PROJECT SUMMARY

Overview:

We propose the establishment of a Critical Zone Observatory (CZO) devoted to the quantification of soil carbon (C) processes. Most of the world's terrestrial carbon is found in the critical zone, where it is predominantly stored as soil C. This important C reservoir is sensitive to climatic and land use change and may act as a source or sink for atmospheric carbon dioxide. Despite its importance, soil C remains a critical source of uncertainty in both C cycling and global climate models. That uncertainty arises due to both an incomplete understanding of the processes dictating soil C fate and the challenge of up-scaling often highly spatially and temporally heterogeneous soil processes to the landscape or global level.

The Reynolds Creek Carbon Critical Zone Observatory (RCC CZO) will address the grand challenge of improving prediction of soil C storage and flux from the pedon to the landscape scale.

Reynolds Creek Experimental Watershed is particularly well suited for this effort because it extends over strong gradients in climate and vegetation with associated dramatic differences in both soil organic and inorganic C. These gradients facilitate both observation-based science and experimental investigations in which the gradients act as primary variables. This new CZO will also be supported by unique long-term, spatially- extensive, meteorological, soil monitoring, and atmospheric datasets that will both inform and constrain conceptual and numerical models of soil C behavior.

Research efforts will be focused along a series of intensively instrumented (eddy flux towers, soil respiration, moisture, temperature, and a suite of climatic monitoring) sites along the elevation gradient. Extensive characterization of C stocks and fluxes, soil C amounts, distribution and characteristics will be undertaken at these sites as well as in a distributed manner across the watershed, producing a massive watershed-scale dataset that can inform soil C research for generations. Experimental research will include long-term manipulations of precipitation regime and fire investigations. Modeling of soil physical, chemical and biological processes will inform our efforts to reveal mechanistic linkages between soil C behavior and key environmental variables. Sophisticated climate-hydrologic models will be used to spatially distribute those controlling variables at a sufficiently high resolution (5 m) to capture the natural heterogeneity on the landscape. This data will allow application of ecosystem-soil C simulations that can be tested against the landscape-scale datasets and used to inform our understanding of soil C behavior and direct our research activities towards the areas of greatest uncertainty.

Intellectual Merit :

Soil C both influences, and is influenced by, climate change and land management practices, yet our predictive capacity is hampered by important gaps in understanding. The proposed CZO will produce one of the largest soil C datasets across a diverse landscape that will be explicitly linked to environmental variables that can be used to develop and test regional and global C models. This CZO will improve our understanding of how land management changes such as prescribed fire will alter soil properties and C inputs and thus stability of SOC at the landscape level.

The proposed intermediate scale research will improve our ability to scale local observations to the landscape and the globe. Simulation evaluation at the intermediate scale will identify areas of weakness in process representation and identify critical research needs. Observations of soil C distribution in complex terrain will provide insights into landscape-scale controls on soil C.

Broader Impacts :

This CZO, with its unique natural laboratory characteristics and temporally and spatially extensive datasets, will become a magnet for global soil modeling community research to address the grand challenge of understanding soil C behavior. In additional to training 10 graduate students, mentoring 2 postdoctoral associates, this CZO will engage >30 undergraduates and graduate student in interdisciplinary research as part of courses offered at ISU and a field camp course cross-listed between ISU and BSU. Soil descriptions will be made available to the NRCS and UC Davis to be posted on the SoilWeb Smartphone application to increase access to these data.

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SCIENTIFIC JUSTIFICATION

Most of the world's terrestrial carbon is found in the Critical Zone, where it is predominantly stored as soil carbon (Lal, 2004). Globally, soil carbon (SC), including both soil organic carbon (SOC) and inorganic carbon (SIC) represents a significant reservoir of carbon (C), 2370-2450 Pg C, compared to living biomass (560 Pg C) and atmospheric C (760 Pg C) (Kirschbaum, 2000; Lal, 2004). Given the size of the SC pool, even small changes in SC dynamics may have a large impact on atmospheric carbon dioxide (CO_2) (Lal, 2004; Baldock, 2007). Indeed, this SC reservoir can act as both an important source and sink to the global carbon budget (e.g., Kirschbaum, 2000; Lal, 2004) and is particularly sensitive to climatic and land use change (Goulden *et al*., 1998; Conant *et al*., 2011; Poeplau *et al*., 2011). These characteristics make soil carbon a particularly important variable in the planet's response to rising atmospheric CO_2 concentrations. Despite its importance, the soil carbon pool remains a source of large uncertainty in both carbon cycling and global climate models (Jones *et al*., 2005; Friedlingstein *et al*., 2006; Cadule *et al*., 2010; Falloon *et al*., 2011; Hopkins *et al*., 2012). That uncertainty arises due to both an incomplete understanding of the processes dictating soil C fate and the challenge of up-scaling often highly spatially and temporally heterogeneous soil processes to the landscape or global level.

Growing evidence indicates that the traditional conceptual model of SOC dynamics is flawed (Conant *et al*., 2011; Schmidt *et al*., 2011; Hopkins *et al*., 2012). There is an emerging consensus that rates of SC storage and release are not particularly sensitive to the chemical properties of the organic carbon (Marschner *et al*., 2008; Amelung *et al*., 2009; Kleber, 2010; Conant *et al*., 2011; Schmidt *et al*., 2011). Instead, soil physical, chemical, and biological variables (e.g. soil moisture, temperature, structure, bacterial assemblage, root behavior, biochar) more strongly dictate SC fate (Torn *et al*., 1997; Jobbágy and Jackson, 2000; Davidson, 2006; Sollins, 2007; Ekschmitt *et al*., 2008; Totsche *et al*., 2010; Conant *et al*., 2011). Currently, traditional SC models do not represent these more recent changes in our conceptual understanding of SC processes, and new experiments and models are needed to predict SC responses to future climate scenarios (Hopkins *et al*., 2012).

Applying this understanding of SC cycling is further complicated by the fact that most studies are conducted at the plot scale, but processes that operate at larger spatial and temporal scales such as fire and vegetation change may ultimately determine the impact of SC on the global budget (Westerling *et al*., 2006; Trumbore and Czimczik, 2008). For example, increasing burn frequency or area, a trend in much of the Western United States (US) (Westerling *et al*., 2006), may return C to the atmosphere faster than it can accumulate, as observed in fire-prone Mediterranean and boreal regions (Harden *et al*., 2000; Trumbore and Czimczik, 2008). In addition, there is a scaling challenge -distributing SC, a Critical Zone property that is highly heterogeneous in nature, across the landscape. To address this challenge, many environmental parameters have been used to describe SC distribution using statistical approaches (Arrouays *et al*., 1998; Jobbágy and Jackson, 2000; Kulmatiski *et al*., 2004; Garcia-Pausas *et al*., 2007; Hirmas *et al*., 2010; Kunkel *et al*., 2011), yet these approaches are limited because they often use surrogates for the soil environment (precipitation, topography, etc) rather than actual soil environment variables (soil water content, temperature or net water flux), and they are not necessarily transferable and grounded in process based understanding. If we accept that soil environmental variables are primary controls on SC fate, then the observed heterogeneity indicates that understanding and quantifying how these variables vary across the landscape will be an essential step to predicting SC distribution at a scale of value.

We propose to establish the Reynolds Creek Carbon Critical Zone Observatory (RCC CZO), a CZO devoted to the quantification of SC processes, to address the grand challenge of improving prediction of SC storage and flux from the pedon to the landscape scale. Our overarching hypothesis is: *Soil environmental variables (e.g. soil water content, soil temperature, net water flux) measured and modeled at the pedon and watershed scale will improve our understanding and prediction of SC storage, flux, and processes.* Located in southwestern Idaho, the Reynolds Creek Experimental Watershed (RCEW) (239 km^2) is particularly well suited to test this hypothesis. The RCEW extends over a steep elevation-climatic gradient (mean annual precipitation 250 - 1100 mm/yr, mean annual temperature 5.5 °C to 11°C). The associated Critical Zone exhibits a strong gradient in water and temperature limitation with both primary soil carbon flux terms, above ground productivity and below ground soil respiration, limited by temperature in winter and water availability in summer (Seyfried and Wilcox, 2006; Seyfried *et al*., 2011; Smith *et al*., 2011). This environment is characterized by strong spatial heterogeneity in SC distribution that has been shown to be statistically correlated to environmental variables (Kunkel *et al*., 2011); a trend suggestive of the promise of developing mechanistic linkages at the landscape scale. The precipitation gradient also produces a dramatic change in the importance of soil inorganic carbon (SIC), with SIC likely the dominant soil reservoir at lower elevations where infiltration is limited, while higher precipitation at upper elevations produces soil profiles dominated by soil organic carbon. These gradients facilitate both

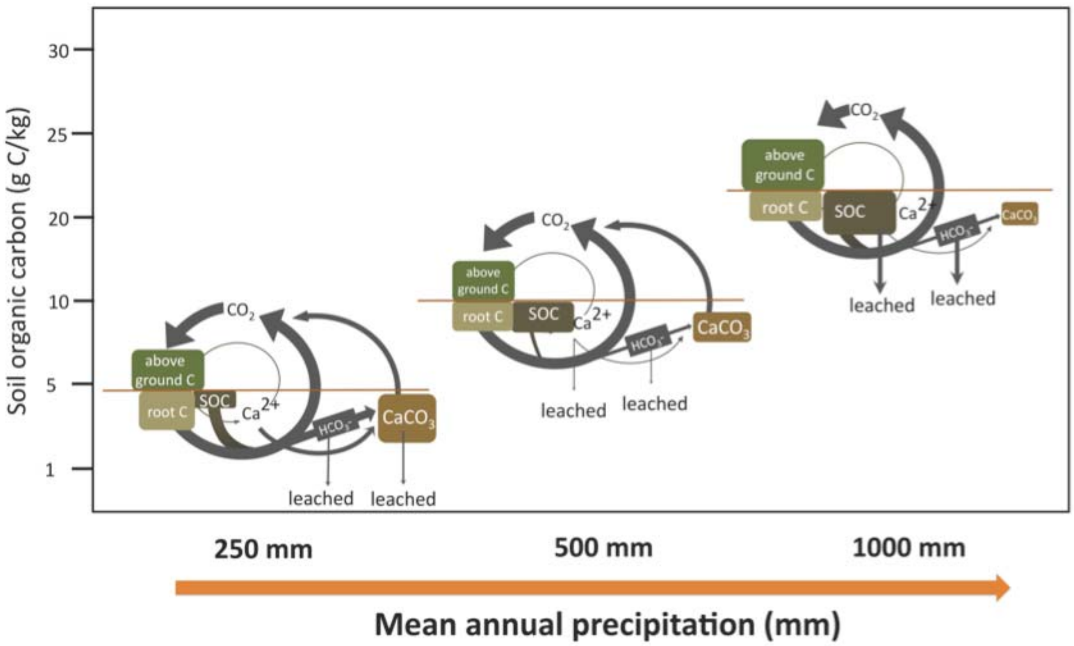

Figure 1: Conceptual framework for Reynolds Creek CZO: Hypothesized carbon pools and fluxes along a precipitation gradient representative of the Reynolds Creek CZO. Soil organic carbon (SOC) and losses via soil respiration/mineralization (CO_2) will dominate at higher rainfall whereas sinks for carbon will be in the forms of soil inorganic carbon and belowground carbon at lower rainfall (250mm) (adapted from Monger and Martinez-Rios (2001).

observation-based science using a ‘space-for-time substitution’ approach and experimental investigations in which these gradients can act as primary variables (Figure 1). The watershed is also uniquely positioned to meet the challenge of modeling SC at the intermediate landscape scale due to an extensive atmospheric, hydrologic and soil spatially distributed monitoring network that extends over as much as 50 years (Seyfried *et al.*, 2001c, site described in more detail below); this data will act both as a tool to convert point-scale understanding to larger scales and provides an important constraint on propagation of environmental variables across the landscape.

The main objectives of the RCC CZO are to:
1) Determine the relationship between measured SC storage and the soil environment at high spatial resolution across a broad, regionally significant environmental gradient;
2) Measure net carbon flux in conjunction with components of the SC cycle (soil respiration, litter decomposition, SC characteristics) and include experiments at the pedon to landscape scale to determine underlying mechanisms;
3) Evaluate SC model performance in terms of a) SC distribution across the landscape and b) representation of critical carbon fluxes at the pedon to landscape scale.

BACKGROUND

The amount and distribution of carbon is a preeminent property of the Critical Zone and a major component of the global carbon balance (Sollins *et al.*, 1996; Malhi *et al.*, 1999; Schmidt *et al.*, 2011). Critical Zone carbon may be partitioned into two highly interactive components based on location; above and below ground carbon. The above ground component is dominated by vegetation and litter, while the below ground component takes two fundamental forms, soil organic carbon (SOC), which is a mixture of organic material and an enormous variety of living creatures, and soil inorganic carbon (SIC), which is usually in the form of carbonates. Interactions between the two components are intimate and extensive. Thus, the roots from above ground vegetation are delicately infused in the soil matrix and often “infected” by soil organisms, which further extend the contact between vegetation and soil. Vegetation is the primary source of SOC supplied in quantities roughly proportional to its productivity (McDonald *et al.*, 1996; Coleman, 2004; Bardgett, 2010), and reciprocally that productivity is largely dependent upon the rate of soil organic matter (SOM) mineralization in the soil, which is a primary source of plant nutrients (Bardgett, 2010). The presence of SIC is largely a function of the depth of water flux in the soil profile, which is heavily modified by the rate and amount of transpiration. Despite these connections, the distinction between above and below ground carbon is useful in a research context because the processes that govern net carbon flux below the ground are very different from those above the ground and because the amount of SC and the rate that it turns over may significantly alter the net global atmospheric carbon balance as well as influence above ground carbon dynamics (Baldock, 2007).

Soil organic carbon Soil organic carbon (SOC) develops as the result of a dynamic tension between the processes of stabilization and destabilization (also referred to as mineralization or decomposition) (Sollins *et al.*, 1996). The effects of climate change on ecosystem net primary productivity, and hence organic C inputs have been extensively researched (e.g., Malhi *et al.*, 1999; Morgan *et al.*, 2004). **However, considerable uncertainty remains concerning how these changes affect carbon stabilization and destabilization processes** (Craine *et al.*, 2010). For example, estimates of the effect of temperature change on soil organic matter (SOM) vary dramatically both in terms of the amount and even direction (Qi *et al.*, 2002; von Lützow and Kögel-Knabner, 2009; Craine *et al.*, 2010; Schmidt *et al.*, 2011). Similarly, the use of prescribed fire as a management practice may increase the production of fire derived organic matter (sometimes called char) under relatively cool burn conditions, but its reactivity is subject to widespread debate (Preston, 2006).

Role of nitrogen in soil carbon stabilization Carbon and nitrogen cycles operate and interact with each other at multiple scales (Lohse *et al.*, 2009), with recycling and release of soil organic N into inorganic forms as a source of nutrients for plants and main control on plant productivity. The role of nitrogen (N) in SC stabilization has received increasing attention due the potential for increased CO_2 to be released as well as mineral N from SOC with global warming (Sollins *et al.*, 2006; Rillig *et al.*, 2007). In particular, attention has been paid to proteins that can either be decomposed and released as inorganic forms of N or be stabilized in soils with sorption of peptidic organics to soil mineral particles being a potentially important process of C and N stabilization (Sollins *et al.*, 2006).

SOC modeling The complexity of the processes involved and the large scales of interest require the use of simulation models. Virtually all current models used to simulate SOC, including those used to estimate global SOC dynamics, are based on a paradigm of progressive recalcitrance of organic matter over time, and simulations are based on the transfer of incoming organic carbon (e.g., litter) among various “pools” of SOC (eg., Parton, 1993). There are a couple of problems associated with this modeling approach. First, these pools cannot be separated physically or chemically or measured directly (Sollins, 2007). Second, distinctions between stabilization of N containing organics and non-N containing organics are not reflected in current SOC model dynamics (Jenkinson *et al.*, 1991; Currie, 2003; Rastetter *et al.*, 2005). Finally, more recent research has called into question the basic paradigm behind those models suggesting that, while chemical properties partially control SOC dynamics, environmental and biological controls are dominant (Schmidt *et al.*, 2011). These points are supported by recent research in sagebrush steppe vegetation in the USA showing that traditional SOC pools may not function as assumed in the paradigm (Hooker and Stark, 2012) and that the impact of different vegetation types on mineralization rates is primarily controlled by environmental factors, such soil moisture, as opposed to the chemical composition of the SOC (Norton *et al.*, 2012). **This emphasis on SC as an ecosystem (or Critical Zone) property dependent on the soil environment in which it is formed, points to the critical need for adequate description of the soil environment to understand SOC dynamics. In addition, the accuracy of current SOC model fluxes need to be evaluated in a range of soil environments to determine if the underlying paradigm supports the need for accurate carbon flux estimation across the landscape.**

Soil inorganic carbon In general, SIC, which is overwhelming composed of $CaCO_3$ (Monger and Martinez-Rios, 2001) and therefore somewhat soluble, accumulates in soils that are sufficiently dry that there is little or no net transport of water through the soil profile most years. These soils dominate in the western USA, for example (Jenny, 1980), where most SIC formation is attributed to the precipitation of downwardly moving carbonates (Marion and Schlesinger, 1994). Because the basic soil reactions governing SIC precipitation are controlled by soil CO_2 concentration, soil temperature and soil water balance (Hirmas *et al.*, 2010); the net accumulation of SIC is sensitive to climate change and land management. This has been demonstrated by retrospective studies of SIC accumulations in the Pleistocene (McDonald *et al.*, 1996; McFadden *et al.*, 1998).

SIC modeling. A quantitative linkage between climate, in particular precipitation, and SIC, has been recognized for many years (Jenny, 1935; Arkley, 1963). This approach has been extended to incorporate chemical processes (Marion and Schlesinger, 1994; Hirmas *et al.*, 2010) and with more explicit, process-based simulation of soil water and temperature dynamics (McDonald *et al.*, 1996). This research has centered on SIC dynamics in arid regions, where pedogenic $CaCO_3$ formation most pronounced. Climate change in those regions often results in an altered vertical distribution of SIC, but not necessarily a net loss or altered rate of gain (Monger and Martinez-Rios, 2001). There is, however, a potential for a net gain or loss of atmospheric CO_2 in the transition zone between calcic and noncalcic soils. It is also likely that secondary influences related to biological interaction, soil morphology or landscape position may be critical (McFadden *et al.*, 1998; Hirmas *et al.*, 2010). A remaining challenge in SIC modeling is the demarcation of the SIC accumulation zone, how it is distributed on the landscape and prediction of how it will migrate under a changing climate.

Processes controlling carbon storage The net retention or loss of C from the soil is the result of the action of biogeochemical processes on incoming C as modulated by the soil environment. This view is consistent with the long-standing view of soil formation as being described by the factors of climate, organisms, relief, parent material, time and human activity (Jenny, 1980), which are state factors that control variations in the soil environment. Thus, SC is expected to vary across the landscape as those factors vary and the larger scale, continental or global atmospheric C flux is an integrated signal from the host of soil environments in the domain. **Understanding that flux implies understanding the mosaic of soil environments that create it**. A fundamental problem associated with modeling these larger scale fluxes is that the models used are generally tested or verified only at a relatively small number of well characterized points (e.g., Parton, 1993; McDonald *et al.*, 1996; Malhi *et al.*, 1999) with practically no verification at the multi-kilometer scale (Running and Hunt, 1993). Scaling these points up to larger scales, as with nonlinear processes in general, may produce large errors (Jarvis, 1993; Craine *et al.*, 2010). Thus we find SC estimates that vary by as much as two orders of magnitude (Monger and Martinez-Rios, 2001). The next logical step in quantifying terrestrial SC dynamics is at the intermediate scale (100 to 1000 km^2), which is large enough to encompass sufficient soil environment variability to have regional implications while not so large as to render characterization impossible in a practical sense. This is also the roughly the scale chosen by other CZO's to investigate critical zone processes.

A CZO FOR SOIL CARBON- A VISION FOR UNDERSTANDING THE ROLE OF CRITICAL ZONE CARBON DYNAMICS IN THE TERRETRIAL CARBON CYCLE

- Findings from this proposed CZO will produce one of the largest soil C datasets across a diverse landscape that will be explicitly linked to environmental variables that can be used to develop and test regional and global carbon models.
- Findings from this observatory will improve our understanding of how land management changes such as prescribed fire will alter soil properties and carbon inputs and thus stability of SOC at the landscape level.
- The proposed intermediate scale research at the RC CZO will improve spatial estimates of net carbon fluxes and provide context for process-oriented research.
- The RC CZO will leverage temporally and spatially extensive hydrologic data at the RCEW to provide a unique research focus on SC processes.
- Knowledge of how changes in the soil environment associated with topographic or geologic gradients will provide the basis for a more accurate spatial representation of SC processes.
- Evaluation of simulations at the intermediate scale will identify areas of weakness in process representation and hence point to critical research needs.

THE CZO FOR CARBON --THE REYNOLDS CREEK EXPERIMENTAL WATERSHED

Reynolds Creek Experimental Watershed (RCEW) is an ideal location for the establishment of a soil carbon CZO for the following reasons: 1) the RCEW fits within the intermediate scale (239 km^2), 2) it is physically diverse and has a wide range of climate conditions, 3) it supports a preexisting, long-term, spatially extensive data collection and 4) it is the site of land management practice evaluation. We expand on these points below.

Environment Located in southwestern Idaho, the RCEW encompasses a wide range of ecohydrological environments typical of the intermountain region of the western USA. An extensive description of the RCEW environment can be found in Seyfried *et al.*, (2001). The environmental variability is driven by the nearly 1000 m elevation range and variable geology. Precipitation in the RCEW is not strictly a function of elevation, but generally increases with elevation from less than 250 mm/y to greater than 1100 mm/y while mean annual temperature decreases about 5°C. Rain is the dominant form of precipitation in the RCEW, with snow dominating in the highest elevations. Corresponding vegetation types include sagebrush steppe in the lower elevations, transitioning to mountain sagebrush, western juniper, aspen and coniferous forest (Figure 2). The edaphic environment

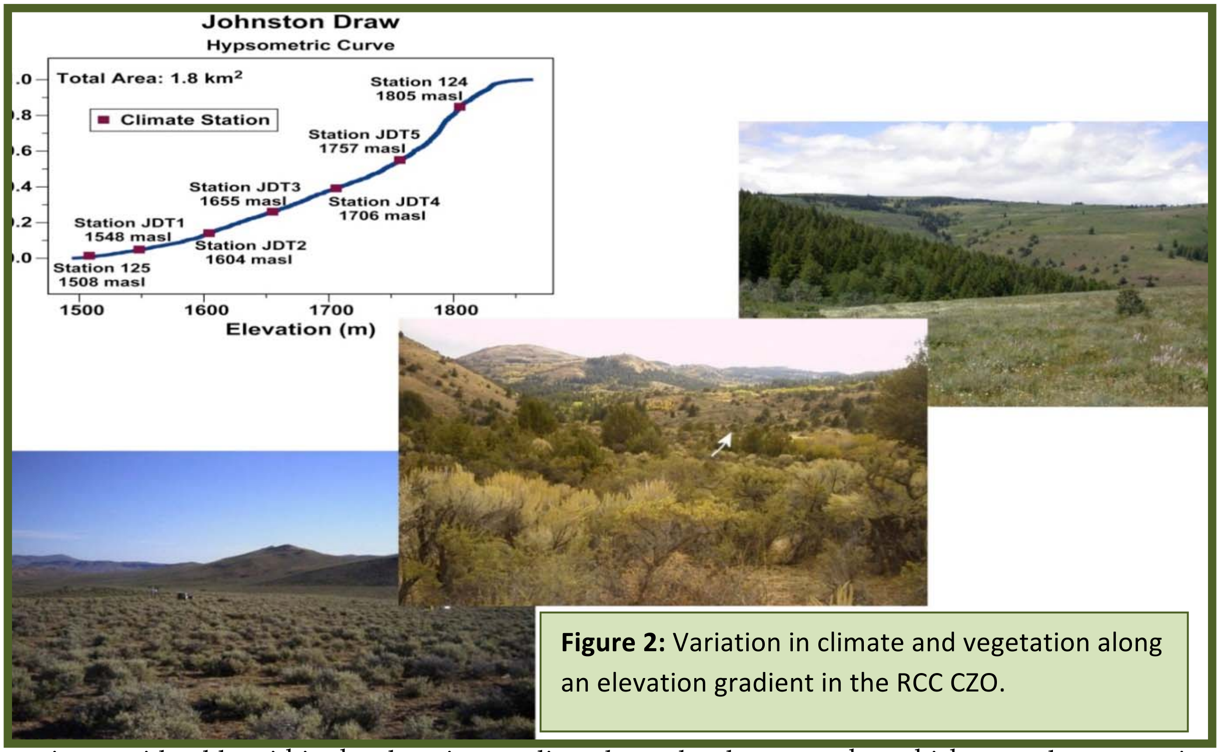

Figure 2: Variation in climate and vegetation along an elevation gradient in the RCC CZO.

varies considerably within the elevation gradient due to local topography, which controls evaporative demand and snow distribution, soil depth and parent material, which includes basalt, granite, rhyolite and large areas of mixed alluvium deposited from a mix of sources. The result is a mosaic soil environments conditions that generally trend with elevation.

As might be expected, SC varies widely within the RCEW, both in amount and type. For example, at one, high elevation site under aspen and affected by snow drifting, the depth-weighted average (to 150 cm) SOC content is 20.3 g C/kg with no measureable SIC. (Soil pH is about 6.3 at all depths). This is contrasted with a depth-weighted average SOC content of 5.0 g C/kg at a low elevation, much drier site under sagebrush. At the low elevation site, however, 39.8 g C/kg of SIC was measured, so that considerably more total SC is stored at the low elevation site. There are strong vertical gradients of SOC in both profiles, and no SIC was detected above 76 cm at the low elevation site. This "flipping" of the predominant SC form with elevation, or more precisely, with soil environment, is evident in the detailed, watershed specific soil survey that was conducted at the watershed (Stephenson, 1977). Although the survey provides only qualitative information, gradients of both SOC and SIC accumulation are clear.

Scientific Infrastructure The existing scientific infrastructure is a key advantage for the RCEW site. Most CZO sites require substantial funding to produce a hydro-meteorological network that falls short of that available currently at the RCEW. This network is critical because it forms the basis for understanding how the soil environment varies over time and space. Here we briefly describe the network and highlight some of the key feature especially relevant to the CZO. Detailed descriptions of the RCEW and published data can be found in Hanson, 2001; Hanson *et al.*, 2001; Marks, 2001; Seyfried *et al.*, 2001a; Seyfried *et al.*, 2001b; Seyfried *et al.*, 2001c; Seyfried *et al.*, 2001d; Slaughter *et al.*, 2001; Nayak *et al.*, 2010; Chauvin *et al.*, 2011; Reba *et al.*, 2011; Seyfried *et al.*, 2011 (see also ftp.nwrc.ars.gov for data).

Historic database The existing, publically available hydroclimatic data are long-term and spatially extensive. The primary data are summarized below (Table 1). The long-term nature of the data research can be conducted in the context of the climate at different locations and how it is changing. An increase in temperature (1-2°C), reduction of snow and temporal shift of streamflow with no change in total precipitation or soil water storage have been documented at the RCEW (Nayak *et al.*, 2010; Seyfried *et al.*, 2011). The spatially extensive nature of the data (see Figure 3) is critical given the now understood horizontal, as well as vertical, variability of the climate within the RCEW. These data are not collected on a regular grid, but spaced with higher density in areas of steeper environmental gradients and at specific special study sites (Figure 3). Four of the most heavily instrumented study sites are included in Figure 3.

Those intensively monitored sites have been used to study specific hydrologic processes and will be useful for SC research at the RCEW. Virtually all data collected in the RCEW are telemetered daily to the database in Boise.

Table 1: Available hydroclimatic data for the RC CZO

Parameter:	Measured Value:	# of Stations			Years of Record:	Data Interval:
		1975	1996	2013		
Precipitation	shielded precipitation unshielded precipitation	53 53	17 17	28 26	1962-2012 1962-2012	Breakpoint (bp),[1] 15 min
Snow	snow course SWE snow pillow SWE snow depth	8 1	8 1	8 2 32	1961-2012 1961-2012 1994-2012	bi-weekly 15 min 15 min
Daily Climate (evap- summer only)	T_{max} and T_{min} pan evaporation	3 3	3 3	32 1	1964-2012 1974-2006	Daily Summer
Weather	air temperature humidity solar radiation thermal radiation wind speed & direction barometric pressure heat flux surface & canopy temp	3 3 3 3 3	5 5 5 4 3	38 36 32 5 32 6 8 3	1981-2012 1981-2012 1981-2012 1995-2012 1981-2012 1981-2012 2002-2012 2003-2012	15 min
Eddy Correlation	H, L_vE, H_2O, C-flux, R_n (4 component)			5	2002-2012	10 Hz & 30 min avg
Sap Flux	Heat dissipation			12	2010-2011	Hourly
Soil Lysimeter	lysimeter water content	4			1976-1991	Hourly
Snowmelt lysimeter	Water flux		8	6	1982-2012	Hourly
Neutron Probe	soil water (various depths)	18	14	35	1970-2012	bi-weekly
Soil Moisture	% water (various depths)			32	2000-2012	Hourly
Soil Temperature	soil temp (various depths)	5	5	32	1981-2012	Hourly
DTS Snow & Soil Temperature	Distributed Temperature (various depths)			2 km	2010-2011	Hourly
Ground Water	GW head	34	12	9	1968-2012	Hourly
Discharge & Sediment	stream discharge suspended sediment	13 3	8 3	10 9	1963-2012 1965-2012	bp,[2] 15 min event-based
Stream Temperature	Water temperature at the weir			4	2000-2012	Hourly
Vegetation	Production, LAI and cover			3	2009-2012	Semiannually

Soil Environment Characterization of the soil environment, as opposed to the climate, is central to the CZO. The original soil water and temperature data collection network, which extends back more than 30 years, has been dramatically expanded in the past ten years to include robust, well calibrated (Seyfried *et al.*, 2005) soil water and temperature sensors. This kind of data is necessary for confirming the accuracy of the SC models used to calculate SC dynamics across the landscape (e.g., RCEW). Note that data collection is spread throughout the RCEW and also concentrated in specific research sites (Figure 3). For example, data collected at Johnston Draw is intended to elucidate topographic influences (Figure 2), while that at Upper Sheep Creek is focused on differential snow distribution. Other sites (not shown) are oriented toward grazing effects in the low elevations.

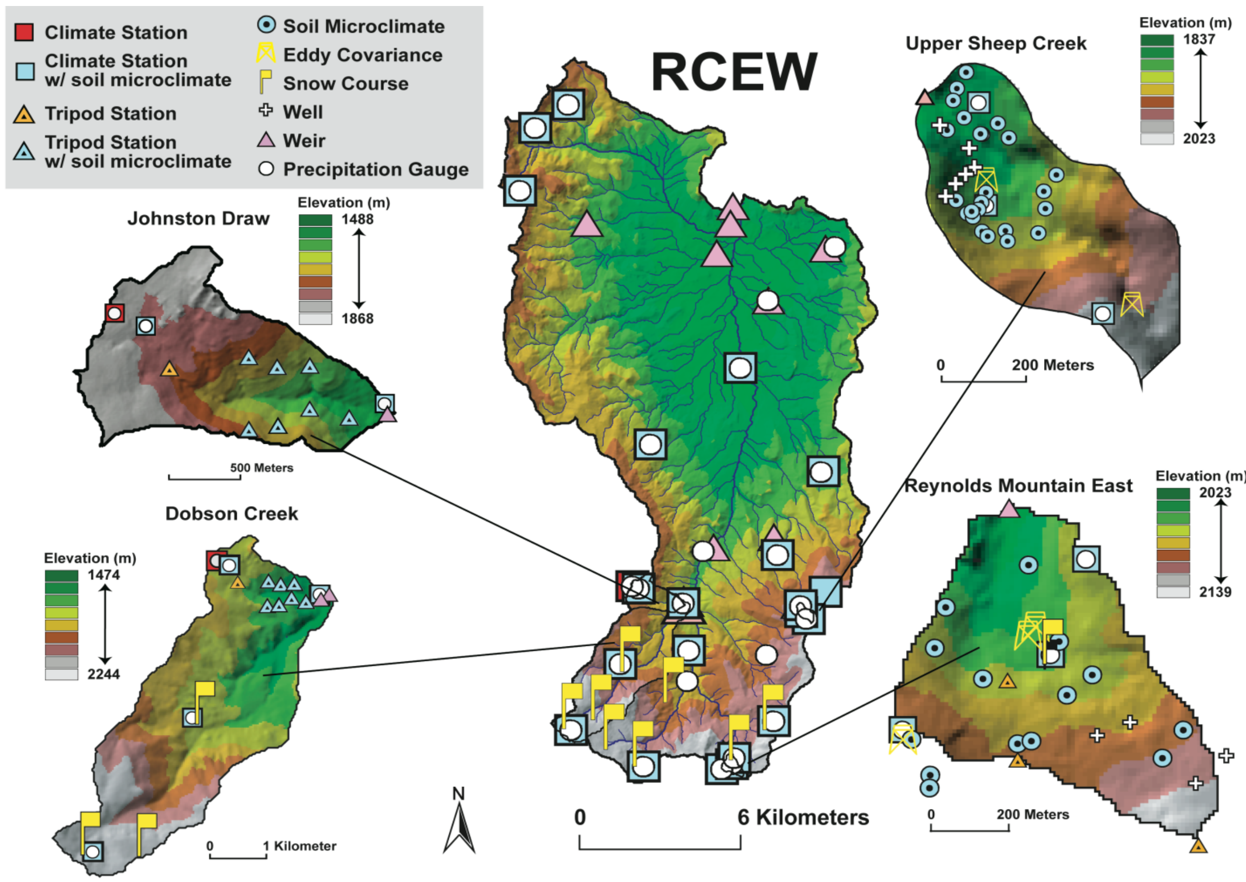

Figure 3: Spatially extensive hydroclimatic data available at the proposed RCC CZO.

Eddy Covariance Determination of present day carbon balance, in conjunction with the water balance will be critical. The existing 5 EC instruments have been used for hydrological research to date (Marks *et al.*, 2008; Reba, 2009; Flerchinger, 2010; Flerchinger *et al.*, 2012; Reba *et al.*, 2012a; Reba *et al.*, 2012b) but carbon flux has been monitored throughout, providing a potentially powerful starting point. The instruments will be redeployed to reflect a shift in research emphasis to include carbon fluxes at drier, SIC dominated sites.

LiDAR Reynolds Creek has LiDAR (point clouds and processed bare earth rasters) for the entire experimental watershed, with a point cloud density of ~5 pts/m^2. The dataset is adequate for estimation of aboveground biomass estimates for large shrubs and trees but are not entirely sufficient to resolve sagebrush steppe aboveground biomass estimates. As described below, we will supplement this spatially extensive data with temporally intensive data from terrestrial laser scanning (TLS) and narrow-band spectroscopy, to resolve sagebrush steppe aboveground estimates of biomass, LAI, and productivity. The temporal remote sensing measurements will be used for model testing. Spectroscopy will provide estimate of changes in foliar N that will be key for productivity estimates and modeling. LiDAR data products will also include: vegetation height, vegetation cover, vegetation roughness, terrain roughness, vegetation patch and connectivity, and derivative products.

Fire and the Prescribed Fire Program Fire frequency and extent are increasing in the Western US with changes in climate (Westerling *et al.*, 2006) and vegetation (introduced species such as *Bromus tectorum* (cheatgrass) (Allen *et al.*, 2011). Use of prescribed fire as a management practice has emerged as a tool to control fuel loads (McIver *et al.*, 2010); the NWRC has undertaken a prescribed fire management program in cooperation with the Bureau of Land Management (BLM). The Northwest Watershed Research Center (NWRC) selects sites, conducts experiments and monitors and evaluates fire effects, while the BLM assists in site selection and conducts the fires. The primary ecohydrological criteria for site selection is that precipitation be sufficient such that invasive species such as cheatgrass, and yellow star thistle do not expand as a result of the fire. To date, three fires (2002, 2004 and 2007) have been conducted in the RCEW. The next fire is scheduled for 2013. The temporal sequence of past fires and the ability to participate in the planning of future fires provides a rare opportunity for research into the effects of fire on SC.

Watershed Management In general, the management and ownership of the RCEW lands are typical of much of the western US, which is to say that the RCEW is a "working" as opposed to a pristine, watershed. Most of the land in the watershed (77%) is owned by either the state or federal government, and, in this case, managed by the Bureau of Land Management (BLM). The remaining, privately held land is managed by local ranchers, primarily four families that live in or adjacent to the watershed and derive their livelihood from cattle ranching. In addition to cattle grazing, a small part of the valley is used to raise hay and there is some timber harvesting. The mission of the NWRC compliments the objectives of the CZO program: "To provide knowledge and technology for management of semi-arid rangeland watersheds; to quantitatively describe the hydrologic processes and interactive influences of climate, soils, vegetation, topography, and management on rangeland systems; to develop information, simulation models, and tools that can be used by action agencies and producers in determining optimum management strategies; and to maintain long-term databases for scientific applications." Much of the success of the unit has been through cooperative research with academic institutions. In fact, the RCEW is intended to provide a spring-board for complimentary research. Accommodation, with wifi and rudimentary lab space is provided for visitors, which typically log about 100 visitor-hours each year.

The long-term maintenance of the scientific infrastructure described above is a major undertaking by the USDA ARS. It requires routine, year-round instrument evaluation, calibration and replacement coordinated with data management. All data collected is subject to scientific oversight by NWRC staff. The NWRC supports a "headquarters" facility where field staff are stationed who are responsible for the day-to-maintenance of both the scientific and physical infrastructure. The latter includes vehicle maintenance, road repair, facilities, etc. In addition, an electronics technician keeps the data flowing and maintains the radio telemetry system and a database manager evaluates incoming data quality and processes those data with scientific supervision.

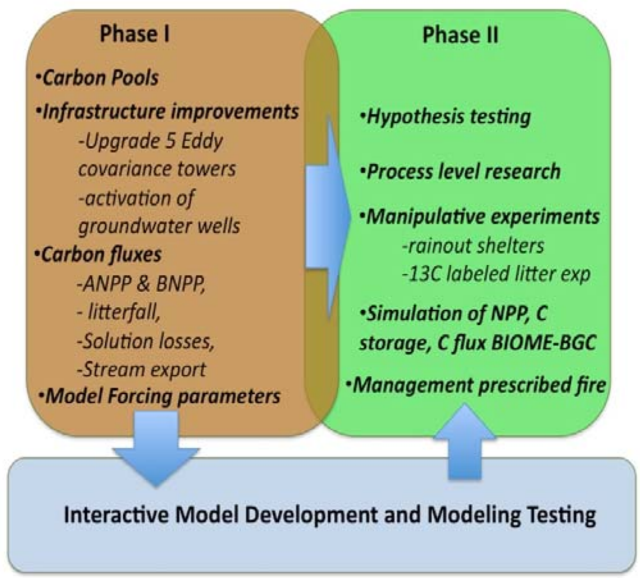

Figure 4: Integration of RCC CZO Phase I and II activities with modeling.

IMPLEMENTATION PLAN

Overview We organize our research around our conceptual framework (Figure 1) and three research objectives: 1) Determine the relationship between measured SC storage and the soil environment at high spatial resolution across a broad, regionally significant environmental gradient; 2) Measure net carbon flux in conjunction with components of the SC cycle (soil respiration, litter decomposition, SC characteristics) and include experiments at the pedon and landscale scale to determine underlying mechanisms; 3) Evaluate SC model performance in terms of a) SC distribution across the landscape and b) representation of critical carbon fluxes at the pedon and landscape scale.

To address these objectives, research will proceed in two, overlapping phases (Figure 4). **Phase I** (yr 1-3) involves 1) measurement of SC stocks, 2) monitoring, development of spatially distributed atmospheric forcing data sets and management treatments, 3) enhancement of current data collection, particularly SC fluxes to address objective 2- 3. **Phase II** will be directed towards process level research, hypothesis testing, manipulative experiments and model testing to address objective 2-3. This phase (3-5 yr) will involve rainfall manipulations to examine the effects of changes rainfall on stabilization and destabilization of SC, and litter labeling experiment to understand the fate of this carbon. We will also utilize a fire chronosequence (prescribed fires in 2002, 2004, 2007, and 2013) to understand the effects of fire and char on SC stabilization and destabilization. Model testing will be integrated in both Phase I and 2 to address Objectives 1-3.

Objective 1) Determine the relationship between measured SC storage and the soil environment at high spatial resolution across a broad, regionally significant environmental gradient
Approach: While the proposed RCC CZO has extensive soil environment data as described above, SC data are limited to descriptions from Stephenson (1977) and a few surveys conducted over the years. Thus quantifying SC stocks across a broad, regionally significant environmental gradient will be a major research thrust in the first three years of the RCC CZO. Variability of SC (or other CZ properties) can be categorized as either deterministic or stochastic (Burrough *et al.*, 1994). The distinction depends on the scale of interest and the scale of critical processes that control SC (Seyfried and Wilcox, 1995). It is important to characterize both kinds of variability. The models used generally address deterministic variability—they will provide an answer for a given set of input variables. Assessment of model performance, however, will require the use of spatially variable SC concentrations. That is, the verification/testing data sets will be imprecise. The level of imprecision defines how rigorous the test is. It will also be important for the SC inventory to capture critical thresholds and gradients (e.g., calcic vs non-calcic soils). We therefore expect to conduct a preliminary survey to identify those thresholds, followed by a more detailed survey that would include variability data.

To be most efficient, we will first conduct an overview survey to determine the ranges of values and the density of change in those values across the landscape. This survey will probably depend on the form of SC. For example, we anticipate that the SIC survey will focus on lower elevations and the transitions zone between calcic and non-calcic soils. On the other hand, the SOC survey will focus on higher elevations, where we expect to see much greater variably in response to environmental conditions. It will be especially critical to determine where, first geographically and then in soil temperature and soil water flux space, the transition from non-calcic to non-calcic soil occurs. Following the initial survey, more intensive surveys will take place that captures the variability across the landscape (toposequence, lithosequence, chronosequence, biosequence (cheatgrass vs sagebrush steppe) (Jenny, 1980) as well as the variability of SC within soil mapping units.
SOC and SIC We have 5 scientists on the team with extensive training and experience in soil description and pedology (Seyfried, Lohse, Pierce, Benner, deGraaf). We will use a combination of soil profile descriptions and augering to obtain soil samples to 2m depth for soil carbon (SOC, SIC) and nitrogen, bulk density, and basic soil physio-chemical characterization using standard methods (Carter and Gregorich, 2008). We will engage a critical mass of participants and students in this activity in yr 1 and 3 as part of summer field course/environmental field methods courses (see engagement plan). Soil excavation and augering methods will be used to determine soil bulk density and coarse fraction. Soil will be divided into multiple subsets depending on time sensitivity and pre-treatment of soils. One set will be immediately dried for gravimetric soil moisture content at 105 degree C, another dried at 55 degree C for determination of soil total C and N, SOC and SIC, and another air-dried for elemental and mineralogical analyses. Soils (<2mm fraction) will be ground, acid fumigated to remove carbonates, packed and analyzed for SOC and isotopes of C and N at the CAMAS isotope facility at ISU. A subset of soils will be analyzed for SIC using a modified pressure calimeter method at BSU.
Soil Physio-Chemical Properties: A subset of soils will be analyzed for time sensitive and other physical and chemical properties following standard methods described in Carter and Gregorich (2008). In particular, a subset of soils will be analyzed for soil pH, EC, and nutrient pools and process rates as described by Lohse and Matson (2005). Another set will be analyzed for microbial biomass, initial microbial community characterizations, and SOC density fractionations at BSU (described in more detail in manipulations). In addition, a subset of air-dried soils will be characterized for cation exchange capacity, exchangeable cations, aluminum, acidity, extractable Al, Fe, Mg, and Si. Other soil subsets will be analyzed for particle size distribution and texture by the hydrometer method at the USDA-ARS. Soil water characteristic curves (WCC) will be determined on a subset of these soils at the USDA-ARS **(Lohse: SOC and nutrients; Seyfried: textural analyses, bulk density, WCC; Pierce/Benner: SIC and elemental analyses: Feris/deGraaf: density fractionations, microbial biomass, initial microbial characterization).**
Model Forcing parameters (postdoc, Marks, Kumar) Detailed simulation of the soil environment and SC dynamics requires detailed and accurate forcing data. This includes an estimate of the distribution and phase of precipitation, and the distribution of air temperature, humidity, radiation and the wind

field. This is a critical research activity because the soil temperature and moisture state is highly sensitive to temperature, radiation and the timing, magnitude and temperature of delivered water. Because the RCEW is a data rich environment, it has been extensively used to develop and validate methods and models for forcing parameter distribution. We will use the methods described by Garen *et al.* (1997) and refined by Kahl *et al*. (2013) to estimate general distributions of precipitation, temperature, humidity, wind and cloud cover over RCEW. The methods described by Winstral *et al.* (2009, 2012) will be used to refine the wind field and its effect on snow distribution and drifting. The methods described by Marks *et al.* (2002; 2012) will be used to determine precipitation phase and the elevation of the rain-snow transition during storms. Solar radiation, including cloud and canopy cover effects will be determined using the methods described by Reba *et al.* (2011).
Soil data collected and data simulations will allow the determination in relationship between measured SC storage and the soil environment at high spatial resolution across a broad, regionally significant environmental gradient.

Objective 2) Measure net carbon flux in conjunction with components of the SC cycle (soil respiration, litter decomposition, SC characteristics) and include experiments at the pedon to landscape scale to determine underlying mechanisms.
Approach: For the first 5 years of the observatory, we propose to focus intensive measurements of SC and aboveground and belowground processes within the vicinity of the 5 eddy covariance towers (to be redeployed as part of this research, and referred to the CORE sites hereafter). In particular, we will redeploy two eddy covariance towers in a soil organic dominated environment, two at the transition, and one in a soil inorganic dominated site (Figure 1-2). **Phase I** (yr 1-3) will include expansion of SC process monitoring. **Phase II** will include hypothesis testing and pedon and landscape scale manipulations.
Phase I Measurements of SC processes will be key to improving our understanding at the pedon scale as they relate to soil environmental variables (Figure 1) and model testing at the pedon and landscape scale in Objective 3. The SC process measurements include: a) eddy covariance upgrade and deployment to determined net ecosystem exchange (NEE), b) high resolution temporal measurements of aboveground vegetation biomass and foliar N, c) aboveground net primary productivity and litterfall quantity and quality inputs to soil, d) litter decomposition, e) soil CO_2 probes at multiple soil depths to determine soil respiration fluxes by gradient method, f) lysimetry to examine solution DOC and DIC chemistry and g) export of particulate organic carbon (POC) and dissolved inorganic (DIC) and organic carbon (DOC) in stream water and dissolved load in groundwater. Some measurements will be used at the pedon scale for process understanding while others will be used for scaling to landscape level or both. For example, accurate aboveground pool estimates are required parameters for both pedon and landscape scale modeling. LiDAR and other remotely sensed data will be coupled to Terrestrial Laser Scanning (TLS) and spectrometry to measure biophysical parameters such as foliar carbon, nitrogen, lignin and cellulose content over time and in space, parameters that are key controls on primary productivity and decomposition.
a) Eddy covariance deployment (Flerchinger) The USDA-ARS currently operates five eddy covariance systems within the Reynolds Creek Experimental watershed that have been used almost extensively for measurement of energy and water balance (Marks *et al.*, 2008; Flerchinger, 2010; Flerchinger *et al.*, 2012; Reba *et al.*, 2012a; Reba *et al.*, 2012b). These systems have been collecting C-flux data since 2002, and some of the data are reported in Flerchinger (2010). They are currently deployed in the upper elevations of the watershed at sites dominated by SOC, and none are currently in sites dominated by SIC. These systems will be redeployed to cover the transition between SOC and SIC and will be co-located with other key measurements and observations. Soil temperature and moisture probes will need to be installed in some of these locations.
All five of the systems are aging and require system upgrades to provide reliable, state-of-the-science data. System upgrades will include replacing the outdated LI-7500 sensors with new LI-7500a and controllers, replacing damaged soil heat flux plates, adding telemetry capability, and completing one system that lacks a four-component net radiometer and HMP45C. Spare components will be purchased to ensure reliability of the systems and to minimize data gaps. A postdoc mentored by Dr Flerchinger will be charged with maintaining, processing, and analyzing the surface energy and carbon flux data from the eddy covariance systems from the historical data (2002-2013) and new data. Data from the eddy covariance systems will be processed, gap-filled and analyzed to characterize the surface energy fluxes, carbon fluxes and net ecosystem exchange (NEE) across the SOC to SIC transition. Surface energy and carbon fluxes will be compared and contrasted to quantify differences in water use, evapotranspiration and carbon flux across the transition zone. Where co-located, eddy covariance measurements will be

combined with soil respiration measurements to differentiate the carbon flux to the plants versus that from the soil. These data will be used to evaluate simulation of carbon storage and carbon flux with landscape level models.

b) High-resolution soil surface, aboveground biomass, and productivity estimates (Glenn)

LiDAR data have been processed for the watershed and is adequate for one time-stamp of bare-earth terrain, vegetation height (Glenn *et al.*, 2011; Spaete *et al*, 2011), and to a limited degree, aboveground biomass. The LiDAR data resolution is not adequate for direct estimation of low-stature vegetation biomass (most sagebrush species, grass, and forbs); however it is useful for large shrubs and trees (Shrestha *et al*., 2012). To spatially and temporally supplement this dataset, we will utilize TLS and field spectroscopy (ASD FieldSpec Pro, 400-2500 nm), for determination of biophysical parameters related to primary productivity, such as foliar carbon, nitrogen, lignin and cellulose content, over time (Mitchell *et al*., 2012b; Mitchell *et al*., 2012a). The TLS will also be used for scaling to enhance low-stature aboveground biomass estimates at the watershed scale. The spectroscopy measurements will be repeated seasonally and data assimilation techniques will be used to relate to wider greenness bands for scaling to Landsat-scale (e.g. 30 m, Landsat 8) and coarser-resolution MODIS (NPP and NDVI products). Existing TLS fine-scale biomass measurements and techniques will also be used (Olsoy, *et al*., in review). Vegetation plots for productivity validation will rely on field spectrometer measurements of the same biophysical parameters and be established near eddy covariance towers and CORE sites for measurement of plant productivity.

c) ***Aboveground and belowground net primary production (ANPP and BNPP) (Reinhardt, deGraaf)***. The mass of C per unit area per year fixed above and below ground (ANPP and BNPP) is a key SC process in the Critical Zone and critical for both pedon and landscape modeling. We will use multiple techniques to measure ANPP and BNPP for estimates at the pedon to landscape scale and for vegetation type at the different CORE sites. For example, continuous measurements of canopy transpiration and stomatal conductance will be key for modeling ANPP at larger scales (e.g. BIOME-BGC) (Warren *et al*., 2011). Here we will focus on diameter growth increment and litterfall for measuring ANPP and root ingrowth cores for BNPP at the pedon scale.

Aboveground net primary production (ANPP). ANPP will be quantified in several ways. For trees, litterfall and manual and automated dendrometer bands (AES, Tucson, AZ) in combination with available allometric equations will be use to estimate ANPP. For shrubs, litterfall and allometric equations will be used that are already available and be developed for other shrub and perennial grass (e.g., Huenneke *et al*, 2002; Nafus *et al*, 2009). Allometric measurements will be coupled with line-intercept methods (e.g., see Böhm, 1979) to quantify the frequency and size of dominant species. Annual grass ANPP will be estimated by collection of biomass (1m x1 m plot) at 4 intervals during the growing season including peak biomass. Finally, sap flux sensors will be installed in the CORE in trees at higher elevations and sagebrush steppe for measures of stomatal conductance, canopy transpiration and stand water use to be used for modeling at larger scales (e.g. BIOME-BGC) (Warren *et al*., 2011). Nine Granier sap flux sensors will be installed in trees at higher elevations, and 9 tissue-heat-balance sap flux sensors will be installed in shrubs at lower elevations at the CORE sites, and connected to dataloggers. Sapflux sensors will also be used in Phase II to estimate belowground autotrophic respiration using girdling treatments (Scott-Denton *et al*., 2006).

Litter production and chemistry: Litter-traps will be used to estimate aboveground litter production and scaled according to the canopy (10-20 0.4m x 0.4m traps for tree CORE site). The litter traps will be constructed of UV resistant polyester mosquito netting suspended on a metal frame. Litter will be collected monthly, dried, weighed, and analyzed for CN content (elemental analyzer at BSU), lignin using the acetyl-bromide method (Ilyama K, 1990), and starch and sugars using the hot ethanol extraction method (Chow, 2004).

Belowground net primary production (BNPP): BNPP will be quantified using a modified root ingrowth core technique (Persson *et al*., 1980; Arnone et *al*., 2008). Holes for cores (12 cm diameter x 50 cm deep) will be lined with a stainless steel mesh cylinder (mesh opening = 3 mm). Soil obtained during coring will be separated by depth horizon (in 10 cm increments), sieved to remove roots and coarse fragments >1 cm, and used to refill cores at approximately the original soil bulk densities for all layers. Rock content will be high (>50%) in some sites. In that case, we will add gravel (<1 cm) to account for rock volume. Twice per year (in the winter and at peak standing biomass), soils will be cored inside each cylinder with a 9.8 cm OD steel pipe. Residual soil and roots inside the cylinder will be vacuumed out using a clean Shop-Vac industrial wet-dry vacuum cleaner. Roots will be washed free of soil, dried at 65°C, and weighed. Immediately after soil cores are removed from each cylinder, cylinders will be refilled with local soil as described above. Root biomass harvested from each cylinder at the end of each year will be expressed as BNPP in $g/m^2/yr^1$ or $g\ C/m^2\ /yr^1$.

d) Litter decomposition (above- and belowground) (deGraaf): Litter decomposition, the physical and chemical breakdown of dead plant material, is a central process in SC dynamics. At each CORE, we will measure litter decomposition using fiberglass mesh litterbags (e.g., Weatherly *et al.,* HE, 2003; Throop and Archer, 2007). Two sets of aboveground litterbags will be deployed sequentially for 12 months. Three sets of bags will contain different litter types (shrub litter collected from local site; two common litter substrates: popsicle sticks and cotton strips), each of which will be decomposed under canopies and in intercanopy microsites in each CORE. We will use buried litterbags to estimate belowground decomposition rates. Due to the difficulty of obtaining uniform roots for decomposition studies, the only litter type used will be a common substrate (wooden dowels). Litterbags will be inserted vertically into the soil extending from 5-10 cm depth (n = 1 litter type x 2 reps x 2 microsite types x 2 reps/microsite x 2 deployment periods x 10 plots = 80 root litterbags per site). Upon collection, litter will be dried, ground, and analyzed for C and N. Data will be corrected by percent ash to correct for soil infiltration into litterbags (Throop HL, 2007). Decomposition will be expressed in terms of ash-free mass loss per year; mass loss data will be used to calculate the decay constant (K) (Olson, 1963).

e) Automated soil CO_2 gas and soil respiration measurements (Benner, postdoc): Soil CO_2 efflux can represent a large fraction of ecosystem respiration and is a key determinant of SC balance and easurement and modeling of soil CO_2 efflux at the pedon and landscape scale will require measurement of the soil environmental (Riveros-Iregui *et al.*, 2007). We proposed to use a CO_2 gradient approach with automated commercial soil CO_2 probes (Vaisala) at the CORE sites to use a CO_2 gradient approach to estimate soil CO_2 fluxes. This technique has been shown to be comparable to automated surface CO_2 flux measurements by Pingintha *et al.,* (2010) and these measurements will also make it possible to obtain winter flux estimates that have been shown to be significant (Monson *et al.,* 2006; Brooks *et al.,* 2011). Soil gas CO_2 data will also be key for SIC modeling. Soil probes will be installed a 5, 10, 20, 50 cm depths at 8-10 locations at each CORE site and co-located with soil moisture and temperature probes to improve estimates using this method as described by Pingintha *et al.,* (2010) and Riveros-Iregui *et al.,* (2007). One automated soil respiration (LICOR 8100A) will be purchased and used at one site to validate the gradient approach. In addition, manual estimates of soil respiration using portable infrared gas analyzer, PP Systems Soil Respiration System, with an EGM-4 Environmental Gas Monitor (PP Systems, Hertfordshire, UK) will be performed at other CORE sites and other locations to get better spatial distribution of this process as it relates to key soil environments.

f) Soil pore water DIC and DOC and chemistry (Lohse, Benner): Soil pore water DOC and DIC chemistry as well as other anions and cations will be a critical component of the pedon scale modeling element. Nested sets of zero-tension and Prenart tension lysimeters will be installed following protocols described by Lohse and Matson (2005) at the CORE sites. Lysimeters will be installed at multiple depths (20 and below the majority of rooting zone to be determined with surveys above) to quantify DOC and DIC solution fluxes. Lysimeters will be co-located with soil temperature, moisture, and water potential sensors at multiple depths for water flux estimations described in Phase II. Solution will be analyzed for dissolved organic carbon and dissolve inorganic carbon on a Shimadzu TOC/TN (Lohse), ammonium, nitrate+nitrite, and orthophosphate on a WestCo Scientific discrete analyzer, anions on a DIONEX ion chromatograph, and cations on an ion coupled plasma mass spectrometer at ISU using standard methods.

g) Stream particulate organic carbon, Dissolved organic carbon and inorganic carbon and groundwater (Godsey, Crosby, Baxter, Lohse): Export of C as particulate and dissolved form and groundwater DOC and DIC losses will be important for model testing at the landscape level. Currently, sediment and temperature are monitored. For the proposed work, particulate organic carbon will be determined on these samples using a loss-on-ignition method. In addition, DOC and DIC as well as basic anion and cation will be measured using available automated samplers and analysis techniques described above. Current groundwater monitoring is limited to a few locations at relatively high elevation. We might expect that some export of carbon, particularly in SIC, will occur in areas of shallow soils and low precipitation. A network of wells was established in the 1970's that demonstrated that, in fact, there is active groundwater recharge even where MAP is less than 250 mm/y. These wells still exist but are currently capped and a select set will be reactivated at relatively little expense. We will plan to sample groundwater wells as part of field camp. These exports will be compared to inputs. A National Atmospheric Deposition Program (NADP) site (1983-present) for wet deposition (and CASTNET (1989-1993) for dry deposition) of cations and anions (but not DOC) is already located at Reynolds Creek providing atmospheric input terms (http://nadp.sws.uiuc.edu/sites/siteinfo.asp?id=ID11&net=NTN).

The USDA-ARS is the operating agency, and during sample collections, samples will be sent to ISU for analysis of POC and DOC.

Phase II-Hypothesis testing, manipulative experiments and model testing examples
In yr 3-5, we will initiate manipulative experiments and hypothesis based measurement and modeling

Manipulation Experiments (deGraaf and Feris): Manipulation experiments will be initiated in yr 3 to evaluate the direct and indirect impacts of climate change on soil C cycling. Rain-out shelters described by Yahdjian and Sala (2002) and Throop *et al.* (2012) will be established in yr 2 near CORE sites established along an elevation gradient, and a litter manipulation experiment with labeled litter will be conducted. At each CORE, we will establish five control and five PPT reduction plots, each approximately 14 m x 14 m and covering at least three shrub and interspace microsites (25 total). The size of plots will be adjusted based on site characteristics, i.e. the size of a representative canopy/interspace area. In the treatment plots, we will reduce PPT by circa. 50% with fixed location rain-out shelters. This reduction is not based on a specific climate change scenario but rather aimed at allowing us to assess mechanistic information on how these ecosystems respond to changes in water availability. Root exclosures will be established in the rainout shelters and in the CORE sites to measure how altered precipitation impacts litter decomposition, soil C respiration and microbial communities in the absence of plant roots (established root exclosures), in the presence of plants, and in plant interspaces. To evaluate how changes in precipitation may alter litter input to soil, above- and belowground litter input using litter traps and root ingrowth cores will be measured as described above. Root and shoot production, litter chemistry, and decomposition will be determined in the rainout shelter and CORE control plots.

We will assess how reduced precipitation affects C in the total soil pool as well as in more labile and more stable SOC fractions on control and rainout plots. Short-term climate induced changes in the total soil C pool are difficult to detect against the large background of native soil C. To increase our sensitivity for detecting changes in total SOC, we will use physical fractionation methods to determine C in particulate organic carbon (POC) and mineral associated organic carbon (MAOC) size fractions. Mineral sorption, the process by which organic matter bonds to minerals and creates MAOC, is an important mechanism in C stabilization (Elliott, 1986), as it can physically protect organic material from microbial decomposition processes (Christensen, 1995; Torn *et al.*, 1997). To assess how PPT treatments, microsite identity, and sites affect POC and MAOC pools, we will conduct size-based soil fractionations as described by Allison and Jastrow (2006) and soil SOC and N. We will also determine microbial biomass by the fumigation-incubation method (Jenkinson DS, 1976). Soil enzyme assays will be used to assess microbial functional activity using enzyme assays. Assayed enzymes will indicate potential degradation of different C and N substrates: phenoloxidase and peroxidase (lignin degradation), ß-glucosidase and cellobiohydrolase (cellulose degradation), ß-xylosidase (hemicellulose degradation), and α-glucosidase (storage carbohydrates), and nitrogen acetylglucosaminidase (mineralization of N from chitin) (Perucci and Scarponi, 1983; O'Connell, 1987; Sinsabough, 1994; Olander and Vitousek, 2000; Saiya-Cork *et al.*, 2002; Tabatabai and Dick, 2002). Soil enzyme assays will be conducted on samples from all collection dates (3x/year), as enzyme activity is temporally dynamic. To determine the role of microbial community structure in controlling ecosystem respiration we will assess responses of the fungal, bacterial, and archaeal community composition associated with the manipulative experiments. Community structural measurements will be conducted via high throughput sequencing of 16S rRNA gene sequences (e.g. bacteria and archaea) and intergenic transcribed spacer (ITS) sequences (e.g. fungi) amplified from community DNA extracted from soils in each experimental replicate and time point. Additionally, relative abundances of fungi, bacteria, and archaea will be determined via quantitative PCR of 16S rRNA genes.

Litter manipulation experiment (deGraaf, Feris): We will manipulate the quality and quantity of substrate input and measure its impacts on the soil microbial community, enzyme production and soil respiration. To this end, we will conduct a decomposition experiment in the field with ^{13}C labeled substrates (10 atom% excess) with a wide variety of chemical characteristics. Specifically, we will use local plant materials with high lignin concentrations, with low C:N ratios and with high concentrations of polyphenols such as big sagebrush (*Artemisia tridentata ssp. tridentata*). To produce uniformly labeled (^{13}C) litter, plants will be exposed to 700 μmol mol-1 atmospheric CO_2 in a controlled environment chamber for 60 days as described by deGraaf *et al.*, (2010). Addition of labeled substrates to the soils, will allow us to measure new C stabilization, decomposition and the impact of new C on SOC priming, providing a powerful tool to assess how changes in precipitation interact with changes in substrate availability to alter soil C respiration. Finally, laboratory incubations will be conducted with soil collected from the subplots containing labeled plant material to measure potential respiration rates of the added litter and native SOC.

Fire effects on soil carbon pools and processes (Seyfried, deGraaff, Lohse): The impact of prescribed fire on SOC will be determined using temporal sequence of fires conducted in RCEW. SOC will be compared from fires conducted in 2002, 2004, 2007 and 2013 (scheduled) under similar vegetation type and fuel load. In each case, control samples will be collected from soils adjacent to the fire to control for site differences. Sites will be evaluated based on changes in SOC density fractionation, and amount of fire-derived soil C and N as described above and water repellency.

Rain-on snow events and episodic stream C export (Godsey): Total precipitation gradients may strongly influence carbon storage and flux. In addition to precipitation totals, the phase or form (e.g., Hayhoe *et al*., 2004; Godsey *et al*., 2009; Pavelsky *et al*., 2012)and rate (e.g., Hayhoe *et al*., 2004; Kingsmill *et al*., 2006; Godsey *et al*., 2009; Lundquist *et al*., 2010; Pavelsky *et al*., 2012) at which precipitation falls may influence hydrological and biogeochemical response. In particular, expected increases in winter rainfall will shift form from snow to rain and will shift timing from snowmelt to the storm event. Antecedent conditions may strongly influence the sensitivity of hydrological and biogeochemical responses to winter rainfall. Winter rain may fall on thawed or frozen ground, which may be saturated or unsaturated, and the landscape may or may not be snow-covered. In Phase 2, we propose to examine rain-on-snow cases. *We hypothesize that rain-on-snow events produce high flows that are capable of flushing old stored material, and that fluvial carbon fluxes and quality will drop following rain-on-snow events.* **1. Field focus:** Focusing on changes across the rain-snow boundary, we propose to opportunistically and intensively sample any rain-on-snow events that occur. We will quantify flows as well as carbon fluxes and changes in carbon quality that are flushed during these events relative to other storms throughout the study period. **2. Lab focus**: Alternately, we propose to collect soil cores across the current rain-snow transition, and then test the C flux from each set of cores subjected to a factorial design of ground temperature (-2, 0, and 5°C), soil moisture gradients (wilting point to field saturation), and simulated snow cover. The effects of soil freeze on C and N fluxes under snowmelt conditions suggests that mild winter temperatures that prevent soil freeze can lead to higher C and N fluxes from soils under some forest vegetation types (Reinmann *et al*., 2012).

Objective 3) Evaluate SC model performance in terms of a) SC distribution across the landscape and b) representation of critical carbon fluxes at the pedon to landscape scale.

Approach: A significant challenge in constraining SC dynamics is that models describing the biogeochemical behavior of soils are conceptualized across large ranges of spatial and temporal scales. By necessity, the formulation of SC models reflects the information and environmental variables available or relevant at those scales. For instance, at the pedon scale (i.e., ~10^{-2} m) the formation of aggregates creates physical impediments to movement of water and solutes. At hillslope- to watershed-scales (i.e., 10^{2}-10^{5} m) heterogeneity in soil-climate-vegetation interactions constrain the input of carbon and nutrients to the soil. Over longer time scales (i.e., 10^{1}-10^{3} yr) ecological succession, soil formation, deposition of $CaCO_3$ and associated feedbacks with the vertical movement of moisture and solutes are important. To date, there has been no concerted effort to perform SC measurement and modeling in an integrated way that can, by focusing efforts on large suite of environmental gradients, can resolve these scale discrepancies. The rich biogeochemical datasets that will be generated in the RCC CZO provide an unprecedented opportunity to reconcile these multi-scale modeling approaches, and thereby catalyze improvements in the modeling of soil biogeochemical processes.

We will adopt a **three-stage approach** in which we will apply modeling tools at scales ranging from pedon to watershed (Figure 5). In this approach, **pedon-scale modeling will promote identifying and describing key processes and controls** (e.g. carbonate dissolution/precipitation, changes in soil structure, gas diffusivity, microbial metabolic rates) on carbon fate. At the watershed scale, state-of-the art **ecohydrology models will be used to produce highly resolved (i.e., spatial resolution 1 m) scale-able environmental datasets** capturing key variables that constrain pedon-scale biogeochemical processes (e.g., soil moisture and temperature). These **distributed environmental datasets will then be used as input to traditional carbon cycling model approaches**, formulated to support the hillslope- to regional-scale prediction of SC distribution. The produced spatiotemporal carbon maps will be calibrated to pedon-scale understanding at the CORE sites and evaluated against both the unprecedented observed measurements (existing and generated in this project) in Reynolds Creek.

The high resolution understanding of the environmental datasets at the watershed scale will allow distinguishing a failure in *process understanding* vs. *poorly constrained input variables* when model does not predict observed SC distributions. We will be able to diagnose how, when, and where in the current models of biogeochemistry fail to capture SC stocks and fluxes.

Pedon scale modeling: At the pedon scale, the focus will be on the highly instrumented sites along the elevation-climosequence (CORE sites) and will be integrated within the context of experimental work conducted at those sites. The extensive CORE datasets will allow modeling efforts to evaluate and improve conceptual models of SC behavior. The our modeling approach will strongly emphasize the role of mass transfer, spatial heterogeneity and soil structure, constrained by thermodynamics and modified by kinetic limitations of both abiotic and biotic processes. While there are a variety of numerical tools and approaches that have proven useful for developing and evaluating mechanisms of carbon cycling in soils and sediments, those that can capture both physical and biogeochemical processes at the pore scale is more limited (e.g., Steefel and Lasaga, 1994; Cheng and Yeh, 1998; Xu *et al.*, 2004; Bethke, 2008). We are prepared to utilize the tool most appropriate for the problem. We will initiate activities using MIN3P (Mayer *et al.*, 2002). This code is familiar to the research team (Mayer *et al* 2001, 2006; Tufano *et al*, 2009), has the capacity to simulate many of the key processes expected to control carbon fate and has been has been successfully applied to carbon degradation in soil profiles (Nowack *et al.*, 2006; Molins and Mayer, 2007; Molins *et al.*, 2010). The code is designed to rigorously simulate the coupling of reactions and aqueous and gas transport (Mayer *et al.*, 2001a; Mayer *et al.*, 2001b; Mayer *et al.*, 2002; Benner *et al.*, in submittal; Mayer *et al.*, in submittal) and allows the consideration of organic and inorganic species and includes biogeochemical reaction rates, aqueous complexation, hydrolysis, ion exchange, surface complexation, isotopic decay, gas phase mass transfer, multi-porosity mass transport, and both equilibrium and kinetically driven mineral dissolution and precipitation processes in structurally complex variably saturated media. Because of the rich datasets at these sites, we anticipate initially developing and calibrating larger-scale hydrologic and biogeochemical models at these locations; these models are described in more detail below. **The primary outcome of this pedon-scale modeling effort will be a) a deeper understanding the pore-scale processes control carbon change, and b) identification of the key environmental variables that drive that change and may be used at the larger scale.**

Hillslope- to Watershed-scale Modeling: A number of models are available to simulate soil moisture and vegetation dynamics in adequate spatiotemporal detail, some of which are dynamically similar to land models used in GCMs (e.g., Oleson *et al.*, 2010). Our team will again select the model most appropriate to the problem. A potential model that our investigator team is prepared to use to simulate ecohydrology is the Noah-MP-CATHY model (Niu *et al.*, 2013). Noah-MP is a multi-physics land surface model available in the Weather Research and Forecasting (WRF) model and available as an offline code (Niu *et al.*, 2011). The Noah-MP model simulates soil moisture and temperature in multiple layers of the soil by solving the 1D Richards equation for moisture redistribution and the heat diffusion equation for temperature. Snow processes are represented with an explicit mass- and energy-balance resolving model in three layers. Noah-MP simulated dynamic vegetation using a Ball-Berry-type formulation for stomatal resistance and photosynthesis rate. The instantaneous change in leaf carbon is the difference of carbon assimilation from photosynthesis and loss due to cold and drought

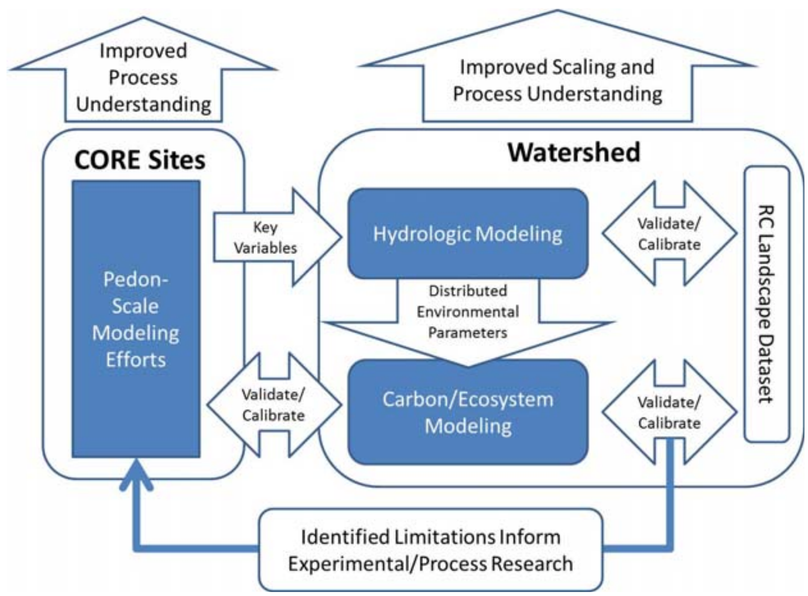

Figure 5. The RCC CZO modeling approach will employ pedon-scale models to improve process understanding, hydrologic modeling to create high resolution distributed environmental parameters and carbon/ecosystem modeling to predict soil carbon distribution and identify weaknesses in conceptual knowledge and scaling efforts.

stress, senescence, herbivory, or mechanical loss, and leaf respiration. Net loss (i.e., potential input to the soil) is proportional to leaf carbon content. Rate constants of leaf carbon loss are assumed intrinsic to plant functional types. CATHY is a groundwater model that solves the 3D Richards equation (Camporese *et al.*, 2010). The coupled model links the soil layers of Noah-MP to the upper layers of CATHY, allowing Noah-MP surface water and energy balance to serve as the upper boundary condition for CATHY. The model has been applied to Sheepers Creek watershed in Vermont at a spatial resolution of 30 m (Niu *et al.*, 2013) and 4 m resolution simulations are currently being evaluated (Niu, personal communication). Model simulations will be carefully calibrated to and conditioned on a rich history of hydrologic data available at Reynolds Creek (Table 1), as well as data collected during CZO activities (i.e., aboveground stocks and litterfall) (e.g., Flores *et al.*, 2012) (Table 2). These data have historically supported a number of process hydrological modeling studies. Among the more relevant to the proposed CZO is the work of Kumar et al. (2013), who used the coupled iSnobal-PIHM integrated hydrologic model (Figure 6). Their study demonstrated that an integrated hydrologic model could produce reliable water balance closure (e.g., basin soil moisture and groundwater storage volume, vs. stream discharge at the outflow) at the scale of the small RME catchment, while resolving the spatial distribution of key ecohydrologic variables like evaporation and transpiration. **The primary outcome of this component of the modeling effort addresses this by first producing a highly resolved (e.g., ~5 m) dataset to capture these key biophysical drivers, which will subsequently be used to derive carbon estimates.**

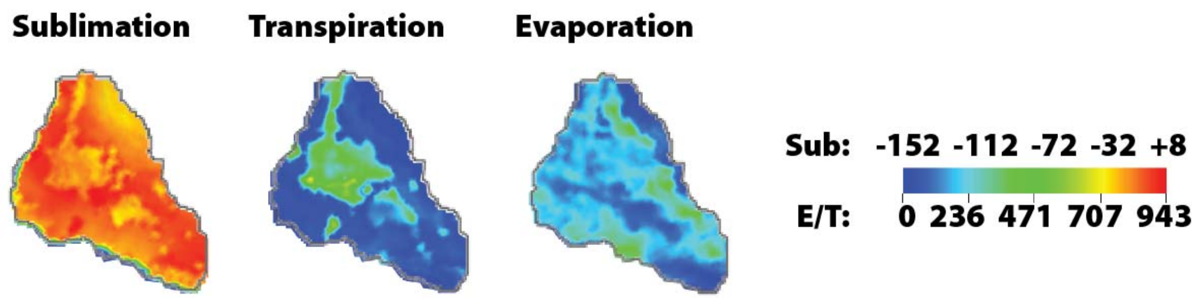

Figure 6: Water year 2007 total sublimation, transpiration and evaporation for the RME catchment as simulated by the coupled *iSnobal*-PIHM model.

Soil Carbon and Ecosystem Modeling: A primary value of SC cycle modeling is realized as the spatial scale increases to global-scales. The accuracy of models targeting these scales, however, is constrained by the correct representation of soil processes operating at the pedon scale. Computational expense in contemporary Earth system models limits representation of land surface ecohydrology and biogeochemical processes to resolutions on the order of 10^2-10^4 m. Many representations of SC respiration within these models (e.g. Biome-BGC, CENTURY or Roth-C), therefore, do not distinguish reactivity mechanisms but rather divide the carbon pool into fractions reflecting how rapid the carbon can be respired (Adair et al 2008). Such an approach limits complexity, but precludes prediction of how reactivity will be altered in response to environmental change (Dungait *et al.*, 2012).
While continued development of integrated earth system models will allow ever more complex representation of biogeochemical processes, up-scaling will always limit the number of variables for parameterization in global models. It is necessary, therefore, to isolate the confounding effects of the coarse scale of representation in the biophysical drivers of SC dynamics (e.g., soil moisture and temperature, ANPP and litter input) from the simplified representation of soil biogeochemical processes. The resulting spatiotemporal dataset will contain variables to drive soil biogeochemical processes and can be input to soil biogeochemical components of ecosystem models used at landscape scales (e.g., CENTURY, Biome-BGC, RHESSys, and Roth-C). The working assumption here is that a soil biogeochemical model driven by a unique, high quality ecohydrologic dataset will represent the "best guess" of the distribution of SC attainable with the current generation of soil biogeochemistry models. Most SC models do not adequately represent $CaCO_3$ deposition/dissolution; a process of profound importance in arid and semi-arid SC budgets. We will address this problem by following the approach in the models CALDEP and CALGYP (Marion and Schlesinger, 1994) within the architecture of the SC and ecosystem modeling framework. The primary output of this landscape-scale carbon modeling exercise will be **a) baseline, high-resolution ecohydrologic simulation data that has been conditioned on available observations and captures the spatiotemporal dynamics of variables controlling soil biogeochemistry and (b) spatiotemporal distribution of SC and nitrogen predicted by applying at least**

one common landscape-scale soil biogeochemistry model, forced by these ecohydrologic simulation data.

Integration of biogeochemical measurements into models: The biogeochemical data we propose to collect support the modeling activities by providing significant and often independent constraints on key biogeochemical pools and fluxes along important environmental gradients in, for example, elevation (precipitation), soil texture, and vegetation cover. Having a rich biogeochemical dataset against which multi-scale models can be assessed is critical for: (1) identifying where these models and their underlying assumptions breakdown, and (2) improving the parameterization of fine-scale processes in large-scale models used, for example, in the simulation of global biogeochemical cycles. Table 2 illustrates how these data are integral to support the multi-scale modeling approach that we outline above.

Table 2: Integration of RCC CZO datasets and models

	Datasets	Pedon-scale modeling	Landscape-scale modeling
Pools	SOC, SIC, nutrients, physical fractionation, other physio-chemical soil properties, mineral phases present	Provides both initial conditions and modeling targets for geochemical modeling	Constrain soil hydraulic and thermal properties, partition soil C between appropriate belowground model pools
	Aboveground ground C stocks, foliar N	Not directly used, may provide system-level constraints	Assess partitioning of assimilated C to leaf and stem C, test assumption of N-limitation on vegetation GPP
Fluxes	Aboveground and belowground NPP	BNPP will constrain carbon production rates.	Assess simulated NPP in vegetation dynamics models
	Litterfall	Input term at upper boundary of model domain	Constrain canopy C loss and input to soil C pools
	Eddy flux NEE	Not directly used, may provide system-level constraints	Evaluate modeled ET and constrain NPP
	Sapflux	Not directly used, may provide system-level constraints	Assess model partitioning of ET as transpiration
	Litter decomposition	May impact upper boundary carbon input term	Constrain net rate of input of C to soil, partitioning of litter loss to decomposition and soil input
	Soil respiration	Modeling target for CO_2 generation/consumption	Evaluate simulated soil respiration rates
	Soil lysimeter	Porewater chemistry will provide both initial conditions and modeling targets for geochemical modeling	Assess model partitioning of ET as soil evaporation

ENGAGEMENT PLAN

We will engage other scientists and fulfill the expectation of being a community resource through multiple activities targeted at a range of disciplines and a broad cadre of scientists. These activities will include: 1) reaching out to an existing network of scientists and collaborators to help build relationships to engage new scientists/stakeholders; 2) using university coursework as an opportunity to engage young scientists; 3) be active members of the CZO network; 4) dissemination of relevant and timely data.

1) Stakeholder engagement: The RCEW has been a focus of hydrologic field research, instrument development and process-oriented modeling resulting in over 450 publications by ARS and collaborating scientists. Example collaborating scientists come from University of Idaho, Duke University, BSU, ISU, University of Texas, University of California (Merced, Santa Barbara), University of Saskatchewan, University of Reading and the Edinburgh University. In addition, RCEW has stakeholders from other ARS units (Reno, Beltsville, Logan, Tucson and Blackland, Texas). There is an average use of 100 visitor nights/year at RCEW (including many students). In addition, research at the RCEW is contributing to management oriented modeling related to fire and snow/water supply with the NRCS and other agencies, and the RCEW is a calibration /validation site for the current NASA soil moisture remote sensing program. With the establishment of the RCC CZO and thus increased local expertise and infrastructure (field and baseline data collection), we expect similar levels of activity from the ecology and biogeochemistry communities, resulting in exciting "cross-fertilization" that results in productive science. For example, the NRCS has initiated a Rapid Soil Carbon Assessment in Idaho (co-PI Glenn facilitated in FY11), and PI Lohse has initiated conversation and interactions with local to state level scientists to explore synergies with NRCS. We will engage Idaho EPSCoR (quarterly newsletter serves over 500 scientists and educators within and outside Idaho), Idaho Climate Impacts Partnership (ICIP), and the EPSCoR Western Tri-State Consortium (ID, NV, NM) and capitalize on products produced from the existing RII Water Resources in a Changing Climate, downscaled climate scenarios that can be applied to BIOME BGC. **We will promote on-going collaboration within the existing RCEW and EPSCoR communities and request that they provide our website and list-serv to their ecology and biogeochemistry collaborators and students. National networks will also be targeted through senior personnel involvement, including NEON, OpenTopography, LTERs, EarthCube, and DataOne. We will also utilize the EAB to help engage scientists at their institutions and within their research and education networks.**

2) **University coursework:** We will integrate several educational/outreach components into the proposed RCC CZO to engage undergraduates and graduate students at ISU, BSU and other universities. **Traditional education and training**: 8-12 graduate students will collaborate with mentors who are experts in the fields of soil science, ecosystem ecology, surface and snow hydrology, microbial ecology, airborne and terrestrial lidar, ecohydrological modeling, plant physiological ecology. This work will offer graduate students hands-on experience with interdisciplinary research and stresses the importance of communicating their knowledge of carbon processes across disciplines. Students will be encouraged to have co-advisors with a primary advisor and second advisor working in another discipline and committee members that challenge them to work at the interface between disciplines. **New field courses on environmental field methods and enhancement of existing courses:** An ISU summer 2 week course in Environmental Field Methods (Lohse, Godsey, Crosby) that is already in the course catalog but has not been implemented will be cross -listed with a field course at BSU to engage a new Critical Mass of graduate students and undergraduates in Critical Zone Research in yr 1 and 3 at the RCC CZO (10-12 student/institution). The first week of the course will cover topics in soil description, traditional and new techniques in vegetation sampling, soil environment instrumentation, surface and groundwater hydrology, microbial ecosystem processes and community structure assessment techniques. The second week will involve independent team research projects. Lohse already teaches a Fall course with a lab (Soils and Critical Zone Processes) that typically involves 4 field trips to train undergraduates and graduates in soil description. We will examine the role of soil age or lithology, for example, on soil development and properties as part of this course. Graduate seminars and reading groups on SC processes at BSU and ISU will be cross-listed between the two institutions and delivered via existing infrastructure for distance education as a means to bring together graduate students from different disciplines and institutions to learn to each others' disciplinary concepts and to promote cross-disciplinary communication. Feris has used a similar mechanism to teach microbial ecology to PhD students across 8 institutions. Similar methods will be employed here. Glenn will target the RCEW for her field-based TLS graduate course (most recently taught statewide to ISU-BSU-UI students).

3) **Active members of CZO:** SC dynamics is of global interest and hence critical at all CZO's. We envision that SC research will be a unifying thread of research throughout all the CZO's, using the RCEW results as a springboard for research at other sites that introduce numerous other conditions not found within the watershed. There is considerable ongoing research at RCEW in conjunction with the CZO program. For example, there continues to be a strong relationship between the Sierra CZO and RCEW, where we have shared expertise in weir construction, snow modeling etc. Also, we have shared graduate students in an effort to establish a unified modeling approach to snow accumulation and melt simulation. The RCEW has also worked with the Pennsylvania CZO, particularly with modeling. There has been a concerted effort to link the PHIM model with Reynolds snow model to integrate soils groundwater and snow.

PI Lohse is a current participant of the University of Arizona JRB CZO (now subaward) and established the lower desert sites in the Santa Catalina Mountain that became cores sites of the CZO as well as established long-term rainon and rainout shelters with soil moisture probes at these and 2 higher elevation sites (oak woodland and mixed conifer). Lohse performed initial characterization of microbial communities and soil C and N. These manipulations are on-going and an obvious place for possible X-CZO opportunities such as ^{13}C litter additions. Lohse maintains a strong relationship with the JRB CZO through adjunct status and as an active participant on 6 students projects/manuscripts. In order to leverage the above activities, we will provide highlights at the weekly CZO meetings to engage other CZO communities. We will network with existing CZOs to learn what successful techniques can be used to engage the community, particularly interdisciplinary scientists. We will develop proposals with other CZO scientists and host themed sessions at professional meetings such as AGU.

4) Quality data management: We will provide timely and relevant data in readable formats such that data can serve as an incentive for the community to participate (see data management plan).

DISSEMINATION PLAN

The dissemination plan centers around 1) production and broad dissemination of high quality materials, 2) annual RCC-CZO meetings, and 3) stakeholder involvement and education.

Producing and disseminating high quality materials: The high quality materials include data, data products and formal and informal education and outreach products. The PIs will be responsible for ensuring the data and data products are of high quality and disseminated in accordance with the data management plan. For example, each project investigator will be required to publish data within 1-2 years of generation, publish peer-reviewed manuscripts and partake in timely presentation of findings at professional meetings. Two approaches will be utilized to achieve broad dissemination of the research products. First a suite of classical outreach and education efforts will be coordinated by our education coordinator and developed with personnel (Crosby, Feris, Lohse, Glenn, Godsey and students) (described in the Engagement Plan). Impactful quality materials will be ensured by the education coordinator, along with external review such as feedback from the EAB and national CZO members. Example types of materials include project synopsis/technical bulletins, and materials to promote discussion on how to integrate novel science findings with best management practices. The PhD students will be encouraged to provide YouTube videos/visualizations of their research for K12 and public audiences. We will also provide opportunities for tours of our natural laboratory at the RCC-CZO as part of the annual meetings. Second, we will ensure broad availability of these materials by website and list-serv use during the outreach and education events, and by providing teaching materials that utilize web-based data repositories and interfaces to outreach program participants. The intent is such that educators and students involved in the activities are trained on the use of the web-based resources and have teaching tools that they can implement in their classrooms, thus increasing the reach of the education effort beyond individual outreach and education events. In addition, dissemination of the data collected through the CZO, in combination with ongoing RCEW data, will promote comparative research with other locations and CZOs. To continue these dissemination activities beyond the scope of support available with this project, beginning in Year 1, RCC-CZO scientists will pursue funding through programs such as the NSF TUES (Transforming Undergraduate Education in STEM) program for development of modules through a sequence of courses (McNamara).

Annual RCC-CZO meeting: We will host an annual RCC-CZO meeting for students, stakeholders, and the broader community. Science team members from the other national CZOs will be invited to present at these meetings as a means to coordinate activities, to solicit ideas on high target dissemination opportunities, as well as solicit ideas and help from our external advisory board. This 1.5 day meeting hosted in Boise will focus on technical talks, focused discussions with stakeholders (see below), and a RCC-CZO field trip aimed at both scientific discussions and outreach opportunities. Co-PIs Glenn, Benner, and Seyfried, have hosted similar meetings for Idaho EPSCoR and USDA ARS initiatives and will be in charge of organizing, along with soliciting help from the graduate students and post-docs.

Stakeholder involvement and education: Amongst our collaborative science, we have PIs and Co-PIs that have numerous interactions across a variety of land management agencies, conservation groups, and policy makers. When these relationships are combined with the influence and efforts of the Idaho EPSCoR program, which all RCC-CZO participants are active in, we have numerous inroads with decision makers to enhance the dissemination of our findings and inform policy and management decisions. The PIs will facilitate such interactions and outcomes by establishing a list of stakeholders in Year 1, along with a means of communication (list-serv, website). The stakeholders will be invited to the annual CZO meeting with a special themed session on alignment of R&D goals with stakeholder needs. In year 1 the PIs will also identify 1-2 stakeholder representations, such as from DOI BLM and USGS and USDA NRCS, to extend an invitation to participate on the external advisory board.

NSF PRIOR SUPPORT **Baxter:** DEB 0516136, 2006-10, $210,802, Collaborative research-Terrestrial Effects of an Aquatic Invader: Does Regional Context Change the Impact of Fish Invasion on Energy Flow to Riparian Predators? Baxter studied consequences of nonnative brook trout replacement of native cutthroat trout for linked stream-forest food webs. Work resulted in 12 publications, 30 presentations, and "Riverwebs" aired via PBS to over 70 million and completed in Japanese. **Benner:** HS 1141690 2012-15, $489,330, Collaborative research-Is the hyporheic zone a source of greenhouse gases? Three graduate students (2 PhD and 1 MS) have been recruited to the project, column experiments have been initiated. **Crosby:** OPP-0806399, 2008-13, $251,570. Influence of Hillslope Instability (Thermokarst) on Arctic Landscapes. Supported 4 graduate and 3 undergraduate students, 4 manuscripts published, 3 in review, 15 presentations. Led to Permafrost Carbon RCN. Data to LTER. **Feris**: DEB 0717449, 2007-10, $126,685, Chronic Stress in Ecosysts Project. The CES project assessed the effects of chronic heavy metal stress on the structure and function of microbial communities. Supported 3 undergraduate and 1 graduate researchers, 2 manuscripts published, 1 in review, numerous presentations. **Finney:** AGS 0402060, 2004-10, $118,376, Collaborative Research: Hydrologic Variability in the Pacific Northwest During the Past 13,000 Years from High-Resolution Studies of Finely Laminated Lake Sediments. Our findings suggest the hydroclimate response in the Pacific Northwest to future warming will be intimately tied to the impact of warming on the Pacific Ocean and how this affects ocean and atmospheric circulation. Two PhD, 2 MS, 4 undergraduate students received training, data was provided to the NOAA Paleoclimatology National Climatic Data Center, 5 publications. **Flores**: RAPID 1235994, 2012-13, $19,912, An unusual opportunity to track snow ablation using stable isotope evolution of the 2011-2012 snowpack near Boise, ID. Stable isotope samples within the snowpack were collected and analyzed using a Los Gatos Research cavity ringdown liquid water isotope analyzer. An early career scientist from an underrepresented group was engaged in research. No publications to date. **Godsey:** ARC 1107440, 2011-14, $246,088, Collaborative Research: Climate-mediated coupling of hydrology and biogeochemistry in arctic hillslopes. This in-progress award is training one MS, Ph.D., and undergraduate student, and one high school teacher. Reached over 300 Grade 8-12 students through an interactive webinar. 3 presentations at conferences and publications planned. **Glenn (Co-PI), Crosby, Benner, Baxter, Feris, Flores, Pierce**: EPS 0814387, $15,000,000; 2008-13. Idaho RII: Water Resources in a Changing Climate. Fostered research capacity for understanding of how the quantity, quality, and timing of water supply are changing with climate, and how changes in water supply are affecting ecosystems and the goods and services they provide. Involved 400 participants at the postsecondary level, and $60.9 million awarded through funded proposals. Added 10 new faculty positions (filled by 60% women and 20% underrepresented minorities) related to this theme. The project has helped train 84 graduate students. A Data Sharing Policy and a Statewide MOU for CI and research data management were developed and resulted in a CI Strategic Action Plan for Idaho Universities. 87 peer-reviewed manuscripts published. **Glenn:** EAR 1226145, 2012-14, $105,000, Collaborative Proposal: Making Point Clouds Useful for Earth Science. Develop next generation analytical and processing tools for airborne and ground-based LiDAR. Two publications and 2 new algorithms (available on google sourcecode) published to date. Will be available on OpenTopogrpahy. **Lohse (PI):** DEB 0918373, EF 1063362, $875,564 total; 2009-13. Collaborative Research: Impacts of Urbanization on Nitrogen Biogeochemistry in Xeric Ecosystems. Findings showed urbanization increases frequency and duration of flow and nitrogen with large consequences for greenhouse gas emissions. This in-progress project has resulted in 8 publications, 5 in review, 3-5 in preparation, >35 presentations/posters, 2 websites, 4 poster awards. 3 articles in newspaper or web. Broader impacts are prescriptions requested for best storm runoff management practices from EPA headquarters and 20 citizen scientists engaged to assist with rainwater collection. EAR 0910666, $527,979, UA portion $143,735; 2009-13. Biotic alteration of soil hydrologic properties. This active study has showed strong geomorphic controls on vegetation distribution on hillslopes and has resulted in 6 papers, and 4 in review or preparation. NSF EAR 0724958, Lohse subaward, $77,204, 2011-13 has resulted in 2 publications, 4-5 in review, 3 in preparation, 5 presentations/posters. **Marks (Co-Pi):** CBET 0854553 Collaborative Research: A WATERS Testbed to Investigate the Impacts of Changing Snow Conditions on Hydrologic Processes in the Western United States $250,400, 2009–13. Project continues to collect and analyze data from RCEW to evaluate how the seasonal snowcover and watershed hydrology are being impacted by changing climate. The project has resulted in 22 publications, 9 papers in revision and 11 in review. Significant impacts of the project have been the coupling of the iSnobal snow model to the PIHM hydrology model, publication of 25 years of hourly modeling data, development of a snow redistribution model to account for snow distribution and drifting, and detailed instrumentation along gradients in the rain/snow transition. All project data are available on the site ftp.nwrc.ars.usda.gov. Spatial data will be available later this year on the same site. **Pierce** NSF-EAR-0720391 Collaborative Research: Assessing Climatic Controls on Intervals of Stability and Deposition on Alluvial Fans $134,914, 2007-2010. Findings showed that OSL dating can successfully be applied to coarse-grained alluvial deposits, and combined with U-series dating of pedogenic soil carbonates to determine ages of previously undated deposits. No Prior NSF support: De Graaf, Reinhardt, Flerchinger and Seyfried.

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