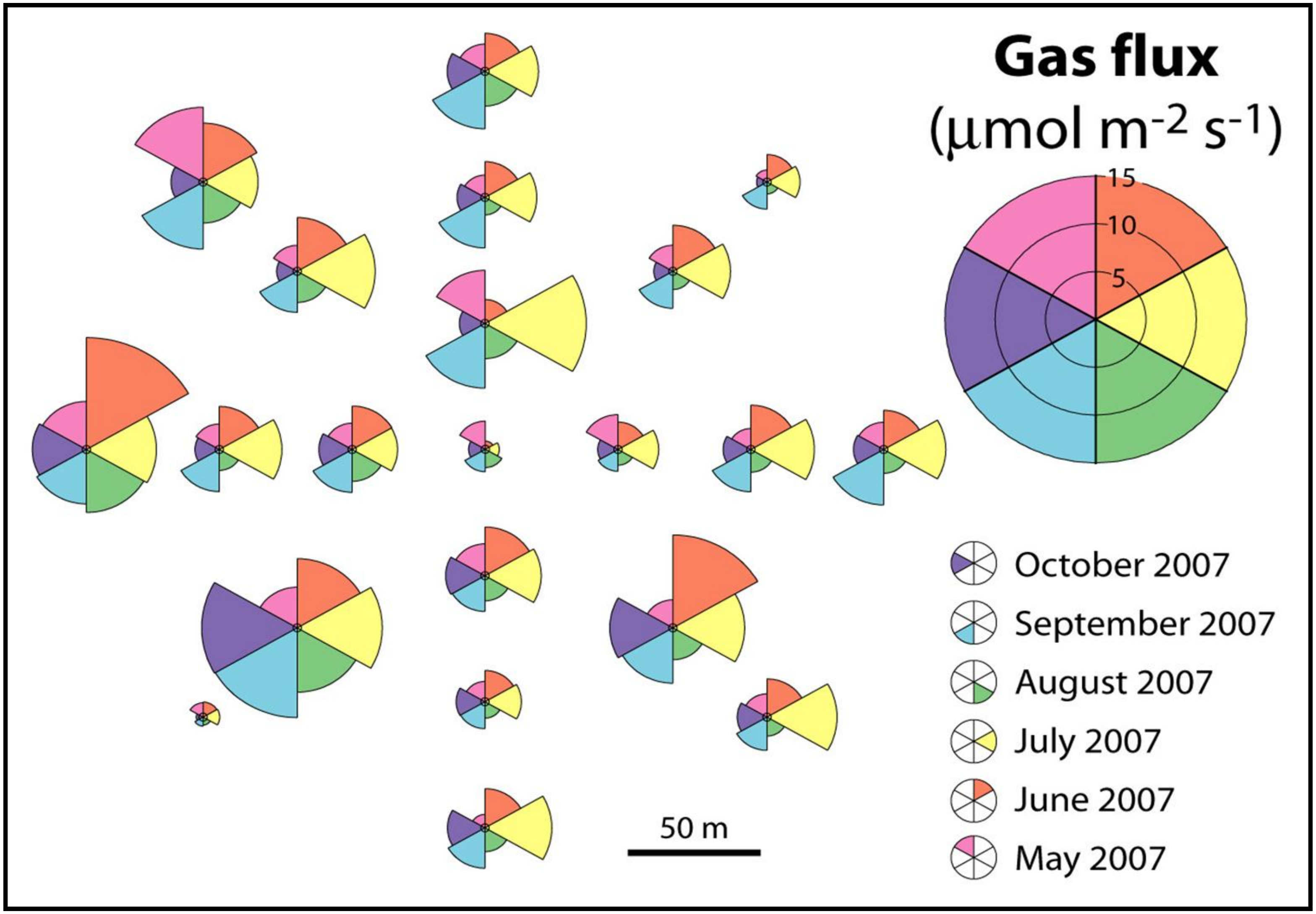
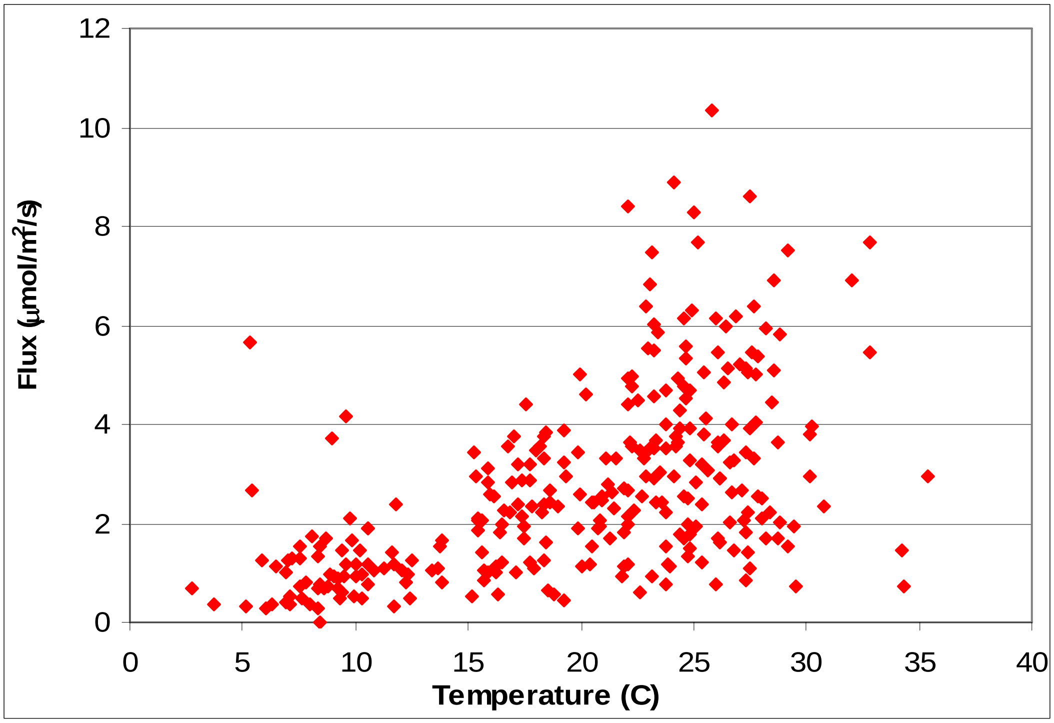
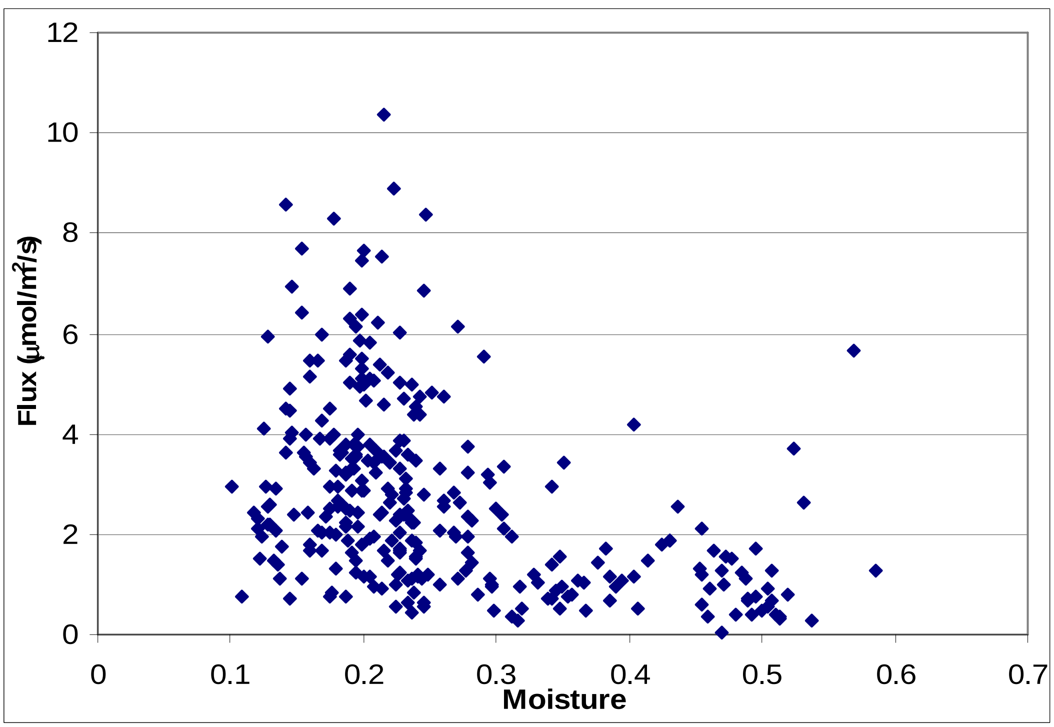


Figure 9. Bubble map of soil CO_2 flux rates from May 2007 to October 2007.



a.



b.

Figure 10. Soil temperature, soil moisture levels, and flux rate. a. Flux vs. soil temperature. b. Flux vs. soil moisture.

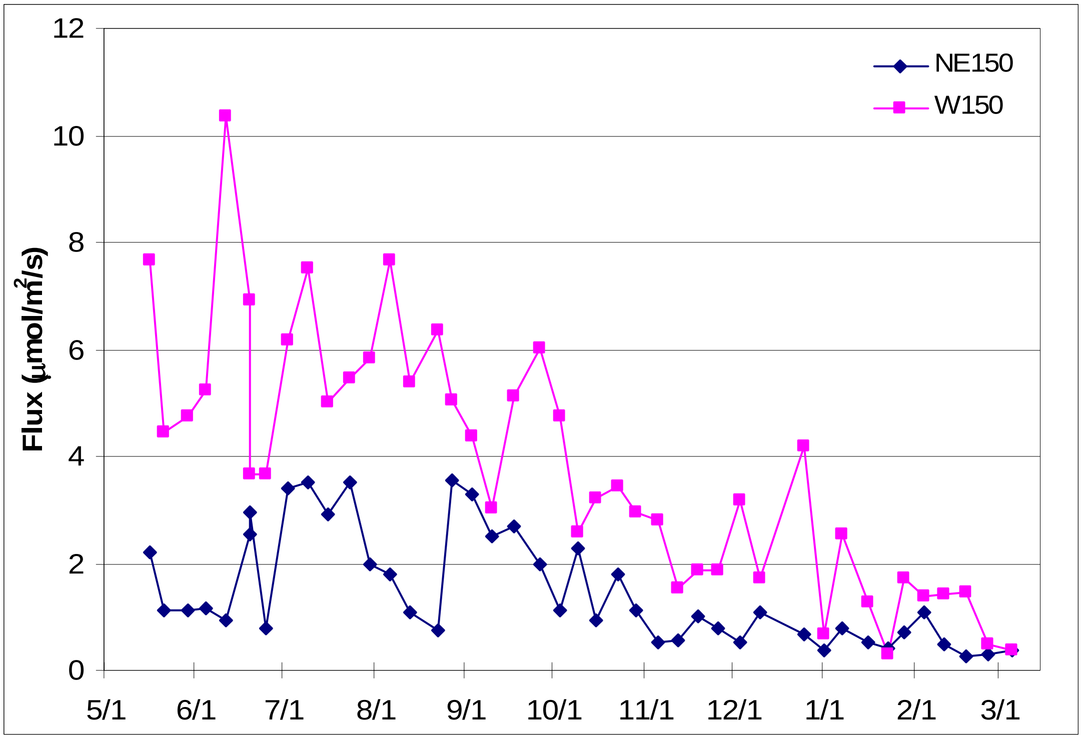
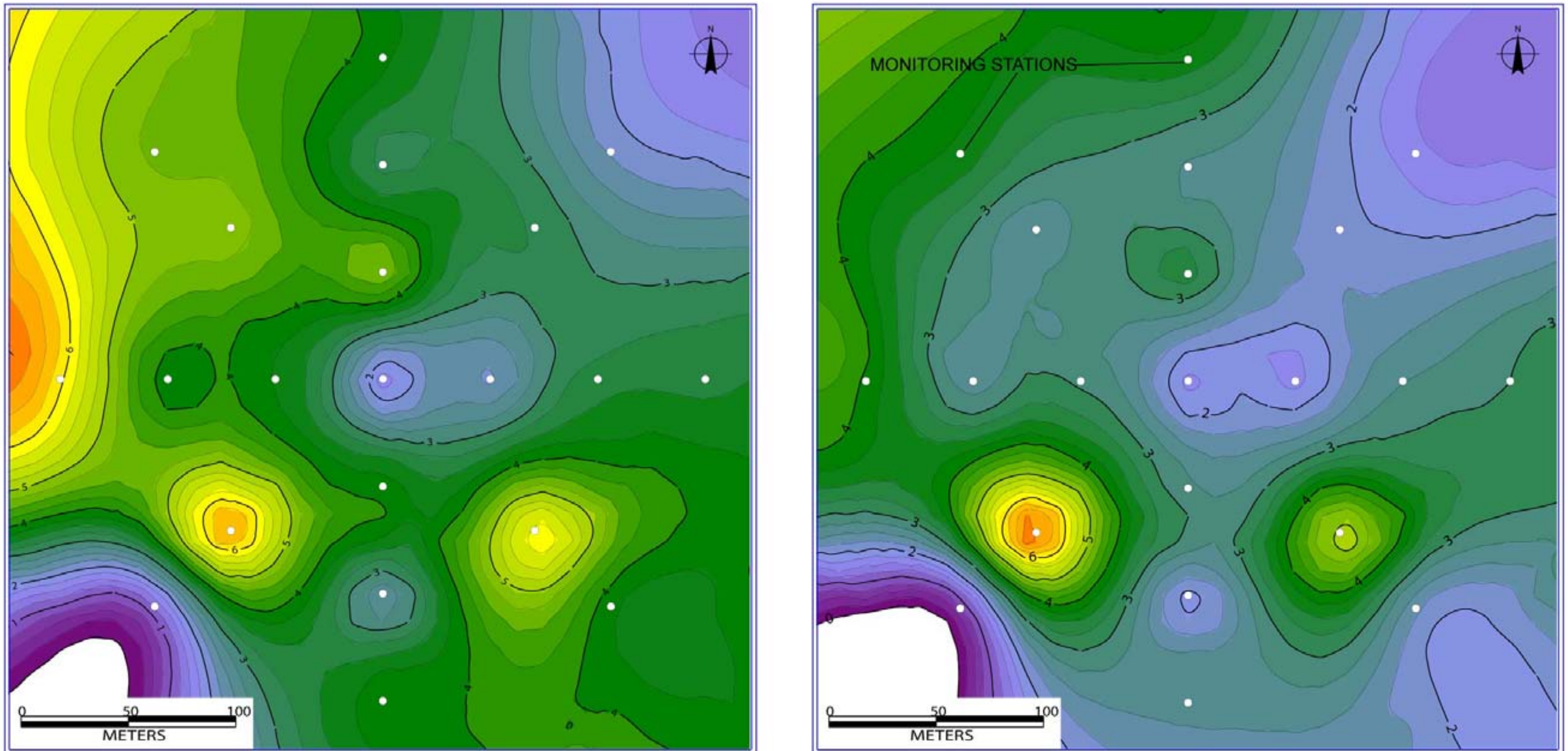
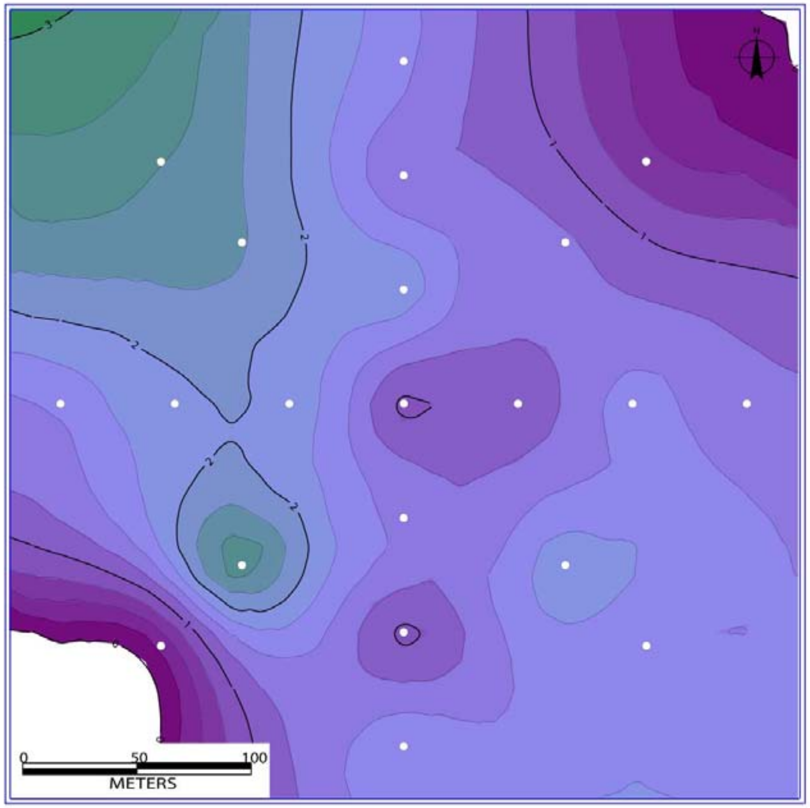


Figure 11. Soil CO_2 rates at stations NE150 and W150 measured weekly from May 2007 to March 2008.



a. b.

Figure 12. Maps of the seasonal averages for soil flux (μmol/m2/s). a. Summer – June July and August. b. Fall – September, October, and November. c. Winter – December, January, and February.



c.

Figure 12 (continued). Maps of the seasonal averages for soil flux (μmol/m2/s). a. Summer – June July and August. b. Fall – September, October, and November. c. Winter – December, January, and February.

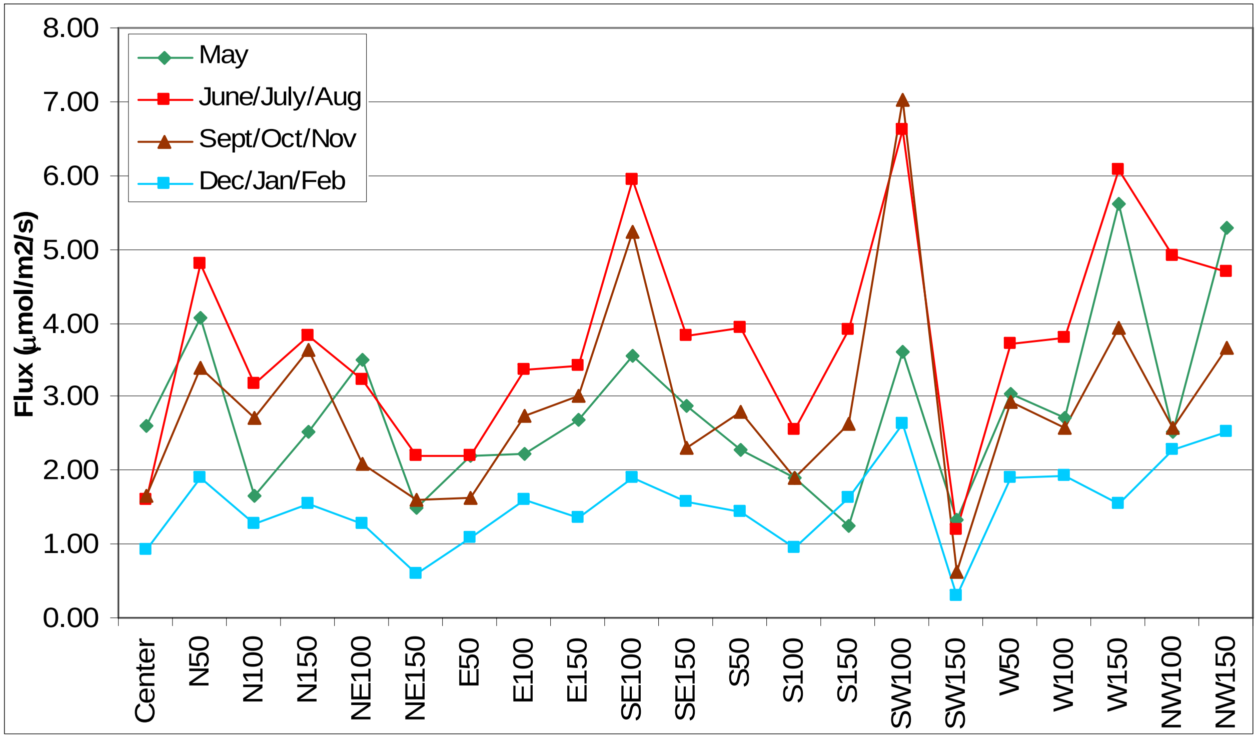


Figure 13. Graph of seasonal averages at each station.