PROJECT SUMMARY

Overview:

This CAREER project will use existing models in an experimental framework to explicitly simulate the autonomous behavior of land management agencies in decadal-scale climate change impacts assessments. Taking a dynamically coupled human and natural systems approach, existing codes will be leveraged to represent the behavior of land management agencies and impacts on landscape vegetation and feedbacks between the land and atmosphere as modulated by human-modified vegetation patterns. Colleagues at key agencies will collaborate in identifying alternative management scenarios and associated policies. Ideally, a simulation model of this complex system would embed behavioral models of agency and manager decision-making into a regional climate model. However, computational expense of the resulting code and the novel nature of this research necessitate a simplified suite of methods. Therefore, the research activities will adopt a ?loose? coupling strategy in which management activities within the landscape will be represented using one model, and regional hydroclimate with another. Information exchange between models will occur in the form of changes to the organization and structure of landscape vegetation as a result of management activities. This modeling framework will be used to understand how management activities and climate change jointly replumb the hydrologic system as the global climate changes. We will focus on quantifying changes in key variables like snow storage, soil moisture, and streamflow in a large water supply basin in southwest Idaho, USA.
The education plan will improve climate literacy in Idaho k-12 education. The PI will develop a pilot program to train and equip educators to engage their students in the fabrication, use, and exploration of miniaturized automated weather stations. Linking the program to Common Core standards, we will ensure that participating k-12 teachers are conferred professional development credits. We will support travel expenses for a small number of teachers of underserved populations.

Intellectual Merit :

Public lands provide important ecosystem services and are particularly extensive in the western US. Climate change impacts the sustainability of these ecosystem services and also elicits a management response. Land management activities (e.g., fire, grazing, selective tree thinning) influence these ecosystem services and feedback to the regional hydroclimate. But quantitative understanding of these feedbacks and how they propagate to ecosystem services like the provisioning of water is lacking. The science plan of this CAREER project will improve fundamental understanding of how land management practices influence regional hydroclimate while facilitating improved modeling of coupled hydroclimate-human systems.
The education plan will adopt an existing framework for climate literacy, while using a series of inquiry learning exercise to engage students in science. We will ensure the long-term sustainability of this program by developing a network of participating teachers, online resources, securing professional development credit for participation, and program assessment and evaluation to ensure it is achieving anticipated outcomes.

Broader Impacts :

This research will broadly impact the hydrologic sciences by contributing to fundamental understanding of how human modification of the landscape contributes to changes in regional hydroclimate. By engaging agency managers as stakeholders in the modeling activities, the research will serve to integrate cutting-edge approaches into land management planning activities. This is particularly important in the western US where federal ownership and management of land has a large spatial and fiscal footprint.
The teacher education pilot program will strengthen broadening participation in the Earth sciences in Idaho and engage k-12 students in science. By training and equipping these teachers, the program has the capacity to reach thousands of additional students in each year of the grant, as the number of program alumni increase. The project will specifically seek to serve the broadest audience possible and will serve Idaho’s underserved populations by identifying and defraying travel expenses for k-12 educators who teach to Idaho?s underserved students. Three important underserved groups of students we will specifically seek to reach include: (1) rural students, (2) refugee populations, and (3) Title I schools.

TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.B.2.

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

Science Plan: The Influences of Land Management on Regional Hydroclimate

1. Research Background and Intellectual Merit

This science plan will improve fundamental understanding of how forest and rangeland management practices influence land-atmosphere interactions and regional hydrology in a changing climate. The approach treats managed landscapes as dynamically coupled human and natural systems. Specifically, the integrated modeling approach leverages existing codes to represent: (1) the behavior of land management agencies and associated impacts on landscape vegetation and (2) feedbacks between the land and atmosphere as modulated by human-modified vegetation patterns. The proposed activities leverage my ongoing involvement in Idaho's Experimental Program to Stimulate Competitive Research (EPSCoR) Research Infrastructure Improvement (RII) Track 1 award "Managing Idaho's Landscapes for Ecosystem Services" and role as Co-Principal Investigator on the Reynolds Creek Carbon Critical Zone Observatory (RCC-CZO). Outcomes of this CAREER project include quantification of the extent and mechanisms by which climate change and land management *replumb* regional hydrology. Parameterization of land management agency behavior will be informed by engagement with researchers for key agencies who will collaborate in identifying stylized alternative management scenarios and associated policies.

Land use and land cover changes like deforestation and cropland expansion play a critically important role in climate change, albeit in a complex and highly uncertain way. Based on a review of the available literature, the 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) concluded that land use change contributed between 6% to 39% of the growth in CO_2 emissions during the 1990s [Forster et al., 2007]. The contribution of these land use-associated CO_2 emissions to the radiative forcing is estimated to be approximately 0.4 W/m^2. Of the total anthropogenic radiative forcing (~1.6 W/ m^2), this implies CO_2 emissions associated with land use change account for about 25% of the total forcing. At the same time, the anthropogenic radiative forcing associated with the effects of land use change on albedo is estimated to vary between approximately -0.06 W/m^2 to -0.38 W/m^2 [Forster et al., 2007]. The effects of land use change on the albedo is particularly large in seasonally snow covered lands where, for instance, deforestation can significantly increase albedo because vegetation is no longer shading the snowpack from incoming solar radiation [Pielke et al., 2002; Bonan, 2008].

And while management of public lands in the United States rarely involves permanent conversions of land use, management tools like grazing, selective thinning, prescribed fire and others involve changing vegetation composition and structure at spatial scales to achieve some objective such as fire and disease prevention, or prevention of invasive vegetation. Feedbacks between these land management practices and regional climate are not well understood, despite the large spatial footprint of public land management. In the western US (excluding Alaska and Hawai'i) approximately 1.4 million km^2 or 47% of lands are owned by the Federal government (**Figure 1**) [Gorte et al., 2012]. According to this same dataset, more than half of all publically owned lands in the US are managed as forest and wildlife (~30%) or grazing (~22%) areas, with another 15% as parks and historic sites. Federal ownership of lands constitutes more than half of the area of Idaho, Oregon, Utah, Alaska, and Nevada. These public lands are critical to the culture and economies of western states because they provide key ecosystem services. These include provisioning services like supply of food, water, timber, fiber, wood, pharmaceuticals; supporting services like nutrient cycling and dispersal; regulating services like sequestration of atmospheric CO_2; and cultural services like habitat for threatened and endangered species, recreational experiences, and cultural and spiritual inspiration [Millennium Ecosystem Assessment, 2005]. However, managing these lands for such broad ranges of ecosystem services is an extremely complex problem. Multiple management agencies with different mandates and objectives introduce an element of complexity in the interactions between human systems and the biophysical landscape. There is also a large diversity of private stakeholders with vested interests in the management of these lands. These include ranchers, forest product companies, environmental and wildlife groups, and energy development companies.

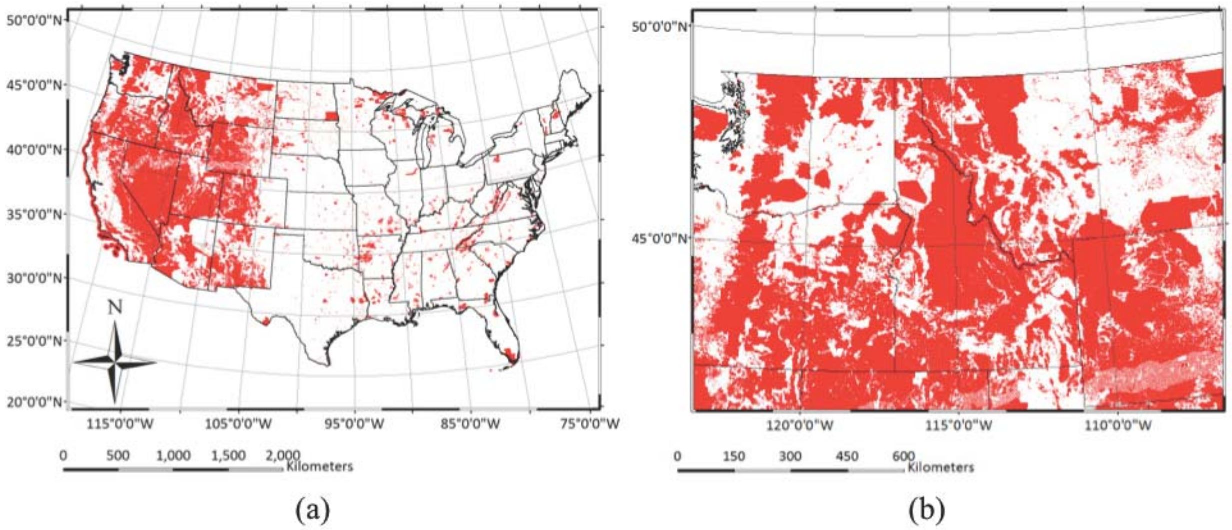

Figure 1: The distribution of federally owned lands in (a) the contiguous 48 states, and (b) the interior Pacific Northwest [GSA, 2004].

Beyond the impact of land use change on radiative forcing, climate change and land use change also act conjunctively to "replumb" the hydrologic system by altering hydrologic pathways and connectivity. In the Great Basin, for instance, invasion of native shrublands by cheatgrass has dramatically changed rooting depths, canopy cover, landscape heterogeneity, water use and fire regimes [Balch et al., 2013]. In cold deserts Wilcox et al. [2012] suggest this leads to increased runoff, reduced evapotranspiration, and potentially increased recharge. Cheatgrass invasion is also associated with changes in biological soil crusts, impacting nutrient cycling and erosion [Belnap, et al. 2001; Kulmatiski et al., 2006; Sperry et al., 2006]. Climate change has been hypothesized to favor invasive grasses in native sagebrush-steppe ecosystems, and land managers have adapted by using techniques to like prescribed fire, grazing, and herbicides in an effort to control these invasions. These management tools, however, also impact the local cycling of water, energy, and nutrients [Keeley and McGinnis, 2007]. In the future, sustainable land management strategic planning in the face of climate change should be informed by explicit information on how management activities feedback to the regional climate.

There is a critical need for improved understanding of how the integrated effects of climate change and management practices replumb regional hydrology and alter the distribution and availability of water. Specifically, there is a need for improved coupling between models of regional climate change and models that simulate the behavior of land management actors responding to changes in the landscape in accordance with specified management objectives. The overarching aim of this CAREER research plan is to enhance understanding of feedbacks between land management practices and regional hydroclimate by promoting improved coupled dynamic modeling of regional climate and human systems.

This CAREER science plan will address these grand challenges by answering the following specific science questions:

1. To what extent do forest management activities such as prescribed fire and forest thinning impact the amount and timing of regional precipitation, snow storage, and runoff?
2. To what degree and at what spatiotemporal scales does grazing impact soil moisture and sensible and latent heat fluxes?
3. How do management activities change the timing and amount of discharge in large water supply basins? And by what mechanisms (e.g., enhanced or reduced ET, etc.)?

2. Overarching Research Vision

Guiding this research vision are three interrelated general goals: (1) improved integrated representation of human systems in regional models of hydroclimate, (2) quantification of the joint impacts of climate change and human activities under alternative scenarios, (3) improved communication of regional impacts of hydroclimate changes to students, citizens, and managers (i.e., decision-makers and those who implement policies) alike. This research is an extension of my professional preparation in hydrologic modeling, uncertainty analysis, water cycle remote sensing, and data assimilation [Flores et al., 2009; 2010; 2012]. It also builds on my experience since arriving at Boise State in the fall of 2009. Since arriving at Boise State, I have engaged in interdisciplinary place-based research focused on characterizing hillslope-scale organization of soil carbon [Kunkel et al., 2011], soil moisture [Smith et al., 2011], snow depth and cover [Anderson et al., in review], vegetation, and slope angles [Poulos et al., 2012]. More recently, I contributed considerable effort to preparing the proposal for and serving as a thematic lead in the integrated modeling component of Idaho's newest EPSCoR RII Track 1 grant. As Co-PI of the RCC-CZO I am responsible for landscape-scale modeling of coupled ecohydrologic-biochemical modeling. In support of these activities I have undertaken considerable professional development, including attending the tutorial for the Weather Research and Forecasting (WRF) model (summer 2012) and Community Earth System Model (CESM, summer 2013), as well as organizing a training session for the Envision integrated modeling framework [Bolte et al., 2007; Guzy et al., 2008; Hulse et al., 2009] in support of Idaho's new EPSCoR RII Track 1 award (summer 2013).

The research project proposed here exists against the backdrop of grand challenges in hydrologic sciences identified in the National Research Council (NRC) *Challenges and Opportunities in the Hydrologic Sciences* [NRC, 2012]. The NRC vision of contemporary and emerging research challenges specifically highlights the need to "**understand replumbing [of the hydrologic system] and how it will change the distribution of water and its availability**." In recognition of the dominant influence of humans on water sustainability at both global and local scales, the NRC also called specifically called for "**model projections to incorporate the impacts of human activities on regional climate to be more useful for management and planning.**"

The proposed research is novel because it seeks to explicitly link the impacts of land management activities in decadal-scale climate change impacts assessments. Regional climate change impacts assessment is an increasingly popular and sophisticated enterprise. In the hydrologic and ecologic sciences this typically entails using outputs of a Global Climate Model (GCM), typically from a large community multi-model experiment (e.g., Taylor et al. [2012]), to force a finer-scale model of hydrology or ecology. There are two distinct, but overlapping, methods for performing these climate downscaling efforts. One method, dynamical downscaling, uses output from a GCM to provide the boundary and initial conditions of a Regional Climate Model that uses the biophysics of the coupled-land atmosphere system to achieve spatial resolutions on the order of kilometers (e.g., see Pan et al. [2011]; Rasmussen et al. [2011]; Gutmann et al. [2012]; Yuan et al. [2012]; Shukla and Lettenmaier [2013]). The other method, statistical downscaling, uses a variety of statistical algorithms to (e.g., Abatzoglou and Brown [2011]; Abatzoglou [2012]) to enhance the resolution of GCM outputs to spatial resolutions of kilometers and temporal resolutions of days (e.g., see Quintana Seguí et al. [2010]; Yoon et al. [2012]). Both approaches have merits and drawbacks in terms of preserving important hydrologic features of interest (Wood et al., 2004). Dynamical downscaling approaches are thought to preserve the physical realism of the land-atmosphere system, while statistical methods are far less computationally expensive. Increasingly, hybrid methods that combine both approaches have been used. For instance,

Managed landscapes like forests and conservation areas, while perhaps perceived to be places of wilderness, are in fact inherently deeply coupled natural and human systems (**Figure 2**). Although the local impacts of land management activities like prescribed fire and timber removal have been heavily studied, there remains a need to understand how these management activities propagate to the climate through land-atmosphere interactions at regional spatial scales and decadal time scales. Efforts to integrate land management activities in a dynamic and autonomous way (i.e., actors within the landscape can "evaluate and respond" to environmental conditions and drivers and alter the landscape in ways that may feedback to the climate) regional hydroclimate are in their infancy [CESM-SDWG, 2011; Adam et al., in review]. There are good reasons for this. First, regional climate and hydrology models are computationally expensive. Running multi-decadal simulations, even with recent advances in community

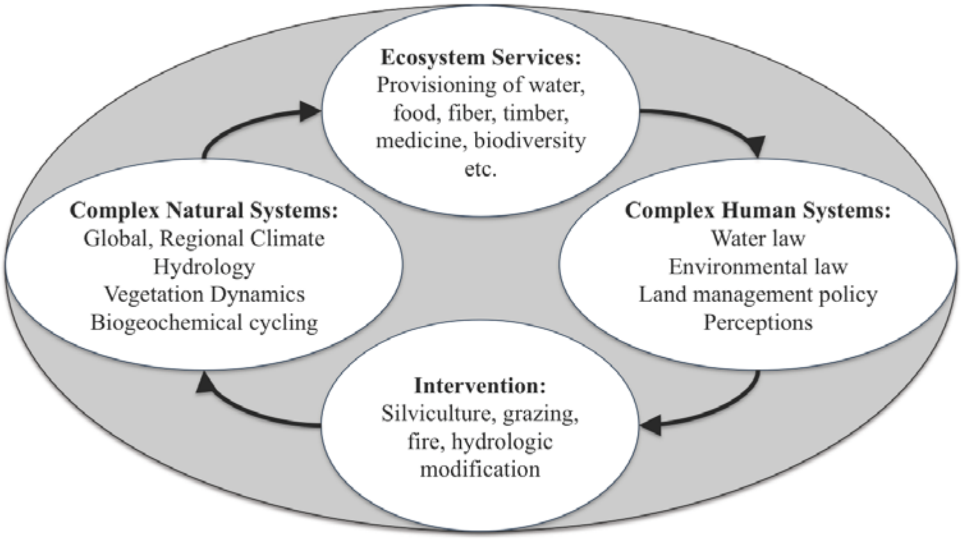

Figure 2: Guiding coupled natural and human systems view that informs the research vision and details of this project.

models and high performance computing, is computationally demanding. Second, there are relatively few frameworks that adequately represent human and management behaviors in a robust way. Capturing the spectrum of ways that human action cascades through earth systems often requires allowing for some degree of randomness in the decision-making of landscape actors in order to capture low probability, high consequence events. Global and regional climate models are still too computationally intensive to embed stochastic behavioral models, such as individual based models (IBMs) and agent based models (ABMs), to dynamically couple the behavior of landscape actors and land-atmosphere system response. In the coming years, however, improved representation of human activity within these models will be a critical requirement because the spatiotemporal resolutions of these models are approaching scales of management actions.

The proposed research activities articulate a logical first step towards this vision. Namely, existing modeling frameworks are used to represent both the impact of human activity on the landscape and the coupled behavior of the land-atmosphere system. A simplified landscape is chosen in which Federal land managers are the predominant stakeholders, and behavioral scenarios center on alternative management strategies.

3. Research Activities

3.1 The Research Setting: Why Idaho?

Idaho and the interior Pacific Northwest, more broadly, is a remarkably well-suited research setting for this project. Approximately half of the land area of Idaho is federally owned, with the US Forest Service and Bureau of Land Management being the single largest stewards. Southwest Idaho encompasses a transition from the traditionally sagebrush steppe rangelands of the Great Basin to evergreen forests of the Northern Rocky Mountains (**Figure 3(a)**). Within this study domain are a number of federally owned management and research land units with a rich heritage of observational capacity and detailed historical information. Three primary sites of interest are discussed below. Two tertiary areas of potential interest in future research projects, Morley Nelson Snake River Birds of Prey National Conservation Area and the Sawtooth National Forest are not discussed but appear in **Figure 3(a)**.

3.1.1 Boise National Forest (BNF) and Boise River Basin (BRB)

The Boise National Forest occupies approximately 10,000 km^2 in the central mountains of Idaho (**Figure 3(a) and 3(b)**). The forest ranges in elevation from approximately 800 to 3000 m and encompasses portions of the Boise, Payette, South and Middle Fork Salmon River watersheds. Conifer trees dominate the forest with ponderosa pine and Douglas fir being predominant at lower elevations and Engelmen

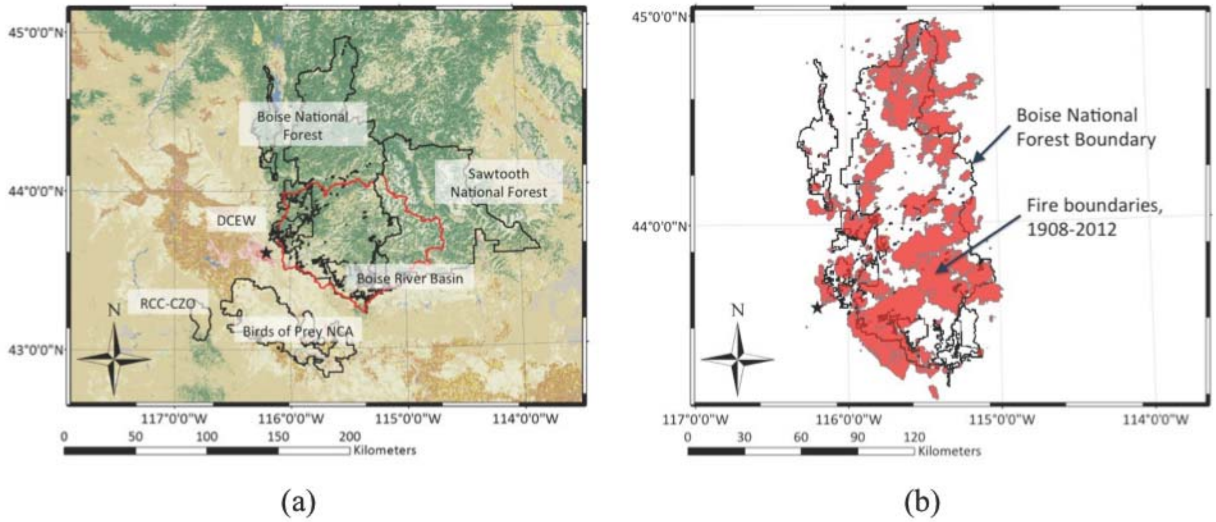

Figure 3: (a) The study domain, centered on southwest Idaho and primarily interested in the Boise River Basin, much of which is within the Boise National Forest. (b) Between 1908-2012, much of the Boise National Forest has been subjected to fire.

spruce and lodgepole pine found at higher elevations. The 2010 revised forest management plan highlights biological diversity; fire and smoke management; habitat fragmentation and disruption; non-native plants; rangelands/grazing resources; hydrologic riparian, and aquatic resources; timberland suitability; and management emphasis areas as management topics that were considerably revised from the previous forest plan [BNF, 2010]. Approximately the southern half of the BNF is coincident with the Boise River Basin (BRB), which is already undergoing dramatic shifts associated with climate change. The BRB straddles the rain-snow transition, and the vast majority of precipitation is delivered as snow to the upper basin. The timing of peak snowmelt in the BRB has moved from July 3 (1960-1980) to June 17 (1986-2006) [Kunkel and Pierce, 2010], while the variability in snowmelt timing has increased from 8-12 days (1960-1980) to 15-23 days (1985-2006). Similar trends have been observed in the nearby Reynolds Creek watershed where the lower elevations have transitioned from exhibiting significant winter snow-storage to rain dominated [Nayak et al., 2010]. The annual water balance in the basin shows increasing interannual variability, with particularly significant declines in dry year flows [Luce and Holden, 2009]. Climate change in the upland watershed is also influencing, and exacerbated by, wildfire return interval [Westerling et al., 2006, Littell et al., 2009, Holden et al., 2011]. Sub-basins impacted by recent fires exhibit 2-week earlier arrival of peak stream flow [Holden et al., 2012]. These changes pose a significant challenge to downstream managers of the Boise River reservoir system, who must balance diverse requirements for downstream agricultural and hydropower use, as well as flood control for Boise metropolitan area.

<u>3.1.2 Reynolds Creek Carbon Critical Zone Observatory (RCC-CZO)</u>

Reynolds Creek Experimental Watershed (RCEW) (239 km^2) is located on rangeland in the Owyhee Mountains in southwestern Idaho, USA, approximately 80 km southwest of Boise, Idaho and is operated by the USDA Agricultural Research Service (**Figure 3(a)**). It drains north to the Snake River and ranges in elevation from 1090 m to 2240 m. Plant communities typical of the Great Basin are found at the lower elevations while alpine communities occur at the highest elevations. Precipitation ranges from approximately 240 mm at lower elevations to1120 mm as higher elevations. Reynolds Mountain East (RME) is a small (0.38 km^2) catchment in the southwestern corner and of RCEW, ranging in elevation from 2028 to 2137 m [Slaughter et al., 2001]. Two meteorological stations are located at a wind-exposed site characterized by mountain sagebrush and wind-sheltered site located in a grove of aspen trees. Upper Sheep Creek (USC) is a 0.26 km^2 semi-arid rangeland catchment located along the eastern edge of RCEW that ranges in elevation from 1840-2036 m and is the focus of long-term hydrologic studies [Flerchinger et al., 1992; Flerchinger et al., 1996; Luce et al., 1998; Flerchinger and Cooley, 2000; Chauvin et al., 2011]. Relevant instrumentation in the USC catchment includes three meteorological stations and three soil moisture profiles. Five eddy covariance sites are installed in RCEW (three in RME and two in USC) will be critical for confirming model-simulated water, heat, and carbon fluxes. A long-term dataset for modeling purposes has recently been published [Reba et al., 2011]. **PI Flores is co-PI of the new Reynolds Creek Carbon Critical Zone Observatory (RCC-CZO) for soil carbon. As part of RCC-CZO activities, PI Flores will oversee landscape-scale ecohydrologic modeling.** In the proposed research activities it will serve as an important confirmation site for hydroclimatic variables like precipitation, snow water equivalent, and soil moisture.

3.1.3 Dry Creek Experimental Watershed (DCEW)

Dry Creek Experimental Watershed (DCEW) drains 27 km^2 in the foothills of the Boise Front Mountains in a predominantly southwest-facing drainage (**Figure 3(b)**). It serves as a site for community research on topics including mountain block recharge, runoff generation, soil moisture and ecohydrologic variability, remote sensing of snow and snowmelt, and carbon and nitrogen cycling [McNamara et al., 2005; Williams et al., 2009; Kunkel et al., 2011; Smith et al., 2011; Anderson et al., in review]. It is operated by Boise State University through a partnership with private and federal landowners. Sage and grasses dominate the lower elevations where precipitation is primarily in the form of rain. Higher elevations contain evergreen forests and receive nearly twice as much annual precipitation, primarily as snow. Instrumentation in the DCEW includes five weather stations at which soil moisture is monitored continuously and seven stream gauging stations at sites draining areas from 0.015 km^2 to 27 km^2. Eight additional soil moisture stations were installed to investigate the dependence of soil moisture on topography within DCEW. **The PI has installed a full energy balance hydrometeorological station as well as** an eddy flux tower at a site within DCEW and data will be used to confirm historical simulations. **A cosmic ray-based sensor to measure terrestrial water storage will be installed in summer 2013 by the PI and will provide key model verification data for modeling and activities.** In a similar fashion to RCEW, DCEW will serve as an important confirmation site for hydroclimatic variables like precipitation, snow water equivalent, and soil moisture.

3.2 Overview of CNH Modeling Approach

The numerical experiments will explicitly represent the managed lands being studied as a coupled natural and human system. Ideally, these systems would be represented as “tightly” coupled. That is, models of decision-maker behavior would be embedded within the dynamics of a regional climate model (RCM) and the integrated system would evolve in response to the input boundary and initial condition (i.e., climate change projections from a GCM). However, there are pragmatic reasons to take a more simplistic approach during the course of this project. Using RCMs to perform dynamical downscaling of GCM output remains numerically expensive. At the same time many forms of behavioral models (e.g., agent-based models, systems dynamics models, etc.) allow for stochastic decision-making on the part of actors or agents. To be meaningful, therefore, many realizations of scenarios must be run so that the “consensus” behavior of decision-makers can emerge and be understood. A tight coupling between models of decision-making and RCMs, for the time being, is prohibitively expensive because it would involve running many simulations of the coupled human and natural system.

The approach taken here is characterized as a “loose” coupling. Management activities within the landscape will be represented using one model, while the regional hydroclimate will be modeled using another. Exchange of information between the models will occur in the form of changes to the organization and structure of landscape vegetation as a result of management activities. Landscape transitions will be represented using the Envision modeling framework, an alternative future scenario, multi-agent modeling framework developed at Oregon State University. Hydroclimate transitions will be represented using the Weather Research and Forecasting (WRF) model, version 3.5 [Skamarock et al., 2008]. Both modeling frameworks will be forced by outputs from the Fifth Coupled Model Intercomparison Project (CMIP5). Inputs to the Envision framework will be bias-corrected, statistically downscaled CMIP5 precipitation and temperature data [Abatzoglou and Brown, 2011; Abaztoglou, 2013]. Input to the WRF model will be raw CMIP5 [Taylor et al., 2012]. Resolutions of the CMIP5 models vary,

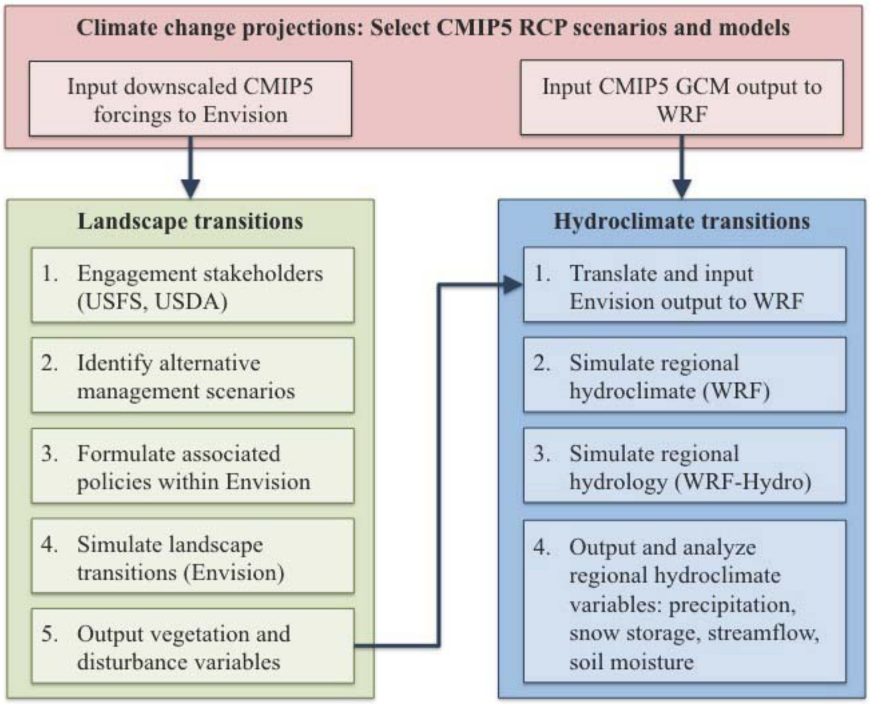

Figure 4: A conceptual schematic of the workflow in the proposed modeling experiments

but for the CESM experiments, for instance, atmospheric variables are available at spatial resolutions of 1 and temporal resolutions of 3-hours. Output from the WRF model will be input to the WRF-Hydro model to allow assessment of changes in seasonal discharge. In all experiments, we will ensure consistency in the GCM model and representative concentration pathway (RCP) between the Envision and WRF simulations. A conceptual diagram of the workflow is shown in **Figure 4**.

3.3 Specific Modeling Tools and Preparation

3.3.1. Envision Alternative Futures Integrated Modeling Platform

The Envision framework is designed to facilitate policy assessments and evaluate alternative futures in landscapes where human activities are tightly coupled to biophysical processes [Bolte et al., 2007; Guzy et al., 2008; Hulse et al., 2009]. At the core of Envision lies a suite of numerical tools to facilitate multidirectional interactions between and among human activities and biophysical processes. These tools take the form of an agent based modeling (ABM) framework that allows autonomous agents or **"actors"** (individuals or groups) to interact with and respond to the behavior of other actors and their environment. Actors are decision makers. They can represent individuals (e.g., large land owners), management agencies (i.e., US Forest Service), or generic classes of decision-makers (e.g., farmers). In the Envision framework actors occupy space in the landscape. The simulation domain is represented as a set of spatially distributed polygons called Integrated Decision Units (IDUs), each of which is associated with an actor. IDUs constitute the fundamental spatial unit for actor decision-making, and represent regions of relatively similar socio-ecological properties (e.g., land use, zoning, soils, elevation, etc.). Actors make decisions in response to environmental conditions in a way that is consistent with their revealed or expressed preferences or values. Environmental conditions are evolved using a suite of **autonomous process models** that are appropriate to the IDU. These models represent key biophysical components of the system being studied like hydrology, vegetation dynamics and succession, fire ignition and growth, and/or soil carbon, and are forced by external climate drivers like precipitation and temperature. Based on landscape variables of interest to the actor occupying an IDU, the actor may apply an available **policy**. Within Envision policies are spatial queries coupled to some action. For example, an Envision policy may specify that actors occupying IDUs on public forestlands with canopy closure greater than 70% can reduce fuel loads by thinning trees to some set tree density. In Envision actors comply with applicable policies probabilistically, depending on the degree to which the policy is mandatory. Thus, adherence or non-adherence to policies has ramifications that can propagate back to the landscape. For instance, persistent non-adherence with the thinning policy above could create conditions suitable for high severity and crown fire. In this way, Envision can capture second-order affects such as the long-term unintended consequences of management activities on disturbance regimes. **Scenarios** are collections of policies that conform to some overarching landscape objective (e.g., maintaining healthy fuel loads through a basket of policies that include thinning and prescribed fire).

In this project, Envision will be applied to southwest Idaho. Simulations associated with this project will focus on the behavior of land management agencies. The PI will work with Dr. Charlie Luce (US Forest Service, see attached letter) to develop and articulate appropriate management scenarios and policies for the Boise National Forest that will be broadly applied to all public forestlands in the simulation domain. These might include fuel load reduction scenarios that involve various policies regarding selective forest thinning. The PI will also work with existing collaborator Dr. Mark Seyfried (USDA Agricultural Research Service, Co-PI on RCC-CZO) to develop appropriate scenarios and policies for rangelands. Rangeland scenarios may include large fire prevention through policies that involve grazing and prescribed fire. We will use existing autonomous process models within Envision to simulate: (1) surface hydrology (HBV, Bergström [1995]), (2) vegetation dynamics and succession (VDDT, ESSA Technologies Ltd. [2008]; Strand et al. [2009]), (3) fire ignition and growth (FLAMMAP, Finney [2004]; Finney et al. [2007]), and (4) soil carbon (CENTURY, Kelly et al. [1997]). Envision has been programmed to natively support the statistically downscaled CMIP5 data available at http://nimbus.cos.uidaho.edu/MACA/ [Abatzoglou and Brown, 2011; Abatzoglou, 2013].

This portion of the work will benefit significantly from ongoing modeling activities led by the PI associated with Idaho's EPSCoR RII Track 1 award. Those modeling activities are focused on assessing the future of water use and availability in the Treasure Valley of southwest Idaho. The Treasure Valley is the population center of the state where landscapes are rapidly transition from agricultural to urban land uses. Outputs of those modeling exercises can conceivably be intersected with the outputs of this project to provide additional realism associated with conversion of agricultural lands.

3.3.2 Weather Research and Forecasting (WRF) model

The dynamical downscaling will be performed using the WRF model, version 3.5 [Skamarock et al., 2008]. The WRF model simulates the coupled land-atmosphere dynamics in response to boundary and initial conditions. Atmospheric variables simulated by WRF include precipitation, air temperature, humidity, wind speed, radiant fluxes, and air pressure. We will use the Noah multi-physics (Noah-MP) land surface model [Niu et al., 2011] that is distributed with WRF. Noah-MP resolves the mass- and energy-balance of the soil, snowpack, and canopy by simulating: (1) soil moisture and temperature in four soil layers, (2) snow temperature, density, and depth in three layers, and (3) vegetation canopy temperature and water storage. There is an increasing body of work showing the skill of using models like WRF for dynamical downscaling in regions of topographic and terrain complexity. For example, Rasmussen et al. [2011] verified that WRF could accurately reproduce USDA National Resource Conservation Service SNOw TELemetry (SNOTEL) precipitation observations to within 10% to 15% in complex terrain, particularly when WRF spatial resolution was limited to 6 km or finer. Approximate simulation domains are shown in **Figure 5**.

WRF-Hydro is a new component to the WRF framework designed to more tightly integrate hydrologic modeling with coupled land-atmosphere modeling [Gochis et al., 2013]. Specifically, a number of modules have been added to route runoff from the land surface model through the subsurface, along hillslopes, and through channel networks. The PI's research group is currently implementing the ParFlow model [Kollet et al., 2010; Maxwell et al., 2011; Maxwell, 2013], one of the options for subsurface and hillslope routing, in the BRB and DCEW in support of NOAA National Weather Service, Army Research Office, and NSF EPSCoR RII Track 2 grants. To support analysis of the joint impacts of climate change and management practices on the seasonality of discharge, we will use ParFlow to route

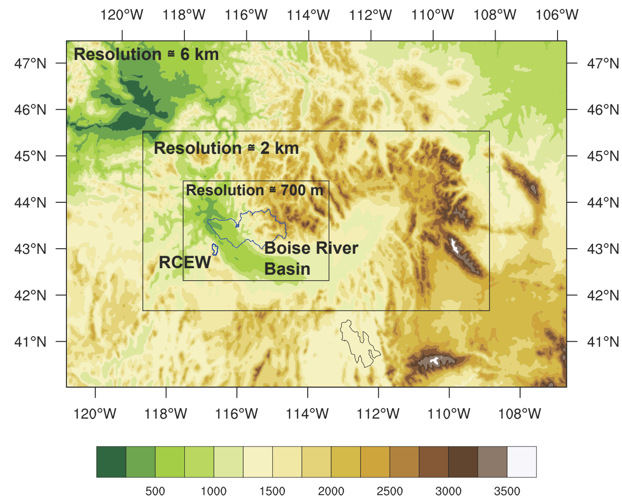

Figure 5: Tentative WRF domains showing the Boise River Basin and RCEW (resolutions not accurate).

natural streamflow into the Boise River reservoir system. We will aggregate flows to monthly volumes to reduce aleatory errors when comparing to historical and alternative future assessments.

3.3.3 Mapping Envision Output to WRF Input

A key activity in this coupling exercise involves mapping the outputs of the Envision framework to the inputs of the WRF/WRF-Hydro land surface and hydrology models. To make these two datasets (Envision outputs and WRF/WRF-Hydro input) interoperable, we will develop lookup tables that map vegetation types and demographic data output from the Envision vegetation dynamics and succession models (e.g., canopy closure, stand age, etc.) to land surface parameters required by WRF (e.g., roughness height, leaf area index, etc.). These will be developed using allometric relationships, published values, and remote sensing datasets when possible. We will also consult with BNF personnel and conduct a suite of sensitivity analysis to investigate the potential ramifications of uncertainties in these relationships on predicted hydrologic states and fluxes.

3.3.4 Important Data Sources

These research products are heavily dependent on large data sources. Specifically, we require both raw outputs of the CMIP5 experiments, as well as statistically downscaled surface forcings. The later will be obtained from outcomes of Idaho's previous EPSCoR RII Track 1 award (*Water Resources in a Changing Climate*) in the form of the previously mentioned bias corrected, statistically downscaled CMIP5 data [Brown and Abatzoglou et al., 2011; Abatzoglou et al., 2012]. We will also obtain appropriate CMIP5 data to force the WRF dynamical downscaling experiments [Taylor et al., 2012]. As previously mentioned, we will ensure consistency in the GCM models and RCPs between the Envision and WRF simulations.

3.4 Identifying and Addressing Uncertainties in Modeling Approach

The proposed activities are not without potentially significant sources of uncertainty. A few important sources, and efforts to address them are articulated here.

3.4.1 Determination of Historical Errors

It is well known that dynamically downscaled simulations can produce significant bias in key hydrologic variables like precipitation and runoff. We will address this in two ways. First, we will identify GCM model outputs from the CMIP5 database that produce historical precipitation and temperature based on the approach outlined by Rupp et al. [in review]. Second, for each CMIP5 GCM considered, we will perform a historical reanalysis for the period from 1990-2010 using the WRF/WRF-Hydro framework. Based on this reanalysis we will quantify errors between dynamically downscaled and historically observed annual and seasonal precipitation, discharge, snow water equivalent, and soil moisture at key locations in the BRB.

3.4.2 Detecting the Influence of Land Management on Regional Hydroclimate

The key signal we are trying to isolate in this modeling framework is the impact of climate change and management activities on hydroclimatic variables relative to the impacts of climate change alone. To accomplish this, for each RCP/GCM pair we will conduct a dynamical downscaling exercise where vegetation input to the WRF/WRF-Hydro framework will consist of potential vegetation types (PVTs) simulated by the MC1 global dynamic vegetation model [Bachelet et al., 2001] within Envision. The MC1 model resolves plant types in a manner that is less detailed than the VDDT model that will be used in the management simulations outlined above. However, the distribution of PVTs should reflect the influence of climate change alone.

3.4.3 Irreducible Uncertainties and Model Error

The proposed workflow decouples the Envision and WRF modeling, which necessitates using CMIP5 data twice. Once using the statistically downscaled data to force the Envision model, and a second time using the raw CMIP5 output to force the WRF model. In all experiments, we will ensure consistency in the GCM model and relative concentration pathway (RCP) between the Envision and WRF simulations. However, errors introduced in the statistical downscaling process are then propagated through Envision and ultimately into WRF. Although these errors are outside the scope of this project, we will work to identify ways to quantify these errors and reduce them where possible.

Further, because Envision and WRF represent land surface hydrology biophysics differently, there will undoubtedly be differences in the, for instance, soil moisture and snow water equivalents between the two models during the same time period. In the scope of this project, we will only be able to quantitatively characterize these differences and qualitatively interpret how they impact conclusions about feedbacks between land management activities and regional hydroclimate.

Finally, there are also limitations to the ABM approach of Envision. For instance, the reliability of actor decision-making behavior is only as good as the corresponding understanding of actors and the associated policies and scenarios. In an effort to minimize these errors (which are less quantifiable), the PI will work closely with identified collaborators at USFS and USDA-ARS.

4. Broader Impacts of Research Plan

This research plan will broadly impact the hydrologic sciences by contributing to fundamental understanding of how human modification of the landscape contributes to changes in regional hydroclimate. It will immediately benefit a graduate student in Geosciences at Boise State who will be trained in Envision and WRF/WRF-Hydro. The student will operate at the quantitative interface between the social and biophysical sciences. The research plan will also produce knowledge and benchmark datasets that will be quickly and broadly disseminated (see Data Management Plan) and contribute to the development of proposals to NSF's Science, Engineering and Education for Sustainability (SEES) programs like the Water, Sustainability, and Climate and Coupled Natural-Human Systems programs. The PI also aspires to creating a culture of improved integration between the social and hydrologic sciences at Boise State and in Idaho, and foresees a potential Innovative Graduate Education Research Traineeship (IGERT) proposal that can grow out of the proposed research plan. The PI previously submitted a Transforming Undergraduate Education in STEM (TUES) proposal on using learner-centered and ability-appropriate visualization to integrate spatially distributed models into the undergraduate classroom. A revision of that proposal will benefit from the modeling frameworks applied and outputs generated by this research. Finally, by engaging stakeholders in a significant way in the modeling activities, the research will lay a path toward integrating cutting-edge approaches into land management planning activities. In the future, the research will facilitate improved engagement with other stakeholders in the federal government (e.g., Bureau of Land Management, US Fish and Wildlife, Bureau of Reclamation, Bureau of Indian Affairs, Army Corps of Engineers, National Interagency Fire Center, etc.) as well as others who have a vested interest in the sustainability of public lands.

5. Results of Prior NSF Funding

Flores: **RAPID 1235994**, $19,912; 2012-13. 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. Manuscript in preparation, title: TBD. **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. As part of this grant, the PI and student developed a terrain physiography based fractional snow-covered area downscaling technique. Walters, R. D., K. A. Watson, H. P. Marshall, J. P. McNamara, and A. N. Flores, A physiographic approach to downscaling remotely sensed fractional snow cover data in mountainous regions, in review.

Education Plan: A Summer Academy for Climate Literacy in Idaho k-12 Schools

Problem Statement, Vision, and Relationship to Standards

The overarching goal of the education plan is to improve climate literacy in Idaho k-12 education. The PI will develop a pilot program to train and equip educators to engage their students in the fabrication of miniaturized automated weather stations. While there has been a meaningful increase since 2009 in the number of Americans agreeing that solid evidence exists that the earth is warming [Dimock et al., 2013], deep misunderstanding of climate and climate change remains. The misconception of the meaning of "irreversibility" of warming due to historical emissions is increasingly cited to justify inaction on policies to reduce atmospheric carbon concentrations in the future [Matthews and Solomon, 2013]. The correlation between acceptance of a warming earth and personal weather observations also underscores this misunderstanding and introduces volatility into opinions on climate change that make long-term planning difficult [Borick and Rabe, 2012]. Improving climate literacy is particularly critical in Idaho because of the degree to which climate change will impact Idaho's ecosystem services and the preeminent role of public land management in potentially adapting to climate change.

The proposed education activities will adopt the framework of climate literacy outlined in *Climate Literacy: The Essential Principles of Climate Science*, a guide for educators produced by the United States Global Change Research Program (USGCRP). Specifically, the guide defines a climate literate individual as someone who (1) understands essential principles of Earth's climate system, (2) knows how to assess scientifically credible information about climate, (3) communicates about climate and climate change in a meaningful way, and (4) is able to make informed and responsible decisions with regard to actions that may affect climate [USGCRP, 2009]. This guide outlines seven specific climate science principles that form the core of climate literacy. These include the preeminence of the Sun as the driver of Earth's climate, the role of complex interactions among components of the Earth system in regulating climate, and how observations, theory, and modeling contribute to continuing improvements in scientific understanding of climate.

Improving climate science literacy in k-12 education must be linked to the new Common Core standards, which Idaho has adopted and is in the process of implementing. The "Idaho Core" emphasizes College and Career Ready Anchor Standards, preparing students to build strong content knowledge; comprehend as well as critique; value evidence; use technology and digital media strategically and capably; and understand other perspectives and cultures (http://www.achievethecore.org). Increasing climate literacy among k-12 educators enables them to prepare students to accomplish authentic tasks in line with content and performance standards of the Common Core.

Overview of Pilot Program

The pilot program will educate and equip Idaho k-12 educators with the knowledge, skills, and equipment to: (1) fabricate miniature weather stations using mass-marketed single-board microcontrollers and computers, and sensors made from recycled/repurposed items, (2) integrate the fabrication process in their classrooms as a series of educational exercises that also coincide with specific Common Core standards, and (3) use the process to teach k-12 students about weather, climate, as well as how and why scientists measure environmental variables.

The building of the miniature weather stations will leverage the explosion in the availability of inexpensive COTS microcontroller and computer devices. In recent years there has been a proliferation of widely available, inexpensive, yet powerful single-board microcontrollers (e.g., Arduino) and single-board computers (e.g., Raspberry Pi). These devices have permeated deeply into the do-it-yourself (DIY) and hobbyist communities. They are used to create novel DIY technologies ranging from light-sensitive alarm clocks to Lego-encased high performance computing clusters. Increasingly, they have also been used in hydrometeorologic research to, for example, enhance the field-portability of measurement technologies, obtain observations of opportunity and/or with a low likelihood of success, develop low-cost hydrometeorologic monitoring networks for malaria early warning in Africa [TAHMO, 2013], and to extend the footprint of monitoring sites using wireless technologies developed specifically for these devices.

Proposed Activities

This pilot program will be implemented as a 2-day summer workshop for k-12 educators at Boise State. **The PI will work with Boise State's Extended Studies program to structure the workshop so that professional development or graduate credit can be conferred for participating teachers.**

In the first two years the summer workshop will target an enrollment of 10-15 teachers. Of these, we will be use grant funds to defray mileage and in-state per diem expenses during the workshop for 5 attendees. **Preference for attendees whose travel is supported by grant funds will be given to teachers of underserved groups (outreach efforts discussed below).** Attending teachers will be provided with learner-centered teaching and assessment materials and a starter kit containing sufficient supplies to build a small and simple, but functional, automated weather station (**Figure 6**) that collects and transmits data to Boise State where it will be aggregated and visualized on the project web portal.

The PI will collaborate with Dr. Jennifer Snow (Curriculum, Instruction, & Foundational Studies, Boise State University, see attached letter) and Dr. Karen Viskupic (Geosciences, Boise State University, see attached letter) to ensure that the developed exercises map to both appropriate Common Core standards and the essential principles of climate science literacy. Conforming to the Common Core standards will influence to which grade-levels the developed activities are initially tailored. We will also ensure that the exercises incorporate the latest understanding about inquiry learning in STEM [de Jong, 2006]. Facilitating this integrated view would include, for example, carefully selecting sensors that simultaneously address elements of the Common Core and Climate Literacy frameworks. Examples of potential sensors with associated scientific concepts and specific climatic variables to be measured are shown in **Table 1**.

The workshop will address four intellectual and skill development areas in half-day modules:
(1) Climate: The core intellectual focus of the proposed activities is improving understanding of climate. This module will take full advantage of the wealth of materials that have been produced to enhance climate and Earth science literacy. The structure of the module will go beyond simply providing key information and principles about Earth's climate. Activities illustrating key principles that could be extended to the classroom will also be presented. For example, the Greenhouse Effect can be illustrated by dissolving an over-the-counter antacid tablet in a stoppered 2-liter soda bottle with a thermometer. Specifically, activities will prompt students to construct testable hypotheses about activities, and then to reflect on the outcomes of the activity in the context of their initial conceptions as articulated in their hypotheses.
(2) Microcontrollers and circuits: The primary goal of this module is to demystify the principles of electric circuits and concepts like voltage, current, and resistance. The module will lead students and teachers through a progression of exercises that seek to isolate and illustrate key concepts. For instance, classic activities like constructing a lemon battery to light an LED can be used to illustrate the concept of electrochemical potential and batteries. These activities will lead to an introduction of the Arduino microcontroller, which will be introduced as a technology that, despite its initially complex and perhaps intimidating appearance, merely coordinates the activities of a discrete number of simple circuits. This serves as a transition of a discussion about the hardware of microcontrollers to the software.
(3) Software development: It is anticipated that the majority of participating teachers will have little or no experience in computer programming. Fortunately, Arduino microcontrollers use a well-supported, high-level programming language similar to the C language. A cross-platform application is downloaded from the Arduino website or other mirrors. This application is a simple user interface where sequences of commands to the microcontroller are written. Upon completion of this program (referred to as a "sketch"), it is uploaded to the device, which immediately reboots and begins executing the sketch. A number of pre-written codes for simple tasks (e.g., making an LED turn on and off at given intervals) are native to the Arduino development environment and can be inserted into the sketch and modified by the user. Among the materials that we will develop and post on the website are sketches to support some of the

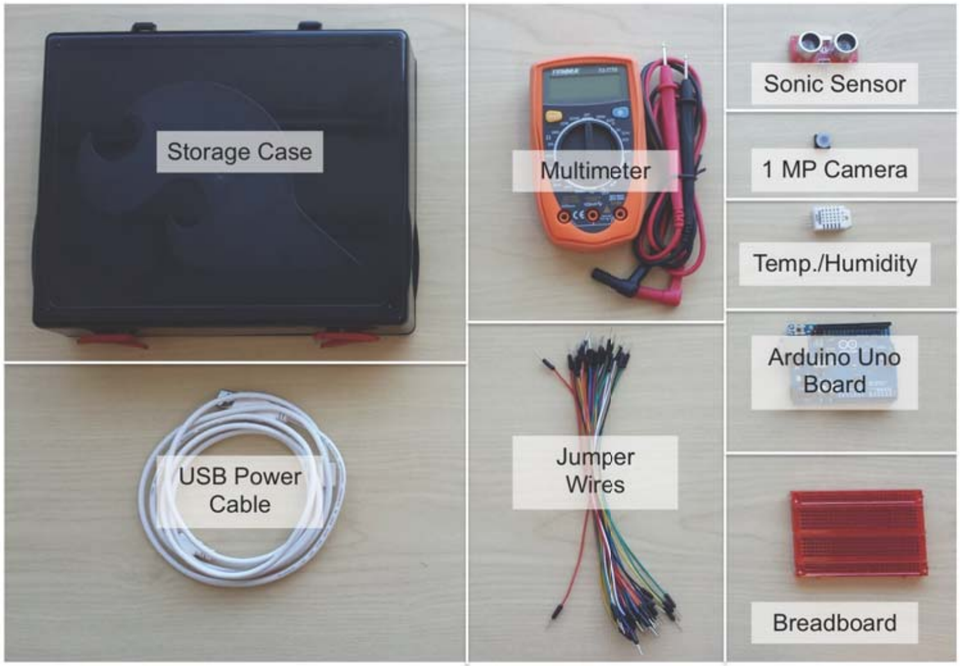

Figure 6: Example contents of kit for participating teachers

Table 1: Potential pairings of sensors and educational concepts

Sensor	General Concept	Measured Climate Variable
Sonic	Distance, speed	Snow depth
Pressure	Pressure	Atmospheric pressure
Temperature	Heat, internal energy	Air temperature
Humidity	Phases of matter	Air humidity
Light density	Photocell	Solar radiation
Pulse counter	Summation	Rainfall, windspeed

accompanying in-class activities. Depending on demand, we will also host sketches and materials contributed by Idaho k-12 teachers for the community.

(4) Sensors and sensor development for hydrometeorologic measurement: The prevailing philosophy of sensors and sensor developments will be to use inexpensive, but functional and easy-to-use sensors. Industrial-grade sensors for temperature, humidity, and pressure can be purchased for approximately $2 each. While these sensors may be associated with higher levels of noise than research-grade sensors, the use of multiple sensors could facilitate discussions about precision and accuracy, and reproducibility in advanced classrooms. To foster creativity in teachers and their students, encourage the use of recycled materials and repurposing of disused items. For instance, functioning bicycle computers can be exploited as pulse counters and used mechanisms to build small tipping bucket rain gages and anemometers.

Assessment, Analysis, and Dissemination of Learning Outcomes

Teachers will complete activities in the workshop and develop curriculum guides for use in their classrooms. Curriculum guides will be evaluated for connections to content knowledge and application/integration with Idaho Core standards. Teachers will complete reflective journal entries on the experience and report back to Dr. Snow for future support and workshop development for future summers. Teachers will be asked to focus on student engagement, student performance, and student interest in connection to climate literacy content.

Educational research will focus on the implementation of climate literacy lessons in Idaho classrooms and the impact on k-12 student learning. Assessment data will be analyzed by the Dr. Snow to address research questions such as: Are students meeting Core standards with this type of authentic science task?

Do students report interest/commitment to climate literacy in the future? How are students prepared for college and career opportunities with activities such as these in their k-12 educational experience? How do teachers perceive the professional development opportunity of the workshop in connection to their abilities to teach the Idaho Core and prepare students to perform well on the Smarter Balanced Assessment?

External Evaluation

An external evaluator will be contracted in the first project year. An evaluator with appropriate skills and experience will be found via the American Evaluation Association (http://www.eval.org). The evaluation strategy will focus on effective implementation of the program and achievement of the outcomes identified above. We expect the evaluator to conduct front-end, formative, and summative evaluation using a variety of approaches including, quantitative, qualitative, and mixed methods. It is further anticipated that the evaluator will work closely with the PI and collaborators to ensure the education plan is making satisfactory progress toward its goals by: (1) identifying and developing appropriate evaluation instruments, (2) determining checkpoints for data collection, (3) recommending evidenced-based adjustments to project plans, (4) determining the value of identified outcomes, and (5) attesting to the integrity of outcomes.

Broader Impacts of the Education Plan

The pilot program will strengthen broadening participation in the Earth sciences in Idaho and engage k-12 students in science. The program also addresses key "Big Ideas" articulated by the Earth Science Literacy Initiative in their *Earth Science Literacy Principles* document. Specifically, the pilot program addresses the scientific method (Big Idea 1), complex interactions of Earth systems (Big Idea 3), and the key role of water in shaping Earth's surface and sustaining life (Big Idea 5) [ESLI, 2010]. Because assessment and evaluation are integrated into the program, we will be able to make appropriate modifications to the program to enhance its efficacy over the lifetime of this grant. Our long-term vision is to develop a STEM-focused k-12 climate literacy program in Idaho that is a model for other states and regions and/or can complement existing climate literacy programs (e.g., at the University of Nevada-Las Vegas, http://climatechange.education.unlv.edu). Dissemination of these activities and their impact will be demonstrated by submitting our findings for publication in peer-reviewed educational research journals like the Journal of Geoscience Education and presenting at appropriate professional national conferences such as the Pacific Northwest Section of the National Association of Geoscience Teachers summer conference and the American Geophysical Union fall meeting. Prior to disseminating results, we will ensure that any data presented comports with Institutional Review Board requirements.

Serving Idaho's Underserved Students

By identifying and defraying travel expenses for k-12 educators who serve Idaho's underserved students, we can dramatically broaden participation in authentic scientific practice. We will focus our efforts at broadening participation on three important underserved groups: (1) rural students, (2) refugee populations, and (3) Title I schools. Idaho's public lands provide a wealth of ecosystem services for its inhabitants and remain critical to the state economy. The high fraction of federally owned lands, mountainous terrain, and relatively small population, however, also make the state's population centers remote and the population more rural than average [Census, 2010]. As a result, rural populations are often underserved from the perspective of outreach activities at Idaho's research universities. There are also underserved populations within the Boise area. For instance, between 2001-2011 approximately 5,300 refugees – many of them women and children – have been resettled to Idaho, primarily to Boise. Furthermore, 50 schools in the three school districts serving the Treasure Valley region of southwest Idaho participate in the Department of Education's Title I program. This includes all 23 schools in the Nampa School District. Teachers serving these students (e.g., teachers of English learners, teachers in Title I schools) will be identified using our professional network and in collaboration with contacts at school districts. To ensure this program addresses needs of underserved populations, activities will be informed by latest understanding of teaching STEM concepts to underserved groups (e.g., Lee [2011]).

We will work with Tanya Rush, the director of refugee services at the Sage International School in Boise to reach out to teachers that serve refugee populations.

Sustainability Planning

Short-term project sustainability goals include: (1) developing adequate resources and activities to implement the project in the first two years, (2) ensuring that participating teachers are adequately supported after completion of the workshop, and (3) confirming that participating teachers are implementing elements of the workshop into their classroom. In order to develop the groundwork for successful k-12 classroom experiences, the PI has budgeted and will engage an undergraduate student in Electrical Engineering at Boise State University to assist in developing circuits, wiring diagrams, sensors, and sketches for the miniature weather stations. This will ensure that a well of resources exists by the first time the workshop is taught. We will support participating teachers by developing and hosting online resources to assist in maintenance and re-training of skills. These include YouTube videos, wiring diagrams and code sketches. These will be hosted on a website that will developed in year 1 of the grant. These online resources will also enable remote participation. To maximize implementation of the developed activities into classrooms, the first group of participating k-12 educators will be actively identified using Drs. Flores and Snow's professional networks at Boise State and within Idaho school districts. We will identify and invite enthusiastic teachers that are ready to integrate the activities and program into their classrooms. We have identified two teachers, Lindsey Lockwood and Guy Falconer, from the Sage International School in Boise (see attached letter) who will attend the summer workshop in the first year.

In the long term, we are committed to the success and sustainability of the pilot program after this CAREER project ends. Therefore, at the beginning of year 3 we will develop a sustainability plan to identify mechanisms to support continuation of the program beyond year 5 of the grant. The sustainability plan will include: (1) an accounting of the number and demographics of teachers and students served in the first two years of the grant, (2) assessment data on how the activities impacted student learning, (3) a summary of external evaluations, (4) a forecast of the number of teachers and students that could be supported in the five years after the grant, and (5) alternative cost scenarios based on the number of participating teachers in each year. We will use this sustainability plan as the basis for pursuing continued financial support through state, federal, and private foundation resources. We will particularly focus on nurturing relationships with private foundations interest in improving STEM education in the state and region.

We will also develop the workshop to be a sufficiently attractive professional development opportunity for teachers and districts that they defray expenses associated with attendance. Dr. Snow's Spring 2014 sabbatical is aimed at identifying specific pedagogies in Boise area schools that are particularly effective in achieving the goals of the Idaho Core. Based on her findings, we will incorporate these pedagogies into the workshop curriculum and develop advertising that articulates how the workshop employs these "best practices." We will, moreover, maintain a database of workshop attendees and engage them to share their workshop experience with colleagues and serve as district points-of-contact for the program. Where appropriate, we will leverage programs at Boise State to enhance the pilot program. For instance, students from our successful GK-12 program could be engaged as co-teachers of the workshop. The PI is also separately developing a Service Learning class for Boise State Hydrologic Science students to develop and deploy miniature weather stations at regional centers of informal science learning (e.g., Foothills Learning Center, Boise WaterShed, etc.). These outreach activities could be used to advertise the workshop to educators and the culminating activity for some Boise State Service Learning students could co-teaching the summer workshop.

References

Abatzoglou J.T. and T.J. Brown (2011), A comparison of statistical downscaling methods suited for wildfire applications, International Journal of Climatology, doi: 10.1002/joc.2313

Abatzoglou, J.T., 2013, Development of gridded surface meteorological data for ecological applications and modeling, International Journal of Climatology, doi: 10.1002/joc.3413

Adam, J.C., J.C. Stephens, S.H. Chung, M.P. Brady, R.D. Evans, C.E. Kruger, B.K. Lamb, M.L. Liu, C.O. Stöckle, J.K. Vaughan, K. Rajagopalan, J.A. Harrison, C.L. Tague, A. Kalyanaraman, Y. Chen, A. Guenther, F.Y. Leung, L.R. Leung, A.B. Perleberg, J. Yoder, E. Allen, S. Anderson, B. Chandrasekharan, K. Malek, T. Mullis, C. Miller, T. Nergui, J. Poinsatte, J. Reyes, J. Zhu, J.S. Choate, X. Jiang, R. Nelson, J.H. Yoon, G.G. Yorgey, K.J. Chinnayakanahalli, A.F. Hamlet, B. Nijssen, BioEarth: A regional biosphere-relevant earth system model to inform agricultural and natural resource management decisions, Climatic Change, *in review*.

Anderson B.T., J.P. McNamara, H.P. Marshall, and A.N. Flores, The evolution of snowpack spatial variability in a semi-arid mountain watershed: Implications for modeling, Submitted to Water Resources Research, in review.

Bachelet D., J.M. Lenihan, C. Daly, R.P. Neilson, D.S. Ojima, and W.J. Parton (2001) MC, a Dynamic Vegetation Model for estimating the distribution of vegetation and associated carbon and nutrient fluxes, Technical Documentation Version 1.0, USDA Forest Service Pacific Northwest Station, General Technical Report PNW-GTR-508, 95pp.

Balch, J.K., B.A. Bradley, C.M. D'Antonio, and J. Gomez-Dans (2013), Introduced annual grass increases regional fire activity across the arid western USA (1980-2009), *Global Change Biology,* 19, 173-183.

Belnap, J., J. H. Kaltenecker, R. Rosentreter, J. Williams, S. Leonard, and D. Eldridge (2001), Biological soil crusts: ecology and management, Technical Reference 1730-2, Denver, CO: U.S. Department of the Interior, Bureau of Land Management, National Science and Technology Center, Information and Communications Group, 110 pp.

Bergström, S. 1995. The HBV model. In: Singh, V.P. (Ed.) Computer Models of Watershed Hydrology. Water Resources Publications, Highlands Ranch, CO., pp. 443-476.

Boise National Forest (2010), Amended Forest Plan – Documents, US Department of Agriculture, http://www.fs.usda.gov/detail/boise/landmanagement/planning/?cid=stelprdb5394192

Bolte, J.P., D.W. Hulse, and S.V. Gregory (2007), Modeling biocomplexity–actors, landscapes and alternative futures, Environmental Modelling & Software, 22(5), 570-579.

Bonan, G. B. (2008), Forests and climate change: forcings, feedbacks, and the climate benefits of forests, Science, 320(5882), 1444-1449.

Borick, C. P. and B. G. Rabe (2012), Fall 2011 National Survey of American Public Opinion on Climate Change, Issues in Governance Studies, The Brookings Institution, February 2012, Washington, DC.

Chauvin, G. M., G. N. Flerchinger, T. E. Link, D. Marks, A. H. Winstral, M. S. Seyfried (2011), Long-term water balance and conceptual model of a semi-arid mountainous catchment, Journal of Hydrology, 400(1-2), 133-143, doi: 10.1016/j.jhydrol.2011.01.031.

Community Earth System Model Societal Dimensions Working Group (2011), White Paper on Societal Dimensions of Earth System Modeling, http://www.cesm.ucar.edu/working_groups/societal/white.paper.pdf

Dimock, M., C. Doherty, and L. Christian (2013), Keystone XL Pipeline Draws Broad Support, Continuing Partisan Divide in Views of Global Warming, Pew Research Center for People & the Press, April 2.

Earth Science Literacy Initiative (2010), Earth Science Literacy Principles, http://www.earthscienceliteracy.org/es_literacy_6may10_.pdf, accessed 04/28/2012.

ESSA Technologies Ltd. (2008), TELSA – Tool for Exploratory Landscape Scenario Analyses: User's Guide Version 3.6., Prepared by ESSA Technologies Ltd., Vancouver, BC., 235 pp.

Finney, M. A. (2004), Landscape fire simulation and fuel treatment optimization. In: Hayes, J. L.; Ager, A. A.; Barbour, J. R., tech. ed. Methods for integrating modeling of landscape change: Interior Northwest Landscape Analysis System. General Technical Report PNW-GTR-610. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Station: 117-131.

Finney, M. A., R.C. Seli, C.W. McHugh, A.A. Ager, B. Bahro, and J.K. Agee (2007), Simulation of long-term landscape-level fuel treatment effects on large wildfires, International Journal of Wildland Fire 16, 712-727.

Fischer, G., M. Shah, F.N. Tubiello, and H. van Velhuizen (2005), Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990–2080, Philosophical Transactions of the Royal Society B: Biological Sciences, 360(1463), 2067-2083.

Flerchinger, G.N., Cooley, K.R., and Ralston, D.R. (1992), Groundwater response to snowmelt in a mountainous watershed, Journal of Hydrology, 133, 293-311.

Flerchinger, G.N., C.L.Hanson, and J.R.Wight (1996), Modeling evapotranspiration and surface energy budgets across a watershed. Water Resources Research, 32 (8), 2539-2548.

Flerchinger, G.N., and K.R. Cooley (2000), A ten-year water balance of a mountainous semi-arid watershed. Journal of Hydrology, 237, 86-99.

Flores, A. N., V. Y. Ivanov, D. Entekhabi, and R. L. Bras (2009), Impacts of hillslope-scale organization in topography, soil moisture, soil temperature, and vegetation on modeling surface microwave radiation emission, IEEE Transactions on Geoscience and Remote Sensing, 47(8), 2557-2571.

Flores, A. N., D. Entekhabi, and R. L. Bras (2010), Reproducibility of soil moisture ensembles when representing soil parameter uncertainty and correlation using a Latin Hypercube-based approach, Water Resources Research, 46, doi:10.1029/2009WR008155.

Flores, A. N., R. L. Bras, and D. Entekhabi (2012), Hydrologic data assimilation with a hillslope-scale-resolving model and L band radar observations: Synthetic experiments with the ensemble Kalman filter, Water Resources Research, 48, W08509, doi:10.1029/2011WR011500.

Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz, and R. Van Dorland (2007), Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Gochis, D., W. Yu, and D. Yates (2013), The NCAR WRF-Hydro Technical Description and User's Guide, Version 1.0,

Gorte, R. W., C. H. Vincent, L. A. Hanson, and M. R. Rosenblum (2012), Federal Land Ownership: Overview and Data, Congressional Research Service, 7-5700, R42346.

Gutmann, E.D., R.M. Rasmussen, C. Liu, K. Ikeda, D.J. Gochis, M.P. Clark, J. Dudhia, and G. Thompson (2012), A comparison of statistical and dynamical downscaling of winter precipitation over complex terrain, Journal of Climate, 25(1), 262-281.

Guzy, M.R., C.L. Smith, J.P. Bolte, D.W. Hulse, and S.V. Gregory (2008), Policy research using agent-based modeling to assess future impacts of urban expansion into farmlands and forests, Ecology and Society, 13(1), 37.

Holden, Z.A., A.M.S. Smith, P. Morgan, M.G. Rollins, and P.E. Gessler (2005), Evaluation of novel thermally enhanced spectral indices for mapping fire perimeters and comparisons with fire atlas data, International Journal of Remote Sensing, 26(21), 4801-4808.

Holden, Z.A., C.H. Luce, M.A. Crimmins, and P. Morgan (2012), Wildfire extent and severity correlated with annual streamflow distribution and timing in the Pacific Northwest, USA (1984–2005), Ecohydrology, 5(5), 677-684.

Hulse, D., A. Branscomb, C. Enright, and J.P. Bolte (2009), Anticipating floodplain trajectories: a comparison of two alternative futures approaches, Landscape ecology, 24(8), 1067-1090.

de Jong, T. (2006), Technological advances in inquiry learning, Science, 312(5773), 532-533, doi:10.1126/science.1127750.

Keeley, J.E., and T.W. McGinnis (2007), Impact of prescribed fire and other factors on cheatgrass persistence in a Sierra Nevada ponderosa pine forest, International Journal of Wildland Fire, 16(1), 96-106.

Kelly, R.H., W.J. Parton, G.J. Crocker, P.R. Graced, J. Klir, M. Körschens, and D.D. Richter (1997), Simulating trends in soil organic carbon in long-term experiments using the century model, Geoderma, 81(1), 75-90.

Kollet, S. J., R. M. Maxwell, C. S. Woodward, S. Smith, J. Vanderborght, H. Vereecken, and C. Simmer (2010), Proof of concept of regional scale hydrologic simulations at hydrologic resolution utilizing massively parallel computer resources, Water Resources Research, 46, W04201, doi:10.1029/2009WR008730.

Kulmatiski A, K.H. Beard, and J.M. Stark (2006), Exotic plant communities shift water-use timing in a shrub-steppe ecosystem, Plant and Soil, 288, 271-284.

Kunkel, M.L. and J.L. Pierce (2010), Reconstructing snowmelt in Idaho's watershed using historic streamflow records, Climatic Change, 98(1-2), 155-176.

Kunkel, M. L., A. N. Flores, T. J. Smith, J. P. McNamara, and S. G. Benner (2011), Spatial distribution of organic carbon in a semi-arid complex terrain, Geoderma, 165(1), 1-11, doi:10.1016/j.geoderma.2011.06.011.

Lee, O. (2011), Effective STEM Education Strategies for Diverse and Underserved Learners, workshop of the Committee on Highly Successful Schools or Programs for K-12 STEM Education, National Research Council, Washington, DC.

Littell, J. S., D. McKenzie, D.L. Peterson, and A.L. Westerling (2009), Climate and wildfire area burned in western US ecoprovinces, 1916-2003, Ecological Applications, 19(4), 1003-1021.

Luce, C. H., D. G. Tarboton, and K. R. Cooley (1998), The influence of the spatial distribution of snow on basin-averaged snowmelt, Hydrological Processes, 12(10-11), 1671-1683.

Luce, C. H., and Z. A. Holden (2009), Declining annual streamflow distributions in the Pacific Northwest United States, 1948–2006, Geophysical Research Letters, 36, L16401, doi:10.1029/2009GL039407

Matthews, H. D. and S. Solomon (2013), Irreversible Does Not Mean Unavoidable, Science 26, 340 (6131), 438-439, doi:10.1126/science.1236372.

Maxwell, R.M., J.K. Lundquist, J.D. Mirocha, S.G. Smith, C.S. Woodward, and A.F.B. Tompson (2011), Development of a coupled groundwater-atmospheric model, Monthly Weather Review, 139(1), 96-116, doi:10.1175/2010MWR3392, 2011.

Maxwell, R.M. (2013), A terrain-following grid transform and preconditioner for parallel, large-scale, integrated hydrologic modeling, Advances in Water Resources, 53:109-117, doi:10.1016/j.advwatres.2012.10.001.

McNamara, J. P., D. G. Chandler, M. Seyfried, and S. Achet (2005) Soil moisture states, lateral flow, and streamflow generation in a semi-arid, snowmelt-driven catchment, Hydrological Processes, 19, 4023-4038.

Millennium Ecosystem Assessment (2005), Ecosystems and Human Well-being: Biodiversity Synthesis, World Resources Institute, Washington, DC.

National Research Council (2012), Challenges and Opportunities in the Hydrologic Sciences, Committee on Challenges and Opportunities in the Hydrologic Sciences, ISBN:9780309222839, National Academies Press, Washington, DC.

Nayak, A., D. Marks, D. G. Chandler, and M. Seyfried (2010), Long-term snow, climate, and streamflow trends at the Reynolds Creek Experimental Watershed, Owyhee Mountains, Idaho, United States, Water Resources Research, 46, W06519, doi:10.1029/2008WR007525.

Niu, G.-Y., Z.-L. Yang, K.E. Mitchell, F. Chen, M.B. Ek, M. Barlage, A. Kumar, K. Manning, D. Niyogi, E. Rosero, M. Tewari, and Y. Xia (2011), The community Noah land surface model with multiparameterization options (Noah-MP): 1. Model description and evaluation with local-scale measurements, Journal of Geophysical Research, 116, D12109, doi:10.1029/2010JD015139.

Pan, L.L., S.H. Chen, D. Cayan, M.Y. Lin, Q. Hart, M.H. Zhang, and J. Wang (2011), Influences of climate change on California and Nevada regions revealed by a high-resolution dynamical downscaling study, Climate Dynamics, 37(9-10), 2005-2020.

Pielke, R. A., G. Marland, R.A. Betts, T.N. Chase, J.L. Eastman, J.O. Niles, and S.W. Running (2002), The influence of land-use change and landscape dynamics on the climate system: relevance to climate-change policy beyond the radiative effect of greenhouse gases, Philosophical Transactions of the Royal Society of London, Series A: Mathematical, Physical and Engineering Sciences, 360(1797), 1705-1719.

Poulos, M. J., J. L. Pierce, A. N. Flores, and S. G. Benner (2012), Hillslope asymmetry maps reveal widespread, multi-scale organization, Geophysical Research Letters, doi:10.1029/2012GL051283.

Quintana Seguí, P., A. Ribes, E. Martin, F. Habets, and J. Boé (2010), Comparison of three downscaling methods in simulating the impact of climate change on the hydrology of Mediterranean basins, Journal of Hydrology, 383(1), 111-124.

Rasmussen, R., and C. Liu, K. Ikeda, D. Gochis, D. Yates, F. Chen, M. Tewari, M. Barlage, J. Dudhia, W. Yu, K. Miller, K. Arsenault, V. Grubišic, G. Thompson, and E. Gutmann (2011), High-Resolution Coupled Climate Runoff Simulations of Seasonal Snowfall over Colorado: A Process Study of Current and Warmer Climate, Journal of Climate, 24, 3015–3048.

Reba, M. L., D. Marks, M. Seyfried, A. Winstral, M. Kumar, and G. Flerchinger (2011), A long-term data set for hydrologic modeling in a snow-dominated mountain catchment, Water Resources Research, 47, W07702, doi:10.1029/2010WR010030.

Rupp, D. E., J. T. Abatzoglou, K. C. Hegewisch, and P. W. Mote, Evaluation of 20th century climate simulations for the Pacific Northwest US, Journal of Geophysical Research:Atmospheres, in review.

Shukla, S., and D.P. Lettenmaier (2013), Multi-RCM ensemble downscaling of NCEP CFS winter season forecasts: Implications for seasonal hydrologic forecast skill, Journal of Geophysical Research: Atmospheres, accepted.

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, M. Duda, X.-Y. Huang, W. Wang and J. G. Powers (2008), A Description of the Advanced Research WRF Version 3, NCAR Tech. Note TN-475+STR, 113 pp.

Slaughter, C. W., D. Marks, G. N. Flerchinger, S. S. V. Vactor, and M. Burgess (2001), 35 years of research data collection at the Reynolds Creek Experimental Watershed, Idaho, USA, Water Resources Research, 37(11), 2819-2824.

Smith, T. J., J. P. McNamara, A. N. Flores, M. M. Gribb, P. S. Aishlin, and S. G. Benner (2011), Small soil storage capacity limits benefit of winter snowpack to upland vegetation, Hydrological Processes, 25(25), 3858-3865, doi:10.1002/hyp.8340.

Sperry L.J., J. Belnap, and R.D. Evans (2006) Bromus tectorum invasion alters nitrogen dynamics in an undisturbed arid grassland ecosystem, Ecology, 87, 603–615.

Strand, E.K., L.A. Vierling and S.C. Bunting (2009), A spatially explicit model to predict future landscape composition of aspen woodlands under various management scenarios, Ecological Modelling, 220(2), 175-191.

Taylor K. E., R. J. Stouffer and G. A. Meehl (2012), An overview of CMIP5 and the experiment design, Bulletin of the American Meteorological Society 93(4), 485 - 498, doi:10.1175/BAMS-D-11-00094.1

Trans-African Hydro-Meteorological Observatory (2013), http://tahmo.info.

United States Census Bureau (2012), 2010 Census Summary File 1-Technical Documentation/prepared by the U.S. Census Bureau, Revised 2012.

United States Global Change Research Program (2009), Climate Literacy: The Essential Principles of Climate Science, http://www.globalchange.gov/resources/educators/climate-literacy.

Westerling, A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam (2006), Warming and earlier spring increase western US forest wildfire activity, Science, 313(5789), 940-943.

Wilcox, B. P., L. Turnbull, M.H. Young, C.J. Williams, S. Ravi, M.S. Seyfried, D.R. Bowling, R.L. Scott, M.J. Germino, T.G. Caldwell, and J. Wainwright, J. (2012), Invasion of shrublands by exotic grasses: ecohydrological consequences in cold versus warm deserts, Ecohydrology, 5, 160–173, doi:10.1002/eco.247

Williams, C.J., J.P. McNamara, and D.G. Chandler (2009), Controls on the spatial and temporal variation of soil moisture in a mountainous landscape: the signatures of snow and complex terrain, Hydrology and Earth System Science, 13, 1325-1336.

Wood, A.W., L.R. Leung, V. Sridhar, and D.P. Lettenmaier (2004), Hydrologic implications of dynamical and statistical approaches to downscaling climate model outputs, Climatic Change, 62(1-3), 189-216.

Yoon, J.H., K. Mo, and E.F. Wood (2012), Dynamic-model-based seasonal prediction of meteorological drought over the contiguous United States, Journal of Hydrometeorology, 13(2), 463-482.

Yuan, X., X. Z. Liang, and E.F. Wood (2012), WRF ensemble downscaling seasonal forecasts of China winter precipitation during 1982–2008, Climate Dynamics, 39(7-8), 2041-2058.