IDENTIFYING CONTROLS ON SURFACE CARBON DIOXIDE EFFLUX IN A SEMI-ARID ECOSYSTEM

By

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ABSTRACT

This study focused on soil respiration, the least constrained process in the terrestrial carbon cycle, and a source of uncertainty for model predicted ecosystem response to climate change. Respiration processes that make up soil respiration respond to environmental influencing factors, temperature, and moisture. Respiration responses vary by site, time of year, and also year to year, confounding determination of individual influence of the factors, making soil respiration difficult to model. This research took advantage of the climate characteristics of a semi-arid system, in order to observe soil temperature and moisture influence on soil respiration. Field measurements of soil surface CO_2 efflux taken using an automated closed dynamic chamber system approximated soil respiration. Analysis of the growing season pattern of soil respiration compared to patterns of environmental variables supported a conceptual model in which soil respiration exhibits variable dependency on both temperature and moisture. A series of mathematical models of soil respiration were evaluated from the literature that featured various moisture dependency modifications to common temperature-dependent relationships. Model performance was assessed by model regression fit to the seasonal trend in soil respiration and the model consistency with conceptual understanding of soil respiration function in the system. The best model fit to the data also reflected the conceptual model of soil respiration, that soil moisture status determines the degree of temperature dependence of soil respiration. The field observations reflected trends seen in

other semi-arid systems, particularly those that experience growing season water limitation in the summer due to lack of access to or availability of deep soil moisture. The research supported common themes observed in all semi-arid ecosystems: the peak soil respiration occurs in spring when warm and wet conditions converge, and the temperature dependency of soil respiration declines as soil moisture declines.

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LIST OF ABBREVIATIONS

C	Carbon
CH_2O	used to generally represent organic carbon molecules (solid)
CO_2	Carbon dioxide (gas)
CO_2 Flux	Soil surface CO_2 efflux, the field measured environmental variable used to represent soil respiration, which is expressed as a molar flux of carbon (as CO_2) with positive direction of mass transfer defined normal to the soil surface from the soil to the atmosphere (μmol m^{-2} s^{-1})
DCEW	Dry Creek Experimental Watershed, the study area
DOY	Julian Day of Year, the numbering of which starts at 1 (one) on January 1st
M	Soil Moisture
Q_{10}	refers to the Q_{10} exponential temperature dependent model
Q_{10}	(in italics) refers to the variable within the Q_{10} model that represents the temperature dependency of soil respiration for the system modeled
R	Soil Respiration
T	Soil Temperature

1. INTRODUCTION

In order to control atmospheric CO_2 levels, a detailed understanding of the global carbon cycle and budget is needed, with particular interest in understanding short-term (1-100 yr) mechanisms of carbon sequestration. Uncertainties in the terrestrial carbon reservoir produce high levels of uncertainty to predictive modeling (Field and Raupach, 2004). The amount of carbon stored in soils exceeds that found in above ground biomass (Hibbard et al., 2005). Therefore, expanding our understanding of controls on this important pool of carbon will improve understanding of the global carbon cycle. The predictive capability of models can be improved by studying short-term terrestrial carbon cycle processes that lead to the release of CO_2 from the soil, a complex process referred to as soil respiration (Trumbore, 2006).

Across ecosystems, the majority of variation in soil respiration is explained by the primary productivity (or growth) of the site and environmental variables soil temperature and moisture (Ryan and Law, 2005). In semi-arid systems, the relative importance of soil temperature and moisture influences on respiration rates varies seasonally (Davidson et al., 1998). Observation of the seasonal variation in soil variables (temperature, moisture, and respiration rate) in semi-arid systems facilitates understanding of the respective individual mechanistic influences of soil temperature and moisture on soil respiration processes (Irvine and Law, 2002; Carbone et al., 2008).

The objective of this thesis is to investigate the influence of soil moisture and temperature on soil respiration in semi-arid ecosystems. This objective was met by undertaking two tasks:

1. The collection of field measurements of soil respiration and important environmental controls on that respiration,
2. The evaluation of a series of mathematical models of respiration to determine the important model characteristics that describe the observed trends in soil respiration while reflecting current conceptual understanding of the influence of environmental controls on soil respiration.

These tasks are guided by the hypothesis that more accurate expressions of soil moisture dependence of soil respiration will result in an improved distinction between soil temperature and moisture influences on soil respiration. The outcome of this thesis will be improved predictive capability of terrestrial carbon cycle models, especially for application to moisture-limited ecosystems.

1.1. Review of Soil Respiration

Soil respiration is a component of the terrestrial carbon cycle. With respect to the cycling of atmospheric CO_2, soil respiration comprises all the processes that convert organic carbon substrates to gaseous CO_2 within the soil. This section describes soil respiration with respect to short-term (1-100 yr) carbon cycle processes.

The terrestrial carbon cycle involves the exchange of carbon from the atmosphere to land where it is stored in plants and soil. It is primarily composed of two large fluxes of carbon due to biological processes, photosynthesis, and ecosystem respiration

(Trumbore, 2006). The total amount of organic carbon produced by photosynthesis, known as gross primary productivity, is strongly controlled by the environmental components of light, water, and temperature. When all of these components are satisfied, gross primary productivity is typically high; when one or more of these components are limited, gross primary productivity is often depressed. While all of the carbon that enters terrestrial ecosystems is due to a single process, photosynthesis, many pathways and processes return carbon to the atmosphere (Trumbore, 2006). With respect to atmospheric CO_2, the terrestrial carbon cycle can be a net source or sink of carbon annually depending on the difference between C uptake through photosynthesis (gross primary productivity) and C release through ecosystem respiration processes and disturbance (Trumbore, 2006).

Photosynthesis converts CO_2 to organic carbon (CH_2O); see Figure 1.1. Organic carbon substrates are allocated to leaves, stems, and roots, or respired during plant metabolism (Ryan and Law, 2005; Trumbore, 2006). Organic carbon stored within terrestrial ecosystems is present in living plants and roots and also within the soil organic carbon reservoir (Jobbagy and Jackson, 2000). Molecules that make up plant tissues ultimately become soil organic carbon (SOC), as dead plant material in the form of roots or surface litter is broken down over time by physical, chemical, and biological processes (Six et al., 2002).

Ecosystem respiration is composed of soil respiration and above-ground plant respiration occurring in the cells of stems and leaves. Respiration processes are reduction-oxidation (red-ox) reactions where an organic carbon substrate is oxidized to CO_2 by gaseous oxygen, O_2, to produce energy. Soil respiration is composed of a range of processes in which different organisms respire CO_2 derived from various organic carbon sources (Figure 1.1). Soil respiration is often separated conceptually by the type of respiration agent based on the organism's method of deriving energy, which is root respiration (the autotrophic component of soil respiration), and microbial respiration (the heterotrophic component) (Kuzyakov, 2006; Trumbore, 2006). Soil respiration may also be divided based on substrate source: processes linked to recent photosynthetic products and those driven by the SOC reservoir (Kuzyakov, 2006). Soil respiration processes respond to driving environmental variables with a range of responses due to the degree of coupling to plant processes. The proportion of the autotrophic to heterotrophic influences on soil respiration can vary from 10 to 90 % depending on biome, season, or time of day (Hanson et al., 2000).

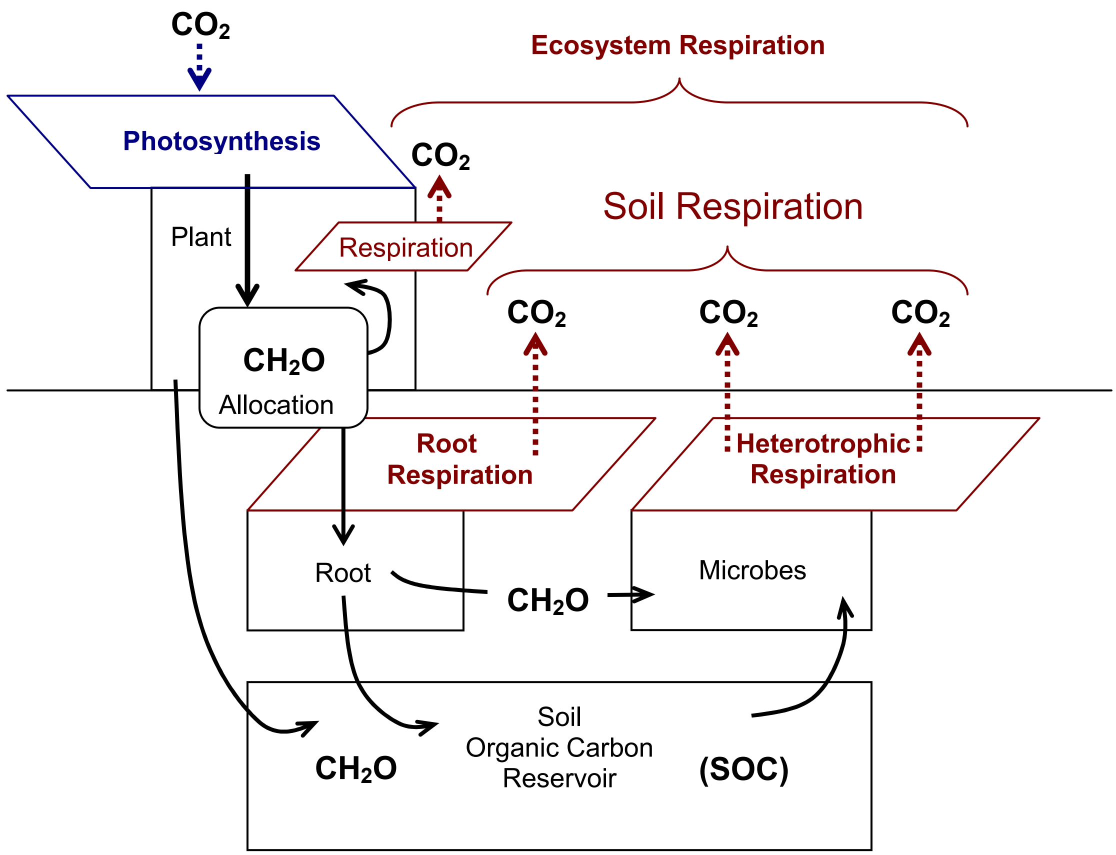

Figure 1.1. Terrestrial Carbon Cycle: C Storage and Exchange Processes
Photosynthesis is the sole process by which the terrestrial biosphere acts as a sink for atmospheric CO_2 (shown in blue). Multiple respiration processes are sources of CO_2 (shown in red). Soil respiration is made up of respiration processes mediated by autotrophic and heterotrophic agents (plant roots and microbes, respectively). Microbes derive carbon from a range of substrates distinguished between plant and soil sources.

1.2 Climatic Influences on Respiration Rate

Soil surface CO_2 flux is column-integrated soil respiration that is a sum of source terms from various depths, which are exposed to different temperature regimes, moisture regimes, and root/nutrient density (Figure 1.2). Soil temperature positively influences the reaction rate of respiration processes occurring within all cells. Soil moisture facilitates nutrient and substrate diffusion to cell membranes, which influences nutrient availability and substrate availability for plants and microbes, respectively (Scott-Denton et al., 2006; Skopp et al., 1990). Overall influences of soil temperature and moisture on soil respiration are often specific to a site due to inter-dependence with plant processes (Hibbard et al., 2005).

A mechanistic understanding of the influences of soil temperature and moisture on soil respiration is needed to predict the stability of the massive soil carbon reservoir under a changing global climate. From biome to biome, soil respiration generally increases with increases in temperature, moisture, and primary productivity (Davidson et al., 2006a; Field and Raupach, 2004; Ryan and Law, 2005). Of particular importance are the distribution patterns of soil temperature and moisture in near-surface soils where the majority of respiration processes occur (Davidson et al., 1998; Davidson et al., 2006b; Tang et al., 2003). Because the climatic variables, temperature, and moisture availability strongly influence both above-ground ecosystem function and below-ground soil respiration, determining the influence of these variables on the soil surface CO_2 flux is difficult (Davidson et al., 2006a; Ryan and Law, 2005).

1.3. Soil Respiration Study in Semi-arid Biomes

In arid biomes, moisture availability often limits ecosystem processes, inclusive of soil respiration. In contrast, in temperate or tropic systems, ecological activity is often limited by temperature or light rather than moisture. In semi-arid systems, especially in continental climate regimes, both temperature and moisture strongly influence respiration rates and the relative importance of these influences can vary seasonally (Davidson et al., 1998; Reichstein et al., 2002; Tang and Baldocchi, 2005). Soil moisture limitation of soil respiration refers to the decrease in the expected temperature response of the system due to moisture-limited conditions. Attempts to use mathematical models to simulate the response of soil respiration to environmental variables has proven challenging in semi-arid biomes, primarily due to soil moisture limitation (Reichstein et al., 2003).

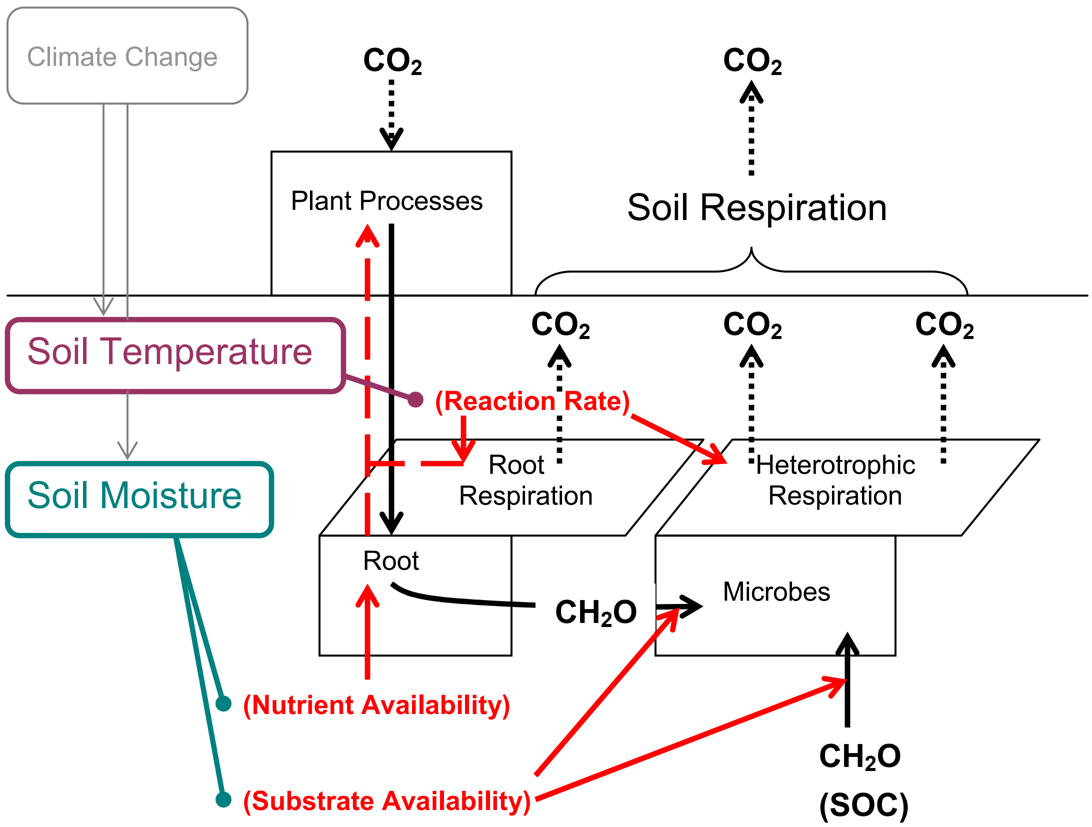

Figure 1.2. Soil Respiration: Soil Temperature and Moisture Influence Influence (red arrows). Soil temperature positively influences the reaction rate of respiration processes occurring within all cells. Soil moisture facilitates nutrient and substrate diffusion to cell membranes, which influences nutrient availability and substrate availability for plants and microbes, respectively. Soil temperature and moisture indirectly influence plant processes (dashed red arrow).

1.4. Modeling

Modeling approaches for semi-arid studies stem from the temperature-only dependent models of soil respiration used in most other studies of soil respiration. Various modeling techniques and formulations that use soil temperature and moisture as driving environmental variables will be introduced by first describing the temperature-dependent models and then describing the model modifications that introduce the influence of soil moisture on soil respiration.

In many studies, the temperature sensitivity of soil respiration is described using an exponential relationship, commonly referred to by a characteristic parameter, Q_{10} (Carbone et al., 2008; Irvine and Law, 2002; Liu et al., 2006; Lloyd and Taylor, 1994; Richardson et al., 2006; Xu and Qi, 2001). In the exponential temperature model of soil respiration (Equation 1.1), Q_{10} is calculated from parameter B (Equation 1.2).

$$R = A \times \exp\left(B \times \left(T - T_{ref}\right)\right) \tag{1.1}$$

$$Q_{10} = \exp\left(B \times 10\right) \tag{1.2}$$

Soil respiration, R (molar flux of Carbon, mol length^{-2} time^{-1}), is a function of a fitting parameter, A (mol l^{-2} t^{-1}), multiplied by an exponential relationship dependent on a fitting parameter, B (^{o} C^{-1}), temperature, T (^{o} C), and a reference temperature, T_{ref} (^{o} C). The reference temperature is commonly set to 10^{o} C in the literature; when T_{ref} is absent, it implies a reference temperature of 0^{o} C. The value of parameter Q_{10} is the factor by which respiration is multiplied when temperature increases by 10^{o} C (Davidson, 2006a).

In this thesis, the Q_{10} formulation presented in Richardson *et al.* (2006) was adopted, in which the relationship involving Q_{10} is functionally equivalent to the Type I exponential relationship as in Equation 1.1 (see also, Equation 1.3). The final form of the Q_{10} relationship used is Equation 1.4, where A and Q_{10} are fitting parameters.

$$Q_{10}^{(T-T_{ref})/10} \equiv \exp\left(B \times \left(T - T_{ref}\right)\right) \tag{1.3}$$

$$R = A \times Q_{10}^{(T-T_{ref})/10} \tag{1.4}$$

The common Q_{10} equation that expresses soil respiration as a function of temperature was initially an empirical formulation used to describe the behavior of biological systems due to its mathematical convenience (Lloyd and Taylor, 1994). Over time, the empirical parameters have been given physical meaning in the literature: the value of Q_{10} represented the temperature sensitivity of soil respiration and the value of A represented the basal respiration of the system.

The Q_{10} model expresses the influence of temperature on reaction rate with an exponential increase with no upper limit, which overestimates soil respiration at high temperatures (Carlyle and Ba Than, 1988; Richardson et al., 2006). The Arrhenius equation limits the increase in rate as temperature increases (Equation 1.5).

$$k = d \times \exp\left[\frac{-E_a}{RT}\right] \tag{1.5}$$

The reaction rate, k (s^{-1}), is modeled as a constant, d (s^{-1}), multiplied by the exponential function raised to a negative term composed of the activation energy, E_a (kcal mol^{-1}), divided by RT, the ideal gas constant, R (kcal mol^{-1} K^{-1}), and temperature, T (K). The equation is written for soil respiration so that the overall reaction rate is expressed relative to a reference temperature, which is usually 10^{o} C (Equation 1.6).

$$R = R_{10} \times \exp\left[\left(\frac{E}{283.15R}\right)\left(1 - \frac{283.15}{T}\right)\right] \tag{1.6}$$

Soil respiration, R (mol l^{-2} t^{-1}), is the soil respiration at the reference temperature, R_{10} (mol l^{-2} t^{-1}), and dependent on temperature, T (K). The Arrhenius equation describes the behavior of many chemical systems using a constant activation energy, and when applied to biological systems, generally provides an improvement over the Q_{10} model at high temperatures since the reaction rate did not increase as dramatically with temperature (Lloyd and Taylor, 1994).

For soil respiration data not limited by soil moisture, the Q_{10} exponential model has been shown to consistently underestimate respiration at low temperatures and overestimate at high temperatures (Lloyd and Taylor, 1994). Similarly, the Arrhenius equation systematically underestimated soil respiration at low temperature and overestimated at high temperature as with the empirical Q_{10} model (Lloyd and Taylor, 1994). The Arrhenius-type temperature dependent model of soil respiration developed in Lloyd and Taylor (1994) was designed to give a decrease in activation energy with increasing temperatures (Equation 1.7).

$$R = R_{10} \times \exp\left[E_0 \times \left(\frac{1}{283.15 - T_0} - \frac{1}{T - T_0}\right)\right] \qquad (1.7)$$

Soil respiration, R (mol l^{-2} t^{-1}), is the soil respiration rate at 10° C, R_{10} (mol l^{-2} t^{-1}), multiplied by an exponential relationship dependent on temperature, T (K), a fitting parameter, E_0 (K), and the lower temperature limit for soil respiration, T_0 (K). The Lloyd and Taylor formulation exhibited a better fit over the entire temperature range. The Lloyd and Taylor model is often used in the literature (Del Grosso et al., 2005; Hibbard et al., 2005; Reichstein et al., 2003). The equation is often used with constant values of E_0 and T_0 (308.56 K and 227.13 K, respectively) selected to produce the best fit to non-moisture-limited data (Lloyd and Taylor, 1994). One drawback in using the Lloyd and Taylor model is that it requires non-linear regression methods to solve for parameter values, in contrast to the Q_{10} model, in which regression parameter values are found using analytical least squares regression methods.

Due to the ubiquitous use of the Q_{10} model in soil respiration studies, the model has often been applied to moisture-limited data. The Q_{10} value is generally lower for moisture-limited datasets than for datasets not moisture-limited. In many systems, moisture-limited conditions often coincided with warmer yearly soil temperatures. Many studies suggested the cause of the lower Q_{10} value was decreased temperature sensitivity of soil respiration at high temperature (e.g., Giardina and Ryan, 2000; an argument challenged by Davidson *et al*. (2000)). Davidson argued that, from a biological perspective, the apparent temperature sensitivity due to Q_{10} variation was most likely pointing to some other influencing factor, such as substrate availability, rather than an actual temperature sensitivity (Davidson et al., 2006a). Therefore, when the Q_{10} model is used to predict moisture-limited data, it is typically considered an empirical approach. Despite this limitation, the Q_{10} model may still be useful for site comparison within similar temperature ranges due to its ease of use (Carbone et al., 2008; Lloyd and Taylor, 1994).

The Q_{10} model has been applied to seasonal, periodical, and daily trends of soil respiration in semi-arid systems. The model performed poorly over an entire season when part of the year was moisture-limited (Irvine and Law, 2002; Richardson et al., 2006). Studies in semi-arid systems that used Q_{10} to model periods throughout the growing season shared the common trend of declining Q_{10} values as soil moisture declined

(Carbone et al., 2008; Liu et al., 2006; Xu and Qi, 2001). The trend in the Q_{10} values could be interpreted to represent soil moisture limitation of the temperature dependency of soil respiration (Carbone et al., 2008). Daily averaged soil respiration data were typically used, but some studies with hourly data available used the Q_{10} model to model daily patterns of soil respiration (Carbone et al., 2008; Liu et al., 2006).

Various model modifications to the commonly used temperature relationships, "Q_{10}" and the Arrhenius-based "Lloyd and Taylor," were intended to represent the decline in temperature dependency of soil respiration at high temperatures. For both models, the gross overestimation at high temperatures is likely due to soil moisture limitation coinciding with warmer times of year (meaning that, had there been enough water during the time of high temperatures, the model predictions of soil respiration would have been much closer to observed rates of soil respiration). For Q_{10} seasonal models, model modifications to achieve the observed changes in the effective values of parameters A and Q_{10} (which together characterize the temperature dependency of soil respiration for a particular system) typically involved dependency on soil moisture (Carbone et al., 2008; Carlyle and Ba Than, 1988; Irvine and Law, 2002), but dependency on time and temperature was used by Richardson *et al*. (2006). The daily time-step model of Reichstein *et al.* (2003) modified the "Lloyd and Taylor" formulation (Equation 1.7) with various dependencies on soil moisture. Several models include the effect of soil moisture limitation of soil respiration as soil moisture declines as a Monod form (Carlyle and Ba Than, 1988; Reichstein et al., 2003). The Monod form allows soil moisture limitation to be slight and gradual at first as moisture declines from maximum to minimum, but increasingly greater as moisture approaches zero.

The introduction of moisture influence in soil respiration models requires the selection of (1) the representation of soil moisture availability, and (2) the functional relationship that describes the influence of soil moisture on soil respiration. With respect to inter-site comparability, sites with similar soils are more comparable than sites with disparate soil, particularly the grain size distribution. Site differences in soil characteristics and subsurface structure result in site-to-site variation in the soil respiration response to soil moisture status. Soil moisture availability was represented relative to site field capacity to make the measurements comparable among the several semi-arid sites studied in Reichstein *et al.* (2003).

1.5. Summary Project Description

In this thesis, I measured soil surface CO_2 flux, which is column-integrated soil respiration, concurrently with soil temperature and moisture, to study distinct effects of each variable on soil respiration. The annual drying trend typical of semi-arid ecosystems generates a unique set of soil temperature and moisture combinations throughout the growing season. A series of mathematical models of soil respiration were evaluated from the literature that featured various moisture-dependency modifications to common temperature-dependent relationships. The moisture influence was found to be strongest over a transitional range of values.

2. MATERIALS AND METHODS

Trends of soil respiration within the study area were explored using the two components of the work conducted for this thesis: (1) field data collected at study sites and (2) modeling of soil respiration using various models from the literature. The data was collected at two elevations exhibiting similar vegetative cover. The primary field data collected was soil surface CO_2 efflux measured using an automated field chamber system. Continuous measurements of environmental variables from weather instruments and instrumented soil pits supported the data analysis and modeling. Data-analysis methods consisted of treatment of field data, correlation analysis, and model application and evaluation.

2.1. Study Area Description

Both field-sampling sites are within the mountainous, semi-arid Dry Creek Experimental Watershed (DCEW), 6.5 km north of Boise, Idaho (Figure 2.1). The DCEW (latitude 43°43' N, longitude 117°51' W, elevation 1000 – 2200 m, area 27 km^2) faces southwest and is drained by streams that deeply incise the basin, resulting in steep slopes. The lower-elevation sampling site (1150 m) is situated in the foothills and is vegetated with grasses and forbs with sparsely interspersed shrubs of sagebrush (*Artemisia sp.*) and bitterbrush (*Purshia tridentata*). The site was grazed by sheep and cattle during the growing season. The upper elevation site (1600 m) exhibits similar species to that found at the lower elevation site, but with a denser shrub distribution.

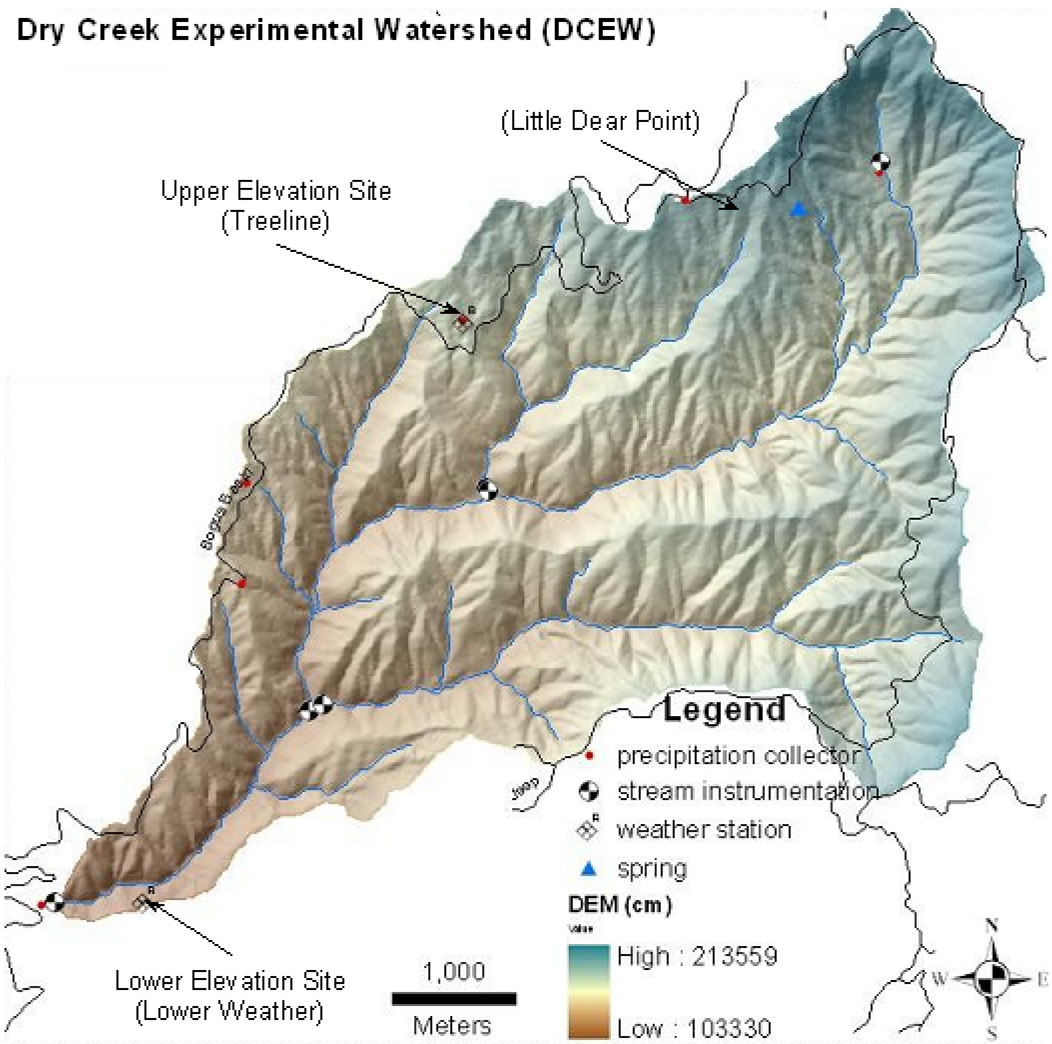

Figure 2.1 Study Area
Measurements were taken at the upper and lower elevation sites (also referred to as Treeline, and Lower Weather, respectively). Measurements taken at the Little Deer Point site are not discussed in this thesis, but are presented in Appendix A.

Soils are freely draining gravelly sandy loams (USDA classification system, unpublished data: Gribb group) and are thin, less than a meter typically, underlain by fractured granite bedrock (Aishlin, 2007). The field area experiences warm, dry summers and cold, wet winters. Persistent winter snowpack is typical for the upper elevation site, in contrast to the lower site, which typically has sparse to no winter snow. The difference in annual precipitation is mostly due to orographically increased snowfall at the upper elevation.

2.2. Field Measurements

The primary data collected at each site was periodically measured short-time interval soil CO_2 flux measurements. These data were collected adjacent to existing weather stations, which provided climatic data as well as continuous soil moisture and temperature datasets. Soil samples were collected and analyzed for carbon content.

2.2.1. Automated Measurements of Soil CO_2 Efflux

An automated, closed dynamic chamber system (LI-8100, LI-COR Inc., Lincoln, NE, USA) was employed at the sites and operated in 2007. The automated Long-Term Chamber (P/N 8100-101, LI-COR) was positioned level with the base-plate gasket sealed around a permanent soil collar. Soil collars were constructed of 20.3 cm (8") PVC sewer pipe resulting in a 317.8 cm^2 sampling area. The soil collars were permanently installed at each site adjacent to existing soil moisture and temperature instrument profiles. The lower edge of each soil collar extended a minimum of 2.5 cm into the soil. Flux measurements were periodically collected at each site. Minimal alteration of incoming solar radiation, temperature, and moisture conditions was achieved by taking hourly, three-minute measurements; the chamber was pivoted vertically and held clear from the soil surface when not in use (95% of the time). The chamber design included pressure equilibration tubing with opening geometry that prevented wind-induced pressure change for wind speed up to 7 m s^{-1}, measured at a height of 0.5 m to ensure accurate estimates of the soil CO_2 efflux (Xu et al., 2006). The chamber was connected to the Analyzer Control Unit (LI-8100, LI-COR) that contained an infrared gas analyzer (IRGA). During a measurement, the chamber pivoted vertically over the measurement soil area and sealed against the base-plate, air circulated between the chamber and IRGA on the high flow-rate setting of 1.5 L min^{-1}, and the concentration of CO_2 was recorded at 1 s intervals over the three-minute measurement period. The increase in CO_2 concentration over the three-minute measurement period was used to determine the rate of soil efflux. An exponential fit was used to estimate the initial rate of CO_2 increase that occurred immediately after the chamber closed (LI-COR, 2005). Initial flux values were computed after the measurement ended and recorded along with the raw data in system-specific data text files. The measurements were manually screened using the LI-8100 Data File Viewer software program provided with the system (FV8100, LI-COR). Measurements with a high coefficient of variation, above 1.5%, were removed from the final dataset if the concentration of CO_2 did not increase predictably over time during the measurement. The Long-Term Chamber and Analyzer Control Unit were moved from site to site every three to four days during the 2007 growing season and operated continuously at a site between moves. The sampling protocol produced intermittent datasets of continuous hourly measurements for each site.

2.2.2. Environmental Variables

Environmental variables were measured at each site using permanently installed weather instruments and instrumented soil pits. Soil temperature and soil moisture depth profile measurements were made continuously at permanent instrumented soil pits (Table

2.1) and automatically recorded hourly. Soil temperature was measured by thermister or thermocouple sensors. Volumetric soil moisture content was estimated by water content reflectometers (CS615, Campbell Scientific, Logan, UT, USA) that were field calibrated (Chandler et al., 2004).

Table 2.1. Sensor Pit Measurement Depths at Upper and Lower Elevation Sites

Site	Pit	Soil depths (cm)	Installation date
Lower	1	5, 15, 30, 50, 100	1999
Lower	2	5, 15, 30, 60, 100	1999
Upper	3	5, 15, 30, 60, 100	1999
Upper	4	5, 15, 30, 45, 65	1999

2.2.3. Site Layouts

The relative positions of the weather instruments, sensor pits, and soil collar varied from site to site due to local site topography. The slope location of each collar closely approximated that of the sensor pit so the soil temperature and moisture profiles of the sensor pits were good approximations of conditions under the collar. The lower elevation site was situated on the north slope of a steep ridge that had a local plateau one third from the crest. The weather instruments were located on the plateau near the edge, and the sensor pits and collar, spaced 5 m apart, were located down-slope 8 m from the edge. The upper site was situated on the northeast-facing slope of an east-draining headwater catchment. The weather instruments were near the top, 5 m from the crest, in the center of the slope, and the sensor pits and collar, spaced 2 m apart, were northwest of the weather instruments, one-third down the slope from the crest.

2.2.4. Soil Organic Carbon

Soil samples were prepared to obtain soil carbon elemental weight percentages, determined by dry combustion. After field sampling, samples were air-dried, then stored at room temperature in plastic bags. The sample was sieved using a 2 mm sieve stacked on a 1 mm sieve to leave the <1 mm portion with a minimum of fine roots. A subsample was hand-ground to pass a 250 μm sieve, oven-dried at 105 ^{o}C, sealed and allowed to cool to room temperature within a container containing desiccant. The processed subsamples were analyzed on a Flash EA 1112 Elemental Analyzer, NC Soils configuration (ThermoElectron Corp.). The instrument uses dry combustion to determine the carbon and nitrogen weight percentages of the sample. Samples weighed 60 to 100 mg depending on the expected organic matter content. Sample weights were determined on an analytical balance (Model XS205DU, Mettler Toledo) to 0.01 mg accuracy.

The carbon weight percent measured was converted to a concentration of carbon mass per total soil mass by assuming no organic carbon was present in the >1 mm portion of soil. In Equation 2.1, the carbon weight percentage, %C, is multiplied by the weight percent of soil in the <1 mm size fraction, $Wt\%_{<1mm}$, to get the carbon concentration, C_C. The weight percent of soil was calculated using air-dry soils. Carbon concentration was converted to C on an area basis using the bulk density of soil; Equation 2.2. Bulk density values used were field measured on separate samples from the same pit for the upper site and estimated from previous study site data (Yenko, 2003) for the lower site.

$$C_C = \left(\frac{\%C}{100}\right) * \left(Wt\%_{<1mm}\right) * \left(\frac{1000g}{kg}\right) \tag{2.1}$$

C_C = carbon concentration of sample, (gC/kg soil)
%C = carbon weight percentage of <1mm fraction, (g/g)
$Wt\%_{<1mm}$ = (Mass of <1mm fraction/ Mass of total sample), (g/g)

$$\frac{C}{area} = \sum\left[(C_C)_h * (\rho_b)_h *\right] Z_h * \left(10^{-2}\,\frac{kg}{g}\,\frac{cm^2}{m^2}\right) \tag{2.2}$$

C/area = carbon content per unit area, (kgC/m^2)
$(\rho_b)_h$ = bulk density of sample h = (Mass of soil/ Volume total), (g/cm^3)
Z_h = vertical span of sample h, (cm)

2.3. Data Analysis Methods

Hourly datasets of soil respiration, temperature, and moisture were grouped by seasonal descriptions and correlated to characterize relationships. The correlation coefficient represents the strength of the linear relationship between two variables, and is calculated as the covariance of the two variables divided by the product of their standard deviations. The value of the correlation coefficient ranges from -1 to 1. Positive or negative values indicate whether the variables vary together or opposite each other. Strong or weak relationships describe the extent to which values move together; values with absolute magnitudes close to 1 are strong and values close to zero are weak.

The likelihood that the sample correlation coefficient, *r*, reflects the population correlation coefficient, ρ, is represented by the 95% confidence interval, which was calculated using the *Z* distribution, and the procedure outlined here. The sample correlation coefficient, *r*, was calculated for each group (Equation 2.3).

$$r = \frac{1}{n-1}\sum_{i=1}^{n}\left(\frac{x_i - \bar{x}}{S_x}\right)\left(\frac{y_i - \bar{y}}{S_y}\right) \tag{2.3}$$

In Equation 2.3, *x*-bar and *y*-bar are the means and S_x and S_y are the sample standard deviations for variables *x* and *y* with *n* observations. The value of *r* is used to calculate an initial *Z* value, Z_i, using Equation 2.4:

$$Z_i = \frac{1}{2}\ln\frac{(1+r)}{(1-r)} \tag{2.4}$$

Upper and lower *Z* values (Z_U and Z_L) are calculated in Equation 2.5:

$$Z = Z_i \pm \frac{z_{\alpha/2}}{\sqrt{n-3}} \tag{2.5}$$

For a 95% confidence interval, $\alpha = 0.05$, and therefore $z_{0.025} = 1.96$. The upper and lower confidence limits for ρ are found by solving for *r* in Equation 2.4 using the values of Z_U and Z_L (Equation 2.6).

$$ConfidenceLimit = -\frac{(1-\exp(2Z))}{(1+\exp(2Z))} \tag{2.6}$$

2.4. Empirical Soil Respiration Models

For seasonal modeling, various formulations were applied and evaluated. The formulations were based on one of two common temperature-dependency models used to predict soil respiration: the exponential Q_{10} model form (Equation 1.4) and the Arrhenius-type Lloyd and Taylor model form (Equation 1.7). Model variants (Table 2.2) modify the temperature-dependent model form to account for the influence of soil moisture or to simply reflect the decrease in temperature dependency of soil respiration that is commonly observed as temperature increases. The models in Table 2.2 include formulas and their sources, and are arranged in the order presented in the results section. For all model variations, the reference temperature, T_{ref}, is 10^{o} C.

The CO_2 flux data selected for seasonal modeling of soil respiration were distributed evenly over the growing season and excluded precipitation-influenced data. Seasonal modeling used mean soil respiration, *R*, volumetric soil moisture, *M*, and soil temperature, *T*, from representative measurement periods from upper and lower elevation sites. The representative measurement periods consisted of consecutive hourly data points in 24-hour increments with at least 24 data points (1 day) and up to 96 (4 days). To model the seasonal trend in soil respiration without bias introduced by short-term effects, data points that occurred shortly after a precipitation event (within 24 hours) were excluded. The influence of short-term effects due to rain pulses can account for a significant portion of annual soil respiration in semi-arid sites (Irvine and Law, 2002; Xu et al., 2004), but without a continuous record of measured soil respiration, the contribution of such events cannot be determined for these sites from the available data.

The empirical seasonal models of soil respiration depended on soil temperature and moisture measurements from the nearby permanent soil pit installations. The selection criteria for the model depth is as follows: (a) the possible depth range for modeling corresponded to the majority of carbon content in the soil from soil-carbon-depth distributions, and (b) common depths used in other studies with similar vegetation and climate were guidelines for selection.

Least squares regression was performed for model fitting. The error sum of squares term (SSE) is minimized to achieve the best fit to the data. The r^2 value is used to describe the percent of the variance in the dependent variable that the independent variable accounts for when the data are fitted to a model. Microsoft Excel Solver was used to solve for the regression parameter values that minimized the error sum of squares (SSE) term. "Microsoft Excel Solver uses the Generalized Reduced Gradient (GRG2) nonlinear optimization code developed by Leon Lasdon, University of Texas at Austin, and Allan Waren, Cleveland State University." (Microsoft Excel Help, 2000). Another measure of goodness of fit, the root mean square error (*RMSE*), for which values close to zero are better, was calculated (Equation 2.7):

$$RMSE(\theta_1, \theta_2) = \sqrt{\frac{\sum (x_{1,i} - x_{2,i})}{n}} \tag{2.7}$$

Each model formulation is assessed individually on how its representation of soil temperature and moisture influence on soil respiration reflects the conceptual model of soil respiration function in the system. Various aspects of the model fit are considered in addition to the goodness of fit itself (i.e., r^2, RMSE), such as model behavior and the physical meaning (or lack thereof) of regression parameter values. Based on individual assessments, the top performing models are evaluated against one another to further assess the model formulations. The best model to describe soil temperature and moisture influence on soil respiration consistent with the conceptual model serves as a tool to (1) quantitatively describe soil temperature and moisture influence on soil respiration, (2) compare the sites in this study to other semi-arid sites, and (3) generate predicted inter-annual variation in soil respiration based on inter-annual site variability in seasonal soil temperature and moisture trends.

Table 2.2. Seasonal Soil Respiration Models

Various formulations predict soil respiration, R (µmol m^{-2} s^{-1}), from soil temperature, T (^{o} C), soil moisture, M (m^{3} m^{-3}), and fitted parameters. Formulations are based on two common temperature-dependent models: (a) the Q_{10} exponential temperature model (Equation 1.4), and (b) the Arrhenius temperature model (Equation 1.6). For the variations based on the Q_{10} model, the first equation within each section shows the primary formulation difference. Subsequent terms show how each variation differs within the section. For a particular model variation, the equation number refers to the complete formulation, which is the first equation within the section combined with the corresponding term.

(a) Variations based on Q_{10} exponential temperature model (Section 3.2.1)

Reference temperature, T_{ref}, (commonly 10^{o} C), soil temperature, T (^{o} C), and relative moisture deficit, RM_{def}.

Q_{10} (Section 3.2.1.1) Equation 1.4:		$R = A \times Q_{10}^{(T-T_{ref})/10}$
Moisture modeled residuals of Q_{10} model, r_T (Section 3.2.1.2)		
Q_{10} + M-dep r_T (Carbone *et al*., 2008)	Eq. 3.1:	$R = A \times Q_{10}^{(T-T_{ref})/10} + r_T$
	Eq. 3.2:	$r_T = a \times M^2 + b \times M + c$
Modulated Q_{10} models, *f(X)* (Section 3.2.1.3)		
		$R = A \times Q_{10}^{(T-T_{ref})/10} \times f(X)$
Monod M-Mod Q_{10}	Eq. 3.3:	$f(M) = \frac{M}{M + a_1}$
Monod & Inhib. (Carlyle and Ba Than, 1988)	Eq. 3.4:	$f(M) = \frac{M}{M + a_1} \times \frac{a_2}{M + a_2}$
Exp-type M-Mod Q_{10} (Irvine and Law, 2002)	Eq. 3.5:	$f(RM_{def}) = (1 - (a_3 \times \exp(a_4 \times RM_{def})))$
	Eq. 3.6:	$RM_{def} = \frac{(M_{\max} - M)}{(M_{\max} - M_{\min})}$
Modified Q_{10} models with variable temperature-dependency, *h(X)* (Section 3.2.1.4)		
		$R = A \times (h(X))^{(T-T_{ref})/10}$
M-dep Var Q_{10} term	Eq. 3.7:	$h(M) = d_1 \times \frac{M}{M + d_2}$
T-dep Var Q_{10} term (Richardson *et al*., 2006)	Eq. 3.8:	$h(T) = c_1 + c_2 \times T$
Time-dep Var Q_{10} term (Richardson *et al*., 2006)	Eq. 3.9:	$h(time) = c_3 + c_4 \times \sin(JD_\pi) + c_5 \times \cos(JD_\pi)$ *where:* JD_π is Julian Day (radians)

Table 2.2. Seasonal Soil Respiration Models (continued)

(b) Variations based on Arrhenius temperature model (Section 3.2.2)
Soil temperature, T (K), soil respiration rate at 10^{o} C, R_{10}, relative soil moisture, RM, and soil moisture at field capacity, M_{FC}.

Restricted L&T
(Lloyd and Taylor, 1994)

Eq. 1.7: $$R = R_{10} \times \exp\left[E_0 \times \left(\frac{1}{283.15 - T_0} - \frac{1}{T - T_0}\right)\right]$$

where: $E_0 = 308.56$ K, $T_0 = 227.13$ K

M-dep Arr-based
Daily time-step model of Reichstein *et al.* (2003)

Eq. 3.10: $$R = R_{10} \times \exp\left[E_0(RM) \times \left(\frac{1}{283.15 - T_0} - \frac{1}{T - T_0}\right)\right] \times g(RM)$$

Eq. 3.11: $$g(RM) = \frac{RM}{(RM_{1/2} + RM)}$$

Eq. 3.12: $$E_0(RM) = a_{REW} + b_{REW} \times RM$$

Eq. 3.13: $$RM = M/M_{FC}$$

3. RESULTS

The observed field data results illustrate both soil moisture and temperature influences on soil respiration permitting division of seasonal trends as a function of the moisture and temperature dependency. This dataset is then used to evaluate a series of seasonal respiration models. Model strengths and weaknesses are described in context of their application to the semi-arid conditions of this study.

3.1. Field Observations

Field observations frame a conceptual picture of soil respiration in this semi-arid system. The experimental protocol produced intermittent datasets of continuous hourly soil surface CO_2 efflux (CO_2 flux) measurements for each site. The measurements coincided with hourly measurements of environmental variables. The observed patterns in CO_2 flux exhibit a strong dependency on changing soil temperature and moisture.

3.1.1. Site Characteristics

Distinguishing site characteristics elevation, mean annual temperature, mean annual precipitation, and soil carbon data for upper and lower elevation sites of Dry Creek are shown in Table 3.1. Soil organic carbon (SOC) is expressed as total carbon per area (kg C m^{-2}) for surface to depth ranges of 0-30 and 0-90 cm. Total carbon was measured in this work; subsequent field measurements showed that total carbon represents organic carbon only as there is no inorganic component (Kunkel, unpublished data). The bulk of soil carbon was distributed in the top 30 cm (upper site: 55%, lower site: 46%), and then soil carbon declined but tapered with depth (Figure 3.1). Within the top meter of soil for ecosystems across the globe, mean values of C per area range from 1.4 kg C m^{-2} for warm deserts to ~20 kg C m^{-2} for tundra and wet tropical and boreal forests (Amundson, 2001). The most similar ecosystem group to the Dry Creek sites reported in Amundson (2001) based on climate data (cool temperate steppe: annual precipitation, 375 mm, and temperature, 9^{o} C), also had comparable C content in the top meter of soil (group mean, 13.3 kg C m^{-2}, Dry Creek site totals to 90 cm: upper, 10.6, and lower, 16.5 kg C m^{-2}). Complete soil carbon results are in Appendix B.

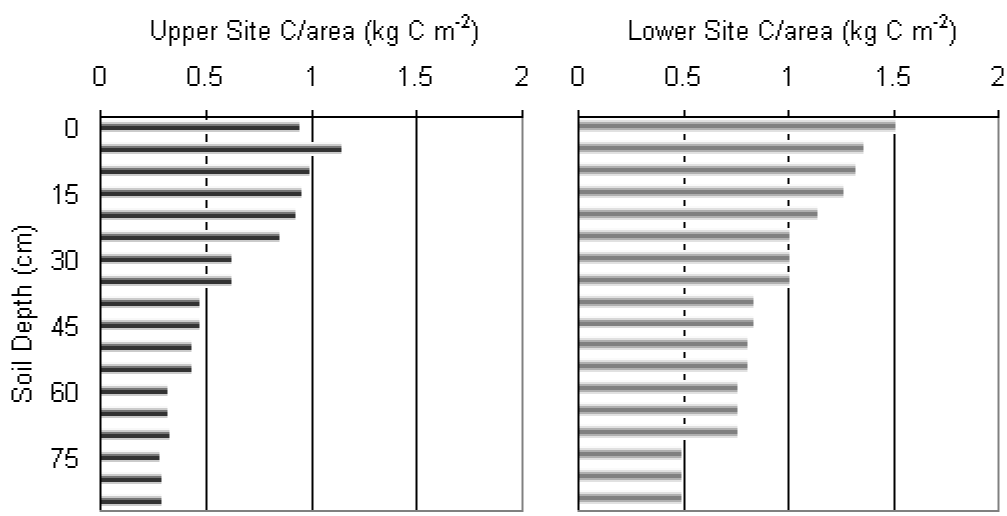

Figure 3.1. Soil Carbon Depth Profiles
Soil carbon content per area (kg C m^{-2}) by 5 cm vertical depth intervals.

Table 3.1. Characteristics of Upper and Lower Elevation Sites

		Upper	Lower
Elevation (m)		1600	1150
Mean Annual Temperature (° C)		8.5	11
Mean Annual Precipitation (mm)		570	370
Soil Organic Carbon	0 - 30 cm Total:	5.8	7.6
(kg C m^{-2})	0 - 90 cm Total:	10.6	16.5

3.1.2. Seasonal Climatic Trends

Seasonal trends in daily averaged environmental data (solar insolation, soil temperature and moisture, and precipitation) illustrate the climatic conditions of the field site. The DCEW is semi-arid, characterized by warm, dry summers and cold, wet winters, for which seasonality is driven by a three-fold variation in solar insolation from summer to winter solstice. Trends in soil temperatures, which closely follow air temperatures, lag solar radiation by approximately 30 days. Winter lows are near 0^{o} C during winter, begin rising in March, peak in July at approximately 25^{o} C, then decline again to winter lows in November (Figure 3.2). Typical of this environment, precipitation is primarily limited to the winter months (delivered as both snow and rain) with the dry season extending from late May to late September. This dry period is punctuated by summer rain events, as evidenced by an early June precipitation spike in the 2007 data.

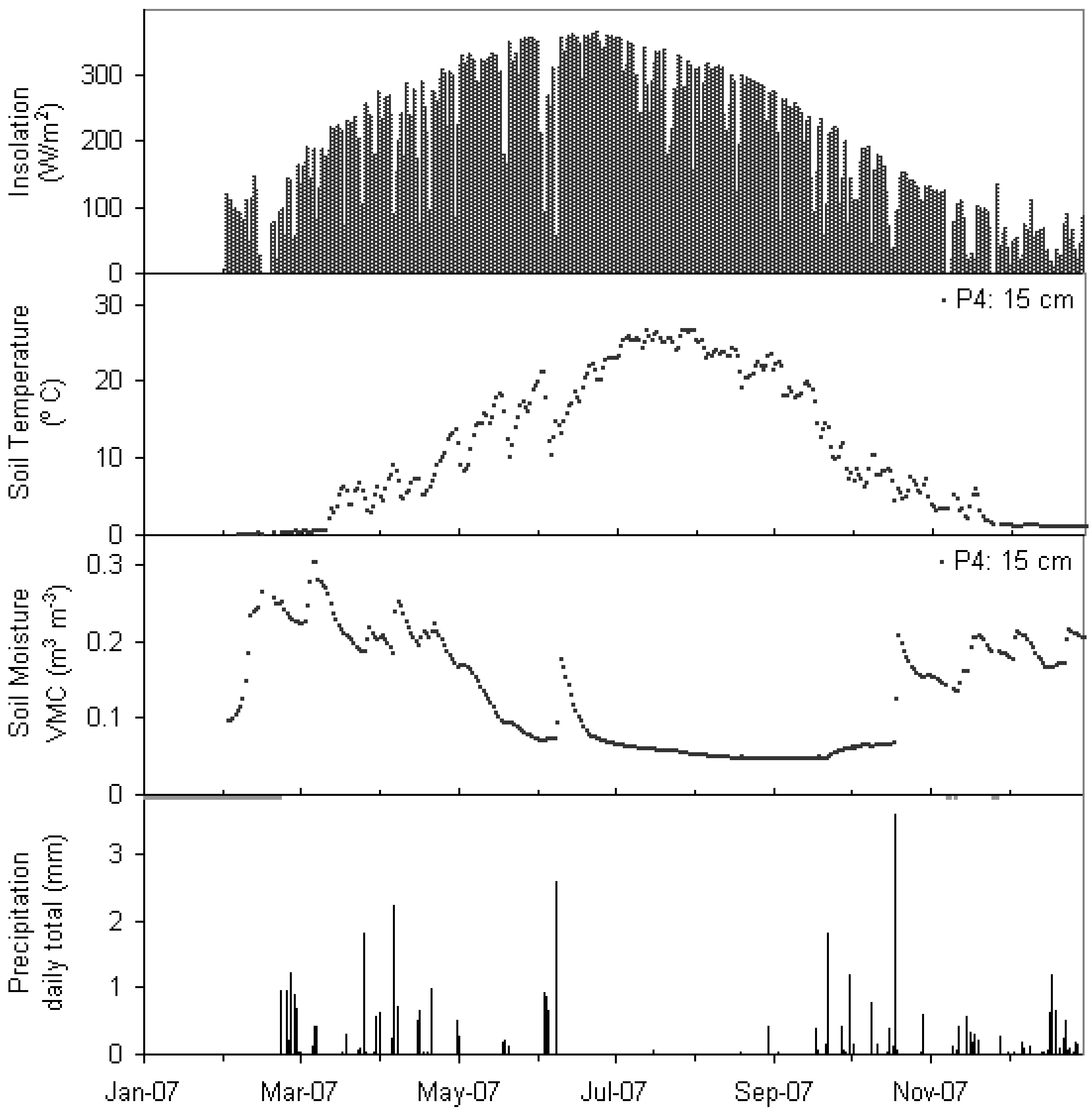

Figure 3.2. Upper Elevation Site 2007 Annual Climatic Trends
(Days missing precipitation data indicated by gray blocks along top inside edge.)

The seasonal pattern in soil moisture is a direct response of the climatic variables, especially precipitation trends. Winter soil moisture is high, declines with increasing summer temperatures, and remains low throughout the summer. An important exception is a June rain event, which produces a noticeable spike in soil volumetric moisture content (Figure 3.2).

3.1.3. Seasonal Soil Respiration Trends

Field measurements of soil surface CO_2 efflux (CO_2 flux) collected over the 2007 growing season represent soil respiration (R) for the upper and lower elevation sampling sites. The hourly measurements of soil respiration exhibit strong diel cycling patterns with peaks in soil respiration corresponding to mid-day and lows corresponding with night-time conditions (Figure 3.3). The magnitude of this diel cycling varies seasonally with a noticeable decline in amplitude as the summer season progresses, a trend most notable at the upper elevation site (top of Figure 3.3). Hourly CO_2 flux measurements were averaged for each measurement period, ranging from 1-4 days, and reported as period mean soil respiration in Table 3.2.

Period mean soil respiration values illustrate a trend in seasonal soil respiration for upper and lower elevation sites (Figure 3.4). Both sites exhibited similar seasonal patterns of soil respiration, low values of mean CO_2 flux (< 1 μmol m^{-2} s^{-1}) in early spring begin rising in April to a double peak in June of approximately 2.8 μmol m^{-2} s^{-1} before dropping to early spring levels by late July. The peak in early June corresponds to a precipitation event. It is noteworthy that peaks in soil respiration do not correspond to maximum soil moisture or soil temperature, but rather correspond to the narrow climatic window when both temperature and soil moisture is elevated. These trends suggest a division of the growing season into three distinct periods: 1) cool, wet spring, 2) dry-down, and 3) hot, dry summer; dry-down was divided into spring dry-down and summer dry-down following the last major rain event, which occurred in the beginning of June (Figure 3.4 with dividing lines at DOY 131, 161 (rain event), and 191).

Table 3.2. Period Mean Values of Soil Variables by Measurement Period
Upper and lower site measurement periods denoted by number, day of year (DOY) and year 2007 date. Mean values of soil respiration, *R* (CO_2 flux, µmol m^{-2} s^{-1}), soil temperature, *T* (°C), and soil moisture, *M* (VMC, m^3 m^{-3}), at 5 cm depth, determined from *n* hourly sample points. Soil measurements are from pit 4 and 2 for upper and lower sites.

Upper Site	1	2	3	4	5	6	7	8	9	10
DOY	100	115	129	148	164	176	191	200	222	242
Date	4/10	4/25	5/9	5/28	6/13	6/25	7/10	7/19	8/10	8/30
n	24	48	48	48	24	72	72	72	72	24
R (µmol m^{-2} s^{-1})	1.01	1.64	2.30	1.66	2.84	2.13	1.55	1.30	0.86	0.66
T (° C)	4.7	10.8	15.9	17.6	17.0	22.1	28.8	28.0	26.1	26.1
M (m^3 m^{-3})	0.131	0.121	0.079	0.043	0.103	0.043	0.030	0.029	0.029	0.028

Lower Site	1	2	3	4	5	6	7
DOY	93	110	135	155	170	183	206
Date	4/3	4/20	5/15	6/4	6/19	7/2	7/25
n	24	24	72	24	72	96	96
R (µmol m^{-2} s^{-1})	1.04	1.15	1.82	1.58	2.43	1.01	0.60
T (° C)	5.1	6.7	16.9	23.1	20.2	26.1	28.3
M (m^3 m^{-3})	0.219	0.211	0.092	0.051	0.087	0.029	0.020

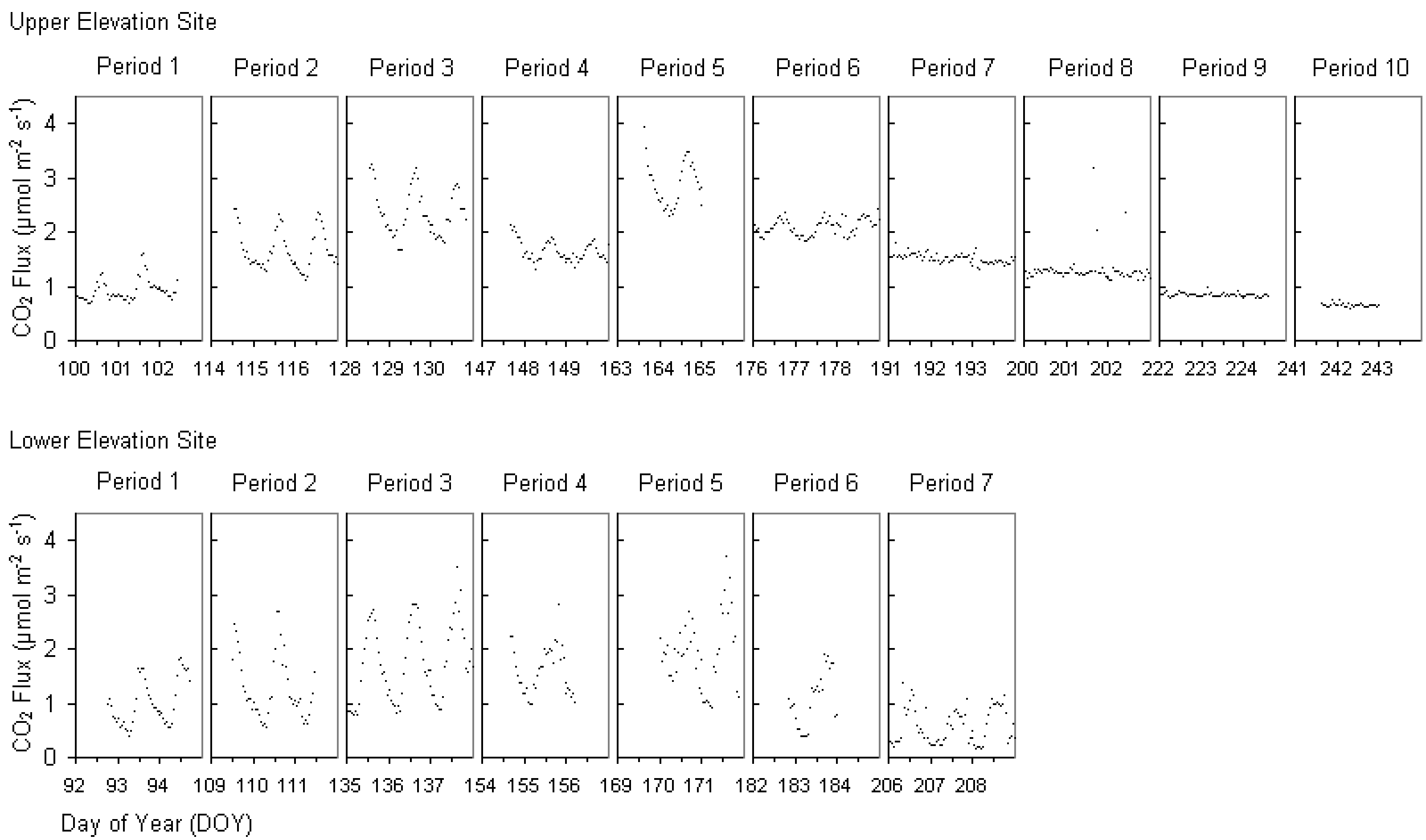

Figure 3.3. Hourly Soil Surface CO_2 Efflux Measurements
Measurements exhibit the growing season trend of diel patterns of soil respiration. The data is shown by measurement periods for the upper site (top) and lower site (bottom).

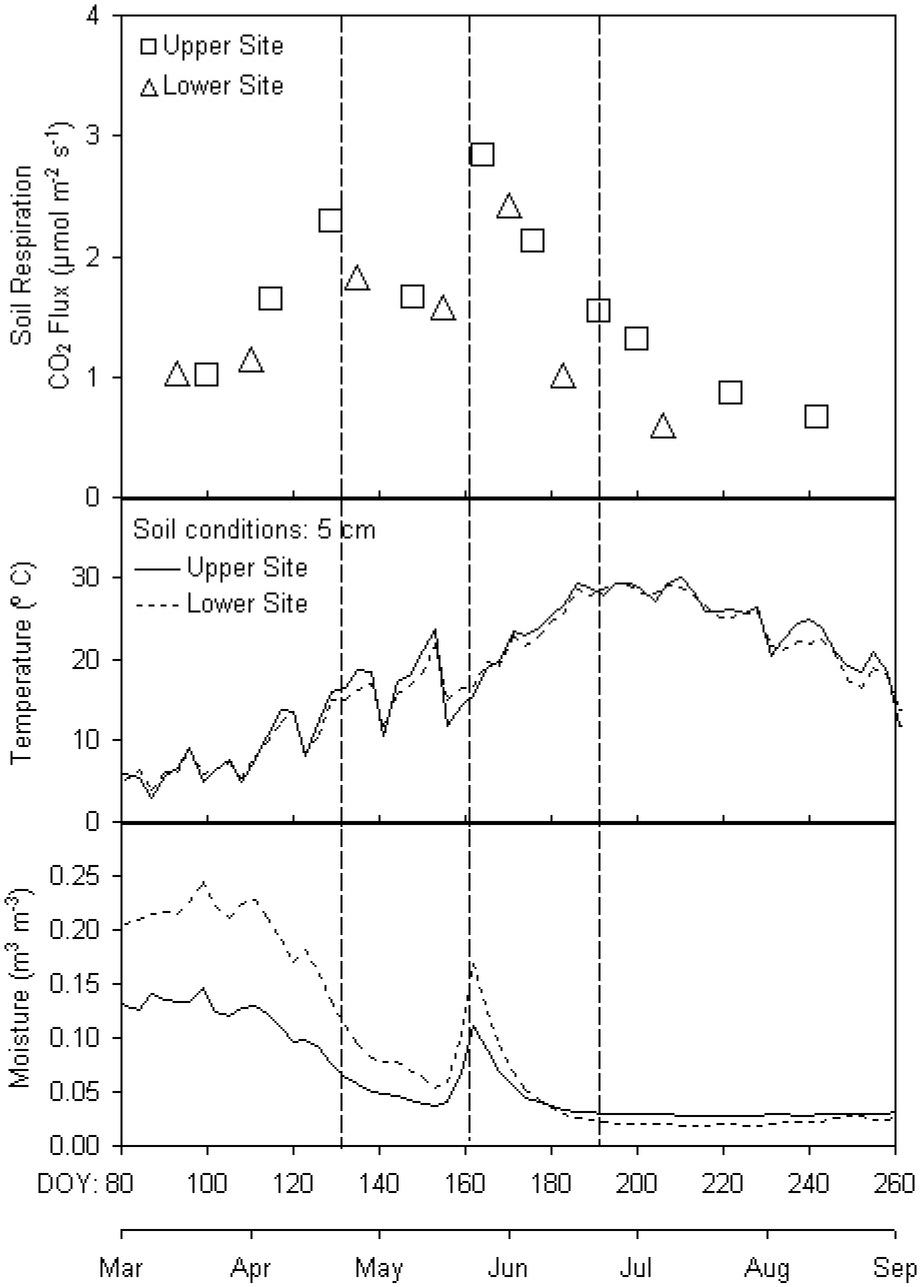

Figure 3.4. Seasonal Trends of Soil Respiration, Temperature, and Moisture
Symbols show period mean soil respiration; lines of 3-day mean values clearly display soil temperature and moisture trends at 5 cm depth. Vertical dashed lines at DOY 131, 161, and 191, roughly divide the growing season from left to right: Spring, Spring Dry-down, the Rain Event (at line 161), Summer Dry-down, and Summer.

3.1.4. Seasonal Group Soil Respiration Trends

Correlation of soil respiration, *R*, and soil temperature, *T* at 5 cm depth was evaluated by seasonal groups based on Figure 3.4 divisions (scatter plots of hourly data by seasonal group are shown in Figure 3.5). For each seasonal group, the sample correlation coefficient, *r*, was calculated (Equation 2.3), and the 95 % confidence interval for the population correlation coefficient, ρ, was calculated (Equations 2.4-2.6 and the method described in Section 2.3). Table 3.3 shows correlation results and descriptive measures of soil respiration, temperature, and moisture data for the seasonal groups: Spring, Spring Dry-down, Rain Event, Summer Dry-down, and Summer.

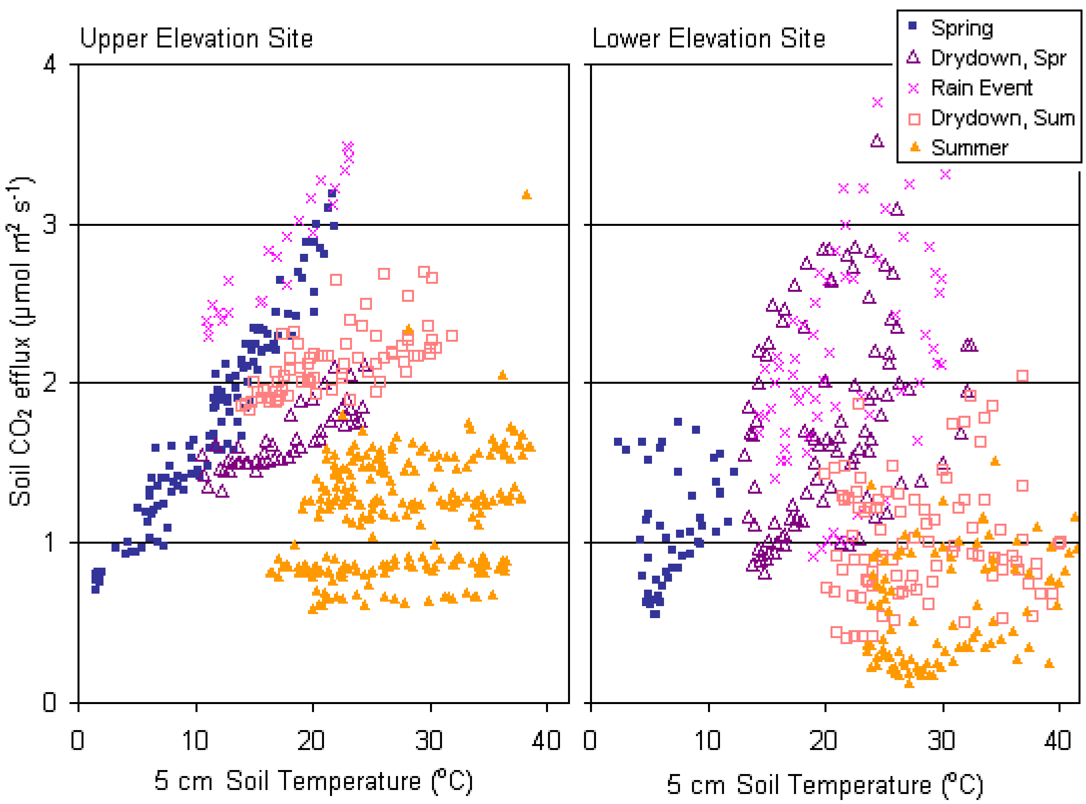

Figure 3.5. Soil Respiration vs. Soil Temperature (5 cm)
Scatter plots of hourly CO_2 flux data versus 5 cm soil temperature by seasonal group for upper elevation site (left) and lower elevation site (right).

The relative temperature influence on soil respiration among groups and between sites is evident by the apparent slope of the data shown in the scatter plots (Figure 3.5). The scatter plots of hourly data, soil respiration, *R*, vs. temperature, *T* at 5 cm depth, show slopes from steep to moderate to zero, indicating relative temperature influence of high, moderate, and none, respectively. The groups with similar temperature influence shared in common similar soil moisture ranges (Table 3.3). The trends in temperature influence and moisture, respectively, by group at the upper site are: Spring and Rain Event: high, 0.07 – 0.13 $m^3\ m^{-3}$; Dry-down groups: moderate, 0.04 $m^3\ m^{-3}$; and, Summer: none, 0.03 $m^3\ m^{-3}$. The trends in temperature influence and moisture, respectively, by group at the lower site are: Spring: high, 0.21 – 0.22 $m^3\ m^{-3}$; Spring Dry-down and Rain Event: moderate, 0.05 – 0.10 $m^3\ m^{-3}$; and Summer Dry-down and Summer: low, 0.02 – 0.03 $m^3\ m^{-3}$. The degree of temperature influence positively corresponds with soil moisture status, indicating soil respiration and temperature relationships vary with soil moisture.

The seasonal group correlation coefficient describes how well the daily cycle in hourly soil respiration corresponds with that of soil temperature at 5 cm depth (Table 3.3). The value can indicate degree of temperature dependency: values close to one indicate strong positive temperature dependency and values close to zero indicate weak dependency. For weak values of the correlation coefficient (such as for the lower site seasonal groups), temperature dependency of soil respiration is not precluded and may suggest a confounding influencing factor such as solar radiation. For the upper site, the values of the correlation coefficients indicate strong positive temperature dependency for Spring and Rain Event groups, moderately strong positive temperature dependency for

Dry-down groups, and weak or no temperature dependency for the Summer group. The groups with similar strength of temperature dependency shared in common similar soil moisture ranges (Table 3.3). The strength of temperature dependency positively corresponds to soil moisture status, indicating that temperature dependency of soil respiration declines as soil moisture declines.

Table 3.3. Seasonal Group Correlation: Soil Respiration vs. Temperature

The 95 % confidence interval for the population correlation coefficient, ρ, is based on the sample correlation coefficient, r, with n sample points.

			Soil Respiration R, CO_2 flux	Soil Temperature T, 5 cm		Correlation: R, T (5 cm) 95 % confidence interval			Soil Moisture M, 5 cm		
Seasonal Group	Period(s)	n	mean (µmol m^{-2} s^{-1})	mean (° C)	range (° C)	LCL	**Corr. coeff., r**	UCL	min (m^3 m^{-3})		max (m^3 m^{-3})
Upper Site											
Spring	1, 2, 3	120	1.78	11.6	20	0.95	**0.97**	0.98	0.07	–	0.13
Spring Dry-down	4	48	1.66	17.6	14	0.71	**0.83**	0.90	0.04	–	0.04
Rain Event	5	24	2.84	17.0	12	0.90	**0.96**	0.98	0.10	–	0.11
Summer Dry-down	6	72	2.13	22.1	18	0.47	**0.63**	0.75	0.04	–	0.04
Summer	7, 8, 9, 10	240	1.18	27.5	22	0.15	**0.27**	0.39	0.03	–	0.03
Lower Site											
Spring	1, 2	48	1.09	5.9	8	-0.15	**0.14**	0.41	0.21	–	0.22
Spring Dry-down	3, 4	96	1.76	18.4	13	0.00	**0.20**	0.38	0.05	–	0.10
Rain Event	5	72	2.43	20.2	12	0.02	**0.25**	0.46	0.07	–	0.10
Summer Dry-down	6	96	1.01	26.1	12	-0.15	**0.05**	0.25	0.02	–	0.03
Summer	7	96	0.60	28.3	10	0.05	**0.25**	0.43	0.02	–	0.02

3.1.5. A Conceptual Model of Soil Respiration

Analysis of the growing season pattern of soil respiration compared to patterns of environmental variables supports a conceptual model in which soil respiration exhibits seasonally variable dependency on both temperature and moisture. During winter and summer, low temperatures and low moisture content suppress soil respiration, respectively. In the spring, when warm and wet conditions converge, maximum soil respiration is observed. Increases in soil respiration in spring corresponded to increasing temperatures. An initial decline in flux in late spring coincided with a decline in soil moisture. Temperatures continued to increase until a peak in July. The peak in soil respiration in June occurred before the peak in temperature and coincided with the last large rain event of the growing season and associated increased soil moisture. The decline in soil respiration after its peak coincided with a steep then gradual decline in soil moisture. The minimum growing season flux values occurred in summer when soil moisture was near its annual minimum even though temperatures were at near maximum. This conceptual model of soil respiration indicates the importance of both temperature and soil moisture controls on respiration rates and suggests that successful mathematical expressions of soil respiration in this system will necessitate inclusion of both of these environmental variables.

3.2. Seasonal Modeling

Each model variation from Table 2.2 is presented and individually assessed based on its model regression fit to the general seasonal trend in mean soil respiration. Soil temperature and moisture were used as input parameters and the observed CO_2 flux values were used as the target soil respiration dataset (Table 3.2, Figure 3.4). Regression parameter values and measures of goodness of fit (r^2, RMSE) are summarized in Table 3.4. For each model variation, the model formulation and regression parameter values together describe soil temperature and moisture influence on soil respiration over the growing season. The model behavior is evaluated within the context of the conceptual model: does the modeled soil respiration reflect our physical understanding of soil temperature and moisture influence (i.e., soil temperature and moisture influences on soil respiration are positive, and the prominence of temperature dependency positively corresponds to soil moisture status)? Since all the available data was used in the regression, each measure of goodness of fit (r^2, RMSE) merely describes how well the model regression fits the observed seasonal trend in soil respiration; these values do not reflect how well the model predicts seasonal soil respiration (this information cannot be determined from the available data). Therefore, with respect to assessing model performance, the primary consideration is the consistency of model behavior with the conceptual model of soil respiration function in this system.

The measurement depth of soil conditions used in the models was selected based on the consideration of two criteria. Based on soil carbon depth distributions (Figure 3.1), the possible depth range of 0 to 30 cm was established, which corresponded to the majority of soil carbon content. A common depth used in soil respiration modeling is 10 cm; between the two closest measurement depths, 5 and 15 cm, the 5 cm depth was chosen for seasonal modeling. In the figures that follow, model-predicted soil respiration and 5 cm soil conditions, temperature, and moisture are 3-day mean values.

Table 3.4. Seasonal Models Regression Parameter Values and Fits.

3.2.1. Variations based on Q_{10} exponential temperature model							**r^2**	***RMSE***
3.2.1.1. Q_{10} model		**A**	**Q_{10}**					
(Equation 1.4)	Upper Site:	1.73	0.92				**0.03**	0.63
	Lower Site:	1.40	0.99				**0.00**	0.57
3.2.1.2. Q_{10} + M-dep r_T		**A**	**Q_{10}**	**a**	**b**	**c**		
(Equations 3.1, 3.2)	Upper Site:	1.73	0.92	-629	98.3	-2.75	**0.76**	0.32
	Lower Site:	1.40	0.99	-150	37.0	-1.34	**0.89**	0.18
3.2.1.3. Modulated Q_{10}								
Monod M-Mod Q_{10}		**A**	**Q_{10}**	**a_1**				
(Equation 3.3)	Upper Site:	10.93	1.78	0.576			**0.58**	0.44
	Lower Site:	9.02	2.41	0.854			**0.98**	0.26
Monod & Inhib. M-Mod Q_{10}		**A**	**Q_{10}**	**a_1**	**a_2**			
(Equation 3.4)	(1) Upper Site:	12.03	1.75	0.608	2.41		**0.59**	0.44
(1. Regressed)	Lower Site:	11.18	2.18	1.036	0.97		**0.99**	0.26
(2. Defined a_1, a_2)	Upper Site:	4.81	1.16	0.08	0.20		**0.70**	0.50
	(2) Lower Site:	3.87	1.22	0.08	0.20		**0.93**	0.34
Exp-type M-Mod Q_{10}		**A**	**Q_{10}**	**a_3**	**a_4**			
(Equations 3.5, 3.6)	Upper Site:	1.61	2.33	0.0026	5.85		**0.99**	0.08
	Lower Site:	3.72	2.98	0.3014	1.18		**0.98**	0.08
3.2.1.4. Variable "*Q_{10}*" term (variable temperature dependency)								
M-dep Var-*Q_{10}* term		**A**		**d_1**	**d_2**			
(Equation 3.7)	Upper Site:	1.54		8.67	0.270		**0.88**	0.23
	Lower Site:	1.45		2.95	0.081		**0.96**	0.11
T-dep Var-*Q_{10}* term		**A**		**c_1**	**c_2**			
(Equation 3.8)	Upper Site:	1.71		2.39	-0.058		**0.51**	0.45
	Lower Site:	1.37		3.23	-0.084		**0.88**	0.20
Time-dep Var-*Q_{10}* term		**A**		**c_3**	**c_4**	**c_5**		
(Equation 3.9)	Upper Site:	1.66		1.532	-0.441	1.286	**0.73**	0.34
	Lower Site:	1.36		-0.746	1.728	1.423	**0.56**	0.38
3.2.2. Variations based on Arrhenius temperature model								
Restricted L&T (constant *E_0*, *T_0* (K))								
(Equation 1.7)		**R_{10}**		E_0	T_0			
	Upper Site:	0.51		308.56	227.13		**0.09**	1.05
	Lower Site:	0.41		308.56	227.13		**0.03**	0.91
M-dep Arr-based		**R_{10}**	**$RM_{1/2}$**	a_{REW}	b_{REW}	T_0		
(Equations 3.10-3.13)	Upper Site:	2.95	0.50	52.4	285	227.13	**0.79**	0.30
	Lower Site:	2.28	0.18	52.4	285	227.13	**0.95**	0.20

3.2.1. Variations Based on the Q_{10} Temperature Model

3.2.1.1. Q_{10} Exponential Temperature Dependent Model

In this section, the most basic Q_{10} model is evaluated. This model is characterized by a single temperature dependency term (Q_{10}) and a basal respiration term (A); it contains no parameters (implicit or explicit) to address moisture limitation in any way (Equation 1.4).

$$R = A \times Q_{10}^{(T - T_{ref})/10} \tag{1.4}$$

The Q_{10} model alone gives a poor fit to the seasonal trend of daily average soil respiration for both the upper and lower elevation sites of this system ($r^2 = 0$, Figure 3.6). The parameter values (Table 3.4) do not reflect the intended definitions for this model. The values of the Q_{10} parameter are near 1, which implies no temperature dependency. The parameter A reflects the seasonal average respiration rather than basal respiration for these sites.

3.2.1.2. Q_{10} with Modeled Residuals

The seasonal modeling approach from Carbone *et al.* (2008) regressed the basic Q_{10} model to seasonal mean soil respiration and temperature data (as in Section 3.2.1), but models the residuals (r_T) as a function of the mean soil moisture (M) with a quadratic polynomial function (Equations 3.1 and 3.2).

$$R = A \times Q_{10}^{(T - T_{ref})/10} + r_T \tag{3.1}$$

$$r_T = a \times M^2 + b \times M + c \tag{3.2}$$

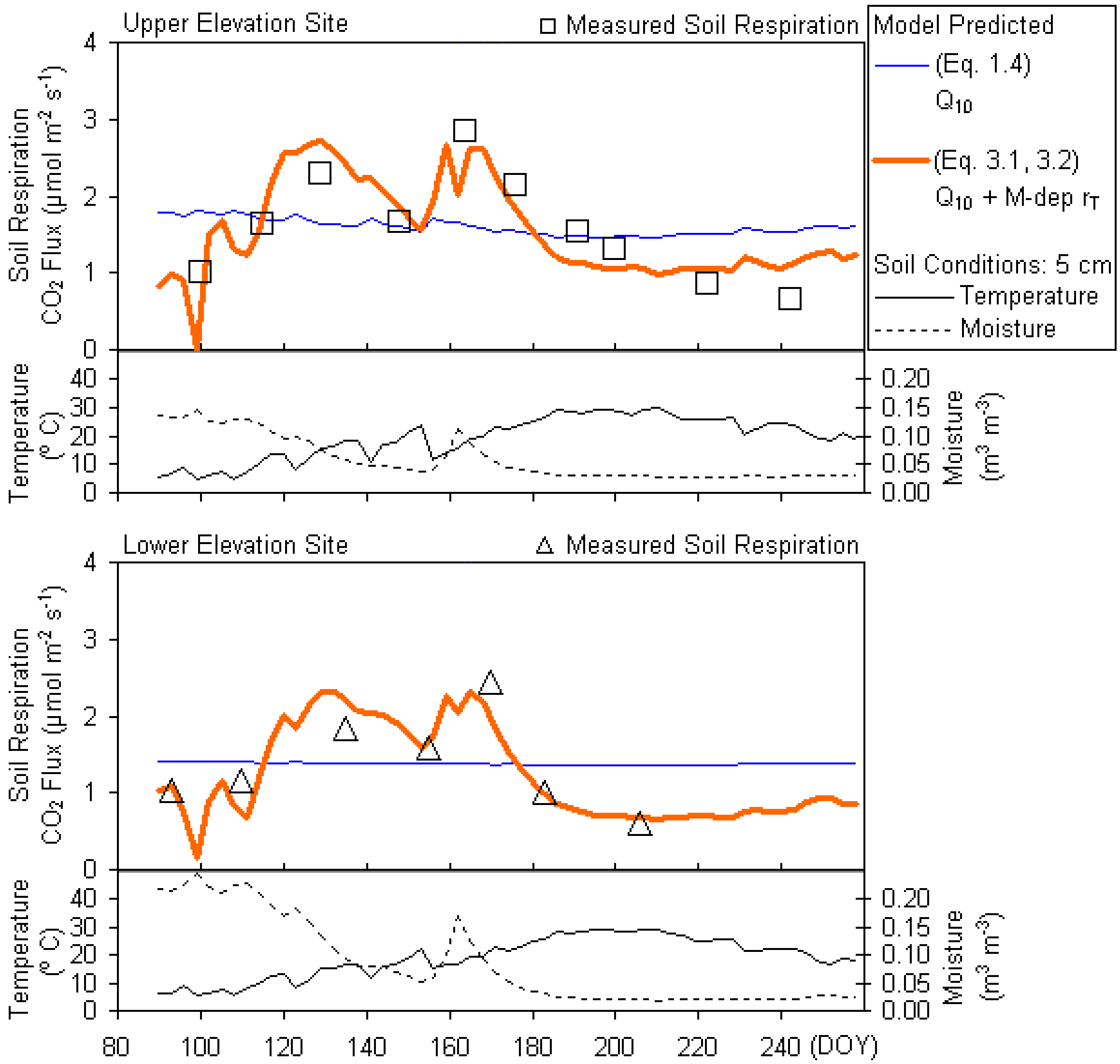

Figure 3.6. **Q_{10} Temperature Dependency Model and Modeled Residuals**
Q_{10} model (Equation 1.4, thin blue line) and with moisture-dependent modeled residuals, r_T (Equations 3.1 and 3.2, thick orange line).

While the model results show a high correlation with the observed data (r^2 of 0.76 and 0.86 for upper and lower sites, Figure 3.6), the model imposes trends that are inconsistent with our understanding of soil respiration. First, since the Q_{10} temperature model is formulated to represent the positive influence of temperature on soil respiration (when moisture is non-limiting), the fitted value for Q_{10} of less than one, suggested that temperature had a negative influence on soil respiration. While this reflects the general seasonal trend of temperature with soil respiration, it does not reflect actual temperature influence. The reason is that positive temperature influence is evident primarily in spring when soil moisture is adequate. As a consequence, the soil moisture fit to the residuals, with a quadratic form, is counterintuitive. For instance, during spring when the temperature model underestimated the soil respiration, the soil moisture model fit implied that soil moisture was responsible for the higher values of soil respiration. In actuality, temperature was the driver of soil respiration in spring, but the temperature model fit to all the data did not represent it. The moisture-dependent formulation as a quadratic of the residuals does not correctly reflect soil moisture limitation.

3.2.1.3. Modulated Q_{10} Formulations

In this class of models, the equations share the core Q_{10} expression of the previous models but each variation is multiplied by a unique moisture-dependent expression, f(x) (Table 2.2). In this model formulation, the term f(x) modulates the temperature response of the system by specifically altering parameter A (intended to be basal respiration). In effect, this formulation leaves a constant Q_{10} parameter (meaning a constant temperature dependency) with a variable basal respiration dependent on moisture, which is expressed as the A parameter multiplied by the, f(x) term.

3.2.1.3.1. Soil Moisture Monod

In this model, the f(x) term consists of a simple Monod term for soil moisture (Equation 3.3).

$$R = A \times Q_{10}^{(T-T_{ref})/10} \times \frac{M}{M + a_1} \tag{3.3}$$

The Monod term makes the actual basal respiration value some fraction of the maximum value depending on soil moisture status. At zero soil moisture, basal respiration is zero. For each site, the half-maximal value of basal respiration corresponds to the moisture value equal to the parameter a_1. As soil moisture exceeds the value of a_1, the Monod term approaches 1 and the basal respiration expression approaches the maximum respiration rate. As the soil moisture drops below the value of a_1, the Monod term becomes an increasingly smaller fractional value and the overall basal respiration declines toward zero. The model is abbreviated "Monod M-Mod Q_{10}" and is shown in Figures 3.7 and 3.8 (Equation 3.3).

This model performed moderately well for the upper elevation site and gave a good seasonal fit for the lower site (r^2 values of 0.58 and 0.85, respectively). The basal respiration varies positively with soil moisture in both cases. However, since the values for the parameter a_1 vary between the sites, the values of parameter A are not comparable between the two. The low value of a_1 for the lower site results in a correspondingly low value for A, whereas a high value of a_1 for the upper elevation site results in a high value of A. For the lower elevation site, the actual basal respiration will approach the maximal value of parameter A for the possible range of soil moistures; in contrast for the upper site, the actual basal respiration will never approach even half of the maximal basal respiration for the possible range of soil moistures. The models overestimated the first period representing early spring for both sites. If this model were extrapolated to wet, cold winter conditions (not measured here), the respiration would likely be overestimated. The model did not capture the nuances in the seasonal trend for the upper site, underestimating through most of spring and overestimating in dry summer. The model captured the seasonal trends better for the lower site.

3.2.1.3.2. Soil Moisture Monod and Inhibition

This Q_{10} model is modulated with both a soil moisture Monod term and a soil moisture inhibitory term (Carlyle and Ba Than, 1988; Table 2.2, Equation 3.4).

$$R = A \times Q_{10}^{(T - T_{ref})/10} \times \frac{M}{M + a_1} \times \frac{a_2}{M + a_2} \qquad (3.4)$$

The model was applied in two ways: (1) standard regression to produce fitted values of all parameters, and (2) only parameters A and Q_{10} were fitted while the values for the moisture parameters, a_1 and a_2, were set to approximate values that reflect the definition and usage of the model in Carlyle and Ba Than (1988).

The first moisture-dependent term (with parameter a_1) is a Monod form that reduces the predicted value of respiration as moisture decreases. The second (with parameter a_2) is an inhibitory form that reduces the predicted value of respiration as moisture increases toward saturation. For approach (2), the intended definitions of parameters, a_1 and a_2, are the percent moisture content that is half of field capacity, and the percent moisture content that is half of saturation, respectively, which are intended to represent the substrate moisture status for microbial soil respiration. Parameter A is the theoretically maximum respiration at the reference temperature, when soil moisture is non-limiting (Carlyle and Ba Than, 1988). However, no moisture value achieves the maximum; for the upper elevation site as an example, the highest possible value of the terms combined results in 37.5% of the maximum respiration, at a moisture status of approximately 30% of saturation. One advantage to the approach is that with common moisture parameters, a_1 and a_2, the A parameter is a site characteristic that can be used to compare site productivity.

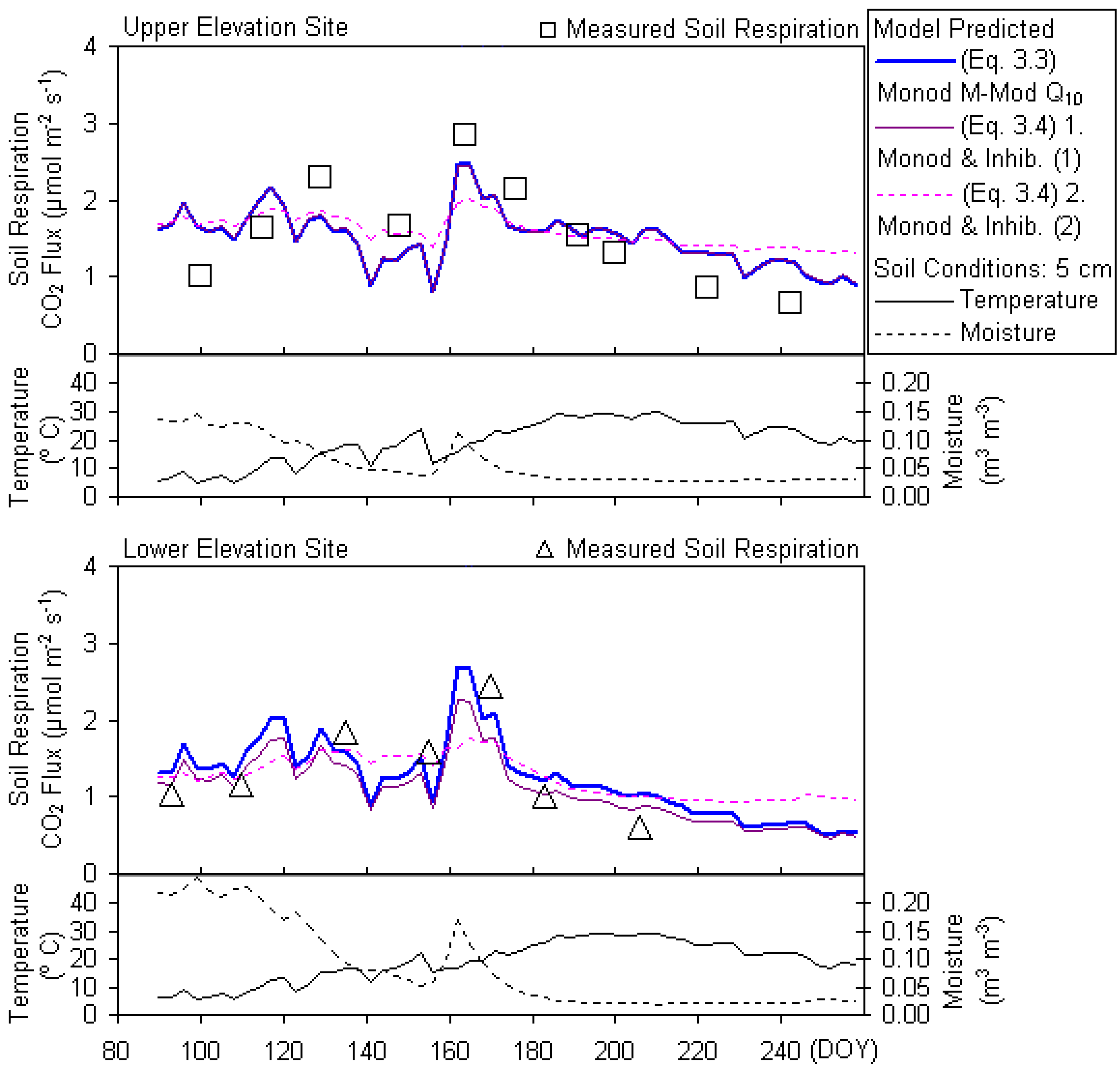

Figure 3.7. Moisture Modulated Q_{10} Model Variations (I)
"Monod M-Mod Q_{10}" (Equation 3.3, medium blue line) and "Monod & Inhib. M-Mod Q_{10}" (Equation 3.4) with two applications: (1) all parameters fitted ("Regressed," thin violet line), and (2) with defined values of a_1 and a_2 ("Defined a_1, a_2," dashed pink line).

The first "Monod & Inhib. M-Mod Q_{10}" model approach, (1) "Regressed," plotted identically to the "Monod M-Mod Q_{10}" model from the preceding section (Equations 3.4-1 and 3.3, respectively, Figure 3.7). For both sites, the model approach (2) "Defined a_1, a_2," produced a fit that dampened the observed variation in seasonal respiration compared to approach (1). Since the model fit using approach (2) did not describe the seasonal trend for the upper site, the value of parameter A for that site is not a reliable indicator of relative site productivity and therefore cannot be compared with the value for the lower site.

3.2.1.3.3. Soil Moisture Deficit Exponential-type

In this modulated Q_{10} model, the soil moisture function utilizes an exponential-type formulation (Irvine and Law, 2002), Equation 3.5, dependent on soil moisture deficit, RM_{def}, Equation 3.6.

$$R = A \times Q_{10}^{(T-T_{ref})/10} \times \left(1-\left(a_3 \times \exp\left(a_4 \times RM_{def}\right)\right)\right) \tag{3.5}$$

$$RM_{def} = \frac{(M_{\max} - M)}{(M_{\max} - M_{\min})} \tag{3.6}$$

The formulation makes parameter A the maximum basal respiration at non-limiting moisture status. The basal respiration is dependent on the soil moisture deficit such that as soil moisture increases from zero toward saturation, the basal respiration increases from a minimum percentage to 100% of maximum with an initially steep then gradual increase. Fitted parameters a_3 and a_4 influence the shape of the curve. The basal respiration varies with the soil moisture deficit from a maximum value (A). As soil moisture decreases from saturation, the basal respiration value remains near the maximum value then declines sharply at lower soil moisture values.

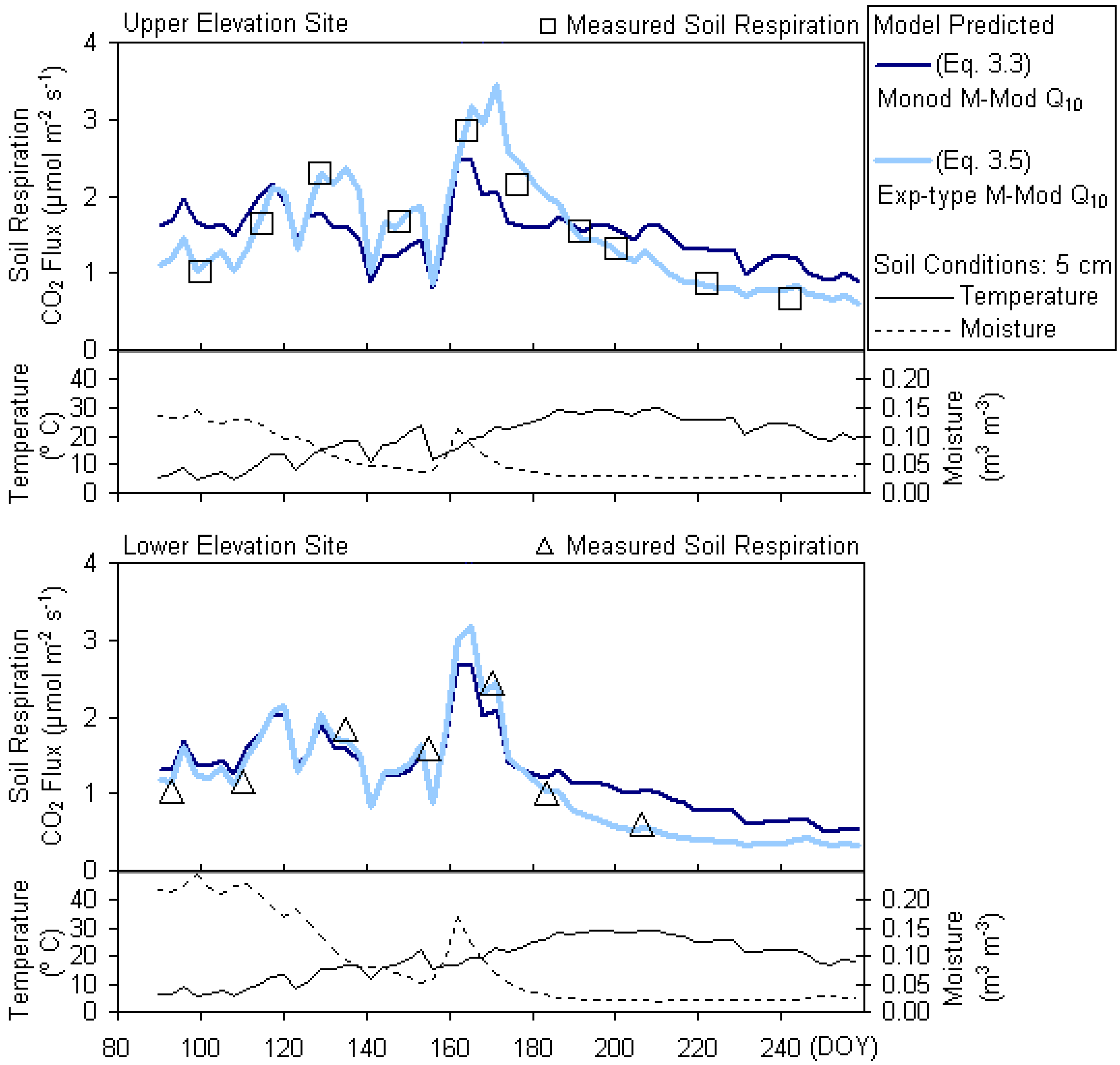

Figure 3.8. Moisture Modulated Q_{10} Model Variations (II)
"Monod M-Mod Q_{10}" model (Equation 3.3, dark blue line), and "Exp-type M-Mod Q_{10}" model (Equation 3.5, light blue line).

The exponential-type moisture-modulated Q_{10} model (Exp-type M-Mod Q_{10}) shows excellent fit when applied individually to the sites (r^2 values of 0.99 and 0.98 for upper and lower sites; Equation 3.5, Figure 3.8). The model captures the overall seasonal trend well, and describes distinct seasonal effects. The model intent is retained through the regression process with all parameters retaining their physical meaning.

3.2.1.4. Modified Q_{10}: Variable Temperature Dependency

A common observation for Q_{10} modeling of multiple individual time periods throughout the growing season is a decrease in the temperature dependency term, Q_{10}, as temperature increases (Carbone et al., 2008; Davidson et al., 2006a; Liu et al., 2006; Richardson et al., 2006; Xu and Qi, 2001). Recall that this trend is not indicative of an actual temperature effect on soil respiration, but rather the combined influence of soil temperature, moisture, and plant phenology (Davidson et al., 2006a). All model formulations used here were intended to reflect the general seasonal trend that Q_{10} decreases as temperature increases; or in other words, the temperature dependency decreases as temperature increases (without implying temperature influence). The Q_{10} base equation is modified by replacing the Q_{10} parameter with a function h(x) (Table 2.2). The h(x) term is dependent on an environmental variable, which makes the effective "Q_{10}" seasonally variable rather than constant, which results in variable temperature dependency of soil respiration. The basal respiration parameter, A, is constant in these formulations.

3.2.1.4.1. Q_{10} Modulation: Soil Moisture Monod

In this model, the "Q_{10}" term varies with a soil moisture Monod term (Equation 3.7).

$$R = A \times \left(d_1 \times \frac{M}{M - d_2} \right)^{(T - T_{ref})/10} \tag{3.7}$$

The parameter d_1 in the formulation represents the relative upper limit of temperature dependency and parameter d_2 is the fitting parameter within the moisture-dependent Monod term. The soil moisture Monod term ensures that the temperature dependency approaches its maximum when soil moisture is not limiting, and drops off toward zero at lower soil moisture values.

The moisture-dependent variable-Q_{10} term (M-dep Var-Q_{10} term) model achieves good seasonal fit to spring and summer dry-down (r^2 values of 0.88 and 0.89 for upper and lower sites; Equation 3.7, Figure 3.9), but imparts increasing soil respiration at very low soil moisture values at the end of summer, a trend not observed in the field data nor consistent with our understanding of the system.

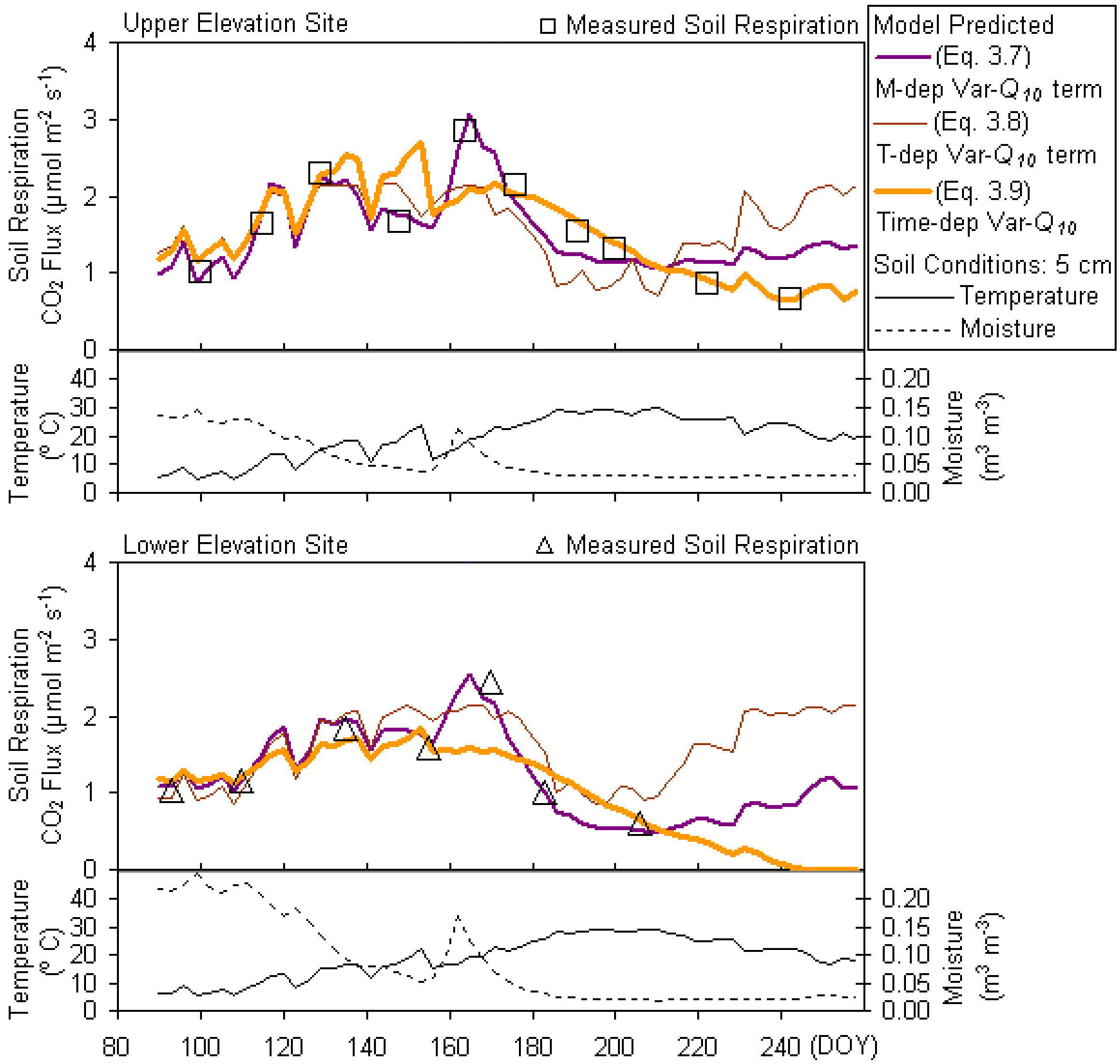

Figure 3.9. Variable "Q_{10}" Term Model Variations
Variable "Q_{10}" terms have dependency on moisture "M-dep Var-Q_{10} term" (Equation 3.7, medium purple line), temperature "T-dep Var-Q_{10} term" (Eqquation 3.8, thin brown line), and time "Time-dep Var-Q_{10} term" (Equation 3.9, thick gold line).

<u>3.2.1.4.2. Modified Q_{10}: Temperature</u>

This variable "Q_{10}" model utilizes a linear temperature relationship term (Table 2.2, Equation 3.8).

$$R = A \times \left(c_1 + c_2 \times T\right)^{\left(T - T_{ref}\right)/10} \qquad (3.8)$$

The temperature-dependent variable-Q_{10} term (T-dep Var-Q_{10} term) model is formulated to allow the temperature dependency to decrease with increasing temperature (Richardson et al., 2006). The model resulted in values that made the temperature dependency of soil respiration negatively correlated with temperature over the growing season for the upper site (r^2 value 0.58; Figure 3.9). The model fit to the upper site data reflected the fact that given the entire dataset, the temperature dependency varied negatively with temperature. With no moisture dependency, the model did not capture the peak soil respiration in June due to the rain event. At the end of the summer, the negative temperature dependency produced greatly increasing soil respiration in response to declining summer temperatures, when in actuality, the soil respiration gradually declined to growing season minimum values. The model performed poorly and if extrapolated to winter would overestimate soil respiration. The model did not converge on a solution for the lower site data (in Figure 3.9, parameter values from upper site modeling are used).

3.2.1.4.3. Modified Q_{10}: Time

In this model, the "Q_{10}" term is simply time-dependent (Table 2.2). The time used is Julian Day expressed in radians, JD_π. The model is intended to reflect the general seasonal trend for any system, with the spring different from the summer (Equation 3.9).

$$R = A \times \left(c_3 + c_4 \times \sin\left(JD_\pi\right) + c_5 \times \cos\left(JD_\pi\right)\right)^{\left(T - T_{ref}\right)/10} \quad (3.9)$$

The time-dependent variable-Q_{10} term (Time-dep Var-Q_{10} term) model formulation represented the spring season as having temperature dependency values that start high and decrease toward one (1) and summer as having a negative correlation with temperature (by generating "Q_{10}" values less than one). The model captured the general trend (r^2 values of 0.72 and 0.82 for upper and lower sites; Figure 3.9), but did not capture the effect of the early June rain event, since it did not include moisture dependency. The model represented the summer as being negatively influenced by soil temperature, which is an observed trend but as mentioned before, not an actual influence of temperature on respiration rate.

3.2.2. Variations Based on Arrhenius Temperature Dependency

This class of models is based on the Arrhenius equation as described in the modeling introduction (Equations 1.5 and 1.6). The main difference between the Q_{10} rate model and the Arrhenius rate model is that while Q_{10} represents an exponentially increasing temperature dependency as temperature increases, the Arrhenius model represents temperature dependence as increasing toward an upper limit so that as temperature increases the rate becomes less sensitive to temperature.

3.2.2.1. Lloyd and Taylor Restricted Model

The Lloyd and Taylor Restricted model is an Arrhenius-based temperature dependent model for soil respiration (Lloyd and Taylor, 1994). The exponential term incorporates temperature dependency and constant activation energy (E_0) determined for non-moisture-limited soil respiration (Equation 1.7):

$$R = R_{10} \times \exp\left[E_0 \times \left(\frac{1}{283.15 - T_0} - \frac{1}{T - T_0}\right)\right] \tag{1.7}$$

Soil respiration, R, is a function of the respiration rate at 10^{o} C, R_{10}, temperature, T, expressed in degrees Kelvin, and constant values for the activation energy, E_0 = 308.56 K, and the lower temperature limit for soil respiration, T_0 = 227.13 K (-46° C).

The formulation was not intended to describe R for moisture-limited conditions (Lloyd and Taylor, 1994), hence, the poor seasonal fit of the "Restricted L&T" model (r^2 = 0) to the sites in this study is expected (Equation 1.7, Figure 3.10). The model followed the seasonal trend in temperature; the model underestimated soil respiration during the moist cool spring and overestimated it during the dry hot summer.

3.2.2.2. Moisture-dependent Arrhenius-based

Daily average CO_2 flux was predicted using a specific formulation of the daily time step model of (Reichstein et al., 2003). The moisture-dependent Arrhenius-based (M-dep Arr-based) model modifies the Lloyd and Taylor model by incorporating moisture dependency (Equations 3.10-3.13).

$$R = R_{10} \times \exp\left[E_0(RM) \times \left(\frac{1}{283.15 - T_0} - \frac{1}{T - T_0}\right)\right] \times g(RM) \tag{3.10}$$

$$g(RM) = \frac{RM}{(RM_{1/2} + RM)} \tag{3.11}$$

$$E_0(RM) = a_{REW} + b_{REW} \times RM \tag{3.12}$$

$$RM = M/M_{FC} \tag{3.13}$$

Equation 3.10 shows an expanded version of the Lloyd and Taylor model multiplied by a function $g(RM)$, which modulates the model with soil moisture (3.11). Note that $g(RM)$ is a Monod term with soil moisture where $RM_{1/2}$ (fraction) is the soil moisture content where half-maximal respiration (at a given temperature) occurs. In contrast to the restricted form, which had a constant activation energy, here E_0 (K^{-1}) is linearly dependent on moisture (Equation 3.12). The relative soil moisture availability, *RM*, was expressed as soil moisture (*M*) relative to the soil moisture at field capacity (M_{FC}) (Equation 3.13). The soil moisture content at field capacity, M_{FC}, was approximated as the soil moisture content after 3 days of drainage after maximum soil moisture content was reached (Reichstein et al., 2003).

The "M-dep Arr-based" model (Equations 3.10 – 3.13) of soil respiration was regressed to the sites in this study using R_{10} (µmol m^{-2} s^{-1}) and $RM_{1/2}$ (m^3 m^{-3}) as fitting parameters, while values for a_{REW} and b_{REW} were set to published values from the regression analysis performed on ecosystems that experienced annual drought (Reichstein et al., 2003); see results and published parameter values used in Table 3.4. The model performed moderately for both sites (r^2 = 0.79 and 0.95, respectively) (Figure 3.10). The model performed best when soil moisture was high but less well when soil moisture was low. Inadequate fit at low soil moisture could be explained by the linear dependence of the activation energy parameter, E_0, on relative moisture, *RM*, a non-linear dependency may have produced a better fit.

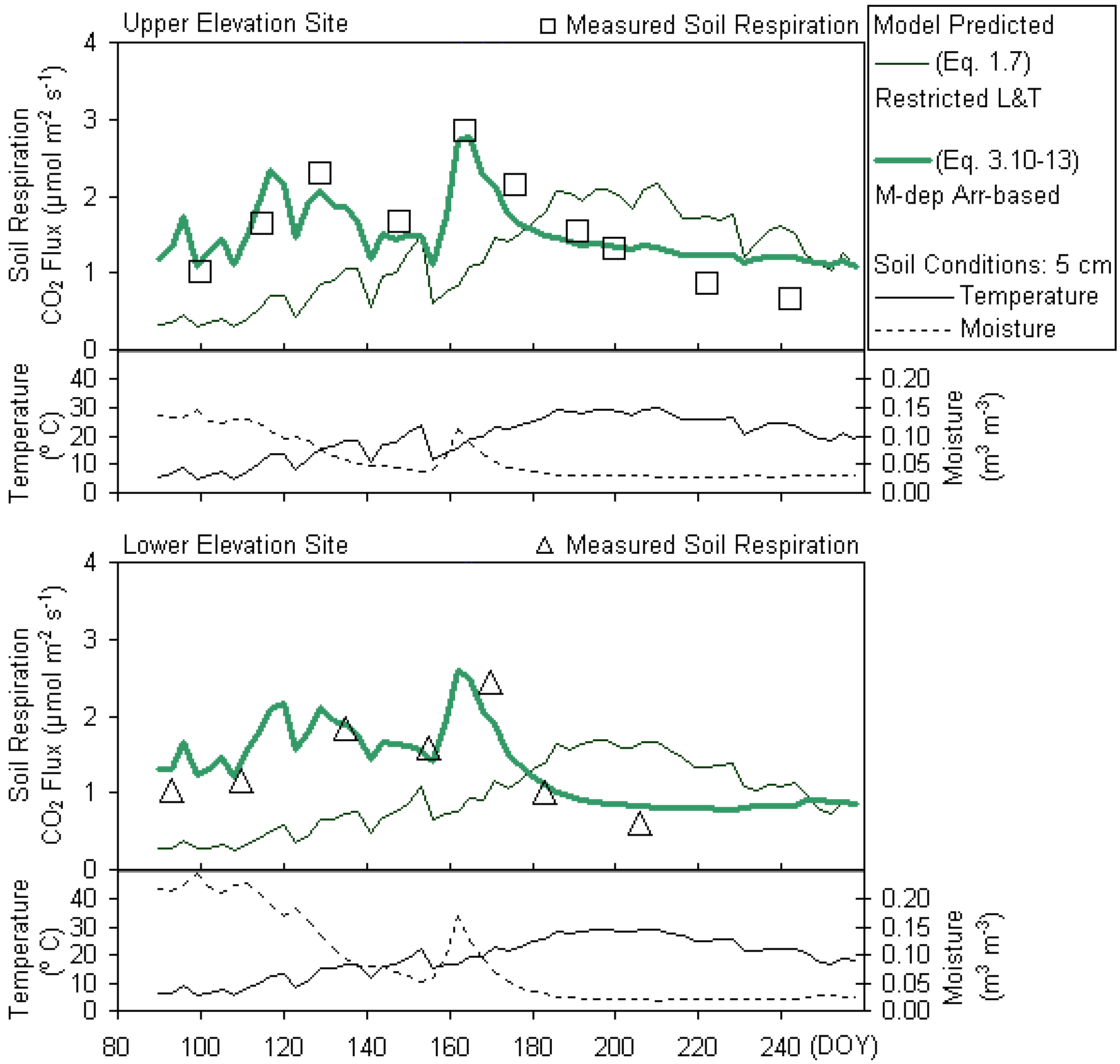

Figure 3.10. Arrhenius-Type Temperature Dependency Model Variations
The temperature dependent restricted Lloyd and Taylor (1994) model (Equation 1.7, thin dark green line), and the temperature and moisture dependent model of Reichstein *et al.* (2003), "M-dep Arr-based" (Equations 3.10 – 3.13, thick sea green line).

3.3. Model Evaluation

Four model variations of soil respiration dependent on both soil temperature and moisture stood out from the individual model assessments based on seasonal fit and consistency with the conceptual model of soil respiration function developed for this semi-arid system. The selected seasonal models are listed here with abbreviations and equation numbers: the Monod moisture-modulated Q_{10} model, "Monod M-Mod Q_{10}" (Equation 3.3); the exponential-type moisture-modulated Q_{10} model, "Exp-type M-Mod Q_{10}" (Equation 3.5); the moisture-dependent variable-Q_{10} term model, "M-dep Var-Q_{10} term" (Equation 3.7); and the moisture-dependent Arrhenius-based model, "M-dep Arr-based" (Equations 3.10-3.13).

A detailed model comparison illustrates how each model represents soil temperature and moisture influence on soil respiration. The growing season model-predicted soil respiration for the four models is compared within primary moisture divisions: 1-maximum, 2-transition, and 3-minimum (Table 3.5). Near surface soil moisture values transition from near the annual maximum in spring to the annual minimum in summer. The transition moisture periods, 2(a) – 2(d), which includes the large rain event, 2(c), occur over the same date range for both upper and lower elevation sites (DOY 120 – 185). A single soil moisture value distinguishes the drier dry-down periods, 2(b) and 2(d), from the wetter periods, 2(a) and 2(c), for each site, but the value is different between the sites: 0.06 m^3 m^{-3} for the upper site and ~0.09 for the lower site. The transition moisture value is denoted by a red dashed horizontal line in Figures 3.11 and 3.12, which also serves to identify the transition moisture periods within the growing season. (Complete seasonal descriptions, soil temperature, and moisture data and average model-predicted soil respiration is summarized in Table 3.5.)

Table 3.5. Model Comparison Over the Growing Season by Seasonal Divisions
The soil moisture values in bold font highlight differences between the upper and lower site seasonal descriptions.

Seasonal Divisions			Soil Temperature T, 5 cm	Soil Moisture M, 5 cm			(Eq. 3.3)	(Eq. 3.5)	(Eq. 3.7)	(Eq. 3.10)
							Model-predicted Soil Respiration mean R, CO_2 flux ($\mu mol\ m^{-2}\ s^{-1}$)			
Description	DOY	n	mean (° C)	min ($m^3\ m^{-3}$)		max ($m^3\ m^{-3}$)				
Upper Site										
1. Max. Moisture:										
Spring, cool	80 - 119	40	7	0.10	–	0.16	1.69	1.25	1.16	1.38
2. M. Transition:										
(a) Spring, warm-up	120 - 134	15	13	0.06	–	0.10	1.71	1.95	1.95	1.90
(b) Spring, dry-down	135 - 160	26	17	0.04	–	**0.06**	1.25	1.67	1.79	1.47
(c) Rain Event	161 - 170	10	18	**0.06**	–	0.12	2.26	2.79	2.69	2.51
(d) Sum., dry-down	171 - 184	14	24	0.03	–	**0.06**	1.71	2.56	1.95	1.73
3. Min. Moisture:										
(a) Summer, max. T	185 - 214	30	29	0.03	–	0.03	1.59	1.39	1.17	1.36
(b) Sum., T decline	215 - 259	45	23	0.03	–	0.03	1.14	0.78	1.24	1.19
Lower Site										
1. Max. Moisture:										
Spring, cool	80 - 119	40	7	0.18	–	0.27	1.43	1.31	1.17	1.36
2. M Transition:										
(a) Spring, warm-up	120 - 134	15	13	0.11	–	0.19	1.70	1.75	1.72	2.01
(b) Spring, dry-down	135 - 160	26	17	0.05	–	**0.10**	1.29	1.35	1.78	1.65
(c) Rain Event	161 - 170	10	18	**0.09**	–	0.19	2.42	2.77	2.34	2.61
(d) Sum., dry-down	171 - 184	14	23	0.03	–	**0.08**	1.48	1.53	1.55	1.43
3. Min. Moisture:										
(a) Summer, max. T	185 - 214	30	28	0.02	–	0.03	1.10	0.66	0.59	0.81
(b) Sum., T decline	215 - 259	45	22	0.02	–	0.03	0.68	0.37	0.84	0.76

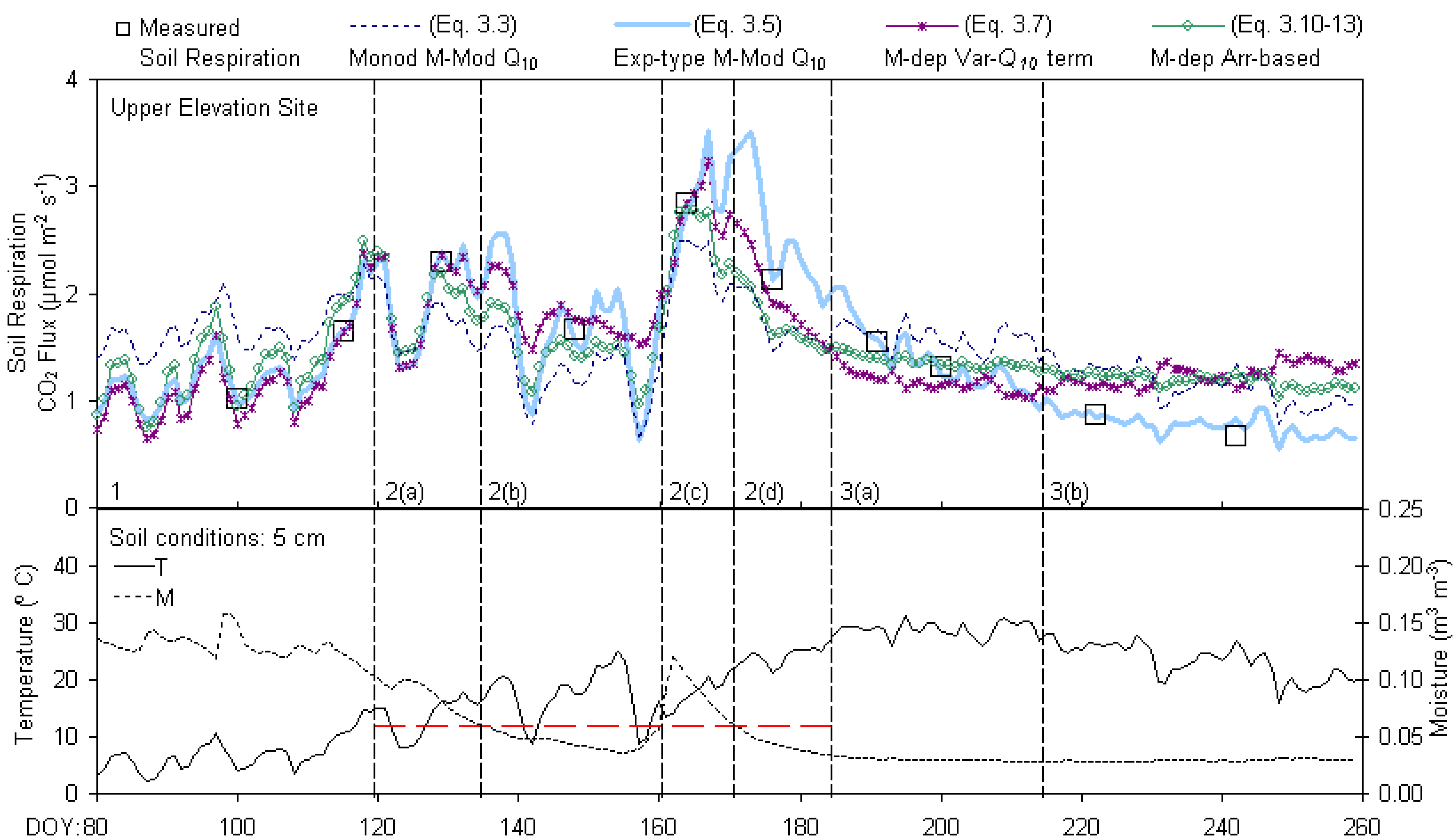

Figure 3.11. Upper Site Selected Seasonal Models
Measured soil respiration (open black squares), model predicted soil respiration:
Monod M-Mod Q_{10} (Eq. 3.3, dashed dark blue), Exp-type M-Mod Q_{10} (Eq. 3.5, solid light blue),
M-dep Var-Q_{10} term (Eq. 3.7, purple with asterisk symbols), M-dep Arr-based (green with open circles).

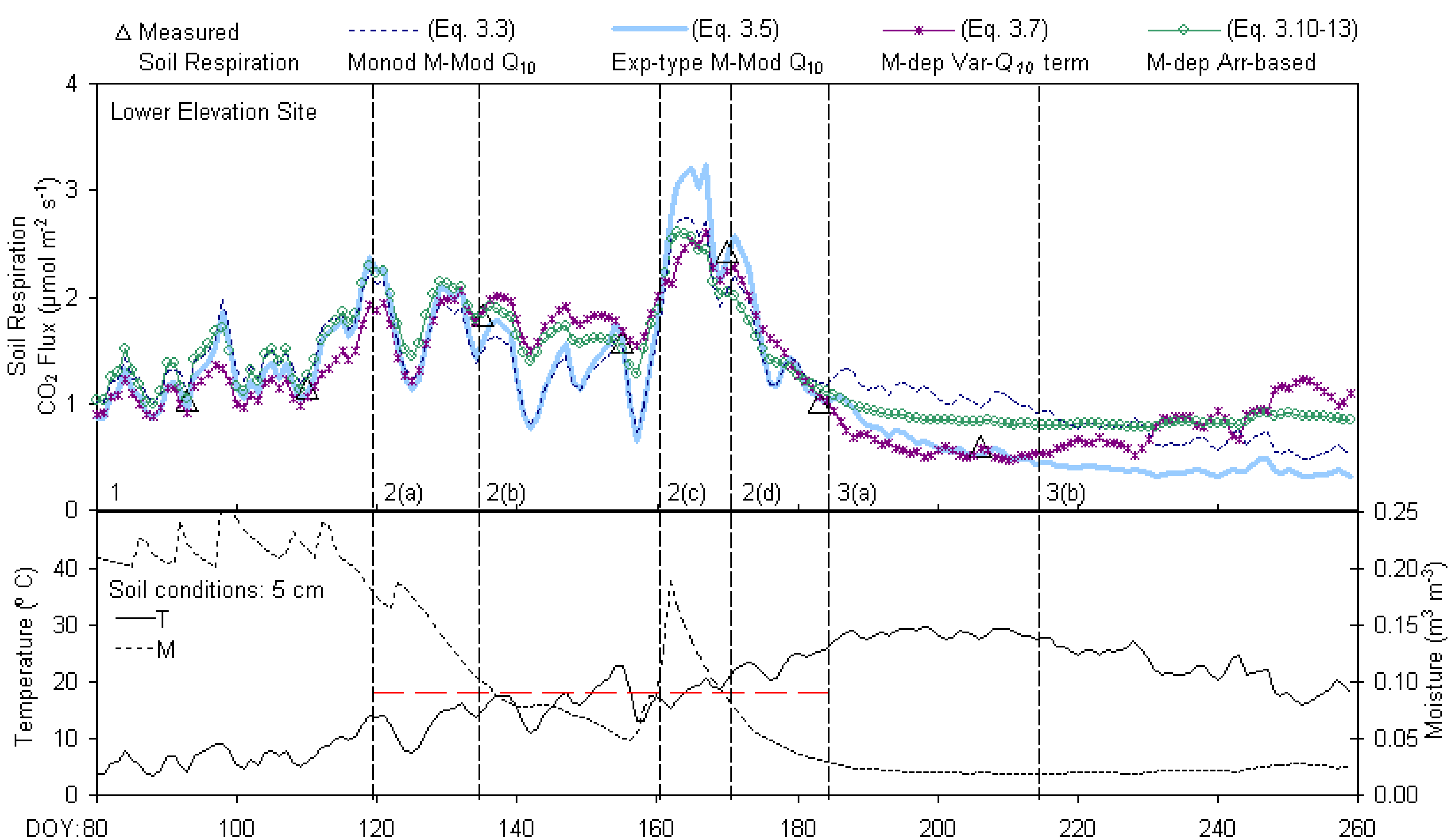

Figure 3.12. Lower Site Selected Seasonal Models
Measured soil respiration (open black triangles), model predicted soil respiration:
Monod M-Mod Q_{10} (Eq. 3.3, dashed dark blue), Exp-type M-Mod Q_{10} (Eq. 3.5, solid light blue),
M-dep Var-Q_{10} term (Eq. 3.7, purple with asterisk symbols), M-dep Arr-based (green with open circles).

The "Monod M-Mod Q_{10}" model (Equation 3.3) attenuates the general seasonal trend in soil respiration compared to the other models. The model overestimates soil respiration in early spring (1), underestimates during the transition moisture periods (2), then overestimates in summer (3). The trend is prominent for the upper site (Figure 3.11), with similar but less prominent behavior for the lower site (Figure 3.12).

During the summer minimum moisture periods, 3(a) and 3(b), the relative model behavior is the same between upper and lower sites. The "Exp-type M-Mod Q_{10}" model (Equation 3.5) predicts soil respiration in line with the observed decline (Figure 3.11). Particularly within summer period 3(b), all other models predicted higher soil respiration (Table 3.5); both sites had similar relative trends: Equation 3.3, a decline; Equation 3.7, an increase; and Equation 3.10 a slight decline (Figures 3.11, 3.12). At soil moisture values near the annual minimum, the "M-dep Var-Q_{10} term" (Equation 3.7) model regression represents soil temperature influence with a negative temperature dependency, which results in the increasing model-predicted soil respiration within the summer period 3(b). Negative temperature influence is contrary to the expected physical influence of temperature on soil respiration.

Over the transition moisture range, 2(a) – (d), the "Monod M-Mod Q_{10}" model (Equation 3.3) average soil respiration is generally lowest for both upper and lower sites (Table 3.5). The "M-dep Var-Q_{10} term" (Equation 3.7) model fluctuates the least (Figure 3.11 and 3.12) relative to the other models, which implies low temperature dependency. Divisions within the transition moisture range, 2(a) – (d), serve to refine the model comparisons for the last two models: "Exp-type M-Mod Q_{10}" (Equation 3.5), and "M-dep Arr-based" (Equation 3.10). Dry-down periods, 2(b) and 2(d), have similar soil moisture ranges: at the upper site, 0.04 – 0.06 m^3 m^{-3}, and at the lower site, 0.03 – 0.10 m^3 m^{-3}. For both sites and both drydown periods, Equation 3.5 fluctuates more than Equation 3.10, indicating a higher relative temperature dependency. The average soil respiration of Equation 3.5 relative to Equation 3.10 for spring dry-down, 2(b), is greater for Equation 3.5 at the upper site but lesser at the lower site (Table 3.5), which means that Equation 3.10 models a higher temperature influence on soil respiration relative to Equation 3.5 at the lower site compared to the upper site for the respective transition moisture ranges.

A comparison of the models "Exp-type M-Mod Q_{10}" (Equation 3.5), and "M-dep Arr-based" (Equation 3.10) reveals consistent relative model behavior for both upper and lower sites for the growing season except for the spring dry-down transition moisture period, 2(b). The precise model fit of Equation 3.5 to the seasonal dataset relied on high sensitivity to temperature at very low moisture values in order to represent the observed trend in the summer, which generated larger variations in model-predicted soil respiration during the transition moisture periods compared to Equation 3.10. Model-predicted soil respiration for Equations 3.5 and 3.10 for prior years are summarized graphically by 20-day intervals in Figure 3.13, which also shows the input datasets of growing season soil temperature and moisture (measurements from the same pit and depth). For Equation 3.5, the large variation in model-predicted soil respiration in summer is inconsistent with the conceptual model: (1) negative soil respiration flux is not possible, and (2) modeled response to changes in soil moisture in the near minimum range should be lesser. The gradual summer decline of model-predicted soil respiration for Equation 3.10 reflects lesser temperature dependency at low soil moisture values compared to Equation 3.5, which is more consistent with the conceptual model of soil respiration function in this system.

When weighing the models against one another, it is important to consider the potential model approach limitations, especially the use of a single depth to represent soil temperature and moisture influence on soil respiration throughout the soil profile. In this system, near-surface measurements were needed to represent the observed increase in soil respiration due to the rain event, which corresponded to soil moisture increase only observed at 5 and 15 cm depths, and not at deeper depths. Over the summer dry period (3. minimum moisture), if soil respiration is responding to deeper soil moisture that dries down more gradually over summer, then none of the model formulations represent that.

Based on the model comparisons, the “M-dep Arr-based” model (Equation 3.10) best represented site soil respiration response to near-surface soil temperature and moisture consistent with the conceptual model of soil respiration function in this system. The model captured the growing season trend in observed soil respiration and slightly overestimated soil respiration in dry late summer for the study year. Based on application of the model to prior year soil temperature and moisture growing season datasets, the greatest inter-annual variation of soil respiration occurred within transition dates, DOY 140 – 200 (Figure 3.13), when intermediate to maximum soil temperature coincided with soil moisture ranging from intermediate values to near minimum.

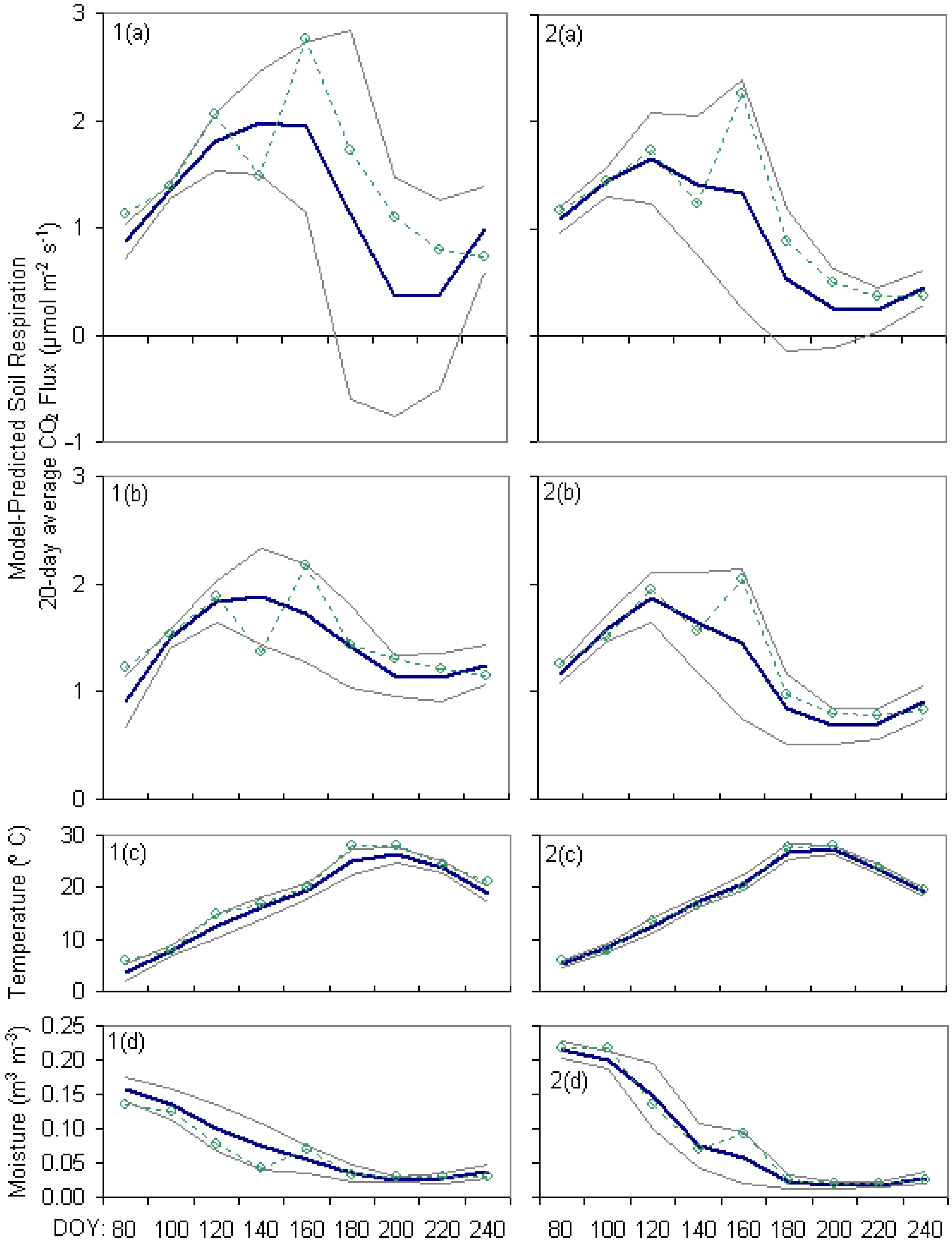

Figure 3.13. Inter-annual Variation Summarized by 20-day Intervals
1: upper site, 2: lower site; model-predicted soil respiration: (a) Equation 3.5, (b) Equation 3.10; 5 cm soil conditions: (c) temperature, (d) moisture. Lines: average (thick blue), standard deviation (gray), the 2007 study year (dashed sea green with open circles).

3.4. Model Application

The inter-annual variability of model-predicted soil respiration of the "M-dep Arr-based" model (Equations 3.10 – 3.13) shows the best estimate of soil respiration response to variation in local climate. Daily averaged soil conditions for the growing season (DOY 80-259) were input datasets for the selected model (Equation 3.10) from the study year (2007) and prior years (2001-2006). Inter-annual trends in modeled soil respiration and observed soil temperature and moisture are summarized by 20-day intervals (Table 3.6, Figure 3.14).

Table 3.6. Upper Site Inter-annual Averages by 20-day Intervals
Averages with standard deviation of growing season (DOY 80-259) soil conditions from years 2001-2007 for the upper site. Model-predicted (Equation 3.10) soil respiration.

20-Day Interval DOY (Start)	Soil Temperature T, 5 cm (^{o} C)	Soil Moisture M, 5 cm (m^3 m^{-3})	Soil Respiration R, (μmol m^{-2} s^{-1})
80	3.6 ± 1.7	0.157 ± 0.017	0.91 ± 0.24
100	7.8 ± 1.0	0.135 ± 0.022	1.49 ± 0.09
120	12.5 ± 2.3	0.101 ± 0.033	1.83 ± 0.19
140	16.0 ± 2.1	0.074 ± 0.034	1.88 ± 0.44
160	19.3 ± 1.5	0.054 ± 0.020	1.73 ± 0.46
180	24.9 ± 2.5	0.035 ± 0.012	1.42 ± 0.38
200	26.2 ± 1.5	0.026 ± 0.004	1.15 ± 0.19
220	23.8 ± 1.2	0.028 ± 0.007	1.13 ± 0.22
240	18.7 ± 1.6	0.037 ± 0.010	1.25 ± 0.18

The 20-day intervals with the highest average soil respiration are DOY (start): 120, 140, 160, which correspond to the late spring season (Table 3.6). The date range corresponds to intermediate average temperatures (13, 16, 19^o C, respectively) and intermediate average soil moistures (0.10, 0.07, 0.05 m^3 m^{-3}, respectively). Based on magnitude of standard deviations, the intervals with the largest inter-annual variability are DOY (start): 140, 160, 180. Since the intervals with high soil respiration rates also exhibit high inter-annual variability, differences in average growing season soil respiration from year to year are most likely attributable to the soil conditions during the late spring season.

Soil moisture accounted for the majority of deviation of the 2007 study year from the inter-annual average trend (Figure 3.14). For the interval starting at DOY 140, model-predicted soil respiration during the study year (2007) was at the minimum of inter-annual variation, which corresponded to the same for its soil moisture status. Soil moisture status also accounted for relative differences for the DOY 160 interval, in which values were near the maximum of inter-annual variation, and for the DOY 180 interval, in which values were near the average. The relative trends in model-predicted soil respiration for the study year for intervals DOY 140, 160, and 180 (minimum, maximum, and average, respectively), did not correspond to the relative trends in soil temperature: slightly above average, slightly above average, and maximum, respectively.

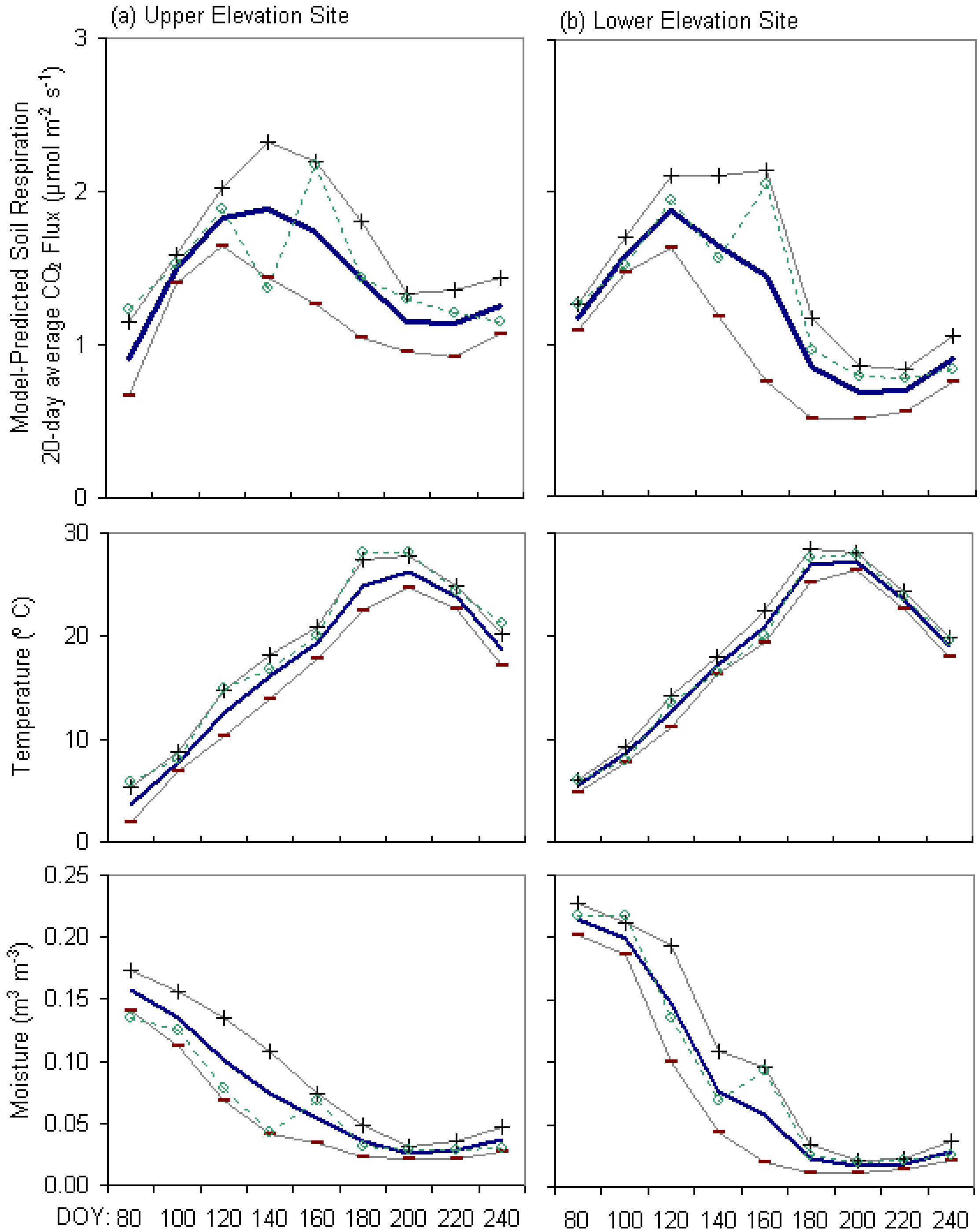

Figure 3.14. Inter-annual Trends of 20-day Interval Average Datasets
(a) Upper site. (b) Lower site. Model-predicted soil respiration (Equation 3.10) and soil conditions at 5 cm depth and for years 2001-2007. The inter-annual average (thick blue line) with standard deviation (upper and lower gray lines) is plotted by 20-day intervals (start DOY). The 2007 study year is shown (dashed green line, open circles).

Ranked data indicate the importance of intermediate soil moisture values to inter-annual variability of model-predicted soil respiration. The 20-day averaged data was ranked by soil moisture and statistics within four groups each representing 25% of the total number of 20-day intervals are shown in Table 3.7. For the upper site, the highest average soil respiration (1.89 μmol m^{-2} s^{-1}) was in the Intermediate-High portion, with an intermediate soil moisture range (0.05 – 0.12 m^3 m^{-3}) with intermediate average soil temperature (15 ± 4° C).

Table 3.7. Inter-annual Trends by Soil Moisture
Data is ranked by 20-day average soil moisture during the growing season (DOY 80 – 259) of years 2001-2007 for the upper site.

	Soil Moisture M, 5 cm (m^3 m^{-3}) average	range	Soil Temperature T, 5 cm (° C)	Model-predicted Soil Respiration R, CO_2 flux (μmol m^{-2} s^{-1})
Upper Site				
High 25%	0.15	0.13 – 0.18	6 ± 3	1.33 ± 0.50
Int.-High 25%	0.08	0.05 – 0.12	15 ± 4	1.89 ± 0.26
Int.-Low 25%	0.04	0.03 – 0.05	21 ± 4	1.39 ± 0.21
Low 25%	0.03	0.02 – 0.03	25 ± 2	1.08 ± 0.17

The 20-day average model-predicted soil respiration data is ranked by percent contribution to the inter-annual growing season average from years 2001-2007 (Table 3.8). Average soil respiration as CO_2 flux for the groups are 1.0, 1.3, 1.7 and 2.1 μmol m^{-2} s^{-1}. The highest values of soil respiration (High 25%) correspond to intermediate soil temperature and moisture. As soil respiration declines, the moisture ranges increase. The data are displayed graphically by symbol size on a plot of the corresponding temperature and moisture for each interval for the upper site in Figure 3.15. The highest soil respiration occurs within an envelope of transitional temperature and moisture, while the lowest soil respiration corresponds to growing season intervals when either soil temperature is low or soil moisture is low.

Table 3.8. Inter-annual Trends by Soil Respiration
Model-predicted soil respiration data is ranked by percent contribution to the inter-annual growing season average soil respiration for the growing season (DOY 80 – 259) of years 2001-2007 for the upper site. Average values with standard deviation are shown.

	Soil Respiration *R*, (μmol m^{-2} s^{-1})	Soil Temperature *T*, 5 cm (° C)	Soil Moisture range *M*, 5 cm (m^3 m^{-3})
Upper Site			
High 25%	2.10 ± 0.17	15.4 ± 2.9	0.06 – 0.14
Int.-High 25%	1.67 ± 0.13	14.8 ± 6.2	0.04 – 0.15
Int.-Low 25%	1.33 ± 0.07	19.6 ± 7.2	0.03 – 0.16
Low 25%	1.01 ± 0.19	17.0 ± 9.8	0.02 – 0.18

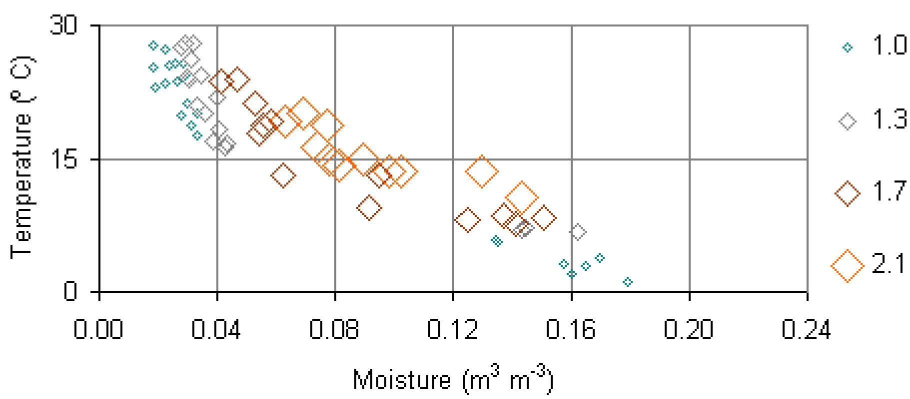

Figure 3.15. Soil Temperature vs. Soil Moisture with Soil Respiration
Average soil conditions at 5 cm depth for years 2001-2007 summarized by 20-day intervals within the growing season (DOY 80-259). Upper site model-predicted soil respiration ranked by percent contribution to inter-annual growing season average.

A broad range of temperature and moisture combinations comprise the transitional envelope that produced the top 50 percent contributing to average soil respiration (R = 1.7, and 2.1). All along this temperature and moisture envelope is a band of temperature and moisture combinations that make up the lower 25% of the top half (R = 1.7). For a given moisture status within the transition range, a higher temperature produced higher soil respiration. At low moisture, small declines in moisture produce significant reductions in soil respiration, regardless of temperature; the trend is shown by the plot of the lower 50 percent values (R = 1.0, 1.3) in relation to values in the upper contributing half (R = 1.7, 2.1) with the same soil temperature status.

The magnitude in average growing season soil respiration from year to year largely corresponded to the proportion of time that soil conditions fell within the transition range (Figure 3.16). For the two lowest years, data plotting within the envelope is all but non-existent, indicating that soils dried down early (while temperature was low) or no significant spring and summer rain events occurred. For the intermediate years, data plotted within the transition range. For the two highest years, data plotted within the transition range, but at higher soil moisture status at comparable temperatures to the intermediate years. Data points with comparable high temperature plotted in the lower 50% for the intermediate years (low moisture), but plotted in the higher 50% for the highest years (higher moisture and within the transitional range).

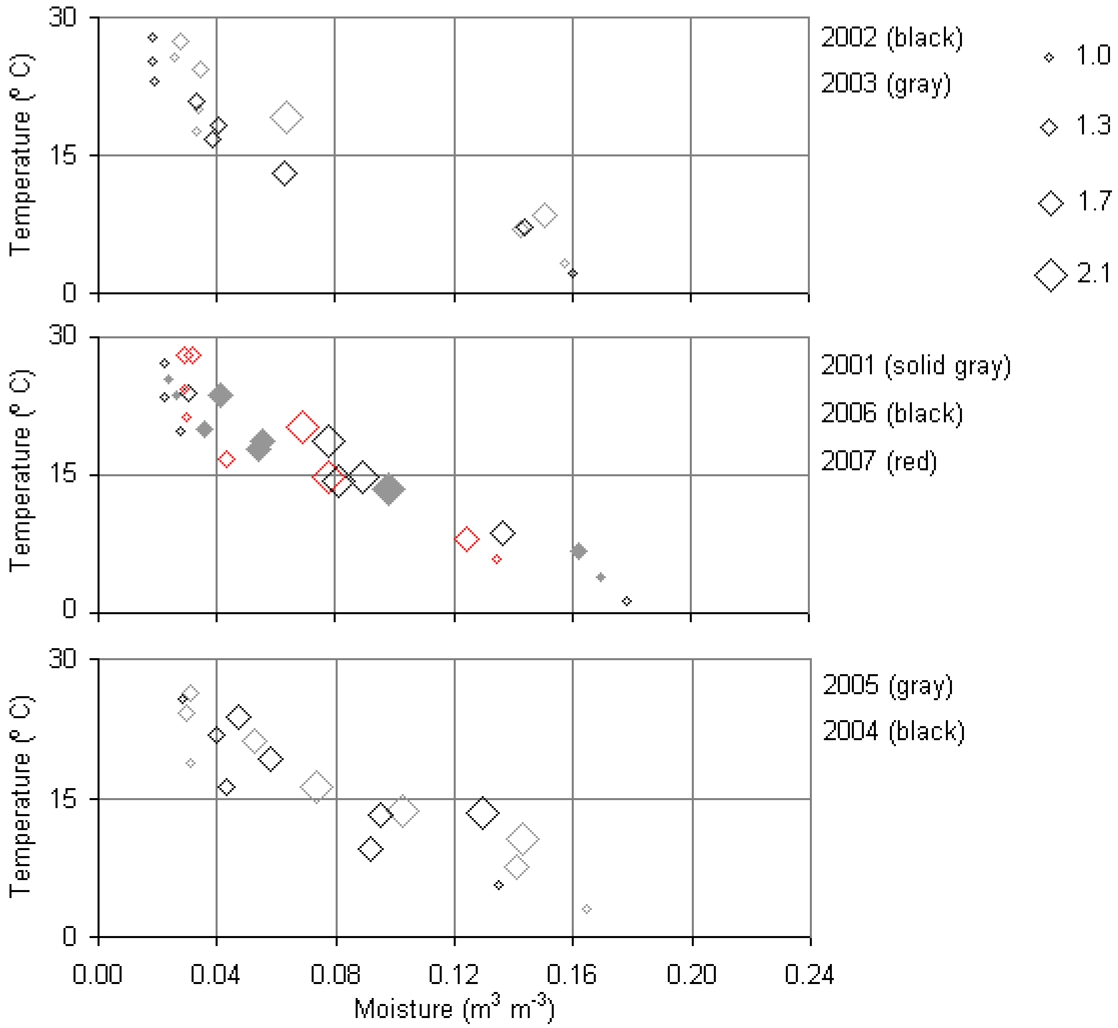

Figure 3.16. Growing Season Profiles by Year of 20-day Interval Datasets
Model-predicted average growing season soil respiration is used to rank the years, 2001-2007 (top to bottom: low, intermediate, high). The nine datapoints (20-day average) for each year make up a profile of soil temperature and moisture combinations with the associated average model-predicted soil respiration (symbol sizes reflect magnitude).

Growing season average soil respiration correlates with relative trends in soil moisture for some years but not for others (Table 3.9). In 2002, with the lowest model-predicted soil respiration, average soil moisture was 18% below the average; in 2005, the second highest soil respiration, average soil moisture was 19% above average; these results show correlation between average soil respiration and moisture. The year with the highest predicted soil respiration, 2004, did not reflect the trend; average soil moisture for 2004 was near the average.

Table 3.9. Model-predicted Growing Season Averages: 2001-2007
Growing season averages for each year with the percent difference from the overall average. Years are in order from lowest to highest model-predicted soil respiration.

	All	2002	2003	2001	2006	2007	2005	2004
Soil Respiration	**1.42**	1.11	1.34	1.42	1.43	1.48	1.57	1.62
(μmol m^{-2} s^{-1})		-22%	-6%	0%	0%	4%	10%	14%
Soil Temperature	**1.70**	17.2	17.0	17.1	16.9	18.6	15.7	16.5
5 cm (^{o} C)		1%	0%	0%	-1%	9%	-8%	-3%
Soil Moisture	**0.072**	0.059	0.074	0.074	0.074	0.063	0.086	0.074
5 cm (m^3 m^{-3})		-18%	3%	3%	3%	-13%	19%	3%

4. DISCUSSION

The measured and modeled soil respiration trends for Dry Creek foothills sites were analyzed concurrently with patterns of environmental variables, soil temperature and moisture, to improve understanding of soil respiration function in this system. In particular, the results showed that (1) soil respiration responded positively to near surface soil temperature and moisture status during the growing season, (2) soil temperature dependence declined as soil moisture declined, which suggested temperature influence was dependent on moisture, (3) soil respiration dependence on moisture became increasingly sensitive to soil moisture status as it declined. The results are compared with observations from other semi-arid studies to explore the potential to use the results to constrain predictions of soil respiration for semi-arid ecosystems in general.

4.1. Comparison with Semi-arid Studies

The sites in this thesis exhibited similar trends in seasonal CO_2 flux with other semi-arid sites suggesting common processes and controls determine soil respiration (Carbone et al., 2008; Hibbard et al., 2005; Irvine and Law, 2002; Reichstein et al., 2003). The most representative group in the analysis of soil respiration in Hibbard *et al.* (2005), the WSV group (representing woodland/savannah and intercontinental and Mediterranean climates), had the lowest mean annual soil respiration at 0.80 (μmol m^{-2} s^{-1}) compared to mean soil respiration that ranged from 2.1 to 3.5 for the four other groups (representing temperate forests and grasslands). The correlations of soil respiration versus temperature exhibit hysteresis for the WSV sites similar to the sites in this study (Figure 3.4). The authors note that the negative influence of temperature on soil respiration is not a direct cause but reflects the interaction of soil moisture availability and temperature influencing soil respiration (Hibbard et al., 2005; Reichstein et al., 2003), which is similar to what is exhibited in Figure 3.5 for the Dry Creek sites. Climate variables and soil respiration, temperature, and moisture data are shown in Table 4.1 for similar sites to this study to show similarity.

Table 4.1. Site Comparison with Semi-arid Studies.
The values of soil respiration for sites GBS and JUN are on an annual basis as published in Hibbard *et al.* (2005). Since the upper and lower sites of this study were studied on a growing season basis, values are shown based on actual growing season data as well as model predicted annual estimates from "M Mod-Q_{10}, Exp-type" model (Equation 3.5).

Site Elev., MAT , MAP	Soil Respiration (μmol m^{-2} s^{-1})			Soil Temperature (^{o}C)			Soil Moisture VMC (m^{3} m^{-3})		
(m) (^{o}C) (mm)	**Mean**	Min	Max	**Mean**	Min	Max	**Mean**	Min	Max
GBS									
1650, 8.8, 299	**1.08**	0.25	2.96	**25**	9	43	**0.07**	0.03	0.19
JUN									
945, -- , --	**0.57**	0.18	1.51	**21**	7	33	**0.09**	0.05	0.16
Upper									
1600, 8.5, 570				**10**	-3	31	**0.08**	0.03	0.19
Growing Season:	**1.57**	0.65	2.84						
Predicted Annual:	**1.07**	0.33	3.56						
Lower									
1150, 11, 370				**11**	-4	32	**0.08**	0.00	0.20
Growing Season:	**1.11**	0.58	1.95						
Predicted Annual:	**0.94**	0.35	2.32						

A common characteristic of many semi-arid sites is a peak in CO_2 prior to the peak in soil temperature indicative of soil moisture limitation. At a regenerating semi-arid forest site (Irvine and Law, 2002), the flux dropped off before maximum soil temperatures where reached, attributed to soil moisture limitation in near surface soils and lack of deep rooting systems to access deep soil moisture. The shrub site of (Carbone et al., 2008) also exhibited pronounced summer soil respiration limitation. In contrast, at the adjacent grass site in Carbone *et al.* (2008), the early summer moisture limited decline in CO_2 was not observed. This divergence was attributed to access to deep soil moisture due to a higher water table for the grass site. Soil respiration limitation attributed to the lack of access to or availability of deep soil moisture is also exhibited by the WSV group of Hibbard *et al*. (2005); the lowest values of respiration corresponded to the highest values of temperature in summer for these sites with intercontinental and Mediterranean climates, which is in common with semi-arid systems and in contrast to the other temperate groups considered in the analysis. The sites in the study presented here are underlain by fractured bedrock and the water table is well below the soil-bedrock interface for all but a few weeks in early spring (Aishlin, 2007). Lack of access to deep soil moisture coupled with warm dry conditions meant that near-surface soil moisture status limited summer soil respiration rates for the Dry Creek sites.

4.2. Predicted Impact of Climate Change on Soil Respiration in this System

The soil respiration sensitivity to soil moisture depth suggests the aspect of climate variability that is most responsible for inter-annual variability in soil respiration. Sites sensitive to deep soil moisture would be sensitive to annual variability in total precipitation and in some cases, amount of annual snowpack and timing of snowmelt. Sites sensitive to near surface soil moisture would be more sensitive to variations in the timing and amounts of precipitation occurrence during the growing season, particularly during soil dry-down in spring, than annual precipitation amounts. Therefore, future impacts of climate variability of soil respiration can be constrained from the knowledge of soil moisture depth sensitivity of soil respiration. The results of this study suggest the Dry Creek sites are sensitive to near surface soil moisture status for the majority of the growing season.

These sites, which are sensitive to near surface soil moisture, will be most sensitive to changes in near surface soil temperature and moisture in late spring, as shown by inter-annual trends of model predictions (Section 3.4). Soil respiration during spring is positively influenced by both soil temperature and moisture, where each variable's status falls within a transition range between annual minimum and maximum values. Changes in climate that affect soil temperature and moisture patterns within the transitional moisture range will have the greatest effect on soil respiration processes. For example, earlier spring dry-down could shorten the period of optimum conditions for respiration and produce a decline in soil respiration. On the other hand, if spring precipitation events increase in combination with earlier soil warming trends, the soil respiration could increase. The overall impact of climate variability on atmospheric CO_2 concentration from these sites requires additional consideration of the impacts on primary production (CO_2 fixation by photosynthesis in plants) to determine whether the ecosystem is a net sink or source for atmospheric CO_2.

5. CONCLUSION

The results in this thesis confirmed previous sentiment from various semi-arid studies that soil moisture limitation exerts considerable control over soil respiration. Soil respiration was greatest in spring, influenced by soil temperature and moisture status each ranging within intermediary values with respect to their annual minimum and maximum values. The soil moisture limitation exhibited in this system was particularly sensitive to soil moisture status of near surface soils. In a model assessment of various formulations based on temperature dependent relationships, the models that included some form of moisture dependent modification performed better. The best model approach, "M-dep Arr-based" (Equations 3.10 – 3.13) of Reichstein *et al.* (2003), reflected the sensitivity to soil moisture status of near surface soils on soil respiration at intermediate to low soil moisture. This study elucidated an important aspect of semi-arid ecosystem modeling that significantly impacts predicted soil respiration: the degree to which soil respiration is dependent on near surface soil moisture. The sites in this study were dependent on near surface soil moisture for the majority of the growing season, which resulted in a peak in soil respiration before the peak in soil temperature, a characteristic common to many but not all semi-arid studies. With respect to future climate change variation, the dependence of these sites on near surface soil moisture means that site soil respiration would be sensitive to the patterns of soil temperature and moisture status during spring, which are more sensitive to timing and amounts of rain during the spring time period than to changes in annual precipitation trends.

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APPENDIX A

CO_2 Flux Measurements

Table A.1. CO_2 Flux Measurements
The column entitled "Per." stands for Period, which denotes the measurement period number for which the data belongs, a value of zero (0) indicates the measurement point was not used for the data analysis and modeling presented in this thesis. Measurements taken at the upper site are listed (page 82 to 99), the lower site (page 82 to 104), and additionally the Little Deer Point (LDP) site (page 99 to 106), the data for which was not used in this thesis.

Upper Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.	**Lower Site** Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.
3/13/2007 11:00	1.00	0	3/16/2007 14:00	4.06	0
3/13/2007 12:00	1.14	0	3/16/2007 15:00	3.54	0
3/13/2007 13:00	1.44	0			
3/13/2007 14:00	1.62	0	3/16/2007 17:00	2.49	0
3/13/2007 15:00	1.34	0	3/16/2007 18:00	2.05	0
3/13/2007 16:00	1.21	0	3/16/2007 19:00	1.93	0
3/13/2007 17:00	1.13	0	3/16/2007 20:00	1.67	0
3/13/2007 18:00	1.11	0	3/16/2007 21:00	1.42	0
3/13/2007 19:00	1.12	0	3/16/2007 22:00	1.27	0
3/13/2007 20:00	0.98	0	3/16/2007 23:00	1.40	0
3/13/2007 21:00	0.89	0	3/17/2007 0:00	1.16	0
3/13/2007 22:00	0.92	0	3/17/2007 1:00	1.12	0
3/13/2007 23:00	0.91	0	3/17/2007 2:00	1.06	0
3/14/2007 0:00	0.86	0	3/17/2007 3:00	1.03	0
3/14/2007 1:00	0.88	0	3/17/2007 4:00	1.08	0
3/14/2007 2:00	0.87	0	3/17/2007 5:00	1.08	0
3/14/2007 3:00	0.86	0	3/17/2007 6:00	1.00	0
3/14/2007 4:00	0.85	0	3/17/2007 7:00	1.02	0
3/14/2007 5:00	0.78	0	3/17/2007 8:00	0.90	0
3/14/2007 6:00	0.80	0	3/17/2007 9:00	1.20	0
3/14/2007 7:00	0.80	0	3/17/2007 10:00	1.66	0
3/14/2007 8:00	0.81	0	3/17/2007 11:00	2.09	0
3/14/2007 9:00	0.81	0	3/17/2007 12:00	2.63	0
3/14/2007 10:00	0.89	0			
3/14/2007 11:00	1.18	0	3/31/2007 13:00	1.68	0
3/14/2007 12:00	1.13	0	3/31/2007 14:00	1.65	0
3/14/2007 13:00	1.35	0	3/31/2007 15:00	1.57	0
3/14/2007 14:00	1.38	0	3/31/2007 16:00	1.40	0
3/14/2007 15:00	1.34	0	3/31/2007 17:00	1.37	0
3/14/2007 16:00	1.29	0	3/31/2007 18:00	1.34	0
3/14/2007 17:00	1.15	0	3/31/2007 19:00	1.42	0
3/14/2007 18:00	1.08	0	3/31/2007 20:00	1.25	0
3/14/2007 19:00	1.01	0	3/31/2007 21:00	1.64	0
3/14/2007 20:00	1.01	0	3/31/2007 22:00	1.34	0
3/14/2007 21:00	0.91	0	3/31/2007 23:00	1.80	0
3/14/2007 22:00	0.79	0	4/1/2007 0:00	1.33	0
3/14/2007 23:00	0.77	0	4/1/2007 1:00	1.21	0
3/15/2007 0:00	0.82	0	4/1/2007 2:00	0.95	0
3/15/2007 1:00	0.91	0	4/1/2007 3:00	0.92	0
3/15/2007 2:00	0.77	0	4/1/2007 4:00	0.82	0

Upper Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.	Lower Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.
3/15/2007 3:00	0.85	0	4/1/2007 5:00	0.89	0
3/15/2007 4:00	0.69	0	4/1/2007 6:00	0.73	0
3/15/2007 5:00	0.68	0	4/1/2007 7:00	0.84	0
3/15/2007 6:00	0.68	0	4/1/2007 8:00	1.16	0
3/15/2007 7:00	0.67	0	4/1/2007 9:00	1.21	0
3/15/2007 8:00	0.67	0	4/1/2007 10:00	1.57	0
3/15/2007 9:00	0.67	0	4/1/2007 11:00	1.65	0
3/15/2007 10:00	0.61	0	4/1/2007 12:00	1.83	0
3/15/2007 11:00	0.76	0	4/1/2007 13:00	1.50	0
3/15/2007 12:00	0.75	0	4/1/2007 14:00	1.44	0
3/15/2007 13:00	1.05	0	4/1/2007 15:00	1.46	0
3/15/2007 14:00	1.29	0	4/1/2007 16:00	1.24	0
3/15/2007 15:00	1.10	0	4/1/2007 17:00	1.27	0
3/15/2007 16:00	0.99	0	4/1/2007 18:00	1.51	0
3/15/2007 17:00	0.84	0	4/1/2007 19:00	1.59	0
3/15/2007 18:00	0.79	0	4/1/2007 20:00	1.33	0
3/15/2007 19:00	0.75	0	4/1/2007 21:00	1.18	0
			4/1/2007 22:00	1.26	0
4/4/2007 19:00	1.05	0	4/1/2007 23:00	1.37	0
			4/2/2007 0:00	1.31	0
4/4/2007 21:00	1.00	0	4/2/2007 1:00	1.20	0
4/4/2007 22:00	0.95	0	4/2/2007 2:00	1.17	0
			4/2/2007 3:00	1.17	0
4/8/2007 14:00	1.18	0	4/2/2007 4:00	1.78	0
			4/2/2007 5:00	1.18	0
4/9/2007 21:00	0.82	0	4/2/2007 6:00	0.98	0
4/9/2007 22:00	0.78	0	4/2/2007 7:00	0.81	0
4/9/2007 23:00	0.84	0	4/2/2007 8:00	0.93	0
4/10/2007 0:00	0.78	0	4/2/2007 9:00	1.10	0
4/10/2007 1:00	0.81	0	4/2/2007 10:00	1.24	0
4/10/2007 2:00	0.78	0	4/2/2007 11:00	1.22	0
4/10/2007 3:00	0.80	0	4/2/2007 12:00	1.69	0
4/10/2007 4:00	0.79	0	4/2/2007 13:00	1.65	0
4/10/2007 5:00	0.74	0	4/2/2007 14:00	1.49	0
4/10/2007 6:00	0.74	0	4/2/2007 15:00	1.42	0
4/10/2007 7:00	0.68	0	4/2/2007 16:00	1.73	0
4/10/2007 8:00	0.69	0	4/2/2007 17:00	1.10	0
4/10/2007 9:00	0.73	0	4/2/2007 18:00	1.00	0
4/10/2007 10:00	0.82	0	4/2/2007 19:00	1.08	0
4/10/2007 11:00	0.91	0	4/2/2007 20:00	0.94	0
4/10/2007 12:00	1.07	0	4/2/2007 21:00	0.75	0
4/10/2007 13:00	0.97	0	4/2/2007 22:00	0.71	0
4/10/2007 14:00	1.22	0	4/2/2007 23:00	0.65	0
4/10/2007 15:00	1.26	0	4/3/2007 0:00	0.71	0
4/10/2007 16:00	1.06	0	4/3/2007 1:00	0.55	0
4/10/2007 17:00	1.03	0	4/3/2007 2:00	0.60	0
4/10/2007 18:00	0.87	0	4/3/2007 3:00	0.65	0
4/10/2007 19:00	0.76	0	4/3/2007 4:00	0.54	0
4/10/2007 20:00	0.81	0	4/3/2007 5:00	0.50	0
4/10/2007 21:00	0.84	0	4/3/2007 6:00	0.38	0

Upper Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.	**Lower Site** Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.
4/10/2007 22:00	0.81	0	4/3/2007 7:00	0.49	0
4/10/2007 23:00	0.81	0	4/3/2007 8:00	0.67	0
4/11/2007 0:00	0.86	0	4/3/2007 9:00	0.84	0
4/11/2007 1:00	0.81	0	4/3/2007 10:00	1.10	0
4/11/2007 2:00	0.82	1	4/3/2007 11:00	1.63	1
4/11/2007 3:00	0.75	1	4/3/2007 12:00	1.58	1
4/11/2007 4:00	0.76	1	4/3/2007 13:00	1.63	1
4/11/2007 5:00	0.82	1	4/3/2007 14:00	1.63	1
4/11/2007 6:00	0.70	1	4/3/2007 15:00	1.44	1
4/11/2007 7:00	0.79	1	4/3/2007 16:00	1.29	1
4/11/2007 8:00	0.77	1	4/3/2007 17:00	1.15	1
4/11/2007 9:00	0.80	1	4/3/2007 18:00	1.10	1
4/11/2007 10:00	0.96	1	4/3/2007 19:00	1.00	1
4/11/2007 11:00	1.21	1	4/3/2007 20:00	0.93	1
4/11/2007 12:00	1.18	1	4/3/2007 21:00	0.91	1
4/11/2007 13:00	1.59	1	4/3/2007 22:00	0.84	1
4/11/2007 14:00	1.60	1	4/3/2007 23:00	0.84	1
4/11/2007 15:00	1.38	1	4/4/2007 0:00	0.78	1
4/11/2007 16:00	1.33	1	4/4/2007 1:00	0.82	1
4/11/2007 17:00	1.09	1	4/4/2007 2:00	0.73	1
4/11/2007 18:00	0.98	1	4/4/2007 3:00	0.63	1
4/11/2007 19:00	1.00	1	4/4/2007 4:00	0.66	1
4/11/2007 20:00	1.03	1	4/4/2007 5:00	0.55	1
4/11/2007 21:00	0.97	1	4/4/2007 6:00	0.55	1
4/11/2007 22:00	0.94	1	4/4/2007 7:00	0.62	1
4/11/2007 23:00	0.94	1	4/4/2007 8:00	0.90	1
4/12/2007 0:00	1.00	1	4/4/2007 9:00	1.14	1
4/12/2007 1:00	0.93	1	4/4/2007 10:00	1.52	1
4/12/2007 2:00	0.92	0	4/4/2007 11:00	1.81	0
4/12/2007 3:00	0.88	0	4/4/2007 12:00	1.84	0
4/12/2007 4:00	0.91	0	4/4/2007 13:00	1.70	0
4/12/2007 5:00	0.83	0	4/4/2007 14:00	1.64	0
4/12/2007 6:00	0.83	0	4/4/2007 15:00	1.60	0
4/12/2007 7:00	0.75	0	4/4/2007 16:00	1.64	0
4/12/2007 8:00	0.90	0	4/4/2007 17:00	1.42	0
4/12/2007 9:00	0.88	0			
4/12/2007 10:00	1.12	0	4/19/2007 12:00	1.80	0
			4/19/2007 13:00	2.47	0
4/24/2007 13:00	2.42	0	4/19/2007 14:00	2.33	0
4/24/2007 14:00	2.42	0	4/19/2007 15:00	2.12	0
4/24/2007 15:00	2.26	0	4/19/2007 16:00	1.93	0
4/24/2007 16:00	2.18	0	4/19/2007 17:00	1.61	0
4/24/2007 17:00	1.82	0	4/19/2007 18:00	1.33	0
4/24/2007 18:00	1.66	0	4/19/2007 19:00	1.22	0
4/24/2007 19:00	1.53	0	4/19/2007 20:00	1.06	0
4/24/2007 20:00	1.65	0	4/19/2007 21:00	1.08	0
4/24/2007 21:00	1.51	0	4/19/2007 22:00	1.08	0
4/24/2007 22:00	1.42	0	4/19/2007 23:00	0.88	0
4/24/2007 23:00	1.43	0	4/20/2007 0:00	1.02	0
4/25/2007 0:00	1.45	0	4/20/2007 1:00	0.89	0

Upper Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.	**Lower Site** Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.
4/25/2007 1:00	1.48	0	4/20/2007 2:00	0.90	0
4/25/2007 2:00	1.40	2	4/20/2007 3:00	0.79	0
4/25/2007 3:00	1.40	2	4/20/2007 4:00	0.66	0
4/25/2007 4:00	1.36	2	4/20/2007 5:00	0.60	0
4/25/2007 5:00	1.40	2	4/20/2007 6:00	0.61	0
4/25/2007 6:00	1.33	2	4/20/2007 7:00	0.57	0
4/25/2007 7:00	1.29	2	4/20/2007 8:00	0.81	0
4/25/2007 8:00	1.48	2	4/20/2007 9:00	1.07	0
4/25/2007 9:00	1.64	2	4/20/2007 10:00	1.13	0
4/25/2007 10:00	1.60	2	4/20/2007 11:00	1.78	0
4/25/2007 11:00	1.75	2	4/20/2007 12:00	2.02	0
4/25/2007 12:00	2.04	2	4/20/2007 13:00	2.69	0
4/25/2007 13:00	2.09	2	4/20/2007 14:00	2.68	0
4/25/2007 14:00	2.34	2	4/20/2007 15:00	2.28	0
4/25/2007 15:00	2.25	2	4/20/2007 16:00	1.70	0
4/25/2007 16:00	2.21	2	4/20/2007 17:00	2.06	0
4/25/2007 17:00	1.84	2	4/20/2007 18:00	1.68	0
4/25/2007 18:00	1.75	2	4/20/2007 19:00	1.44	2
4/25/2007 19:00	1.62	2	4/20/2007 20:00	1.13	2
4/25/2007 20:00	1.58	2	4/20/2007 21:00	1.07	2
4/25/2007 21:00	1.48	2	4/20/2007 22:00	0.99	2
4/25/2007 22:00	1.42	2	4/20/2007 23:00	1.06	2
4/25/2007 23:00	1.43	2	4/21/2007 0:00	1.05	2
4/26/2007 0:00	1.40	2	4/21/2007 1:00	0.95	2
4/26/2007 1:00	1.36	2	4/21/2007 2:00	1.03	2
4/26/2007 2:00	1.31	2	4/21/2007 3:00	1.10	2
4/26/2007 3:00	1.24	2	4/21/2007 4:00	0.76	2
4/26/2007 4:00	1.23	2	4/21/2007 5:00	0.64	2
4/26/2007 5:00	1.20	2	4/21/2007 6:00	0.68	2
4/26/2007 6:00	1.13	2	4/21/2007 7:00	0.63	2
4/26/2007 7:00	1.19	2	4/21/2007 8:00	0.79	2
4/26/2007 8:00	1.40	2	4/21/2007 9:00	1.01	2
4/26/2007 9:00	1.60	2	4/21/2007 10:00	1.18	2
4/26/2007 10:00	1.86	2	4/21/2007 11:00	1.59	2
4/26/2007 11:00	1.91	2	4/21/2007 12:00	1.76	2
4/26/2007 12:00	2.24	2	4/21/2007 13:00	1.71	2
4/26/2007 13:00	2.35	2	4/21/2007 14:00	1.53	2
4/26/2007 14:00	2.33	2	4/21/2007 15:00	1.38	2
4/26/2007 15:00	2.21	2	4/21/2007 16:00	1.55	2
4/26/2007 16:00	2.08	2	4/21/2007 17:00	1.30	2
4/26/2007 17:00	1.88	2	4/21/2007 18:00	1.31	2
4/26/2007 18:00	1.67	2	4/21/2007 19:00	1.25	0
4/26/2007 19:00	1.58	2	4/21/2007 20:00	1.19	0
4/26/2007 20:00	1.58	2	4/21/2007 21:00	1.19	0
4/26/2007 21:00	1.59	2	4/21/2007 22:00	1.15	0
4/26/2007 22:00	1.45	2	4/21/2007 23:00	1.24	0
4/26/2007 23:00	1.53	2	4/22/2007 0:00	1.59	0
4/27/2007 0:00	1.41	2	4/22/2007 1:00	1.77	0
4/27/2007 1:00	1.42	2	4/22/2007 2:00	1.64	0
4/27/2007 2:00	1.53	0	4/22/2007 3:00	1.70	0

Upper Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.	**Lower Site** Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.
4/27/2007 3:00	1.39	0	4/22/2007 4:00	1.80	0
4/27/2007 4:00	1.37	0	4/22/2007 5:00	2.17	0
			4/22/2007 6:00	1.51	0
5/8/2007 13:00	3.20	0	4/22/2007 7:00	1.49	0
5/8/2007 14:00	3.24	0	4/22/2007 8:00	1.40	0
5/8/2007 15:00	3.15	0	4/22/2007 9:00	1.71	0
5/8/2007 16:00	3.00	0	4/22/2007 10:00	1.96	0
5/8/2007 17:00	2.60	0	4/22/2007 11:00	2.18	0
5/8/2007 18:00	2.47	0	4/22/2007 12:00	1.88	0
5/8/2007 19:00	2.38	0	4/22/2007 13:00	2.11	0
5/8/2007 20:00	2.31	0	4/22/2007 14:00	2.38	0
5/8/2007 21:00	2.33	3	4/22/2007 15:00	2.87	0
5/8/2007 22:00	2.11	3	4/22/2007 16:00	2.97	0
5/8/2007 23:00	2.12	3	4/22/2007 17:00	2.39	0
5/9/2007 0:00	2.04	3	4/22/2007 18:00	6.04	0
5/9/2007 1:00	2.03	3	4/22/2007 19:00	3.70	0
5/9/2007 2:00	1.91	3	4/22/2007 20:00	2.06	0
5/9/2007 3:00	1.94	3	4/22/2007 21:00	2.45	0
5/9/2007 4:00	2.05	3	4/22/2007 22:00	2.34	0
5/9/2007 5:00	1.67	3	4/22/2007 23:00	1.83	0
5/9/2007 6:00	1.67	3	4/23/2007 0:00	1.65	0
5/9/2007 7:00	1.68	3	4/23/2007 1:00	1.78	0
5/9/2007 8:00	2.12	3	4/23/2007 2:00	1.73	0
5/9/2007 9:00	2.22	3	4/23/2007 3:00	1.57	0
5/9/2007 10:00	2.44	3	4/23/2007 4:00	1.47	0
5/9/2007 11:00	2.70	3	4/23/2007 5:00	1.30	0
5/9/2007 12:00	2.88	3	4/23/2007 6:00	1.00	0
5/9/2007 13:00	3.00	3	4/23/2007 7:00	1.24	0
5/9/2007 14:00	3.10	3	4/23/2007 8:00	1.30	0
5/9/2007 15:00	3.19	3	4/23/2007 9:00	1.98	0
5/9/2007 16:00	2.98	3	4/23/2007 10:00	2.70	0
5/9/2007 17:00	2.57	3	4/23/2007 11:00	3.44	0
5/9/2007 18:00	2.66	3	4/23/2007 12:00	3.56	0
5/9/2007 19:00	2.29	3	4/23/2007 13:00	3.22	0
5/9/2007 20:00	2.29	3	4/23/2007 14:00	2.85	0
5/9/2007 21:00	2.31	3	4/23/2007 15:00	2.56	0
5/9/2007 22:00	2.19	3	4/23/2007 16:00	2.78	0
5/9/2007 23:00	2.13	3	4/23/2007 17:00	3.35	0
5/10/2007 0:00	2.00	3	4/23/2007 18:00	3.13	0
5/10/2007 1:00	2.14	3	4/23/2007 19:00	2.48	0
5/10/2007 2:00	1.97	3	4/23/2007 20:00	2.86	0
5/10/2007 3:00	1.88	3	4/23/2007 21:00	2.91	0
5/10/2007 4:00	1.89	3	4/23/2007 22:00	2.81	0
5/10/2007 5:00	1.95	3	4/23/2007 23:00	1.81	0
5/10/2007 6:00	1.90	3	4/24/2007 0:00	1.15	0
5/10/2007 7:00	1.84	3	4/24/2007 1:00	0.87	0
5/10/2007 8:00	1.82	3	4/24/2007 2:00	0.95	0
5/10/2007 9:00	2.24	3	4/24/2007 3:00	0.85	0
5/10/2007 10:00	2.22	3	4/24/2007 4:00	0.93	0
5/10/2007 11:00	2.20	3	4/24/2007 5:00	0.84	0

Upper Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.	**Lower Site** Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.
5/10/2007 12:00	2.64	3	4/24/2007 6:00	0.95	0
5/10/2007 13:00	2.78	3	4/24/2007 7:00	1.12	0
5/10/2007 14:00	2.85	3	4/24/2007 8:00	1.39	0
5/10/2007 15:00	2.88	3	4/24/2007 9:00	1.68	0
5/10/2007 16:00	2.81	3			
5/10/2007 17:00	2.44	3	5/12/2007 14:00	3.70	0
5/10/2007 18:00	2.42	3	5/12/2007 15:00	3.09	0
5/10/2007 19:00	2.43	3	5/12/2007 16:00	3.09	0
5/10/2007 20:00	2.24	3	5/12/2007 17:00	3.43	0
			5/12/2007 18:00	2.59	0
5/11/2007 13:00	3.35	0	5/12/2007 19:00	2.04	0
5/11/2007 14:00	2.99	0	5/12/2007 20:00	3.59	0
			5/12/2007 21:00	2.76	0
5/27/2007 16:00	2.12	4	5/12/2007 22:00	3.45	0
5/27/2007 17:00	2.05	4	5/12/2007 23:00	1.87	0
5/27/2007 18:00	2.10	4	5/13/2007 0:00	2.38	0
5/27/2007 19:00	2.00	4	5/13/2007 1:00	1.43	0
5/27/2007 20:00	1.91	4	5/13/2007 2:00	1.85	0
5/27/2007 21:00	1.89	4	5/13/2007 3:00	1.46	0
5/27/2007 22:00	1.80	4	5/13/2007 4:00	1.59	0
5/27/2007 23:00	1.53	4	5/13/2007 5:00	2.89	0
5/28/2007 0:00	1.62	4	5/13/2007 6:00	1.94	0
5/28/2007 1:00	1.64	4	5/13/2007 7:00	1.76	0
5/28/2007 2:00	1.52	4	5/13/2007 8:00	1.93	0
5/28/2007 3:00	1.51	4	5/13/2007 9:00	2.27	0
5/28/2007 4:00	1.61	4	5/13/2007 10:00	2.28	0
5/28/2007 5:00	1.45	4	5/13/2007 11:00	2.90	0
5/28/2007 6:00	1.33	4	5/13/2007 12:00	3.05	0
5/28/2007 7:00	1.47	4	5/13/2007 13:00	4.37	0
5/28/2007 8:00	1.50	4	5/13/2007 14:00	2.84	0
5/28/2007 9:00	1.52	4	5/13/2007 15:00	2.48	0
5/28/2007 10:00	1.66	4	5/13/2007 16:00	2.89	0
5/28/2007 11:00	1.71	4	5/13/2007 17:00	3.05	0
5/28/2007 12:00	1.80	4	5/13/2007 18:00	2.80	0
5/28/2007 13:00	1.84	4	5/13/2007 19:00	2.42	0
5/28/2007 14:00	1.80	4	5/13/2007 20:00	3.01	0
5/28/2007 15:00	1.91	4	5/13/2007 21:00	2.84	0
5/28/2007 16:00	1.86	4	5/13/2007 22:00	1.81	0
5/28/2007 17:00	1.77	4	5/13/2007 23:00	2.83	0
5/28/2007 18:00	1.64	4	5/14/2007 0:00	1.70	0
5/28/2007 19:00	1.60	4	5/14/2007 1:00	1.02	0
5/28/2007 20:00	1.54	4	5/14/2007 2:00	1.03	0
5/28/2007 21:00	1.53	4	5/14/2007 3:00	0.89	0
5/28/2007 22:00	1.57	4	5/14/2007 4:00	0.72	0
5/28/2007 23:00	1.45	4	5/14/2007 5:00	0.88	0
5/29/2007 0:00	1.50	4	5/14/2007 6:00	0.82	0
5/29/2007 1:00	1.50	4	5/14/2007 7:00	1.08	0
5/29/2007 2:00	1.51	4	5/14/2007 8:00	1.39	0
5/29/2007 3:00	1.45	4	5/14/2007 9:00	1.72	0
5/29/2007 4:00	1.62	4	5/14/2007 10:00	1.89	0

Upper Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.	**Lower Site** Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.
5/29/2007 5:00	1.35	4	5/14/2007 11:00	2.47	0
5/29/2007 6:00	1.56	4	5/14/2007 12:00	2.29	0
5/29/2007 7:00	1.43	4	5/14/2007 13:00	2.51	0
5/29/2007 8:00	1.52	4	5/14/2007 14:00	2.44	0
5/29/2007 9:00	1.51	4	5/14/2007 15:00	2.68	0
5/29/2007 10:00	1.58	4	5/14/2007 16:00	2.52	0
5/29/2007 11:00	1.66	4	5/14/2007 17:00	2.50	0
5/29/2007 12:00	1.74	4	5/14/2007 18:00	2.55	0
5/29/2007 13:00	1.76	4	5/14/2007 19:00	2.09	0
5/29/2007 14:00	1.77	4	5/14/2007 20:00	2.10	0
5/29/2007 15:00	1.85	4	5/14/2007 21:00	1.44	0
5/29/2007 16:00	1.86	0	5/14/2007 22:00	1.42	0
5/29/2007 17:00	1.72	0	5/14/2007 23:00	1.22	0
5/29/2007 18:00	1.62	0	5/15/2007 0:00	1.07	0
5/29/2007 19:00	1.54	0	5/15/2007 1:00	0.85	0
5/29/2007 20:00	1.56	0	5/15/2007 2:00	0.86	0
5/29/2007 21:00	1.57	0	5/15/2007 3:00	0.83	0
5/29/2007 22:00	1.51	0	5/15/2007 4:00	0.79	0
5/29/2007 23:00	1.45	0	5/15/2007 5:00	0.86	0
5/30/2007 0:00	1.78	0	5/15/2007 6:00	0.78	0
5/30/2007 1:00	1.69	0	5/15/2007 7:00	0.97	0
5/30/2007 2:00	1.69	0	5/15/2007 8:00	1.42	0
5/30/2007 3:00	1.47	0	5/15/2007 9:00	1.73	0
5/30/2007 4:00	1.51	0	5/15/2007 10:00	2.01	0
5/30/2007 5:00	1.53	0	5/15/2007 11:00	2.19	0
5/30/2007 6:00	1.43	0	5/15/2007 12:00	2.52	0
5/30/2007 7:00	1.50	0	5/15/2007 13:00	2.58	0
5/30/2007 8:00	1.61	0	5/15/2007 14:00	2.66	3
5/30/2007 9:00	1.63	0	5/15/2007 15:00	2.73	3
			5/15/2007 16:00	2.54	3
6/12/2007 15:00	3.94	0	5/15/2007 17:00	2.20	3
6/12/2007 16:00	3.55	0	5/15/2007 18:00	1.94	3
6/12/2007 17:00	3.21	0	5/15/2007 19:00	1.71	3
6/12/2007 18:00	3.06	0	5/15/2007 20:00	1.54	3
6/12/2007 19:00	3.07	0	5/15/2007 21:00	1.58	3
6/12/2007 20:00	2.94	0	5/15/2007 22:00	1.40	3
6/12/2007 21:00	2.80	0	5/15/2007 23:00	1.14	3
6/12/2007 22:00	2.74	0	5/16/2007 0:00	1.24	3
6/12/2007 23:00	2.60	0	5/16/2007 1:00	1.04	3
6/13/2007 0:00	2.56	0	5/16/2007 2:00	1.00	3
6/13/2007 1:00	2.64	5	5/16/2007 3:00	0.94	3
6/13/2007 2:00	2.39	5	5/16/2007 4:00	0.82	3
6/13/2007 3:00	2.44	5	5/16/2007 5:00	0.96	3
6/13/2007 4:00	2.49	5	5/16/2007 6:00	0.86	3
6/13/2007 5:00	2.29	5	5/16/2007 7:00	1.17	3
6/13/2007 6:00	2.39	5	5/16/2007 8:00	1.56	3
6/13/2007 7:00	2.34	5	5/16/2007 9:00	1.85	3
6/13/2007 8:00	2.44	5	5/16/2007 10:00	2.20	3
6/13/2007 9:00	2.52	5	5/16/2007 11:00	2.49	3
6/13/2007 10:00	2.62	5	5/16/2007 12:00	2.62	3

Upper Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.	**Lower Site** Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.
6/13/2007 11:00	2.94	5	5/16/2007 13:00	2.84	3
6/13/2007 12:00	3.12	5	5/16/2007 14:00	2.81	3
6/13/2007 13:00	3.33	5	5/16/2007 15:00	2.83	3
6/13/2007 14:00	3.41	5	5/16/2007 16:00	2.75	3
6/13/2007 15:00	3.47	5	5/16/2007 17:00	2.41	3
6/13/2007 16:00	3.49	5	5/16/2007 18:00	2.13	3
6/13/2007 17:00	3.22	5	5/16/2007 19:00	1.81	3
6/13/2007 18:00	3.27	5	5/16/2007 20:00	1.58	3
6/13/2007 19:00	3.16	5	5/16/2007 21:00	1.51	3
6/13/2007 20:00	3.02	5	5/16/2007 22:00	1.62	3
6/13/2007 21:00	2.92	5	5/16/2007 23:00	1.62	3
6/13/2007 22:00	2.79	5	5/17/2007 0:00	1.31	3
6/13/2007 23:00	2.83	5	5/17/2007 1:00	1.15	3
6/14/2007 0:00	2.51	5	5/17/2007 2:00	1.15	3
			5/17/2007 3:00	0.99	3
6/24/2007 15:00	2.66	6	5/17/2007 4:00	0.94	3
6/24/2007 16:00	2.70	6	5/17/2007 5:00	0.90	3
6/24/2007 17:00	2.54	6	5/17/2007 6:00	0.89	3
6/24/2007 18:00	2.68	6	5/17/2007 7:00	1.12	3
6/24/2007 19:00	2.50	6	5/17/2007 8:00	1.68	3
6/24/2007 20:00	2.39	6	5/17/2007 9:00	1.77	3
6/24/2007 21:00	2.64	6	5/17/2007 10:00	2.18	3
6/24/2007 22:00	2.17	6	5/17/2007 11:00	2.39	3
6/24/2007 23:00	2.15	6	5/17/2007 12:00	2.36	3
6/25/2007 0:00	2.24	6	5/17/2007 13:00	2.65	3
6/25/2007 1:00	2.15	6	5/17/2007 14:00	2.86	3
6/25/2007 2:00	2.04	6	5/17/2007 15:00	3.52	3
6/25/2007 3:00	2.07	6	5/17/2007 16:00	2.69	3
6/25/2007 4:00	1.91	6	5/17/2007 17:00	3.10	3
6/25/2007 5:00	1.91	6	5/17/2007 18:00	2.36	3
6/25/2007 6:00	1.88	6	5/17/2007 19:00	2.19	3
6/25/2007 7:00	2.01	6	5/17/2007 20:00	1.65	3
6/25/2007 8:00	2.01	6	5/17/2007 21:00	1.59	3
6/25/2007 9:00	2.01	6	5/17/2007 22:00	1.77	3
6/25/2007 10:00	2.06	6	5/17/2007 23:00	2.02	3
6/25/2007 11:00	2.07	6	5/18/2007 0:00	1.68	3
6/25/2007 12:00	2.12	6	5/18/2007 1:00	1.71	3
6/25/2007 13:00	2.18	6	5/18/2007 2:00	1.12	3
6/25/2007 14:00	2.27	6	5/18/2007 3:00	1.05	3
6/25/2007 15:00	2.30	6	5/18/2007 4:00	1.13	3
6/25/2007 16:00	2.23	6	5/18/2007 5:00	1.01	3
6/25/2007 17:00	2.16	6	5/18/2007 6:00	0.93	3
6/25/2007 18:00	2.36	6	5/18/2007 7:00	1.36	3
6/25/2007 19:00	2.25	6	5/18/2007 8:00	1.69	3
6/25/2007 20:00	2.17	6	5/18/2007 9:00	2.01	3
6/25/2007 21:00	2.03	6	5/18/2007 10:00	2.26	3
6/25/2007 22:00	2.00	6	5/18/2007 11:00	2.47	3
6/25/2007 23:00	2.08	6	5/18/2007 12:00	2.76	3
6/26/2007 0:00	1.95	6	5/18/2007 13:00	2.84	3
6/26/2007 1:00	1.94	6	5/18/2007 14:00	3.00	0

Upper Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux ($\mu mol\ m^{-2}\ s^{-1}$)	Per.	**Lower Site** Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux ($\mu mol\ m^{-2}\ s^{-1}$)	Per.
6/26/2007 2:00	1.88	6	5/18/2007 15:00	2.68	0
6/26/2007 3:00	1.95	6	5/18/2007 16:00	2.41	0
6/26/2007 4:00	1.94	6	5/18/2007 17:00	2.88	0
6/26/2007 5:00	1.83	6	5/18/2007 18:00	2.09	0
6/26/2007 6:00	1.85	6	5/18/2007 19:00	1.68	0
6/26/2007 7:00	1.87	6	5/18/2007 20:00	1.94	0
6/26/2007 8:00	1.89	6	5/18/2007 21:00	1.63	0
6/26/2007 9:00	1.93	6	5/18/2007 22:00	1.34	0
6/26/2007 10:00	1.89	6	5/18/2007 23:00	1.20	0
6/26/2007 11:00	2.01	6	5/19/2007 0:00	1.27	0
6/26/2007 12:00	2.13	6	5/19/2007 1:00	1.20	0
6/26/2007 13:00	2.17	6	5/19/2007 2:00	1.66	0
6/26/2007 14:00	2.18	6	5/19/2007 3:00	1.21	0
6/26/2007 15:00	2.27	6	5/19/2007 4:00	1.27	0
6/26/2007 16:00	2.36	6	5/19/2007 5:00	1.37	0
6/26/2007 17:00	2.17	6	5/19/2007 6:00	1.13	0
6/26/2007 18:00	2.19	6	5/19/2007 7:00	1.19	0
6/26/2007 19:00	2.29	6	5/19/2007 8:00	1.38	0
6/26/2007 20:00	2.15	6	5/19/2007 9:00	2.01	0
6/26/2007 21:00	2.12	6	5/19/2007 10:00	2.32	0
6/26/2007 22:00	1.96	6	5/19/2007 11:00	2.22	0
6/26/2007 23:00	2.17	6	5/19/2007 12:00	2.88	0
6/27/2007 0:00	2.18	6	5/19/2007 13:00	2.98	0
6/27/2007 1:00	2.12	6	5/19/2007 14:00	2.49	0
6/27/2007 2:00	2.09	6	5/19/2007 15:00	2.33	0
6/27/2007 3:00	2.32	6	5/19/2007 16:00	3.37	0
6/27/2007 4:00	1.92	6	5/19/2007 17:00	4.13	0
6/27/2007 5:00	2.31	6	5/19/2007 18:00	2.98	0
6/27/2007 6:00	1.88	6	5/19/2007 19:00	2.68	0
6/27/2007 7:00	1.92	6	5/19/2007 20:00	2.55	0
6/27/2007 8:00	2.02	6	5/19/2007 21:00	2.18	0
6/27/2007 9:00	2.03	6	5/19/2007 22:00	1.66	0
6/27/2007 10:00	1.94	6	5/19/2007 23:00	1.30	0
6/27/2007 11:00	2.07	6	5/20/2007 0:00	1.33	0
6/27/2007 12:00	2.22	6	5/20/2007 1:00	1.17	0
6/27/2007 13:00	2.22	6	5/20/2007 2:00	1.43	0
6/27/2007 14:00	2.29	6	5/20/2007 3:00	1.36	0
6/27/2007 15:00	2.32	0	5/20/2007 4:00	1.36	0
6/27/2007 16:00	2.27	0	5/20/2007 5:00	1.53	0
6/27/2007 17:00	2.31	0	5/20/2007 6:00	1.20	0
6/27/2007 18:00	2.30	0	5/20/2007 7:00	1.21	0
6/27/2007 19:00	2.20	0	5/20/2007 8:00	1.62	0
6/27/2007 20:00	2.09	0	5/20/2007 9:00	1.92	0
6/27/2007 21:00	2.15	0	5/20/2007 10:00	2.86	0
6/27/2007 22:00	2.14	0	5/20/2007 11:00	3.30	0
6/27/2007 23:00	2.43	0	5/20/2007 12:00	2.79	0
6/28/2007 0:00	2.23	0	5/20/2007 13:00	2.46	0
6/28/2007 1:00	2.17	0	5/20/2007 14:00	2.20	0
6/28/2007 2:00	2.19	0	5/20/2007 15:00	2.14	0
6/28/2007 3:00	1.99	0	5/20/2007 16:00	1.79	0

Upper Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.	Lower Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.
6/28/2007 4:00	2.37	0	5/20/2007 17:00	2.77	0
6/28/2007 5:00	1.91	0	5/20/2007 18:00	4.38	0
6/28/2007 6:00	2.02	0	5/20/2007 19:00	2.34	0
6/28/2007 7:00	1.97	0	5/20/2007 20:00	2.23	0
6/28/2007 8:00	1.99	0	5/20/2007 21:00	2.25	0
			5/20/2007 22:00	2.20	0
7/9/2007 16:00	1.71	7	5/20/2007 23:00	1.82	0
7/9/2007 17:00	1.60	7	5/21/2007 0:00	1.55	0
7/9/2007 18:00	1.75	7	5/21/2007 1:00	1.58	0
7/9/2007 19:00	1.54	7	5/21/2007 2:00	1.33	0
7/9/2007 20:00	1.60	7	5/21/2007 3:00	1.36	0
7/9/2007 21:00	1.51	7	5/21/2007 4:00	1.47	0
7/9/2007 22:00	1.62	7	5/21/2007 5:00	2.70	0
7/9/2007 23:00	1.58	7	5/21/2007 6:00	2.53	0
7/10/2007 0:00	1.48	7	5/21/2007 7:00	2.20	0
7/10/2007 1:00	1.56	7	5/21/2007 8:00	2.95	0
7/10/2007 2:00	1.54	7	5/21/2007 9:00	2.85	0
7/10/2007 3:00	1.58	7	5/21/2007 10:00	2.46	0
7/10/2007 4:00	1.80	7	5/21/2007 11:00	2.19	0
7/10/2007 5:00	1.55	7	5/21/2007 12:00	2.45	0
7/10/2007 6:00	1.59	7	5/21/2007 13:00	2.65	0
7/10/2007 7:00	1.53	7	5/21/2007 14:00	3.87	0
7/10/2007 8:00	1.52	7	5/21/2007 15:00	2.81	0
7/10/2007 9:00	1.59	7	5/21/2007 16:00	2.52	0
7/10/2007 10:00	1.54	7	5/21/2007 17:00	2.16	0
7/10/2007 11:00	1.72	7	5/21/2007 18:00	2.80	0
7/10/2007 12:00	1.59	7	5/21/2007 19:00	2.43	0
7/10/2007 13:00	1.62	7	5/21/2007 20:00	2.56	0
7/10/2007 14:00	1.60	7	5/21/2007 21:00	2.04	0
7/10/2007 15:00	1.61	7	5/21/2007 22:00	2.06	0
7/10/2007 16:00	1.55	7	5/21/2007 23:00	3.03	0
7/10/2007 17:00	1.63	7	5/22/2007 0:00	3.20	0
7/10/2007 18:00	1.57	7	5/22/2007 1:00	2.82	0
7/10/2007 19:00	1.47	7	5/22/2007 2:00	2.63	0
7/10/2007 20:00	1.54	7	5/22/2007 3:00	2.38	0
7/10/2007 21:00	1.63	7	5/22/2007 4:00	1.71	0
7/10/2007 22:00	1.67	7	5/22/2007 5:00	2.05	0
7/10/2007 23:00	1.47	7	5/22/2007 6:00	1.53	0
7/11/2007 0:00	1.53	7	5/22/2007 7:00	1.81	0
7/11/2007 1:00	1.48	7	5/22/2007 8:00	3.45	0
7/11/2007 2:00	1.48	7	5/22/2007 9:00	5.26	0
7/11/2007 3:00	1.62	7	5/22/2007 10:00	5.56	0
7/11/2007 4:00	1.47	7	5/22/2007 11:00	2.94	0
7/11/2007 5:00	1.40	7	5/22/2007 12:00	5.06	0
7/11/2007 6:00	1.44	7	5/22/2007 13:00	4.14	0
7/11/2007 7:00	1.49	7	5/22/2007 14:00	4.25	0
7/11/2007 8:00	1.54	7	5/22/2007 15:00	2.48	0
7/11/2007 9:00	1.56	7	5/22/2007 16:00	2.13	0
7/11/2007 10:00	1.46	7	5/22/2007 17:00	2.65	0
7/11/2007 11:00	1.48	7	5/22/2007 18:00	2.70	0

Upper Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.	Lower Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.
7/11/2007 12:00	1.48	7	5/22/2007 19:00	4.71	0
7/11/2007 13:00	1.55	7	5/22/2007 20:00	3.17	0
7/11/2007 14:00	1.57	7	5/22/2007 21:00	3.65	0
7/11/2007 15:00	1.53	7	5/22/2007 22:00	2.17	0
7/11/2007 16:00	1.55	7	5/22/2007 23:00	1.77	0
7/11/2007 17:00	1.61	7	5/23/2007 0:00	2.13	0
7/11/2007 18:00	1.53	7	5/23/2007 1:00	1.32	0
7/11/2007 19:00	1.54	7	5/23/2007 2:00	1.07	0
7/11/2007 20:00	1.55	7	5/23/2007 3:00	1.11	0
7/11/2007 21:00	1.58	7	5/23/2007 4:00	1.04	0
7/11/2007 22:00	1.45	7	5/23/2007 5:00	0.86	0
7/11/2007 23:00	1.39	7	5/23/2007 6:00	0.91	0
7/12/2007 0:00	1.51	7	5/23/2007 7:00	1.28	0
7/12/2007 1:00	1.60	7	5/23/2007 8:00	1.60	0
7/12/2007 2:00	1.71	7	5/23/2007 9:00	1.95	0
7/12/2007 3:00	1.36	7			
7/12/2007 4:00	1.30	7	5/30/2007 12:00	2.41	0
7/12/2007 5:00	1.47	7	5/30/2007 13:00	2.35	0
7/12/2007 6:00	1.43	7	5/30/2007 14:00	2.55	0
7/12/2007 7:00	1.44	7	5/30/2007 15:00	2.51	0
7/12/2007 8:00	1.43	7	5/30/2007 16:00	2.86	0
7/12/2007 9:00	1.41	7	5/30/2007 17:00	2.57	0
7/12/2007 10:00	1.45	7			
7/12/2007 11:00	1.44	7	6/3/2007 16:00	2.25	4
7/12/2007 12:00	1.42	0	6/3/2007 17:00	2.24	4
7/12/2007 13:00	1.49	0	6/3/2007 18:00	1.95	4
7/12/2007 14:00	1.45	0	6/3/2007 19:00	1.69	4
7/12/2007 15:00	1.49	0	6/3/2007 20:00	1.50	4
7/12/2007 16:00	1.49	0	6/3/2007 21:00	1.39	4
7/12/2007 17:00	1.45	0	6/3/2007 22:00	1.38	4
7/12/2007 18:00	1.38	0	6/3/2007 23:00	1.19	4
7/12/2007 19:00	1.43	0	6/4/2007 0:00	1.17	4
7/12/2007 20:00	1.41	0	6/4/2007 1:00	1.29	4
7/12/2007 21:00	1.42	0	6/4/2007 2:00	1.03	4
7/12/2007 22:00	1.55	0	6/4/2007 3:00	0.99	4
7/12/2007 23:00	1.47	0	6/4/2007 4:00	1.00	4
7/13/2007 0:00	1.55	0	6/4/2007 5:00	1.35	4
7/13/2007 1:00	1.44	0	6/4/2007 6:00	1.27	4
7/13/2007 2:00	1.37	0	6/4/2007 7:00	1.51	4
7/13/2007 3:00	1.39	0	6/4/2007 8:00	1.65	4
7/13/2007 4:00	1.39	0	6/4/2007 9:00	1.66	4
7/13/2007 5:00	1.35	0	6/4/2007 10:00	1.67	4
7/13/2007 6:00	1.42	0	6/4/2007 11:00	1.99	4
7/13/2007 7:00	1.41	0	6/4/2007 12:00	1.91	4
7/13/2007 8:00	1.53	0	6/4/2007 13:00	1.93	4
			6/4/2007 14:00	2.01	4
7/18/2007 10:00	1.57	0	6/4/2007 15:00	1.97	4
7/18/2007 11:00	1.50	0	6/4/2007 16:00	1.73	0
7/18/2007 12:00	1.49	0	6/4/2007 17:00	2.18	0
7/18/2007 13:00	1.44	0	6/4/2007 18:00	2.12	0

Upper Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.	**Lower Site** Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.
7/18/2007 14:00	1.45	0	6/4/2007 19:00	2.83	0
7/18/2007 15:00	1.46	0	6/4/2007 20:00	1.80	0
7/18/2007 16:00	1.45	0	6/4/2007 21:00	2.06	0
7/18/2007 17:00	1.42	0	6/4/2007 22:00	1.83	0
7/18/2007 18:00	1.35	0	6/4/2007 23:00	1.19	0
7/18/2007 19:00	1.30	0	6/5/2007 0:00	1.37	0
7/18/2007 20:00	1.31	0	6/5/2007 1:00	1.28	0
7/18/2007 21:00	1.32	0	6/5/2007 2:00	1.26	0
7/18/2007 22:00	1.36	0	6/5/2007 3:00	1.11	0
7/18/2007 23:00	1.33	0	6/5/2007 4:00	1.18	0
7/19/2007 0:00	1.30	0	6/5/2007 5:00	1.03	0
7/19/2007 1:00	1.27	0	6/5/2007 6:00	1.05	0
7/19/2007 2:00	1.15	0	6/5/2007 7:00	1.07	0
7/19/2007 3:00	1.24	0	6/5/2007 8:00	1.49	0
7/19/2007 4:00	1.18	0	6/5/2007 9:00	1.59	0
7/19/2007 5:00	1.17	0	6/5/2007 10:00	2.89	0
7/19/2007 6:00	1.32	0	6/5/2007 11:00	3.86	0
7/19/2007 7:00	1.26	0	6/5/2007 12:00	4.44	0
7/19/2007 8:00	1.32	0	6/5/2007 13:00	4.49	0
7/19/2007 9:00	1.28	8	6/5/2007 14:00	4.33	0
7/19/2007 10:00	1.25	8	6/5/2007 15:00	4.32	0
7/19/2007 11:00	1.32	8	6/5/2007 16:00	4.74	0
7/19/2007 12:00	1.30	8	6/5/2007 17:00	4.30	0
7/19/2007 13:00	1.31	8	6/5/2007 18:00	4.15	0
7/19/2007 14:00	1.28	8	6/5/2007 19:00	3.30	0
7/19/2007 15:00	1.36	8	6/5/2007 20:00	3.60	0
7/19/2007 16:00	1.30	8	6/5/2007 21:00	3.73	0
7/19/2007 17:00	1.26	8	6/5/2007 22:00	3.41	0
7/19/2007 18:00	1.29	8	6/5/2007 23:00	3.54	0
7/19/2007 19:00	1.24	8	6/6/2007 0:00	2.97	0
7/19/2007 20:00	1.24	8	6/6/2007 1:00	3.72	0
7/19/2007 21:00	1.25	8	6/6/2007 2:00	3.72	0
7/19/2007 22:00	1.18	8	6/6/2007 3:00	3.87	0
7/19/2007 23:00	1.25	8	6/6/2007 4:00	3.28	0
7/20/2007 0:00	1.24	8	6/6/2007 5:00	2.99	0
7/20/2007 1:00	1.26	8	6/6/2007 6:00	2.67	0
7/20/2007 2:00	1.36	8	6/6/2007 7:00	3.12	0
7/20/2007 3:00	1.33	8	6/6/2007 8:00	3.02	0
7/20/2007 4:00	1.40	8	6/6/2007 9:00	3.64	0
7/20/2007 5:00	1.26	8	6/6/2007 10:00	3.10	0
7/20/2007 6:00	1.26	8	6/6/2007 11:00	3.81	0
7/20/2007 7:00	1.21	8	6/6/2007 12:00	3.86	0
7/20/2007 8:00	1.24	8	6/6/2007 13:00	3.35	0
7/20/2007 9:00	1.22	8	6/6/2007 14:00	2.74	0
7/20/2007 10:00	1.22	8	6/6/2007 15:00	2.69	0
7/20/2007 11:00	1.25	8	6/6/2007 16:00	2.36	0
7/20/2007 12:00	1.24	8	6/6/2007 17:00	2.29	0
7/20/2007 13:00	1.27	8	6/6/2007 18:00	2.29	0
7/20/2007 14:00	1.29	8	6/6/2007 19:00	1.94	0
7/20/2007 15:00	3.18	8	6/6/2007 20:00	2.52	0

Upper Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.	**Lower Site** Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.
7/20/2007 16:00	1.28	8	6/6/2007 21:00	2.95	0
7/20/2007 17:00	2.05	8	6/6/2007 22:00	2.78	0
7/20/2007 18:00	1.25	8	6/6/2007 23:00	2.50	0
7/20/2007 19:00	1.26	8	6/7/2007 0:00	2.30	0
7/20/2007 20:00	1.36	8	6/7/2007 1:00	1.90	0
7/20/2007 21:00	1.24	8	6/7/2007 2:00	2.19	0
7/20/2007 22:00	1.17	8	6/7/2007 3:00	2.03	0
7/20/2007 23:00	1.19	8	6/7/2007 4:00	2.09	0
7/21/2007 0:00	1.16	8	6/7/2007 5:00	1.96	0
7/21/2007 1:00	1.12	8	6/7/2007 6:00	1.75	0
7/21/2007 2:00	1.13	8	6/7/2007 7:00	2.66	0
7/21/2007 3:00	1.34	8	6/7/2007 8:00	2.68	0
7/21/2007 4:00	1.29	8	6/7/2007 9:00	2.66	0
7/21/2007 5:00	1.27	8	6/7/2007 10:00	4.94	0
7/21/2007 6:00	1.28	8			
7/21/2007 7:00	1.21	8	6/17/2007 20:00	3.76	5
7/21/2007 8:00	1.26	8	6/17/2007 21:00	3.22	5
7/21/2007 9:00	1.17	8	6/17/2007 22:00	3.00	5
7/21/2007 10:00	2.35	8	6/17/2007 23:00	2.64	5
7/21/2007 11:00	1.23	8	6/18/2007 0:00	2.51	5
7/21/2007 12:00	1.17	8	6/18/2007 1:00	2.37	5
7/21/2007 13:00	1.19	8	6/18/2007 2:00	2.16	5
7/21/2007 14:00	1.24	8	6/18/2007 3:00	1.69	5
7/21/2007 15:00	1.27	8	6/18/2007 4:00	2.10	5
7/21/2007 16:00	1.27	8	6/18/2007 5:00	1.84	5
7/21/2007 17:00	1.12	8	6/18/2007 6:00	1.79	5
7/21/2007 18:00	1.27	8	6/18/2007 7:00	1.69	5
7/21/2007 19:00	1.26	8	6/18/2007 8:00	1.80	5
7/21/2007 20:00	1.12	8	6/18/2007 9:00	2.09	5
7/21/2007 21:00	1.18	8	6/18/2007 10:00	2.17	5
7/21/2007 22:00	1.33	8	6/18/2007 11:00	2.39	5
7/21/2007 23:00	1.26	8	6/18/2007 12:00	2.69	5
7/22/2007 0:00	1.15	8	6/18/2007 13:00	2.67	5
7/22/2007 1:00	1.24	8	6/18/2007 14:00	2.78	5
7/22/2007 2:00	1.29	8	6/18/2007 15:00	2.92	5
7/22/2007 3:00	1.24	8	6/18/2007 16:00	3.40	5
7/22/2007 4:00	1.43	8	6/18/2007 17:00	4.90	5
7/22/2007 5:00	1.22	8	6/18/2007 18:00	3.57	5
7/22/2007 6:00	1.36	8	6/18/2007 19:00	3.25	5
7/22/2007 7:00	1.16	8	6/18/2007 20:00	12.34	5
7/22/2007 8:00	1.15	8	6/18/2007 21:00	5.35	5
7/22/2007 9:00	1.17	0	6/18/2007 22:00	4.14	5
7/22/2007 10:00	1.19	0	6/18/2007 23:00	3.22	5
7/22/2007 11:00	1.22	0	6/19/2007 0:00	2.19	5
7/22/2007 12:00	1.23	0	6/19/2007 1:00	1.79	5
7/22/2007 13:00	1.25	0	6/19/2007 2:00	1.95	5
7/22/2007 14:00	1.27	0	6/19/2007 3:00	1.89	5
7/22/2007 15:00	1.28	0	6/19/2007 4:00	2.06	5
7/22/2007 16:00	1.30	0	6/19/2007 5:00	1.52	5
7/22/2007 17:00	1.18	0	6/19/2007 6:00	1.52	5

Upper Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.	**Lower Site** Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.
7/22/2007 18:00	1.20	0	6/19/2007 7:00	1.41	5
7/22/2007 19:00	1.17	0	6/19/2007 8:00	2.00	5
7/22/2007 20:00	1.17	0	6/19/2007 9:00	1.59	5
7/22/2007 21:00	1.18	0	6/19/2007 10:00	1.94	5
7/22/2007 22:00	1.16	0	6/19/2007 11:00	2.31	5
7/22/2007 23:00	1.13	0	6/19/2007 12:00	1.86	5
7/23/2007 0:00	1.11	0	6/19/2007 13:00	1.92	5
7/23/2007 1:00	1.21	0	6/19/2007 14:00	2.43	5
7/23/2007 2:00	1.23	0	6/19/2007 15:00	2.00	5
7/23/2007 3:00	1.29	0	6/19/2007 16:00	2.70	5
			6/19/2007 17:00	2.12	5
8/9/2007 10:00	0.90	9	6/19/2007 18:00	2.57	5
8/9/2007 11:00	0.85	9	6/19/2007 19:00	2.31	5
8/9/2007 12:00	0.91	9	6/19/2007 20:00	1.64	5
8/9/2007 13:00	0.92	9	6/19/2007 21:00	1.96	5
8/9/2007 14:00	0.89	9	6/19/2007 22:00	1.27	5
8/9/2007 15:00	0.85	9	6/19/2007 23:00	1.81	5
8/9/2007 16:00	0.89	9	6/20/2007 0:00	1.18	5
8/9/2007 17:00	0.87	9	6/20/2007 1:00	1.01	5
8/9/2007 18:00	0.90	9	6/20/2007 2:00	1.01	5
8/9/2007 19:00	0.99	9	6/20/2007 3:00	1.06	5
8/9/2007 20:00	0.85	9	6/20/2007 4:00	1.01	5
8/9/2007 21:00	0.86	9	6/20/2007 5:00	0.96	5
8/9/2007 22:00	0.87	9	6/20/2007 6:00	0.91	5
8/9/2007 23:00	1.04	9	6/20/2007 7:00	1.67	5
8/10/2007 0:00	0.80	9	6/20/2007 8:00	1.57	5
8/10/2007 1:00	0.87	9	6/20/2007 9:00	1.91	5
8/10/2007 2:00	0.86	9	6/20/2007 10:00	2.02	5
8/10/2007 3:00	0.90	9	6/20/2007 11:00	2.83	5
8/10/2007 4:00	0.91	9	6/20/2007 12:00	2.66	5
8/10/2007 5:00	0.82	9	6/20/2007 13:00	3.09	5
8/10/2007 6:00	0.79	9	6/20/2007 14:00	3.70	5
8/10/2007 7:00	0.82	9	6/20/2007 15:00	2.66	5
8/10/2007 8:00	0.83	9	6/20/2007 16:00	3.31	5
8/10/2007 9:00	0.84	9	6/20/2007 17:00	2.86	5
8/10/2007 10:00	0.86	9	6/20/2007 18:00	2.13	5
8/10/2007 11:00	0.91	9	6/20/2007 19:00	2.22	5
8/10/2007 12:00	0.90	9	6/20/2007 20:00	1.22	0
8/10/2007 13:00	0.88	9	6/20/2007 21:00	1.12	0
8/10/2007 14:00	0.90	9	6/20/2007 22:00	4.20	0
8/10/2007 15:00	0.86	9	6/20/2007 23:00	3.44	0
8/10/2007 16:00	0.82	9	6/21/2007 0:00	2.84	0
8/10/2007 17:00	0.87	9	6/21/2007 1:00	2.27	0
8/10/2007 18:00	0.84	9	6/21/2007 2:00	1.76	0
8/10/2007 19:00	0.87	9	6/21/2007 3:00	1.68	0
8/10/2007 20:00	0.86	9	6/21/2007 4:00	1.66	0
8/10/2007 21:00	0.81	9	6/21/2007 5:00	1.14	0
8/10/2007 22:00	0.83	9	6/21/2007 6:00	1.07	0
8/10/2007 23:00	0.81	9	6/21/2007 7:00	1.83	0
8/11/2007 0:00	0.82	9	6/21/2007 8:00	1.67	0

Upper Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.	**Lower Site** Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.
8/11/2007 1:00	0.85	9			
8/11/2007 2:00	0.87	9	7/1/2007 20:00	1.08	6
8/11/2007 3:00	0.99	9	7/1/2007 21:00	0.91	6
8/11/2007 4:00	0.86	9	7/1/2007 22:00	0.94	6
8/11/2007 5:00	0.90	9	7/1/2007 23:00	1.00	6
8/11/2007 6:00	0.82	9	7/2/2007 0:00	0.73	6
8/11/2007 7:00	0.82	9	7/2/2007 1:00	0.52	6
8/11/2007 8:00	0.82	9	7/2/2007 2:00	0.54	6
8/11/2007 9:00	0.83	9	7/2/2007 3:00	0.41	6
8/11/2007 10:00	0.82	9	7/2/2007 4:00	0.41	6
8/11/2007 11:00	0.86	9	7/2/2007 5:00	0.41	6
8/11/2007 12:00	0.90	9	7/2/2007 6:00	0.40	6
8/11/2007 13:00	0.82	9	7/2/2007 7:00	0.44	6
8/11/2007 14:00	0.84	9	7/2/2007 8:00	0.91	6
8/11/2007 15:00	0.83	9	7/2/2007 9:00	1.29	6
8/11/2007 16:00	0.84	9	7/2/2007 10:00	1.22	6
8/11/2007 17:00	0.85	9	7/2/2007 11:00	1.26	6
8/11/2007 18:00	0.86	9	7/2/2007 12:00	1.30	6
8/11/2007 19:00	0.83	9	7/2/2007 13:00	1.20	6
8/11/2007 20:00	0.91	9	7/2/2007 14:00	1.46	6
8/11/2007 21:00	0.85	9	7/2/2007 15:00	1.26	6
8/11/2007 22:00	0.83	9	7/2/2007 16:00	1.92	6
8/11/2007 23:00	0.83	9	7/2/2007 17:00	1.78	6
8/12/2007 0:00	0.80	9	7/2/2007 18:00	1.86	6
8/12/2007 1:00	0.83	9	7/2/2007 19:00	1.63	6
8/12/2007 2:00	0.85	9	7/2/2007 20:00	1.75	6
8/12/2007 3:00	0.85	9	7/2/2007 21:00	1.74	6
8/12/2007 4:00	0.85	9	7/2/2007 22:00	0.75	6
8/12/2007 5:00	0.85	9	7/2/2007 23:00	0.79	6
8/12/2007 6:00	0.85	9	7/3/2007 0:00	0.79	6
8/12/2007 7:00	0.79	9	7/3/2007 1:00	0.89	6
8/12/2007 8:00	0.82	9	7/3/2007 2:00	0.73	6
8/12/2007 9:00	0.79	9	7/3/2007 3:00	0.65	6
8/12/2007 10:00	0.80	0	7/3/2007 4:00	0.66	6
8/12/2007 11:00	0.83	0	7/3/2007 5:00	0.83	6
8/12/2007 12:00	0.86	0	7/3/2007 6:00	0.69	6
8/12/2007 13:00	0.87	0	7/3/2007 7:00	0.72	6
8/12/2007 14:00	0.81	0	7/3/2007 8:00	1.43	6
			7/3/2007 9:00	1.47	6
8/19/2007 15:00	0.72	0	7/3/2007 10:00	1.28	6
8/19/2007 16:00	0.68	0	7/3/2007 11:00	1.21	6
8/19/2007 17:00	3.90	0	7/3/2007 12:00	1.19	6
8/19/2007 18:00	1.93	0	7/3/2007 13:00	0.85	6
8/19/2007 19:00	1.43	0	7/3/2007 14:00	0.93	6
8/19/2007 20:00	1.24	0	7/3/2007 15:00	0.83	6
8/19/2007 21:00	1.24	0	7/3/2007 16:00	0.83	6
8/19/2007 22:00	1.10	0	7/3/2007 17:00	2.04	6
8/19/2007 23:00	1.03	0	7/3/2007 18:00	1.01	6
8/20/2007 0:00	0.95	0	7/3/2007 19:00	0.88	6
8/20/2007 1:00	0.94	0	7/3/2007 20:00	0.89	6

Upper Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (µmol m^{-2} s^{-1})	Per.	**Lower Site** Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (µmol m^{-2} s^{-1})	Per.
			7/3/2007 21:00	1.26	6
8/29/2007 15:00	0.68	10	7/3/2007 22:00	1.22	6
8/29/2007 16:00	0.67	10	7/3/2007 23:00	1.14	6
8/29/2007 17:00	0.65	10	7/4/2007 0:00	1.03	6
8/29/2007 18:00	0.64	10	7/4/2007 1:00	0.99	6
8/29/2007 19:00	0.63	10	7/4/2007 2:00	1.48	6
8/29/2007 20:00	0.66	10	7/4/2007 3:00	1.08	6
8/29/2007 21:00	0.74	10	7/4/2007 4:00	0.75	6
8/29/2007 22:00	0.68	10	7/4/2007 5:00	1.40	6
8/29/2007 23:00	0.65	10	7/4/2007 6:00	0.89	6
8/30/2007 0:00	0.67	10	7/4/2007 7:00	1.27	6
8/30/2007 1:00	0.77	10	7/4/2007 8:00	1.48	6
8/30/2007 2:00	0.67	10	7/4/2007 9:00	1.04	6
8/30/2007 3:00	0.69	10	7/4/2007 10:00	0.89	6
8/30/2007 4:00	0.61	10	7/4/2007 11:00	1.32	6
8/30/2007 5:00	0.62	10	7/4/2007 12:00	0.70	6
8/30/2007 6:00	0.70	10	7/4/2007 13:00	0.98	6
8/30/2007 7:00	0.59	10	7/4/2007 14:00	0.79	6
8/30/2007 8:00	0.65	10	7/4/2007 15:00	1.36	6
8/30/2007 9:00	0.62	10	7/4/2007 16:00	0.87	6
8/30/2007 10:00	0.65	10	7/4/2007 17:00	0.68	6
8/30/2007 11:00	0.67	10	7/4/2007 18:00	0.80	6
8/30/2007 12:00	0.66	10	7/4/2007 19:00	0.74	6
8/30/2007 13:00	0.69	10	7/4/2007 20:00	0.92	6
8/30/2007 14:00	0.67	10	7/4/2007 21:00	0.90	6
8/30/2007 15:00	0.62	0	7/4/2007 22:00	1.09	6
8/30/2007 16:00	0.64	0	7/4/2007 23:00	1.41	6
8/30/2007 17:00	0.63	0	7/5/2007 0:00	1.12	6
8/30/2007 18:00	0.65	0	7/5/2007 1:00	1.27	6
8/30/2007 19:00	0.66	0	7/5/2007 2:00	0.69	6
8/30/2007 20:00	0.65	0	7/5/2007 3:00	0.89	6
8/30/2007 21:00	0.65	0	7/5/2007 4:00	0.91	6
8/30/2007 22:00	0.61	0	7/5/2007 5:00	0.81	6
8/30/2007 23:00	0.66	0	7/5/2007 6:00	0.76	6
8/31/2007 0:00	0.95	0	7/5/2007 7:00	1.87	6
8/31/2007 1:00	1.25	0	7/5/2007 8:00	1.32	6
8/31/2007 2:00	0.83	0	7/5/2007 9:00	1.19	6
8/31/2007 3:00	0.70	0	7/5/2007 10:00	1.22	6
8/31/2007 4:00	0.67	0	7/5/2007 11:00	0.68	6
8/31/2007 5:00	0.68	0	7/5/2007 12:00	0.62	6
			7/5/2007 13:00	0.50	6
9/26/2007 16:00	1.39	0	7/5/2007 14:00	0.53	6
9/26/2007 17:00	1.25	0	7/5/2007 15:00	0.54	6
9/26/2007 18:00	1.27	0	7/5/2007 16:00	0.68	6
9/26/2007 19:00	1.32	0	7/5/2007 17:00	1.00	6
9/26/2007 20:00	1.25	0	7/5/2007 18:00	0.99	6
9/26/2007 21:00	1.21	0	7/5/2007 19:00	0.61	6
9/26/2007 22:00	1.09	0	7/5/2007 20:00	0.75	0
			7/5/2007 21:00	1.27	0
10/4/2007 19:00	1.34	0	7/5/2007 22:00	1.18	0

Upper Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.	**Lower Site** Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.
10/4/2007 20:00	1.34	0	7/5/2007 23:00	1.05	0
10/4/2007 21:00	1.22	0	7/6/2007 0:00	0.71	0
10/4/2007 22:00	1.21	0	7/6/2007 1:00	0.47	0
10/4/2007 23:00	1.23	0	7/6/2007 2:00	0.52	0
10/5/2007 0:00	1.10	0	7/6/2007 3:00	0.52	0
10/5/2007 1:00	1.15	0	7/6/2007 4:00	0.92	0
10/5/2007 2:00	1.15	0	7/6/2007 5:00	0.73	0
10/5/2007 3:00	1.11	0	7/6/2007 6:00	0.91	0
10/5/2007 4:00	1.15	0	7/6/2007 7:00	0.84	0
10/5/2007 5:00	1.09	0	7/6/2007 8:00	0.80	0
10/5/2007 6:00	1.01	0	7/24/2007 10:00	0.70	7
10/5/2007 7:00	1.09	0	7/24/2007 11:00	0.95	7
10/5/2007 8:00	1.00	0	7/24/2007 12:00	0.94	7
10/5/2007 9:00	0.99	0	7/24/2007 13:00	0.94	7
10/5/2007 10:00	0.91	0	7/24/2007 14:00	1.01	7
10/5/2007 11:00	0.97	0	7/24/2007 15:00	1.05	7
10/5/2007 12:00	1.04	0	7/24/2007 16:00	0.85	7
10/5/2007 13:00	1.07	0	7/24/2007 17:00	1.52	7
			7/24/2007 18:00	1.15	7
10/12/2007 18:00	1.43	0	7/24/2007 19:00	0.84	7
10/12/2007 19:00	1.29	0	7/24/2007 20:00	0.35	7
10/12/2007 20:00	1.38	0	7/24/2007 21:00	0.41	7
10/12/2007 21:00	1.21	0	7/24/2007 22:00	0.26	7
10/12/2007 22:00	1.37	0	7/24/2007 23:00	0.25	7
10/12/2007 23:00	1.27	0	7/25/2007 0:00	0.21	7
10/13/2007 0:00	1.21	0	7/25/2007 1:00	0.28	7
10/13/2007 1:00	1.19	0	7/25/2007 2:00	0.26	7
10/13/2007 2:00	1.16	0	7/25/2007 3:00	0.19	7
10/13/2007 3:00	1.14	0	7/25/2007 4:00	0.29	7
10/13/2007 4:00	1.20	0	7/25/2007 5:00	0.30	7
10/13/2007 5:00	1.06	0	7/25/2007 6:00	0.29	7
10/13/2007 6:00	1.07	0	7/25/2007 7:00	0.36	7
10/13/2007 7:00	1.10	0	7/25/2007 8:00	1.37	7
10/13/2007 8:00	1.15	0	7/25/2007 9:00	0.92	7
10/13/2007 9:00	1.03	0	7/25/2007 10:00	0.80	7
10/13/2007 10:00	1.00	0	7/25/2007 11:00	0.89	7
10/13/2007 11:00	1.00	0	7/25/2007 12:00	1.05	7
10/13/2007 12:00	1.15	0	7/25/2007 13:00	1.26	7
10/13/2007 13:00	1.31	0	7/25/2007 14:00	1.16	7
10/13/2007 14:00	1.49	0	7/25/2007 15:00	0.84	7
10/13/2007 15:00	1.53	0	7/25/2007 16:00	0.58	7
10/13/2007 16:00	1.29	0	7/25/2007 17:00	0.45	7
10/13/2007 17:00	1.19	0	7/25/2007 18:00	0.51	7
10/13/2007 18:00	1.11	0	7/25/2007 19:00	0.45	7
10/13/2007 19:00	1.06	0	7/25/2007 20:00	0.36	7
10/13/2007 20:00	1.10	0	7/25/2007 21:00	0.91	7
10/13/2007 21:00	1.13	0	7/25/2007 22:00	0.37	7
10/13/2007 22:00	1.15	0	7/25/2007 23:00	0.25	7
10/13/2007 23:00	1.11	0	7/26/2007 0:00	0.23	7
10/14/2007 0:00	1.10	0	7/26/2007 1:00	0.24	7

Upper Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.
10/14/2007 1:00	1.02	0
10/14/2007 2:00	1.03	0
10/14/2007 3:00	0.97	0
10/14/2007 4:00	1.09	0
10/14/2007 5:00	0.97	0
10/14/2007 6:00	1.06	0
10/18/2007 14:00	0.90	0
10/18/2007 15:00	0.94	0

LDP Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})
5/1/2007 12:00	1.76
5/1/2007 13:00	1.92
5/1/2007 14:00	1.87
5/1/2007 15:00	1.9
5/1/2007 16:00	1.85
5/1/2007 17:00	1.95
5/1/2007 18:00	1.78
5/1/2007 19:00	1.71
5/1/2007 20:00	1.92
5/1/2007 21:00	1.78
5/1/2007 22:00	1.48
5/1/2007 23:00	1.63
5/2/2007 0:00	1.57
5/2/2007 1:00	1.67
5/2/2007 2:00	1.66
5/2/2007 3:00	1.64
5/2/2007 4:00	1.59
5/2/2007 5:00	1.49
5/2/2007 6:00	1.59
5/2/2007 7:00	1.67
5/2/2007 8:00	1.66
5/2/2007 9:00	1.65
5/2/2007 10:00	1.71
5/2/2007 11:00	1.6
5/2/2007 12:00	1.57
5/2/2007 13:00	1.66
5/2/2007 14:00	2.16
5/2/2007 15:00	2.14
5/2/2007 16:00	2.32
5/2/2007 17:00	2.09

Lower Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.
7/26/2007 2:00	0.22	7
7/26/2007 3:00	0.30	7
7/26/2007 4:00	0.34	7
7/26/2007 5:00	0.24	7
7/26/2007 6:00	0.23	7
7/26/2007 7:00	0.32	7
7/26/2007 8:00	0.36	7
7/26/2007 9:00	0.61	7
7/26/2007 10:00	0.74	7
7/26/2007 11:00	0.58	7
7/26/2007 12:00	0.51	7
7/26/2007 13:00	0.84	7
7/26/2007 14:00	0.90	7
7/26/2007 15:00	0.82	7
7/26/2007 16:00	0.77	7
7/26/2007 17:00	0.75	7
7/26/2007 18:00	0.62	7
7/26/2007 19:00	0.78	7
7/26/2007 20:00	1.10	7
7/26/2007 21:00	0.27	7
7/26/2007 22:00	0.37	7
7/26/2007 23:00	0.35	7
7/27/2007 0:00	0.49	7
7/27/2007 1:00	0.23	7
7/27/2007 2:00	0.17	7
7/27/2007 3:00	0.20	7
7/27/2007 4:00	0.19	7
7/27/2007 5:00	0.17	7
7/27/2007 6:00	0.21	7
7/27/2007 7:00	0.40	7
7/27/2007 8:00	0.61	7
7/27/2007 9:00	0.78	7
7/27/2007 10:00	0.93	7
7/27/2007 11:00	1.07	7
7/27/2007 12:00	0.98	7
7/27/2007 13:00	1.00	7
7/27/2007 14:00	1.02	7
7/27/2007 15:00	0.98	7
7/27/2007 16:00	0.94	7
7/27/2007 17:00	0.97	7
7/27/2007 18:00	1.16	7
7/27/2007 19:00	0.83	7
7/27/2007 20:00	0.25	7
7/27/2007 21:00	0.35	7
7/27/2007 22:00	0.40	7
7/27/2007 23:00	0.62	7
7/28/2007 0:00	0.35	7
7/28/2007 1:00	0.32	7
7/28/2007 2:00	0.17	7
7/28/2007 3:00	0.17	7

LDP Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux ($\mu mol\ m^{-2}\ s^{-1}$)	Per.	**Lower Site** Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux ($\mu mol\ m^{-2}\ s^{-1}$)	Per.
5/2/2007 18:00	2.08		7/28/2007 4:00	0.13	7
5/2/2007 19:00	1.97		7/28/2007 5:00	0.32	7
5/2/2007 20:00	1.7		7/28/2007 6:00	0.47	7
5/2/2007 21:00	1.87		7/28/2007 7:00	0.65	7
5/2/2007 22:00	1.96		7/28/2007 8:00	0.94	7
5/2/2007 23:00	1.84		7/28/2007 9:00	0.71	7
5/3/2007 0:00	1.73		7/28/2007 10:00	1.78	0
5/3/2007 1:00	1.65		7/28/2007 11:00	0.99	0
5/3/2007 2:00	1.65		7/28/2007 12:00	0.90	0
5/3/2007 3:00	1.65		7/28/2007 13:00	1.06	0
5/3/2007 4:00	1.58		7/28/2007 14:00	1.20	0
5/3/2007 5:00	1.56		7/28/2007 15:00	1.22	0
5/3/2007 6:00	1.62		7/28/2007 16:00	0.93	0
5/3/2007 7:00	1.52		7/28/2007 17:00	0.82	0
5/3/2007 8:00	1.51		7/28/2007 18:00	0.54	0
5/3/2007 9:00	1.55		7/28/2007 19:00	0.58	0
5/3/2007 10:00	1.48		7/28/2007 20:00	0.37	0
5/3/2007 11:00	1.46		7/28/2007 21:00	0.85	0
5/3/2007 12:00	1.43		7/28/2007 22:00	0.15	0
5/3/2007 13:00	1.58		7/28/2007 23:00	0.20	0
5/3/2007 14:00	1.57		7/29/2007 0:00	0.17	0
5/3/2007 15:00	1.52		7/29/2007 1:00	0.73	0
5/3/2007 16:00	1.55		7/29/2007 2:00	0.38	0
5/3/2007 17:00	1.51		7/29/2007 3:00	0.55	0
5/3/2007 18:00	1.51		7/29/2007 4:00	0.59	0
5/3/2007 19:00	1.43		7/29/2007 5:00	0.50	0
5/3/2007 20:00	1.54		7/29/2007 6:00	0.41	0
5/3/2007 21:00	1.4		7/29/2007 7:00	0.60	0
5/3/2007 22:00	1.42		7/29/2007 8:00	0.65	0
5/3/2007 23:00	1.27		7/29/2007 9:00	0.81	0
5/4/2007 0:00	1.35		7/29/2007 10:00	1.08	0
5/4/2007 1:00	1.24		7/29/2007 11:00	0.56	0
5/4/2007 2:00	1.25		7/29/2007 12:00	0.70	0
5/4/2007 3:00	1.22		7/29/2007 13:00	0.83	0
5/4/2007 4:00	1.26		7/29/2007 14:00	0.87	0
5/4/2007 5:00	1.22		7/29/2007 15:00	1.30	0
5/4/2007 6:00	1.17		7/29/2007 16:00	1.20	0
5/4/2007 7:00	1.21		7/29/2007 17:00	0.85	0
5/4/2007 8:00	1.28		7/29/2007 18:00	0.77	0
5/4/2007 9:00	1.22		7/29/2007 19:00	0.77	0
5/4/2007 10:00	1.35		7/29/2007 20:00	1.17	0
5/4/2007 11:00	1.25		7/29/2007 21:00	1.62	0
5/4/2007 12:00	1.34		7/29/2007 22:00	1.65	0
5/4/2007 13:00	1.41		7/29/2007 23:00	0.79	0
5/4/2007 14:00	1.48		7/30/2007 0:00	0.80	0
5/4/2007 15:00	1.36		7/30/2007 1:00	0.68	0
5/4/2007 16:00	1.39		7/30/2007 2:00	1.13	0
5/4/2007 17:00	1.39		7/30/2007 3:00	0.97	0
5/4/2007 18:00	1.36		7/30/2007 4:00	0.80	0
5/4/2007 19:00	1.33		7/30/2007 5:00	0.98	0

LDP Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux ($\mu mol\ m^{-2}\ s^{-1}$)	Per.	**Lower Site** Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux ($\mu mol\ m^{-2}\ s^{-1}$)	Per.
			7/30/2007 6:00	1.03	0
5/23/2007 14:00	2.32		7/30/2007 7:00	0.88	0
5/23/2007 15:00	2.25		7/30/2007 8:00	1.03	0
5/23/2007 16:00	2.03		7/30/2007 9:00	0.82	0
5/23/2007 17:00	2.17		7/30/2007 10:00	0.73	0
5/23/2007 18:00	2.1		7/30/2007 11:00	0.81	0
5/23/2007 19:00	1.93		7/30/2007 12:00	1.31	0
5/23/2007 20:00	1.74		7/30/2007 13:00	1.06	0
5/23/2007 21:00	1.7		7/30/2007 14:00	0.68	0
5/23/2007 22:00	1.62		7/30/2007 15:00	0.57	0
5/23/2007 23:00	1.63		7/30/2007 16:00	0.77	0
5/24/2007 0:00	1.83		7/30/2007 17:00	0.84	0
5/24/2007 1:00	1.72		7/30/2007 18:00	2.08	0
5/24/2007 2:00	1.9		7/30/2007 19:00	1.51	0
			7/30/2007 20:00	1.57	0
6/7/2007 15:00	2.41		7/30/2007 21:00	1.05	0
6/7/2007 16:00	2.46		7/30/2007 22:00	0.28	0
6/7/2007 17:00	2.3		7/30/2007 23:00	0.91	0
6/7/2007 18:00	2.44		7/31/2007 0:00	1.15	0
6/7/2007 19:00	2.43		7/31/2007 1:00	1.59	0
6/7/2007 20:00	2.13		7/31/2007 2:00	1.33	0
			7/31/2007 3:00	1.96	0
6/8/2007 21:00	2.35		7/31/2007 4:00	2.05	0
6/8/2007 22:00	2.13		7/31/2007 5:00	1.84	0
6/8/2007 23:00	2.53		7/31/2007 6:00	1.38	0
6/9/2007 0:00	2.45		7/31/2007 7:00	1.39	0
6/9/2007 1:00	2.35		7/31/2007 8:00	1.16	0
6/9/2007 2:00	2.43		7/31/2007 9:00	1.17	0
6/9/2007 3:00	2.33		7/31/2007 10:00	1.25	0
6/9/2007 4:00	2.52		7/31/2007 11:00	0.99	0
6/9/2007 5:00	2.5		7/31/2007 12:00	0.69	0
6/9/2007 6:00	2.28		7/31/2007 13:00	1.17	0
6/9/2007 7:00	2.38		7/31/2007 14:00	1.10	0
6/9/2007 8:00	2.97		7/31/2007 15:00	0.91	0
6/9/2007 9:00	2.41		7/31/2007 16:00	1.06	0
6/9/2007 10:00	2.81		7/31/2007 17:00	1.77	0
6/9/2007 11:00	2.64		7/31/2007 18:00	1.16	0
6/9/2007 12:00	2.85		7/31/2007 19:00	1.50	0
6/9/2007 13:00	2.59		7/31/2007 20:00	2.38	0
6/9/2007 14:00	2.73		7/31/2007 21:00	8.17	0
6/9/2007 15:00	2.98		7/31/2007 22:00	4.11	0
6/9/2007 16:00	3		7/31/2007 23:00	2.61	0
6/9/2007 17:00	2.76		8/1/2007 0:00	1.99	0
6/9/2007 18:00	2.7		8/1/2007 1:00	2.16	0
6/9/2007 19:00	2.78		8/1/2007 2:00	0.83	0
6/9/2007 20:00	2.5		8/1/2007 3:00	1.07	0
6/9/2007 21:00	2.57		8/1/2007 4:00	2.31	0
6/9/2007 22:00	2.65		8/1/2007 5:00	1.31	0
6/9/2007 23:00	2.3		8/1/2007 6:00	0.92	0
6/10/2007 0:00	2.37		8/1/2007 7:00	0.60	0

LDP Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.	**Lower Site** Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.
6/10/2007 1:00	2.37		8/1/2007 8:00	0.79	0
6/10/2007 2:00	2.48		8/1/2007 9:00	0.82	0
6/10/2007 3:00	2.34				
6/10/2007 4:00	2.56		8/31/2007 12:00	0.26	0
6/10/2007 5:00	2.92		8/31/2007 13:00	0.38	0
6/10/2007 6:00	3.09		8/31/2007 14:00	0.28	0
6/10/2007 7:00	8.03		8/31/2007 15:00	0.20	0
6/10/2007 8:00	8.54		8/31/2007 16:00	7.15	0
6/10/2007 9:00	10.41		8/31/2007 17:00	6.91	0
6/10/2007 10:00	11.65				
6/10/2007 11:00	9.91		10/5/2007 16:00	2.09	0
6/10/2007 12:00	8.24		10/5/2007 17:00	1.95	0
6/10/2007 13:00	9.27		10/5/2007 18:00	2.84	0
6/10/2007 14:00	8.06		10/5/2007 19:00	1.73	0
6/10/2007 15:00	9		10/5/2007 20:00	1.69	0
6/10/2007 16:00	4.78		10/5/2007 21:00	1.45	0
6/10/2007 17:00	5.37		10/5/2007 22:00	0.85	0
6/10/2007 18:00	5.98		10/5/2007 23:00	1.16	0
6/10/2007 19:00	5.94		10/6/2007 0:00	1.11	0
6/10/2007 20:00	5.47		10/6/2007 1:00	1.62	0
6/10/2007 21:00	5.29		10/6/2007 2:00	1.10	0
6/10/2007 22:00	5.41		10/6/2007 3:00	1.21	0
6/10/2007 23:00	5.44		10/6/2007 4:00	1.40	0
6/11/2007 0:00	5.43		10/6/2007 5:00	0.73	0
6/11/2007 1:00	5.33		10/6/2007 6:00	0.85	0
6/11/2007 2:00	7.89		10/6/2007 7:00	0.87	0
6/11/2007 3:00	8.24		10/6/2007 8:00	0.39	0
6/11/2007 4:00	9.18		10/6/2007 9:00	1.03	0
6/11/2007 5:00	9.33		10/6/2007 10:00	0.41	0
6/11/2007 6:00	8.68		10/6/2007 11:00	0.83	0
6/11/2007 7:00	9.55		10/6/2007 12:00	0.62	0
6/11/2007 8:00	7.95		10/6/2007 13:00	0.89	0
6/11/2007 9:00	9.88		10/6/2007 14:00	1.10	0
6/11/2007 10:00	8.21		10/6/2007 15:00	1.57	0
6/11/2007 11:00	7.95		10/6/2007 16:00	1.44	0
6/11/2007 12:00	8.23		10/6/2007 17:00	0.94	0
6/11/2007 13:00	7.34		10/6/2007 18:00	0.88	0
6/11/2007 14:00	8.05		10/6/2007 19:00	0.93	0
6/11/2007 15:00	7.13		10/6/2007 20:00	0.74	0
6/11/2007 16:00	7.73		10/6/2007 21:00	0.63	0
6/11/2007 17:00	7.89		10/6/2007 22:00	0.79	0
6/11/2007 18:00	11.92		10/6/2007 23:00	0.25	0
6/11/2007 19:00	8.37		10/7/2007 0:00	0.70	0
6/11/2007 20:00	8.04		10/7/2007 1:00	0.52	0
6/11/2007 21:00	7.43		10/7/2007 2:00	0.29	0
6/11/2007 22:00	6.98		10/7/2007 3:00	0.20	0
6/11/2007 23:00	6.96		10/7/2007 4:00	0.25	0
6/12/2007 0:00	6.96		10/7/2007 5:00	0.24	0
6/12/2007 1:00	7.24		10/7/2007 6:00	0.29	0
6/12/2007 2:00	7.59		10/7/2007 7:00	0.26	0

LDP Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux ($\mu mol\ m^{-2}\ s^{-1}$)	Per.	**Lower Site** Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux ($\mu mol\ m^{-2}\ s^{-1}$)	Per.
6/12/2007 3:00	7.36		10/7/2007 8:00	0.20	0
6/12/2007 4:00	7.33		10/7/2007 9:00	0.24	0
6/12/2007 5:00	7.16		10/7/2007 10:00	0.29	0
6/12/2007 6:00	7.32		10/7/2007 11:00	0.56	0
6/12/2007 7:00	7.12		10/7/2007 12:00	0.63	0
6/12/2007 8:00	9.25		10/7/2007 13:00	0.72	0
6/12/2007 9:00	8.53		10/7/2007 14:00	0.80	0
6/12/2007 10:00	8.54		10/7/2007 15:00	1.04	0
6/12/2007 11:00	8.83		10/7/2007 16:00	0.94	0
			10/7/2007 17:00	1.09	0
6/21/2007 12:00	2.37		10/7/2007 18:00	0.82	0
6/21/2007 13:00	2.55		10/7/2007 19:00	0.70	0
6/21/2007 14:00	2.29		10/7/2007 20:00	0.80	0
6/21/2007 15:00	2.46		10/7/2007 21:00	0.48	0
6/21/2007 16:00	2.75		10/7/2007 22:00	0.53	0
6/21/2007 17:00	2.49		10/7/2007 23:00	0.46	0
6/21/2007 18:00	2.32		10/8/2007 0:00	0.33	0
6/21/2007 19:00	2.2		10/8/2007 1:00	0.27	0
6/21/2007 20:00	2.2		10/8/2007 2:00	0.26	0
6/21/2007 21:00	2.28		10/8/2007 3:00	0.31	0
6/21/2007 22:00	2.2		10/8/2007 4:00	0.29	0
6/21/2007 23:00	2.19		10/8/2007 5:00	0.25	0
6/22/2007 0:00	2.15		10/8/2007 6:00	0.25	0
6/22/2007 1:00	2.21		10/8/2007 7:00	0.26	0
6/22/2007 2:00	2.1		10/8/2007 8:00	0.27	0
6/22/2007 3:00	2.17		10/8/2007 9:00	0.25	0
6/22/2007 4:00	2.14		10/8/2007 10:00	0.25	0
6/22/2007 5:00	2.08		10/8/2007 11:00	0.27	0
6/22/2007 6:00	2.11		10/8/2007 12:00	0.32	0
6/22/2007 7:00	2.03		10/8/2007 13:00	0.52	0
6/22/2007 8:00	2.15		10/8/2007 14:00	0.66	0
6/22/2007 9:00	2.18		10/8/2007 15:00	0.91	0
6/22/2007 10:00	2.22		10/8/2007 16:00	0.96	0
6/22/2007 11:00	2.35		10/8/2007 17:00	1.17	0
6/22/2007 12:00	2.46		10/8/2007 18:00	0.79	0
6/22/2007 13:00	2.35		10/8/2007 19:00	0.83	0
6/22/2007 14:00	2.38		10/8/2007 20:00	0.86	0
6/22/2007 15:00	2.44		10/8/2007 21:00	0.37	0
6/22/2007 16:00	2.58		10/8/2007 22:00	0.56	0
6/22/2007 17:00	2.4		10/8/2007 23:00	0.59	0
6/22/2007 18:00	2.22		10/9/2007 0:00	0.63	0
6/22/2007 19:00	2.3		10/9/2007 1:00	0.55	0
6/22/2007 20:00	2.3		10/9/2007 2:00	0.50	0
6/22/2007 21:00	2.13		10/9/2007 3:00	0.59	0
6/22/2007 22:00	2.59		10/9/2007 4:00	0.56	0
6/22/2007 23:00	2.27		10/9/2007 5:00	0.45	0
6/23/2007 0:00	2.15		10/9/2007 6:00	0.83	0
6/23/2007 1:00	2.3		10/9/2007 7:00	0.36	0
6/23/2007 2:00	2.09		10/9/2007 8:00	0.31	0
6/23/2007 3:00	2.2		10/9/2007 9:00	0.53	0

LDP Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.	**Lower Site** Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.
6/23/2007 4:00	2.28		10/9/2007 10:00	0.35	0
6/23/2007 5:00	2.24		10/9/2007 11:00	0.39	0
6/23/2007 6:00	2.31		10/9/2007 12:00	0.36	0
6/23/2007 7:00	2.28		10/9/2007 13:00	0.40	0
6/23/2007 8:00	2.25		10/9/2007 14:00	0.66	0
6/23/2007 9:00	2.26		10/9/2007 15:00	0.86	0
6/23/2007 10:00	2.23		10/9/2007 16:00	1.31	0
6/23/2007 11:00	2.29		10/9/2007 17:00	1.08	0
6/23/2007 12:00	2.26		10/9/2007 18:00	0.75	0
6/23/2007 13:00	2.33		10/9/2007 19:00	0.47	0
6/23/2007 14:00	2.33		10/9/2007 20:00	0.39	0
6/23/2007 15:00	2.43		10/9/2007 21:00	0.33	0
6/23/2007 16:00	2.34		10/9/2007 22:00	0.32	0
			10/9/2007 23:00	0.35	0
6/28/2007 10:00	1.9		10/10/2007 0:00	0.31	0
6/28/2007 11:00	2.07		10/10/2007 1:00	0.31	0
6/28/2007 12:00	2.14		10/10/2007 2:00	0.31	0
6/28/2007 13:00	2.12		10/10/2007 3:00	0.27	0
6/28/2007 14:00	2.01		10/10/2007 4:00	0.41	0
6/28/2007 15:00	2.26		10/10/2007 5:00	0.69	0
6/28/2007 16:00	2.14		10/10/2007 6:00	0.54	0
6/28/2007 17:00	2.14		10/10/2007 7:00	0.58	0
6/28/2007 18:00	1.98		10/10/2007 8:00	0.56	0
6/28/2007 19:00	2.05		10/10/2007 9:00	0.34	0
6/28/2007 20:00	2.12		10/10/2007 10:00	0.41	0
6/28/2007 21:00	1.91		10/10/2007 11:00	1.15	0
6/28/2007 22:00	1.86		10/10/2007 12:00	1.29	0
6/28/2007 23:00	1.85		10/10/2007 13:00	2.07	0
6/29/2007 0:00	1.81		10/10/2007 14:00	1.43	0
6/29/2007 1:00	1.96		10/10/2007 15:00	1.56	0
6/29/2007 2:00	1.89		10/10/2007 16:00	1.18	0
6/29/2007 3:00	2.01		10/10/2007 17:00	1.29	0
6/29/2007 4:00	2.01		10/10/2007 18:00	1.90	0
6/29/2007 5:00	1.94		10/10/2007 19:00	1.01	0
6/29/2007 6:00	1.94		10/10/2007 20:00	1.40	0
6/29/2007 7:00	1.93		10/10/2007 21:00	1.09	0
6/29/2007 8:00	2		10/10/2007 22:00	1.10	0
6/29/2007 9:00	1.98		10/10/2007 23:00	0.98	0
6/29/2007 10:00	2.05		10/11/2007 0:00	0.96	0
6/29/2007 11:00	2.05		10/11/2007 1:00	0.80	0
6/29/2007 12:00	2.08		10/11/2007 2:00	0.64	0
6/29/2007 13:00	2.07		10/11/2007 3:00	0.77	0
6/29/2007 14:00	2.12		10/11/2007 4:00	0.57	0
6/30/2007 12:00	1.91				
7/1/2007 12:00	2.07				
7/6/2007 11:00	2.14				
7/6/2007 12:00	2.23				

LDP Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.	**LDP Site** Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.
7/6/2007 13:00	2.2		7/14/2007 7:00	2.32	
7/6/2007 14:00	2.24		7/14/2007 8:00	2.22	
7/6/2007 15:00	2.32		7/14/2007 9:00	2.1	
7/6/2007 16:00	2.42		7/14/2007 10:00	2.03	
7/6/2007 17:00	2.15		7/14/2007 11:00	2.06	
7/6/2007 18:00	2.14		7/14/2007 12:00	2.13	
7/6/2007 19:00	2.24		7/14/2007 13:00	2.13	
7/6/2007 20:00	2.38		7/14/2007 14:00	2.14	
7/6/2007 21:00	2.3		7/14/2007 15:00	2.04	
7/6/2007 22:00	2.2		7/14/2007 16:00	2.18	
7/6/2007 23:00	2.16		7/14/2007 17:00	2.21	
7/7/2007 0:00	2.44		7/14/2007 18:00	2.07	
7/7/2007 1:00	2.35		7/14/2007 19:00	2.02	
7/7/2007 2:00	2.27		7/14/2007 20:00	2.02	
7/7/2007 3:00	2.15				
7/7/2007 4:00	2		7/16/2007 11:00	2.04	
7/7/2007 5:00	2.05				
7/7/2007 6:00	2.08		7/17/2007 11:00	2.06	
7/7/2007 7:00	2.17				
7/7/2007 8:00	2.15		8/6/2007 11:00	1.41	
7/7/2007 9:00	2.13		8/6/2007 12:00	1.47	
7/7/2007 10:00	2.15		8/6/2007 13:00	1.68	
7/7/2007 11:00	2.16		8/6/2007 14:00	1.55	
7/7/2007 12:00	2.26		8/6/2007 15:00	1.55	
7/7/2007 13:00	2.1		8/6/2007 16:00	1.45	
7/7/2007 14:00	2.16		8/6/2007 17:00	1.7	
			8/6/2007 18:00	1.4	
7/8/2007 11:00	2.12		8/6/2007 19:00	1.33	
			8/6/2007 20:00	1.37	
7/13/2007 10:00	2.12		8/6/2007 21:00	1.24	
7/13/2007 11:00	2.25		8/6/2007 22:00	1.27	
7/13/2007 12:00	2.04		8/6/2007 23:00	1.27	
7/13/2007 13:00	2.08		8/7/2007 0:00	1.25	
7/13/2007 14:00	2.23		8/7/2007 1:00	1.29	
7/13/2007 15:00	2.06		8/7/2007 2:00	1.22	
7/13/2007 16:00	2.01		8/7/2007 3:00	1.31	
7/13/2007 17:00	2.22		8/7/2007 4:00	1.25	
7/13/2007 18:00	2.06		8/7/2007 5:00	1.13	
7/13/2007 19:00	2.1		8/7/2007 6:00	1.23	
7/13/2007 20:00	1.84		8/7/2007 7:00	1.25	
7/13/2007 21:00	1.91		8/7/2007 8:00	1.55	
7/13/2007 22:00	1.94		8/7/2007 9:00	1.2	
7/13/2007 23:00	2.05		8/7/2007 10:00	1.47	
7/14/2007 0:00	2.02		8/7/2007 11:00	1.38	
7/14/2007 1:00	2.06		8/7/2007 12:00	1.37	
7/14/2007 2:00	2.05		8/7/2007 13:00	1.51	
7/14/2007 3:00	2.07		8/7/2007 14:00	1.41	
7/14/2007 4:00	2.08		8/7/2007 15:00	1.4	
7/14/2007 5:00	2.21		8/7/2007 16:00	1.45	
7/14/2007 6:00	2.1		8/7/2007 17:00	1.44	

LDP Site Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.	**LDP Site** Date & Time (M/D/YYYY H:MM)	Measurement: CO_2 flux (μmol m^{-2} s^{-1})	Per.
8/7/2007 18:00	1.45		9/22/2007 4:00	1.09	
8/7/2007 19:00	1.39		9/22/2007 5:00	1.07	
8/7/2007 20:00	1.18		9/22/2007 6:00	0.99	
8/7/2007 21:00	1.05		9/22/2007 7:00	1.01	
8/7/2007 22:00	1.05		9/22/2007 8:00	0.96	
8/7/2007 23:00	1.11		9/22/2007 9:00	1.18	
8/8/2007 0:00	1.09		9/22/2007 10:00	1.25	
8/8/2007 1:00	1.14		9/22/2007 11:00	1.27	
8/8/2007 2:00	1.2		9/22/2007 12:00	1.58	
8/8/2007 3:00	1.16		9/22/2007 13:00	1.6	
8/8/2007 4:00	1.23		9/22/2007 14:00	1.5	
8/8/2007 5:00	1.18		9/22/2007 15:00	1.48	
8/8/2007 6:00	1.15		9/22/2007 16:00	1.56	
8/8/2007 7:00	1.22		9/22/2007 17:00	1.48	
8/8/2007 8:00	1.31		9/22/2007 18:00	1.57	
8/8/2007 9:00	1.34		9/22/2007 19:00	1.31	
8/8/2007 10:00	1.33		9/22/2007 20:00	1.32	
8/8/2007 11:00	1.33		9/22/2007 21:00	1.34	
8/8/2007 12:00	1.26		9/22/2007 22:00	1.22	
8/8/2007 13:00	1.49		9/22/2007 23:00	1.19	
8/8/2007 14:00	1.28		9/23/2007 0:00	1.42	
8/8/2007 15:00	1.37		9/23/2007 1:00	1.82	
8/8/2007 16:00	1.45		9/23/2007 2:00	1.74	
8/8/2007 17:00	1.4		9/23/2007 3:00	1.48	
8/8/2007 18:00	1.39		9/23/2007 4:00	1.43	
8/8/2007 19:00	1.36		9/23/2007 5:00	1.78	
			9/23/2007 6:00	1.92	
8/22/2007 13:00	1.2		9/23/2007 7:00	1.96	
8/22/2007 14:00	1.16				
8/22/2007 15:00	1.1		10/1/2007 14:00	1.55	
8/22/2007 16:00	1.19		10/1/2007 15:00	1.71	
8/22/2007 17:00	1.1		10/1/2007 16:00	2.4	
8/22/2007 18:00	1.16		10/1/2007 17:00	1.61	
9/21/2007 13:00	1.35		10/15/2007 13:00	1.71	
9/21/2007 14:00	1.09		10/15/2007 14:00	1.72	
9/21/2007 15:00	1.13		10/15/2007 15:00	1.79	
9/21/2007 16:00	1.14		10/15/2007 16:00	1.75	
9/21/2007 17:00	1.1				
9/21/2007 18:00	1.06				
9/21/2007 19:00	1.01				
9/21/2007 20:00	0.97				
9/21/2007 21:00	0.94				
9/21/2007 22:00	0.98				
9/21/2007 23:00	0.96				
9/22/2007 0:00	0.99				
9/22/2007 1:00	0.97				
9/22/2007 2:00	1.06				
9/22/2007 3:00	1.09				

APPENDIX B

Soil Carbon Measurements

Table B.1. Soil Sample Carbon Measurements
The heading abbreviations stand for: TD – top depth, BD – bottom depth, %C - carbon percent by weight as determined by dry combustion. "SP % of Total" is the less than 1mm sieve portion percent of total sample weight as determined by air dry weight. Carbon concentration of sample, C_C, is determined by Equation 2.1.

(a) Lower site

TD (cm)	BD (cm)	%C (g/g)	SP % of Total	C_C (gC/kg soil)
0	5	3.374	61%	20.7
5	10	2.645	70%	18.6
10	15	2.759	66%	18.1
15	20	2.403	69%	16.6
20	25	2.018	74%	15.0
25	30	1.951	68%	13.2
30	40	1.903	69%	13.2
40	50	1.580	70%	11.0
50	60	1.557	68%	10.6
60	75	1.424	70%	10.0
75	90	0.939	68%	6.4

(b) Upper site: Average %C used to calculate C_C.

TD (cm)	BD (cm)	%C (g/g)	%C (g/g)	%C (g/g)	%C (g/g)	Average %C (g/g)	SP % of Total	Average C_C (gC/kg soil)
0	5	2.183	2.126	2.244	2.351	2.2260	55%	12.2
5	10	2.577	2.575	2.581	2.257	2.4977	59%	14.8
10	15	2.211	2.168	1.978	2.048	2.1011	61%	12.9
15	20	1.887	1.915	1.87	1.919	1.8978	66%	12.4
20	25	1.92	1.936	1.884	1.803	1.8857	64%	12.0
25	30	1.514	1.522	1.724	1.961	1.6805	66%	11.0
30	40	1.247	1.187	1.224	1.335	1.2481	64%	8.0
40	50	0.889	0.935	0.855	0.943	0.9058	66%	6.0
50	60	0.77	1.069	0.87	0.741	0.8624	64%	5.5
60	75	0.61	0.644	0.667	0.629	0.6372	63%	4.0
75	90	0.591	0.599	0.614	0.566	0.5926	58%	3.4
90	105	0.307	0.337	0.351	0.362	0.3392	83%	2.8
105	120	0.497	0.53	0.509	0.526	0.5154	65%	3.4
120	135	0.211	0.206	0.199	0.228	0.2110	56%	1.2

Table B.2. Soil Bulk Density (ρ_b) Measurements

Lower Site: (Yenko, 2003)					Upper Site (Treeline: Pit T1 samples)			
Top Depth (cm)	Bottom Depth (cm)	Porosity	Assumed SG soil (g/cm^3)	Est. ρ_b (g/cm^3)	Soil Depth (cm)	Sample No.	ρ_b (g/cm^3)	Average ρ_b (g/cm^3)
0	15	0.45	2.65	1.4575	30	2	1.5	1.535
15	50	0.43	2.65	1.5105	30	5	1.57	
50	88	0.43	2.65	1.5105	60	2	1.55	1.55
					90	1	1.68	1.685
					90	3	1.69	

Table B.3. Estimate of Carbon Content by 5 cm Depth Intervals
Carbon concentration (C_C) values from Table B.1, soil bulk density (ρ_b) is estimated from values in Table B.2, and C/area is calculated from Equation 2.2.

	Upper Site			Lower Site		
Depth Interval (cm)	Average C_C (gC/kg soil)	ρ_b (g/cm^3)	C/area (kgC m^{-2})	C_C (gC/kg soil)	ρ_b (g/cm^3)	C/area (kgC m^{-2})
0 - 5	12.2	1.535	0.94	20.7	1.4575	1.51
5 - 10	14.8	1.535	1.14	18.6	1.4575	1.36
10 - 15	12.9	1.535	0.99	18.1	1.4575	1.32
15 - 20	12.4	1.535	0.95	16.6	1.5105	1.25
20 - 25	12.0	1.535	0.92	15.0	1.5105	1.13
25 - 30	11.0	1.535	0.84	13.2	1.5105	1.00
30 - 35	8.0	1.535	0.61	13.2	1.5105	1.00
35 - 40	8.0	1.538	0.62	13.2	1.5105	1.00
40 - 45	6.0	1.541	0.46	11.0	1.5105	0.83
45 - 50	6.0	1.544	0.46	11.0	1.5105	0.83
50 - 55	5.5	1.547	0.43	10.6	1.5105	0.80
55 - 60	5.5	1.55	0.43	10.6	1.5105	0.80
60 - 65	4.0	1.55	0.31	10.0	1.5105	0.76
65 - 70	4.0	1.577	0.32	10.0	1.5105	0.76
70 - 75	4.0	1.604	0.32	10.0	1.5105	0.76
75 - 80	3.4	1.631	0.28	6.4	1.5105	0.48
80 - 85	3.4	1.658	0.28	6.4	1.5105	0.48
85 - 90	3.4	1.685	0.29	6.4	1.5105	0.48