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The Role of Land-Cover Change in the High Latitude Ecosystems: Implications for the Global Carbon Cycle
(Second Performance Period: 15 April 1998 - 14 February 2000)

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Statement of Proposed Research and Scope of Progress Report

The land cover of northern boreal regions is likely to change substantially during the next century because of disturbances related to climate change, fire, logging, and insects. Changes in land cover of high latitude regions may potentially affect the earth's climate system by influencing the global carbon cycle. In our proposal (LCLUC-0016) we proposed a study focused on Alaska to develop a prototype spatially explicit modeling framework capable of using satellite-derived data to estimate how changes in land cover cause changes in ecosystem carbon storage at high latitudes. Our strategy for this study involves four tasks: (1) development of spatially explicit contemporary land-cover data sets in Alaska; (2) development of transient spatially explicit land-cover data sets for the historical satellite record in Alaska; (3) development of a successional biogeochemical model; and (4) application of the modeling framework for estimating the consequences of land-cover change on terrestrial metabolism in retrospective, contemporary, and prognostic analyses. This report summarizes progress for the second performance period of the project (15 April 1998 - 14 February 2000). We focus separately on progress related to the spatial analysis of historical land cover change and on the development and application of the modeling framework. Additional details can be found on the project's web site (http://alces.sel.uaf.edu).

Progress on the spatial analysis of historical land cover change

The development of contemporary and historic land-cover data sets are needed to link with the modeling framework for understanding how these landscape changes influence the carbon budget of high latitude ecosystems. To investigate different types of disturbance, we are focusing the development of land-cover data sets on four regions of Alaska (see Figure ; also see http://www.lter.alaska.edu/~dverbyla/nasa/spatial.html#regions for more information): Tanana River Valley (fire and logging), Copper River Valley (insect infestation), North Slope (climate change), and Seward Peninsula (climate change). For each of these regions, we have identified and acquired a number of spatially explicit data sets and imagery that span the time period from the 1950's to the present (see progress report of April 1998). Important data sets and imagery acquired include (1) a GIS data set of fire polygons, (2) GIS data sets of insect infestation, logging, and tree inventory, (3) "contemporary" vegetation classifications funded by agencies, (4) aerial photography, and (5) MSS and TM imagery. An overview of our efforts in spatial database development can be found at the following website: http://www.lter.alaska.edu/~dverbyla/nasa/spatial.html.

To obtain spatially explicit data sets we met with a number of agencies to explain our project. The USGS Alaska Field Office of the EROS Data Center agreed to collaborate with us and help us acquire imagery and other data sets for Alaska. We also met with the Regional Office of the National Park Service (NPS) to indicate our interest in a project funded by the NPS to create a "contemporary" vegetation map of the Copper River Valley region based on TM imagery. This has led to the development of a no-cost proposal by McGuire and Verbyla to the NPS to share information between the NPS project and our LCLUC project. We also met with the Bureau of Land Management regional personnel, who agreed to share their "contemporary" vegetation maps based on TM imagery as well as their ground truth data. We also met with personnel of the Alaska Department of Natural Resources, who agreed to share GIS data sets of insect infestation, logging, and tree inventory with our project. Finally, Dr. Eric Kasischke, who is a principal investigator on another high latitude LCLUC project, has generously shared his GIS data set of fire timing and extent for Alaska. This data set, which has annual temporal resolution and approximately 1-km spatial resolution, was developed in collaboration with the Alaska Fire Service of the Bureau of Land Management.

We have classified vegetation for a number of TM scenes associated with the four regions of interest identified in Figure 1. Verbyla is coordinating the classification of the scenes for these regions (see http://www.lter.alaska.edu/~dverbyla/nasa/spatial.html#strategy for a description of the classification strategy). Land-cover change analyses based on these classifications constitute the Master's level thesis work of three graduate students on the project: Matt Macander for interior Alaska, Aaron Woods for the North Slope, and Cherie Silapaswan for the Seward Peninsula. Verbyla is conducting change detection analyses for the Copper River Basin, and has conducted theoretical studies concerning how false change detection is influenced by the grain size of the imagery and the number of vegetation classes in the classification (Figure 2). The initial exploration of this issue identified that bias can occur at any spatial scale, bias is more significant for more heterogeneous landscapes, false change detection can exceed real landscape change, and that subpixel co-registration may not solve the problem (Table 1). Verbyla is currently investigating whether false change detection can be minimized through the use of more ground control points in co-registration of imagery. See the following website for additional information: http://www.lter.alaska.edu/~dverbyla/change_detection/index.html. We anticipate submitting a paper on this investigation before the end of the project (see Verbyla et al. in preparation in Table 2).

Our change detection studies are most advanced for interior Alaska. We have compared the fire scar data base provided by Kasischke (Figure 3) and have found that the boundaries match quite well with contemporary TM imagery (Figure 4). Our fine-scale analyses of land cover change in interior Alaska are focused on the Rosie Creek burn, which occurred in 1983 and has been extensively studies by the Bonanza Creek Long Term Ecological Research (LTER) Program at the University of Alaska Fairbanks (Figure 5). Through use of airphoto mosaics before the burn, immediately after the burn, and a decade after the burn (see http://www.lter.alaska.edu/~dverbyla/nasa/airphotos/scanned_air_photos.html to view the airphoto mosaics), we have been able to analyze the relationship between pre-burn vegetation and fire severity on vegetation structure detected a decade after the burn (Figure 6; Table 3). We are currently evaluating how the use of TM imagery for defining these relationships compares with the analysis based on airphoto mosaics (Figure 7). We are currently preparing a paper on this subject (see Macander et al. in preparation-a in Table 2).

We have also been conducting research in collaboration with the Carbon Cycle Model Linkage Project (CCMLP) to investigate how data on the cropland establishment and abandonment influences global carbon dynamics. This required the development of a boolean data set of historical land-cover change at 0.5-degrees (latitude by longitude) from 1860 to 1992 that is tied down to the IGBP DISCover data set (see Ramankutty and Foley, 1998: *Global Biogeochemical Cycles* 12:667-685). This data set has been useful for (1) comparing the historical global carbon dynamics of four terrestrial biosphere models to global inversions of the terrestrial carbon dynamics (Figure 8), and (2) for comparing the simulations regional contributions of cropland establishment and abandonment to terrestrial source-sink activity (Figure 9) with regional analyses based on atmospheric inversions of the carbon cycle (Figure 10). The results of this collaboration are contributing to the Working Group I chapter on the carbon cycle in the Third Assessment Report of the Intergovernmental Panel on Climate Change. A paper describing this study is in preparation by McGuire and is planned for journal submission before the end of 1999 (see McGuire et al. in preparation-a in Table 2).

Progress on the development and application of the modeling framework

Our overall modeling framework focuses on how interactions among the function and structure of terrestrial ecosystems, which include the effects of physical properties of ecosystems and human activities, are both impacted and influence climate and disturbance dynamics in high latitude regions (Figure 11). We have focused on model development and applications in a number of parallel activities: (a) modeling the physical properties of high latitude ecosystems, (b) modeling interactions between physical properties and ecosystem function, (c) modeling the effects of disturbance on ecosystem function, (d) modeling the disturbance regime, and (e) modeling the effects of the disturbance regime on ecosystem structure and function.

Our activities in modeling the physical properties of high latitude ecosystems have focused on modeling permafrost dynamics. The dynamics of permafrost are important in high latitude regions for a number of reasons. First, the dynamics of permafrost influence the physical environment, ecosystem function, ecosystem structure, and the disturbance regime. Second, the effects of disturbance on permafrost dynamics influences the trajectory of vegetation dynamics after disturbance. Third, permafrost is warming in a number of high latitude regions. Fourth, areas of discontinuous permafrost, which is where high densities of human populations live in boreal regions, are vulnerable to melting. Finally, the thawing of permafrost has important impacts for humans living in high latitude regions. We have successfully scaled our permafrost model (Figure 12) to be driven by monthly inputs (Figure 13), which is compatible with the temporal resolution represented by the temporal compositing of satellite-derived drivers. See http://alces.sel.uaf.edu/physical.html for more information.

Our activities in modeling interactions between physical properties and ecosystem function have focused on coupling our permafrost model with the Terrestrial Ecosystem Model (TEM). We have successfully used this model to simulate both soil temperature (Figure 14) and carbon fluxes (Figure 15) for the old black spruce (OBS) stand of the northern study area (NSA) in the Boreal Ecosystem Atmosphere Study (BOREAS) (see http://alces.sel.uaf.edu/physprocess.html for more information). We are currently preparing a manuscript on this study (see Zhuang et al. in preparation-a in Table 2). We have joined the NASA-sponsored BOREAS follow-on activity as a no-cost project and are participating in the model comparisons being conducted among the carbon cycle models in the activity. There are two manuscripts currently be prepared on this model comparison (see Table 2 for Amthor et al. in preparation and Potter et al. in preparation).

Our activities in modeling the effects of fire disturbance on ecosystem function have focused on modeling the post-fire response of net primary production (NPP), heterotropic respiration (R_H), and net biome production (NBP) (see Figures 16 and 17). We have conducted simulations for a chronosequence of stands in interior Alaska in which recent burned stands were paired with unburned control stands. The patterns of simulated carbon fluxes and storage in 1997 (Figures 18 and 19) are qualitatively similar to patterns observed in the field (Figures 20 and 21); see http://alces.sel.uaf.edu/ecodist.html for more information. We are currently preparing a manuscript on this study (Zhuang et al. in preparation-b in Table 2). We have also developed a protocol for taking 1-km data on fire disturbance to identify cohorts with unique trajectories of fire disturbance and vegetation dynamics across the period of interest (Figure 22). This protocol will allow us to extend our simulations with 1-km data from MODIS and other sensors on fire disturbance and vegetation dynamics. We have applied this protocol based on the state-wide fire scar database from 1950 through 1995 and have conducted state-wide simulations to evaluate the potential sensitivity of annual state-wide net carbon flux to different assumptions about how fire severity affects the release of vegetation and soil carbon (Figures 23 and 24); see http://alces.sel.uaf.edu/ecodist.html for more information. These simulations of fire emissions (Figure 25) and net carbon flux (Figure 26) allow us to compare the temporal and spatial patterns of these carbon fluxes to estimates of fire emissions and net carbon flux estimated from atmospherically based data. We are currently preparing a paper on this comparison (see McGuire et al. in preparation-b in Table 2).

Our activities in modeling the disturbance regime have focused on analyzing the historical spatial and temporal variability of fire in Alaska, developing simple models that relate state-wide area burned to climate, and analyzing how fire history affects the fire regime (see http://alces.sel.uaf.edu/distregime.html for more information). Our analysis of the historical and temporal variability of fire in Alaska indicate that a substantial proportion of the landscape that burns in a decade is burned during the maximum fire year (Figure 27). A simple logistic regression model indicates that fire is more likely to occur in years with low spring snowpack and warm summers (Figure 28). Our analysis of fire history also indicates that in comparison to cohorts that have burned in recent decades, the probability of fire is more likely in stands that have not burned in recent decades (Figure 29). We are currently preparing a paper on this comparison (see Macander et al. in preparation-b in Table 2). We are also analyzing the role of thunderstorm activity to develop models for the probability of ignition (see http://www.lter.alaska.edu/~dverbyla/dorte.html for more details). We are currently preparing a manuscript on this activity (see Dissing and Verbyla, in preparation in Table 2).

Our activities in modeling the effects of the disturbance regime on ecosystem structure and function focus on a model coupling between the Alaska Frame Based Ecosystem Code (ALFRESCO) and TEM to simulate historical and projected changes in the fire regime, vegetation dynamics, and carbon dynamics for the Seward Peninsula of Alaska (Figure 30). ALFRESCO (see Starfield and Chapin 1996: *Ecological Applications* 6:842-864; also see Rupp et al. in press and Rupp et al. submitted in Table 2) operates on a landscape of 2 X 2 km grid cells with a time step of 10 years. Each cell can, at any time step, be in one of four ecosystem types (or "frames"): upland tundra, white spruce forest, broad-leaved deciduous forest, and dry grassland (Figure 31). Model inputs include maps of the initial ecosystem distribution, growing-season temperature and precipitation, topography (elevation), and herbivore density (probability of moose herbivory). Across the historical period of our simulation, the simulated area burned similar to the observed area burned (Table 3). We have applied ALFRESCO to simulate historical and projected fire disturbance and vegetation dynamics from 1950 to 2100 (Figure 32). See http://alces.sel.uaf.edu/alfresco.html for more details. We are currently using the outputs of ALFRESCO as inputs to TEM for simulating carbon dynamics across the time period. We plan two manuscripts on this activity (see Rupp et al. in preparation and McGuire et al. in preparation-c in Table 2).