1. COVER PAGE DATA ELEMENTS

Federal Agency: U.S. Department of Energy
Federal Grant: DE-FC02-06ER64159
Project Title: Western Regional Center of the National Institute for Climatic Change Research
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928-523-
Submission Date : May 2, 2013
DUNS Number: 80-634-5542
Recipient Organization: Arizona Board of Regents for and on behalf of Northern Arizona University
Project/Grant Period: 12/01/2005 – 11/30/2012
Reporting Period End Date: 2/28/2013
Report Term: Final

Signature of Submitting Official: 

2. ACCOMPLISHMENTS:

What are the major goals of the project?

The major goal of this project was fostering, integrating, synthesizing, and disseminating experimental, observational, and modeling research on predicted climate change in the western region of the U.S. and the impacts of that change on the structure, productivity, and climatic interactions of the region's natural and managed ecological systems. This was accomplished through administering a competitive grants program developed in collaboration with the other four regional centers of the NICCR. The activities supported included efforts to synthesize research on climate change in the western U.S. through meta-analysis studies, model comparisons, and data synthesis workshops. Results from this work were disseminated to the scientific and public media. This project also supported the development of the NICCR web site, hosted at NAU, which was used as the means to accept pre-proposal and proposal submissions for each funding cycle, and served as a clearing house for public outreach for results from NICCR-funded research.

What was accomplished under these goals?

Thirty-six projects were supported under the award, including experimental, modeling, and synthesis activities. The work supported was regionally relevant and comprehensive: research was conducted on all thirteen of the western states, and three of the funded projects supported work across regions with global implications.

What opportunities for training and professional development has the project provided?

The administration of this project supported professional development for a postdoctoral research associate (Matthew Hurteau), a data manager (Paul Heinrich), a Grants & Contracts Administrator (Sally Evans).
Hurteau gained experience in scientific outreach, drafting the text on the NICCR web site and working with a local artist to design the visual. Heinrich gained technical experience by successfully implementing the online proposal submission system. Evans received certification as a Certified Research Administrator. All participated in national NICCR meetings.
Individual projects provided support for 18 Ph.D students, 10 M.S. students, 16 B.S students and 5 post-doctoral researchers.

How have the results been disseminated to communities of interest?

Results from the research have been published as listed below. In addition, information has been posted at the following sites: http://moab.colorado.edu/Boreal/main.html; http://Chem.atmos.colostate.edu/FLAME; http://public.ornl.gov/ameriflux; heep://datadryad.org/
We also received extensive media coverage for articles in Nature.

3. PRODUCTS:

Publications, conference papers, and presentations

Publications

Adams, H. D., M. Guardiola-Claramonte, G. A. Barron-Gafford, J. C. Villegas, D. D. Breshears, C. B. Zou, P. A. Troch, and T. E. Huxman. 2009a. Reply to Leuzinger et al.: Drought-induced tree mortality temperature sensitivity requires pressing forward with best available science. Proceedings of the National Academy of Sciences of the United States of America 106:E107-E107.

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Regan, H. Evaluation of assisted colonization strategies under climate change for a rare, firedependent plant. Invited Lecture, University of Copenhagen, Copenhagen, Denmark, 04/29/2011.

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Franklin, J., A. D. Syphard and H. M Regan. The response of a key plant functional type to thetriple threat of land use change, climate change and altered fire regimes in Mediterranean-type ecosystems. Invited paper, symposium: "Feedbacks & synergisms: mechanisms driving novel ecosystems in the context of climate and land-use changes,"Association of American Geographers Annual Meeting, Seattle, WA. 12-16 Apr, 2011.

Franklin, J., H. M Regan, A. D. Syphard, R. Swab and E. Conlisk. The response of plant functional types to land use change, climate change and altered fire regimes in a Mediterranean-type ecosystem. Oral presentation, Annual Symposium, International Association for Landscape Ecology-US Chapter, Portland, OR, April 3-7, 2011.

Swab, R., H. M. Regan, D. Keith, J. Franklin, A. Syphard, T. Regan, M. Ooi and J. Crookston.Which is worse, the fire or the frying pan? Evaluating plant vulnerability to climatechange and altered fire regimes. Oral presentation, British Ecological Society Annual Symposium University of Cambridge, UK. 28-30 Mar, 2011.

Swab, R., H. M. Regan, D. Keith, J. Franklin, A. Syphard, T. Regan, M Ooi and J. Crookston. Vulnerability of obligate fire seeders to simultaneous changing fire regimes and climate change. Oral presentation, International Biogeography Society 5th International Conference, Iraklion, Crete, Greece, 7-11 Jan, 2011.

Conlisk, E., Dispersal, disturbance, and altered fecundity in a population model of Quercus engelmannii's response to the combined effects of land use change, climate change, and altered fire regime. Invited Lecture, Department of Biology Colloquium, University of California, Riverside, CA, Dec 2, 2010.

Davis, F.W., Franklin, J., Ikegami, M., Syphard, A., Flint, A., Hannah, L. Modeling plant species distributions under future climates: how fine-scale do climate models need to be? Oral presentation, American Geophysical Union Fall Meeting, San Francisco, CA, 13-17 Dec, 2010.

Syphard. A., H. Regan, J. Franklin, R. Swab and P. Zedler, A framework for assessing climate mitigation and adaptation strategies. Oral presentation, Workshop on Bridging the Gap: Downscaling Climate Models to Inform Management Actions, CA Department of Fish & Game, US Geological Survey, and US Fish and Wildlife Service, Sacramento, CA, 3Nov, 2010.

Swab, Rebecca. Climate change, fires, and species responses. Oral Presentation, CMEC Forum Session. University of Copenhagen, Denmark. November 9, 2010.

Syphard, A., J. Franklin and H. Regan, Does translocation of a rare fire dependent plant mitigate the effects of climate change? Oral presentation, Tecate Cypress Symposium, The Nature Conservancy and the Bureau of Land Management, Rancho Jamul Ecological Reserve, Jamul, CA, 16 Jun, 2010.

Regan, H.M. Assessing risks of global change to plants in a Mediterranean-type ecosystem. Invited

Lect Lecture, University of Amsterdam, The Netherlands, June 15th 2010

Carbon, Water and Land-Use in Conservation Reserve Program Lands of the Shortgrass Steppe Niall Hanan, Jack Morgan, Keith Paustian and Indy Burke, Shortgrass Steppe Symposium, NIGEC-GPRC 2002 Annual Meeting, Lincoln, Nebraska, May, 2002.

Carbon, Water and Land-Use in Conservation Reserve Program Lands of the Shortgrass Steppe Thomas Peterson, Niall Hanan, Jack Morgan, Jean Reeder, Indy Burke, and Keith Paustian, Shortgrass Steppe Symposium, Fort Collins, CO January 8, 2003.

Niall Hanan, Jack Morgan, Thomas Peterson, Jean Reader, Indy Burke and Keith Paustian, Carbon, Water and Land-Use in Conservation Reserve Program Lands of the Shortgrass Prairie, NIGEC-GPRC 2003 Annual Meeting, Lincoln, Nebraska, August 18, 2003.

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Niall Hanan, Thomas Peterson and Christopher Williams, Carbon, Water and Land Use in the Western Great Plains: Management Impacts on Local and Regional Biosphere-Atmosphere Interactions, Seventh International Carbon Dioxide Conference (ICDC7), Broomfield, Colorado, September 19-23, 2005.

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Hicke, J. A., "Integrated analysis of disturbance and recovery," Integration of disturbance ecology and biogeochemistry to predict future dynamics of terrestrial carbon cycle under global change, National Institute for Mathematical and Biological Synthesis Investigative Workshop, 13-15 February 2012, Knoxville, TN.

Hicke, J. A., A. J. Meddens*, S. L. Edburg*, E. P. Creeden*, H. K. Priesler, "Impacts of Western Bark Beetle Outbreaks on Carbon Cycling," Oak Ridge National Laboratory, Department of Energy, 16 February 2012, Oak Ridge, TN.

Hicke, J. A., A. J. Meddens*, and C. A. Ferguson, "Impacts of Bark Beetle Outbreaks in the Western US on Biogeochemical Cycling," American Geophysical Union Fall Meeting, 5-9 December 2011, San Francisco, CA.

Edburg, S.L., J.A. Hicke, D.M. Lawrence, P.E. Thornton, and A.J. Meddens. The Impact of Bark Beetle Outbreaks on Carbon Cycling in the Western US. The Land Model Working Group Meeting, March 2011, Boulder, CO, USA.

Edburg, S. L., J.A. Hicke, D.M. Lawrence, P.E. Thornton, and Arjan J.H. Meddens. Quantifying the impact of bark beetle outbreaks on carbon cycling in the western US from 1997 to 2009, North American Carbon Program, February 2011, New Orleans, LA, USA.

Hicke, J. A., C. D. Allen, A. R. Desai, M. C. Dietze, R. J. Hall, E. T. Hogg, D. M. Kashian, D. J. Moore, K. Raffa, R. Sturrock, J. Vogelmann, "The Impacts of Biotic Disturbances on Carbon Budgets of North American Forests," 3rd North American Carbon Program All-Investigators Meeting, 1-4 February 2011, New Orleans, LA.

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Edburg, S.L., A.J. Meddens, J.A. Hicke, B. Pettit, D.M. Lawrence, and P.E. Thornton. A Gridded Forest Insect Disturbance Data set derived from USDA Aerial Detection Surveys and its Application in the Community Land Model. 29th Conference on Agricultural and Forest Meteorology, August 2010, Keystone, CO, USA.
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Cheng, L., Y. Luo, L. Wu, Y. Deng, Y. Qin, J.V. Nostrand, Z. He, M.B. Leigh, E.A.G. Schuur, J. Tiedje, and J. Zhou. 2012. Experimental warming increases old carbon decomposition through shifting functional microbial communities in a tallgrass prairie. Abstract COS 41-10, 97th Annual Meeting, ESA, Portland, OR, 5-10 Aug.
Natali, S.M., E.A.G. Schuur, and E. Webb. 2012. Shifting carbon dynamics in a warmer world: Increasing respiration from frozen soils. Abstract OOS 4-8, 97th Annual Meeting, ESA, Portland, OR,

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Website(s) or other Internet site(s)

National website developed by WRC for submission purposes: http://www.niccr.nau.edu/

WRC NICCR website with link to full reports: http://www.climate.nau.edu

4. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS:

What individuals have worked on the project?

Name: Bruce Hungate
Project Role: Principal Investigator
Nearest person month worked: 1 month per year
Contribution to Project: Dr. Hungate supervised the project, taking the lead role in evaluating pre-proposals
Collaborated with individual in foreign country: No
Country(ies) of foreign collaborator: N/A
Travelled to foreign country: N/A
If traveled to foreign country(ies), duration of stay: N/A

Name: George Koch
Project Role: co-Principal Investigator
Nearest person month worked: 1 month per year
Contribution to Project: Dr. Koch participated in the proposal evaluations and web site development
Collaborated with individual in foreign country: No
Country(ies) of foreign collaborator: N/A
Travelled to foreign country: N/A
If traveled to foreign country(ies), duration of stay: N/A

Name: Sally Evans
Project Role: Grants & Contracts Administrator
Nearest person month worked: 6 months per year
Contribution to Project: Financial administration and oversight; overall project coordination
Collaborated with individual in foreign country: No
Country(ies) of foreign collaborator: N/A
Travelled to foreign country: N/A
If traveled to foreign country(ies), duration of stay: N/A

Name: Matthew Hurteau
Project Role: Post-Doctoral Research Associate
Nearest person month worked: 4 months per year for years 2 and 3
Contribution to Project: Dr. Hurteau developed the content for the web site, prepared outreach materials, and conducted primary research on one of the specific projects (land-cover change)
Collaborated with individual in foreign country: No
Country(ies) of foreign collaborator: N/A
Travelled to foreign country: N/A
If traveled to foreign country(ies), duration of stay: N/A
Name: Paul Dijkstra

Project Role: Post-Doctoral Research Associate
Nearest person month worked: 12 months total
Contribution to Project: Dr. Dijkstra conducted primary research on carbon cycle synthesis
Collaborated with individual in foreign country: No
Country(ies) of foreign collaborator: N/A
Travelled to foreign country: N/A
If traveled to foreign country(ies), duration of stay: N/A

Name: Paul Heinrich
Project Role: Data Manager
Nearest person month worked: 3 months per year
Contribution to Project: Mr. Heinrich developed the on-line submission system and the project website, www.nau.edu/niccr
Collaborated with individual in foreign country: No
Country(ies) of foreign collaborator: N/A
Travelled to foreign country: N/A
If traveled to foreign country(ies), duration of stay: N/A

What other organizations have been involved as partners?
Nothing to report

Have other collaborators or contacts been involved?
This project involved significant collaboration with the Office of Grants and Contract Services at Northern Arizona University in order to administer sub-contracts.

Name: Bobbie Ursin
Project Role: Grants & Contracts Administrator
Nearest person month worked: X months per year
Contribution to Project: Bobbie Ursin collaborated with NICCR-WRC in the administration of sub-contract awards supported by the project.
Funding Support: The State of Arizona
Collaborated with individual in foreign country: No
Country(ies) of foreign collaborator: N/A
Travelled to foreign country: N/A
If traveled to foreign country(ies), duration of stay: N/A

5. IMPACT:

What is the impact on the development of the principal discipline(s) of the project?
The project contributed new knowledge in the impacts of climate change on ecosystems of the western US, at scales from the cell to the leaf to the organism to the region. The project contributed to establishing new experimental infrastructure (e.g., the rain manipulation experiment in New Mexico, and the CO_2 and temperature manipulation experiment in Wyoming), new modeling activities (for example, the modeling effort describing the impacts of insect outbreaks on forest carbon balance), and new synthesis activities (for example, the meta-analyses published in 2011 and 2012 in Nature and Nature Climate Change). The particular disciplines that the project supported include Biological Sciences, Environmental Sciences, Atmospheric Sciences

What is the impact on other disciplines?
The specific impacts of the project were often strongest at the interfaces among core disciplines. For example, work supported by the project linked atmospheric and climatic change to insect population biology, and how changes in insects feed back to affect the atmosphere and climate. Similarly, work supported by this project showed that changes in atmospheric composition altered the microbial processes in the soil that produce and consume radiatively active greenhouse gases, which then change the composition of the atmosphere. In these ways, work advanced knowledge at the interface of core disciplines. Specific impacts from the individual projects are outlined in the attached reports from each sub-award.

What is the impact on the development of human resources?
The project provided opportunities for scientists to participate in research planning and development, to contribute to developing the research mission, and to administer grants. These are elements of the research enterprise with which scientists are often not involved, and thus the project provided unique opportunities and experiences for the project team. The net result of these experiences has been to increase the appreciation for and understanding of the synergy between research and research administration.

What is the impact on physical, institutional, and information resources that form infrastructure?
Specific projects funded by the NICCR WRC had impacts on physical and information resources, including new experimental infrastructure, new modeling platforms, and new databases. These are described in the individual project reports.

Abstracts from NICCR funded projects appear below:

David D. Breshears, The University Of Arizona

Determining vegetation responses to global-change-type drought extremes: will warming amplify tree die-off?

The patterns, causes and implications of drought- and heat-induced tree mortality was studied using approaches that included summaries of previous collected data and/or literature, modeling, and glasshouse and field experiments. Major findings for piñon pine (Pinus edulis) included that soil

moisture depletion resulted in protracted water stress prior to tree mortality; that mortality occurred more rapidly with warmer temperatures, in association with more rapid cumulative respiration; and that warmer temperatures alone, without complete precipitation exclusion, triggered more rapid mortality. Ecohydrological and biogeochemical variables in semiarid woodlands are largely influenced by tree presence, so tree die-off pervasively impacts most ecosystem goods and services of concern. The mortality results from the project experiment enable refinement of climate envelope that defines conditions specific to mortality. This project substantially advanced research on and visibility for drought- and heat-induced tree mortality.

Neil S. Cobb, Northern Arizona University

Collaborative Project: Regional Dynamic Vegetation Model for the Colorado Plateau: A Species-Specific Approach

The goal of this study is to develop predictive models reflecting the potential distributional responses of 32 regionally-dominant plant species to climate change and land use. We have compared several modern climate datasets, and found PRISM products provided the best accuracy and spatio-temporal resolution required for modeling. We ranked 21 AR4 IPCC General Circulation Model (GCM) A1B simulation results based on their ability to simulate the later 20th Century, 1950-2000 AD, precipitation seasonality, spatial patterns, and quantity in the western United States. Among the top ranked GCMs five were selected for downscaling to a 4 km grid. This resulted in downscaled GCM simulation results for the models commonly referred to as Ukmo_Hadgem1, Mpi_Echam5, Cnrm_Cm3, Csiro_mk3, and Ncar_Ccsm3. We have also developed two multi-model averages, one from 48 AR4 AIB GCM runs which has also been downscaled to a 4 km resolution, and one 5 GCM average of the top 5 ranked models in our intercomparison project. We have developed several programmatic tools for working these model results to summarize and calculated statistics from. We have assembled species location data representing species ranges and abundance across the study area. All the proposed species suitable climate models have been developed and with the testing of several model assumptions for their ability to alter predicted climate change impacts. Several additions and modifications have been made to the SIMPPLLE applications that will allow users to incorporate GCM simulation results into dynamic vegetation modeling. We have developed two atlases, one showing maps of species suitable climate models and predicted changes under seven climate change scenarios for three future time periods; 2010-2039, 2040-2069, and 2070-2099. The other atlas provides maps depicting the change in precipitation and temperature projected by the seven climate change scenarios. These atlases are nearing finalization for posting to the online project website and also will be served through a web mapping application.

Paul DeMott, Colorado State University

Investigation of Hygroscopicity and Cloud- and Ice- nucleating Activities of Combustion Aerosols

This work addresses the extent to which the carbonaceous particles generated by combustion of fossil and other fuels interact with water vapor and serve as nuclei for cloud formation in the atmosphere. These interactions with water are critically important for understanding the implications of altered burdens (more fuel or biomass combustion) or properties (modified fuel sources) of such particles on climate via directly scattering and absorbing light at different wavelengths, via affecting the numbers and sizes of cloud particles that also interact with radiation, and by impacting the lifetime of and

precipitating properties of clouds. The key objectives of this study are to utilize realistic combustion particles from burned fuels and biomass in a laboratory setting and to quantify their growth with increasing relative humidity, and their liquid and ice cloud activation abilities using specialized instruments. Results to date emphasize the critical link between particles already possessing or acquiring (through atmospheric processing) soluble chemical content and their subsequent water and cloud interactions, and their general lack of special properties for actively initiating ice formation in clouds. Integrated theories are being developed to simplify the prediction of particle growth with relative humidity, liquid and ice cloud formation properties of combustion-derived particles in relation to other atmospheric particles.

Janet Franklin, Arizona State University and Helen Regan, University of California-Riverside

Collaborative Project: Climate change impacts on a plant functional group in a biodiversity hotspot

The objective of this research project was to evaluation of the potential effects of urban growth, altered fire regime and distribution changes due to climate change on populations of key Plant Functional Types (PFTs) in Mediterranean-type Ecosystems (MTEs), focusing specifically on the biodiversity hotspot of the California Floristic Province.
We sought to determine how climate change projections add to the effects of existing threats, in specifically urban development and altered fire regime, to dominant PFTs, and if future climate change pose a larger risk to population persistence of dominant PFTs than these existing threats. We examined three major PFTs defined on the basis of their growth form and response to fire: fire-obligate seeding long-lived woody perennials shrubs and trees, resprouting shrubs and trees, and annuals.
We found that the projected impact of climate change on plant populations was more negative in many cases when based on population models (accounting for life history traits and vital rates) than on species distribution models (SDM). Linking these models resulted in forecasts that, for an important plant group that structures the region's terrestrial ecosystems, long-lived obligate seeders, there is a greater negative impact of increased fire frequency than of habitat loss due to climate change on abundance. Frequent fires are the most dominant driver of population decline for this plant functional type. For both resprouters and obligate seeders (but especially obligate seeders), seed dispersal (natural or assisted) is only effective at mitigating the effects of habitat loss (due to anthropogenic climate change) if the fire regime is optimal for the species.

Matt Germino, Idaho State University, Lisa Graumlich, University of Washington, Nathan Mantua, University of Washington

Collaborative Project: Climatic and Biotic Co-limitation of Conifer Establishment at Treelines: Addressing Uncertainty in Bio-climatic Model Forecasts of Forest Change

Changes in tree establishment at or beyond the geographic distribution of forest ecosystems are considered to be a bellwether for climate change impacts. Our objective was to assess tree establishment patterns as they relate to climate and weather, as well as biotic factors, at the upper and lower elevation limits of forest. Specifically, we aimed to inform bioclimate models of the dominant western conifers for establishment (in contrast to presence of adult trees) and for their biotic interactions with surrounding plants that might exacerbate or suppress climate responses. We evaluated tree establishment in response to historic climate variability across nine mountain ranges in the Western US (observational study), and in response to experimental climate treatments. Natural

seedling establishment patterns were episodic and although some climate relationships were identified at local scales, there were few climate-establishment patterns evident over the larger dataset. Instead, seedling establishment tended to relate strongly to background vegetation cover. Experimental climate manipulations revealed a strong positive biotic effect of herb cover on seedling establishment at upper treeline, and a strong negative effect at lower treeline. Climate responses were stronger at lower compared to upper treeline. Whereas our observational data did not reveal strong enough climate responses to generate bioclimate models, response functions were obtainable from the experimental studies, and they tended to reveal a different climate response for establishment than would be predicted for presence of adult trees. Biotic interactions and demographic stages that relate to forest boundary change and resilience to disturbance are factors that can likely help improve effectiveness of species distribution models in climate vulnerability assessments.

Alan Goldstein, University of California at Berkeley

Carbon exchange in a Ponderosa Pine Plantation: Strategies of Water Use, Seasonality of Plant Physiology, and the Impact of Aerosols on Photosynthesis

This research enhanced an existing AmeriFlux research site where the components of ecosystem carbon cycling and the processes controlling them are being studied in detail. A database on important new emerging processes of ecosystem carbon exchange was collected to complement ongoing measurement over time scales from minutes to years for comparison with other AmeriFlux and Fluxnet sites, particularly western US sites such as Wind River, Metolious and the Oak/Savana sites, and for testing biophysical ecosystem models. This study provided a unique and critical contribution to NICCR and DOE research goals to understand ecosystem exchange of carbon, ecological effects of environmental change, and to engage in the development and testing of models needed for integrated assessments. Since the beginning of the project, we provided new results concerning 1/ the effects of anthropogenic aerosols and dew formation on net ecosystem carbon exchange, 2/ the factors affecting photosynthetic parameters for different species, and how these seasonal changes affect the carbon balance of an ecosystem, 3/ the influences of recovery from clear-cut, climate variability, and thinning on interannual variations of the ecosystem carbon balance, 4/ the influences of photosynthesis and summer rain pulses on root dynamics and soil respiration, 5/ the difference in soil respiration with and without roots in a ponderosa pine ecosystem, 6/ the partitioning of forest carbon fluxes with overstory and understory eddy-covariance measurements, and 7/ what the towers don't see at night: nocturnal sap flow in trees and shrubs at AmeriFlux sites in California.

Niall Hanan, Colorado State University

Carbon, water and land-use in Conservation Reserve Program lands of the shortgrass prairie

We have been investigating how land management options in the Central Great Plains affect ecosystems function, carbon, water and energy exchange dynamics. We used both direct measurement and model studies to better understand the role of past and future land use on the productivity, water balance, and atmospheric dynamics of the Central Plains. Moderate grazing by cattle has relatively subtle effects on both carbon and water dynamics in these grasslands in the short term, but there is evidence that differences between grazed and ungrazed systems are accentuated in dry years during which grazing reduces growth and carbon uptake in the water-stressed grassland. Conversion of grassland to a wheat-millet rotation resulted in a large loss of carbon to the

atmosphere during conversion (~600 g m-2 CO2) that is only partially offset during subsequent crop growth. If all the CRP land in Colorado (~800,000 Ha) were transformed back to dryland agriculture the resulting loss in perennial grass biomass could release as much as 4.8 Tg CO2 to the atmosphere. We are implementing new physiological modules for the DayCent biogeochemical model to simulate hourly fluxes of carbon and water, to provide coupled growth, biochemical and biophysical models that will facilitate a more sophisticated regionalization of the point measurements.

Jeffrey Hicke, University of Idaho

Climate Change, Insect Outbreaks, and Carbon Fluxes: Using an Earth System Model to Study Interactions in the Western United States

Climate change has influenced insect outbreaks that have affected millions of ha of forests in North America in recent decades. In turn, outbreaks will influence future climate change through altered carbon (C) cycling between the atmosphere and biosphere. Climate is an important driver of outbreaks through temperature effects on insects as well as drought effects on host trees (e.g., Ayres and Lombardero 2000, Logan et al. 2003). Bark beetle outbreaks kill millions of ha of trees each year (USDA Forest Service 2006), yet despite this large extent, carbon cycle models have not included these disturbances in studies of regional carbon budgets. This gap contributes to incomplete estimates of carbon exchange between the terrestrial biosphere and the atmosphere and hence uncertainties in future forest C sequestration and subsequent climate change. Our long-term goal was an understanding of the interaction of climate and insect outbreaks. The overall objective of this research proposal was to quantify the role of outbreaks in forest carbon budgets in the recent past and in the future across the western US using an updated land surface component of the National Center for Atmospheric Research Earth system model (known as the Community Climate System Model, CCSM) and to predict how future climate change will affect insect disturbances and therefore carbon cycling. The central hypothesis of this work was that insect infestations cause significant impacts to regional forest carbon cycling in the western United States because of their large areal extent and tree-killing behavior, and that the strong influence of climate change on epidemics will modify future forest carbon cycling in these regions. The rationale for this research was that estimates of future ecosystem, carbon cycle, and climate dynamics do not include this widespread disturbance, and the addition of outbreaks to these studies will produce more complete estimates of current carbon sources and sinks and reduce uncertainty in future predictions of carbon budgets of the West. Furthermore, this project provided the infrastructure to allow an Earth system model to address future studies of other insect disturbances and of interactions among disturbances (e.g., wildfire and insect infestations). We addressed the overall objective and test the central hypothesis of this research with two specific questions:
Question 1. How did past outbreaks affect carbon exchange between the forest ecosystems of the western US and the atmosphere? Our hypothesis was that including the extensive outbreaks in the last 25 years in modeled carbon budget estimates will substantially reduce plant growth and increase decomposition compared with simulations that do not include insect disturbances, leading to an updated estimate of the carbon balance in this region. For this question, we included tree mortality from all insect species.
Question 2. How will projected climate change affect simulated outbreaks and therefore forest carbon budgets in the West? We will develop a prognostic model for the mountain pine beetle (Dendroctonus ponderosae Hopkins), associated with its major host, lodgepole pine (Pinus contorta var. latifolia Englem. Ex Wats). Among the insect species that affect forest health in the US, the mountain pine beetle is the best candidate for initial inclusion into a carbon cycle model because it affects the largest area and is the best studied. As a result, models of climate suitability and stand

susceptibility have been developed for mountain pine beetle in lodgepole pine. We hypothesize that including mountain pine beetle disturbances will result in a significant reduction in carbon storage in higher elevation western forest ecosystems as a result of more frequent outbreaks in the coming century, and increased storage at lower elevations following less frequent outbreaks in the future. We updated and used a state-of-the-art land/carbon cycle model (the Community Land Model) to address the above questions (Figure 1) because it 1) estimated spatially explicit forest characteristics (e.g., C stocks, stand and tree information) at fine spatial and temporal resolution (currently unavailable from observations); 2) provided information on the full carbon cycle (i.e., stocks and fluxes); and 3) permits predicting future effects based on climate change scenarios.

Janneke Hille Ris Lambers, Univeristy of Washington

The Heat is on: Forecasting range shifts of Pacific Northwest conifers with Cllimate Change

Global warming is predicted to have large impacts of biodiversity. A remaining question is whether species are able to keep up with rapid rates of warming by shifting their ranges upward or poleward. To estimate how several economically important western tree species will respond to warming forecast in the Pacific Northwest, the PI combined measurements of species performance (growth, mortality) with microclimate (temperature, snow duration) on Mt. Rainier National Park. Results help outline the complex effects of climate change on species distributions. First, competitive interactions can be more important that climatic constraints on some range limits; second, seed dispersal of most species may be too limited to colonize all newly available habitats, and finally, tree mortality is so slow it could take decades for trees to disappear once climate becomes unsuitable due to warming. The PI and her team is continuing to incorporate these complexities into better forecasting tools.

Bruce Hungate, Northern Arizona University and J.T. Randerson, University of California, Irvine

Climate Impacts of Land Cover Change in the Western U.S.

This project quantified carbon loss from wildfire in western forests and carbon losses from stands to which restoration treatments had been applied. Our main finding in this area from this work was that restoration thinning can promote carbon storage. The project also worked to develop frameworks to compare the biogeochmical and biophysical impacts of forests on climate. Here, we found that both are substantial and that better frameworks are needed before quantitative application is feasible.

Bruce Hungate, Northern Arizona University

Responses of carbon cycling, carbon content, and trace gas exchange to climatic forcing: a meta-analysis

This project estimated responses of ecosystem C content and trace gas exchange to climate and atmospheric change through meta-analysis, expanding current meta-analytic approaches to quantitatively estimate responses at ecosystem and larger scales. One major finding was that rising CO2 concentrations stimulate methane release from wetlands and nitrous oxide release from uplands, a positive feedback to atmospheric change and quantitatively significant impact on projected warming. Related, another finding was that rice agriculture is expected to become more greenhouse

gas intensive with expected changes in atmospheric CO2 and warming, such that more methane will be released per kilogram of rice produced. Finally, this project developed a new approach that blends meta-analysis and data assimilation, a way to generate parameter estimates from ecosystem models in a meta-analytic framework.

Daniel Kashian, Wayne State University

Carbon storage responses of subalpine forests to mountain pine beetle outbreaks under current and altered climate regimes in western North America

The potential for altered disturbance regimes on forested landscapes to affect the global carbon (C) budget is considerable, especially when feedbacks between disturbance-mediated C loss from ecosystems and climate change are likely. In addition to wildfires, insect outbreaks affect the distribution of live and dead biomass and rates of forest productivity and recovery, but few empirical data exist to quantify insect-mediated changes in C storage. I estimated C budgets of forests across the Greater Yellowstone Ecosystem (GYE) to examine short- and long-term changes in C storage following mountain pine beetle (MPB) outbreaks. I sampled stands at multiple times since they were initially attacked by MPB, and replicated those samples across stands that experienced 30-50% mortality and > 50% mortality. Aboveground biomass and coarse roots of trees were estimated using site-specific allometric equations, and C in dead wood, forest floor, fine roots, soil, and understory aboveground biomass were measured directly. All stands experiencing MPB-caused mortality exhibited a shift in C storage from live to dead biomass, but the magnitude of this shift varied with the severity of the outbreak. Given that most stands in the GYE are currently experiencing relatively low levels of mortality, MPB outbreaks in the area are likely to create only very short sources of C to the atmosphere (5 years), the longevity of which is limited by rapid recovery of forest productivity supported by the competitive release of surviving trees (by 15 years). Regional effects of insect outbreaks on forest C budgets may be more substantial and perhaps unprecedented.

Tom Kolb, Northern Arizona University

Does climate-change-associated drought predispose trees to insect attack?

The overall project objective is to understand the role of drought in resistance of piñon pine to insect attacks and to understand mechanisms of piñon pine mortality during severe drought. From an experiment that manipulated precipitation to large plots of mature piñon pine/juniper woodland we learned that 1-2 years of severe drought (half normal precipitation) predisposed piñon pine to bark beetle attacks and rapid tree mortality. The same drought stressed but did not kill juniper. Piñons that died had smaller resin ducts than trees that lived, suggesting a role of physical resin defense in tree resistance to beetles. A retrospective field study of piñon trees that died during the 2002 drought and trees that lived supports multiple mechanisms of tree death, including chronically low photosynthesis and resin defense, hydraulic failure, and bark beetle attacks.

Sonia M. Kreidenweis, Colorado State University

Laboratory measurements of aerosol scattering and extinction properties

The optical properties of particles dominated by carbonaceous species continue to be a major uncertainty in estimates of climate forcing. Carbonaceous particles, especially those derived from uncontrolled combustion sources, can generally both absorb and scatter visible and ultraviolet light.

This absorbing nature can completely alter the predicted climate effects – warming or cooling – of these particles. We have developed and applied state-of-the-art technology to measure the scattering and absorption properties of atmospherically-important carbon-containing aerosols. Our first application has examined the properties of smoke particles generated from the combustion of a large variety of wildland fuels from various regions of the U.S. Smoke optical properties vary widely, from nearly-white, non-absorbing smoke from smoldering duff and pine fires, to very black smoke, produced by combustion of western chapparal species. Our findings will be applied to improve estimates of the climate effects of prescribed and wild fires.

Kate Lajtha, Oregon State University

Differential effects of asymmetric versus symmetric warming on soil organic matter stability

To determine the effect of symmetric versus asymmetrically elevated temperature profiles on soil C dynamics in constructed grassland mesocosms. DOE funded a study on the "Effect of Asymmetric Versus Symmetric Warming on Grassland Mesocosms." Our project was funded to expand the focus of that grant to include the impact of asymmetric (ASYM) versus symmetric (SYM) warming patterns on SOM dynamics. Our central objective was to determine whether ASYM warming exacerbates or ameliorates SYM warming effects on SOM-C fractions, key soil enzyme activities, microbial community, and dissolved organic matter (DOM) as early indicators of changes in soil C stability.

Michael Loik, University of California, Santa Cruz

Climate Change Impacts on a Shrub – Forest Ecotone

This research is motivated by the importance of snow as a dominant form of precipitation for a large portion of arid and semi-arid regions of the western United States. Our objective is to experimentally test hypotheses linking snow depth, soil water, vegetation recruitment, and species composition driven by snow climate change. Experiments are being conducted at the ecotone between Great Basin Desert sagebrush steppe and Sierra Nevada conifer forest, near Mammoth Lakes, California. We utilize long-term (>50 yr) snow fences arrayed across the landscape to increase and decrease snow depth and compare responses to ambient-depth control plots. There were more seedlings on ambient and –snow plots than on +snow plots for Artemisia tridentata. Of naturally recruited seedlings of Purshia tridentata and A. tridentata, 58 to 86% survived one year. Recruitment for the conifers Pinus contorta and Pi. jeffreyi was highest under the canopy of the N-fixing shrub Pu. tridentata, and lower on +snow compared to ambient and –snow plots. Light and air temperature were higher in open, intershrub microsites compared to under the canopy of the two shrub species. Only one of 747 planted Pinus jeffreyi seedlings survived the first year, due largely to herbivory and drought. Results indicate that feedbacks from vegetation structure and function will be as important as soil moisture availability in shaping ecosystem responses to climate change at this widespread western U.S. vegetation ecotone

Jason Neff, University of Colorado at Boulder

The Role of Boreal and Arctic Soils in Climate Feedbacks; Model Development and Testing

Approximately one-third of world's carbon is stored in the northern high-latitude. Even a small perturbation on these carbon stocks could have significant impacts on the global climate if these soils are decomposed to CO2 or CH4 . This research project focused on the evaluation of the vulnerability of Alaskan soil organic carbon under the context of climate change. Using the inversion modeling techniques, mechanistic soil biophysical/biogeochemical models, along with the extensive links to the ongoing field research, our results indicated that 1) deeper soil carbon stocks are likely to be critically important to the future carbon dynamics, 2) wet sites with deep OC layers would experience larger proportional increases in soil temperature compared to the drier sites, and 3) movement of dissolved organic carbon was highly dependent on the component and structure of the OC layers. These results are significant since wet sites contain the vast majority of the carbon stores and represent a major potential feedback to 21st century climate change

Michael Notaro, University of Wisconsin, Madison

Ecosystem Response to Future Climate Change and the Impact of Vegetation Feedback in the Southwest United States

Using satellite data, observations, and a dynamic vegetation model, we studied the seasonal cycle of vegetation, soil moisture, climate, and evapotranspiration across the Southwest United States (SWUS). The bimodal seasonal cycle in vegetation greenness across eastern Arizona-western New Mexico is found to deviate from the traditional pulse-reserve paradigm and to be primarily driven by soil moisture patterns and the break in cold dormancy, rather than the preferred photosynthetic temperatures of C3 versus C4 species. We examined the expected response of SWUS vegetation to projected 21st century climate change using complementary tools of a dynamic vegetation model for plant functional types and a bioclimatic envelope model for species and biodiversity. We simulated dramatic declines in vegetation carbon, loss of high-elevation evergreen forests, general northward progression of tree species, and complex responses in plant species richness. Through ensemble experiments using a fully coupled global climate model, we investigated the impact of vegetation variability on climate across the North American monsoon region. Reduced vegetation cover fraction resulted in an increase in surface air temperature, a dampened hydrologic cycle in spring and autumn, and an earlier monsoon season over the SWUS.

Walter Oechel, San Diego State University

Controls on Carbon and Methane Flux Across a Complex Coastal Arctic Landscape

The objective of this project was to evaluate the ecosystem controls on CO,and methane (CH 4) flux of the Arctic coastal tundra of Alaska, focusing on the vegetated drained thaw lake basins (DTLB) which comprise a large proportion of the land surface in this area. We deployed portable meteorological towers to replicated age-sequences of these features, classified by a previous remote sensing study (Hinkel et al. 2003). Measurements included land-atmosphere fluxes of CO,and CH,in addition to supporting environmental variables. We found the controls on C02 and CH4 flux to be complex, but that the age classification of DTLBs yields useful information for constraining estimates of C02 and CH4 flux in this region. In general,young basins exhibited the largest C0 2

uptake which corresponded with higher plant biomass, higher nitrogen content, higher plant water content and lower litter. Average CH. emissions did not differ significantly among age classes, but the variability in emissions declined with
age. CH4 fluxes were largely controlled by soil moisture and the depth to frozen soil. Results from this project provide key information on spatial variability and controls of co, and CH4 fluxes to aid future
predictions of greenhouse gas emissions from the Arctic coastal tundra near Barrow using remotely sensed landscape classifications and flux modeling

Kiona Ogle, Arizona State University

Quantifying the importance of aboveground controls on soil carbon efflux in deserts of the Southwest

The goal of this project was to develop a better understanding of the factors that affect soil respiration (the loss of CO2 from the soil to the atmosphere). We synthesized existing data from previous field studies to develop models of soil respiration that incorporate aboveground influences and other important factors, such as past (antecedent) soil water availability and temperature conditions. For example, we found that soil respiration rates under desert shrubs were linked to shrub photosynthesis rates that occurred 4 days ago, reflecting potential delays in the transport of photosynthates (e.g., sugars) from the leaves to the roots (Barron-Gafford et al. in revision). We are extending this approach to understand the lagged relationship between photosynthesis and soil respiration across multiple deserts (Cable et al. in prep.). We developed a stochastic approach to accounting for the effects of antecedent conditions on soil respiration and other carbon cycle processes (Ogle et al. in prep); the application of this approach revealed that shrub encroachment changes the time scales over which soil moisture and temperature affect soil respiration (Cable et al. in press). This work is improving our ability to predict soil carbon fluxes, an important component of the global carbon cycle

Kiona Ogle, University of Wyoming

Synthesis of existing datasets to explore the implications of altered precipitation for carbon and water dynamics in desert ecosystems of the southwestern US

The objective of this study is to synthesize existing data related to carbon and water fluxes, spanning leaves to ecosystems, across four major deserts in the Southwest. The synthesis utilizes modern statistical methods that couple diverse data sources and mechanistic models. We had our first group meeting in November 2006, and we identified critical datasets and developed standardized protocols for compiling data. Personnel at each site are working to provide all relevant data by the end of August 2007. We have developed an MS Access database and have populated it with subsets of data from three sites, including the Jornada Basin (an additional site in the Chihuahuan desert). We are currently working on two projects that utilize these data: (1) exploring ecological “memory” where we are estimating lag, threshold, and acclimation responses of leaf- and ecosystem-level processes to changes in water availability across the four deserts, and (2) identifying which components of photosynthesis are most sensitive to changes in water availability, and how these components differ between plant species and deserts.

WT Pockman, University of New Mexico

Ecosystem consequences of precipitation variability and extremes in semiarid grassland and

shrubland

We studied the effect of the extremes of inter-annual precipitation variability (prolonged drought and extended periods of above average precipitation) and the effect of variation in annual precipitation regime. Grassland, shrubland and ecotone plots subjected to prolonged rainout exhibited large decreases in grass cover and no change in shrub cover (Baez et al. 2012). Grassland production and cover was restored within 4 years of the end of treatment.

Edward Schuur, University of Florida

During the next century, scientists predict the greatest degree of both climate warming and precipitation increase for boreal and arctic ecosystems. Our research objective was to address the possible effects of these climatic changes on the C cycling of boreal black spruce forests and arctic tundra. The study design involves making soil radiocarbon measurements along a regional temperature and precipitation gradient, and in an experimental manipulation of soil and air temperature, both in black spruce forests. Radiocarbon measurements allow for estimates of rates of soil C turnover and plant C allocation. We additionally maintained a warming experiment in tundra to address similar questions about ecosystem C balance response to warming. Here we extended our approach using radiocarbon to also include paired stable C isotope measurements. This dual isotope approach allowed for greater separation of plant and soil sources that contribute to total ecosystem C exchange. This tundra warming experiment was also paired with a study across a permafrost thaw gradient in tundra such that both the boreal and tundra studies included an experimental gradient, and a warming manipulation

Lloyd Stark, University of Nevada, Las Vegas

We sought to determine how the Mojave Desert biological soil crust (containing cyanobacteria, lichens, and mosses that are critical in nutrient cycling) responds to projected climate change that includes increased levels of summer precipitation, nitrogen deposition, and CO2. We measured changes in field cover, pigments, sugar and protein levels, regeneration, and responses to disturbance and desiccation by either making direct field measurements or controlled lab experiments. Major findings to date indicate that (i) lichen and moss cover was unaffected by projected climate change over the three-year period, with lichens more highly sensitive to local precipitation levels than previously thought; (ii) drought resistance of cyanobacteria was improved by summer precipitation and N amendments; (iii) the mosses are adversely affected by projected increases in summer monsoon frequency, exhibiting lower biomass, lower sexual function, and reduced cyanobacterial associations; (iv) mosses may down-regulate their growth responses when exposed to elevated levels of carbon dioxide; (v) recovery of protein synthesis in mosses (a measure of desiccation tolerance) was unaffected by CO2 level; and (vi) sucrose concentrations in mosses showed a tendency toward higher concentrations under elevated CO2 conditions, but not sufficiently enough to alter their desiccation tolerance capabilities.

Jeffrey K. Stone, Oregon State University

Factors influencing the distribution of a foliar fungal pathogen and its effect on carbon dioxide flux in multiple-aged Douglas-fir forests

We have been studying the effects of a native foliar fungal pathogen of Douglas-fir trees, Phaeocryptopus gaeumannii, on CO2 sequestration in coniferous forest canopies. We are examining

how host, pathogen, and climatic factors affect the distribution of the pathogen to better estimate future disease levels in response to climate change. Fruiting bodies of the pathogen emerge from and occlude stomata, thereby impeding gas exchange (i.e. photosynthesis) between the plant and the atmosphere. We have quantified the effect of this pathogen on photosynthetic rates in young and old trees, and through the development of fungal distribution models, a goal of the current research, we will be able to estimate the effect of this pathogen on regional carbon assimilation levels. This research is unique in documenting the role of a canopy microbe and pathogen on regional forest canopy CO2 dynamics.

David G. Williams, University of Wyoming

Direct and indirect effects of warming, elevated CO2 and non-native plant invasion on carbon and water cycling in semiarid grassland

Our work expanded on the Prairie Heating and CO2 Enrichment (PHACE) experiment in semiarid grassland of Wyoming. We evaluated the relative sensitivities of carbon and water cycles to elevated [CO2] and warming at the leaf and ecosystem scales, and examined how global change feedbacks on soil moisture influenced invasion of the non-native tap-rooted forb, Linaria dalmatica (Dalmatian toadflax).

What is the impact on technology transfer?
Nothing to report.

What dollar amount of the award's budget is being spent in foreign country(ies)?
No funding from the project was spent in foreign countries.

6. CHANGES/PROBLEMS:
Nothing to report

7. SPECIAL REPORTING REQUIREMENTS:
Nothing to report