Final Report – Project 05-2-1-07

Post-Fire Studies Supporting Computer-Assisted Management of Fire and Fuels During a Regime of Changing Climate in the Alaskan Boreal Forest

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Abstract

Our research goal is to provide a scale-integrative planning and monitoring tool for wildland fuels and fire management that is specifically tailored to Alaska's ecological conditions and that addresses particular threats (notably climate change) to its natural fire regimes. To accomplish this, we analyze the processes that determine burn severity in the boreal forest and quantify the impacts of climate change on fire regimes and forest age structures. These results are used to further develop the Boreal ALFRESCO computer model and extend the technology transfer process initiated by our previous JFSP project (01-1-1-02).

The modeling component of the study first simulated historic fire data based on an empirically derived relationship between climate and fire, and linked those simulated historic fires with the actual recorded fire perimeters for the same period. These "ground-truth-tested" historical simulation results were then applied to the five best performing predicted climate models for Alaska used by the Intergovernmental Panel on Climate Change, as well as to a sixth model scenario that represents a composite of the previous five. These models have been downscaled from a global scale to one covering Alaska at 2km resolution using a well established technique that incorporates elevation to refine the local models.

We currently hold the most confidence in the simulation results for the interior region of Alaska. It should be noted that the predictions included in this study become less certain as we look farther into the future, and that it isn't possible, using this data, to simulate either the exact location of future fire occurrence or vegetation type.

In general, we expect climate change to result in substantial increases in landscape flammability during the coming century. Although precipitation is expected to increase during this time period as well, that increase is not likely to be sufficient to counter the increased evaporation and general drying resulting from projected higher temperatures. Preliminary results from statewide simulations identify consistent trends in projected future fire activity and vegetation response. The simulation results strongly suggest that boreal forest vegetation will change dramatically from the spruce dominated landscapes of the last century. In the wake of this fire activity, we predict that deciduous vegetation will become increasingly dominant on the landscape. This transition results from the intersection between an aging forest containing large numbers of flammable stands and rapidly warming climate that is triggering nonlinear responses in both area burned and forest succession. If boreal forests in other parts of the world cross similar ecological thresholds, together they could have globally significant effects on trace-gas emissions and radiation budgets.

Background and Purpose

Alaska's boreal forest differs in several fundamental ways from forest types in the lower 48 states. It covers a large contiguous area, most of which is still in a pristine state, and it occurs in a region of marked climatic instability. The burnable acreage in Alaska exceeds the combined areas of the states of Montana and Idaho. Although the Alaskan boreal forest makes up a significant fraction of fire-prone ecosystems in the United States, there is much we do not understand about its fire ecology. While there are several hundred studies of fire history in the intermountain West, there are only five in Alaska. Direct human impacts like logging and land clearing are relatively unimportant in Alaska, but the indirect impacts of anthropogenic climate change are of immediate concern there. Climate models indicate that high latitude regions like Alaska will be the first to experience global warming. Climate-induced changes to Alaska's fire regimes could provide important lessons for managers working in other regions. The unique qualities of the Alaskan boreal forest and our relative ignorance about it pose special challenges for the design and implementation of landscape-level fire and fuels management.

The design of this project evolved through discussions and workshops with Alaskan land managers. Managers and administrators indicated four priority needs:

1) Empirical data describing the effects of stand age, vegetation type, and weather/climate on burn severity in the Alaskan boreal forest.
2) Predictions about how future changes in climate will affect the natural fire regime.
3) Methods and assistance for adapting FRCC to the unique conditions of Alaska's forests.
4) Modeling tools for exploring different scenarios of fire-management strategy, climate change, and human population growth across multiple scales of space and time.

We address these needs by a combined field and modeling approach. New field data describes the relative importance of climate, vegetation type, and stand age in determining burn severity during the extreme 2004 fire season in Alaska. This data was used to further develop the Boreal ALFRESCO model, which is a spatially explicit, frame-based model capable of integrating climate-change scenarios within simulations of fire-vegetation interactions across time scales of years to centuries and spatial scales of hectares to 1000s of square kilometers (Rupp et al., 2000, 2004). The modeling component of this project provides land managers with the ability to simulate the response of future fire regimes to a changing climate. These model simulations also inform potential natural vegetation groups (PNVGs) and estimates of fire return intervals required for FRCC mapping. These combined capabilities will enable Boreal ALFRESCO to simulate the impacts of climate change including informing the FRCC process –novel capabilities that have important ramifications for long-term forest and fire management.

Study Description and Location

<u>*Field Component*</u>
We sampled burn severity at 392 plots from 10 different fires (Figure 1) distributed across interior Alaska. We restricted our sampling to large burned areas (>40,000 ac).

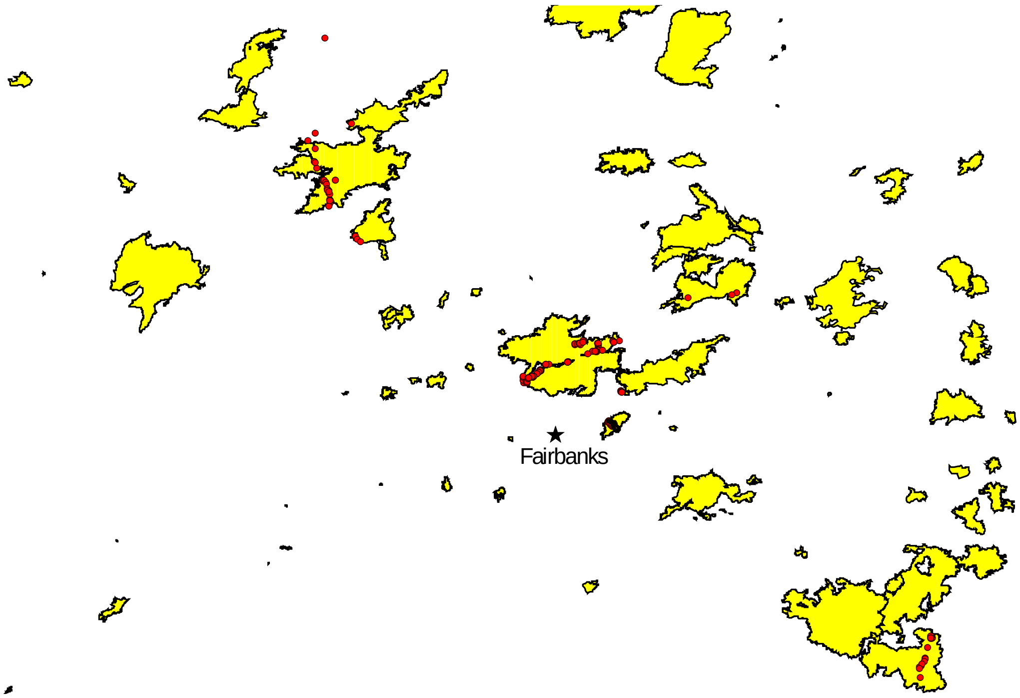

Figure 1 – Map of study plot locations in the vicinity of Fairbanks, Alaska. Yellow polygons identify 2004 fire perimeters and red dots indicate plots.

Plots were established randomly along transects with a minimum of 300 m between plots. In each plot we felled two co-dominant trees and retrieved cross-section samples at the root collar. In the laboratory, cross sections were sanded, cross-dated, and their rings counted under a dissecting microscope. Also, at each plot burn severity was quantified using Composite Burn Index (CBI) methodology (Key and Benson 2002). CBI is designed to define burn severity ecologically, and measure ground effects which collectively provide a signal detected at moderate resolution by the Landsat Thematic Mapper (TM). Average conditions of the community are evaluated ocularly by vegetative strata within 30 m radius plots. Attributes are rated by criteria that correspond to identified burn levels along a gradient from unburned to extremely burned conditions. The criteria scale considers not only specific physical properties, but also the distribution of traits within plots. Attribute scores then are segregated hierarchically by strata and averaged into understory, overstory, and overall composite ratings. In addition, we measured the thickness of the pre- and post-fire organic horizon in plots located in two of the burns. Adventitious roots of burned black spruce trees within our study plots were used to provide an estimate of prefire organic layer depths in sites where we judged severe burns had occurred. We measured the distance between the base of the rooting zone to the uppermost adventitious roots following Kasischke and Johnstone (2005). We also measured the depth of the remaining organic horizon to mineral soil.

Modeling Component

The model simulation design provides for a statewide (Figure 2) analysis of historical fire activity by (1) simulating historic fires (1860-2007) based on an empirically derived relationship between climate and fire (Duffy et al. 2005), and (2) linking simulated historic fires (1860-1949), based on the empirical climate-fire relationship, with known fire perimeters (1950-2007; http://agdc.usgs.gov/data/blm/fire/index.html). The historical simulation results were then applied to a suite of 6 future climate scenarios (2008-2099) and one emission scenarios (A1B; see IPCC 2007).

In all simulations historic climate (1860-2002) was generated using spatially explicit input data from the Climate Research Unit (CRU; http://www.cru.uea.ac.uk/) and the Potsdam Institute for Climate Impact Research (PICIR). The PICAR dataset is a modified version of that presented in Leemans and Cramer (1991). The modification is presented in McGuire et al. (2001).

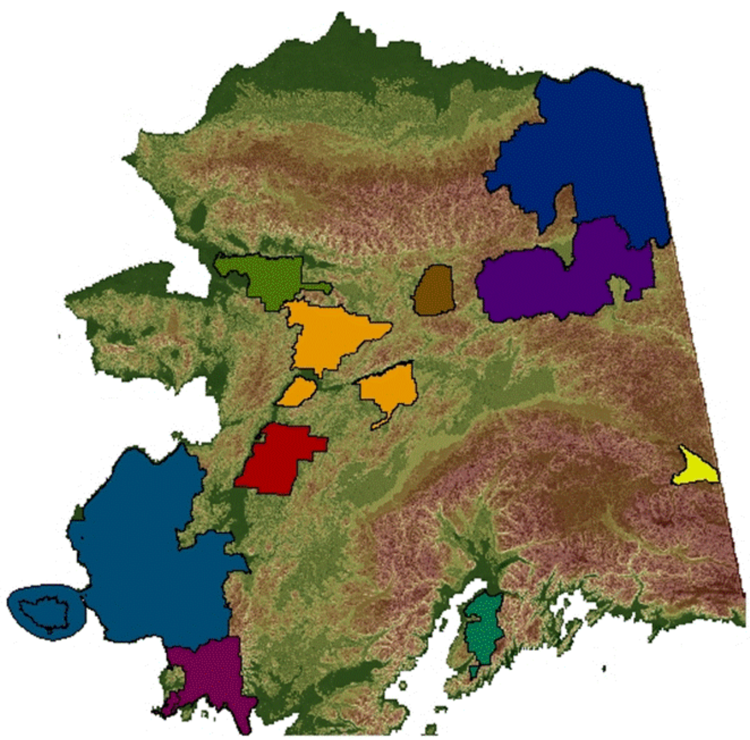

Figure 2 – Statewide simulation domain with FWS collaborator's refuge boundaries identified (colored polygons).

Results and Key Findings

Age- and Stand-dependent Flammability

Three components of forest flammability were assessed using the stand aged data collected from 2004 fires: stand-age dependent flammability; abiotic and biotic stand characteristics; and climatic controls. The specific objective of this research component was to first identify whether or not a relationship between stand age (an easily measurable index) and fire severity exists, and secondly to further our understanding of other potential biotic (e.g., forest structure and type) and abiotic (e.g., slope and aspect) controls over fire severity.

We found a statistically significant, negative relationship between stand age and the understory CBI fire severity rating across all 10 burns (P-value = 0.0091), but no model prediction power (Adj. $R^2 = 0.02$; Figure 3). The relationship between stand age and the overstory CBI fire severity rating was not significant and showed no trend. None of the environmental covariates (slope, aspect, elevation) were statistically significant with either understory or overstory CBI rating. However, timing (early-season versus late-season) of the burn was significant (P-value = 0.002053) between two of the fires (the early-season Boundary fire and late-season Granite Tors fire) and marginally improved the model fit (Adj. $R^2 = 0.1007$; Figure 4).

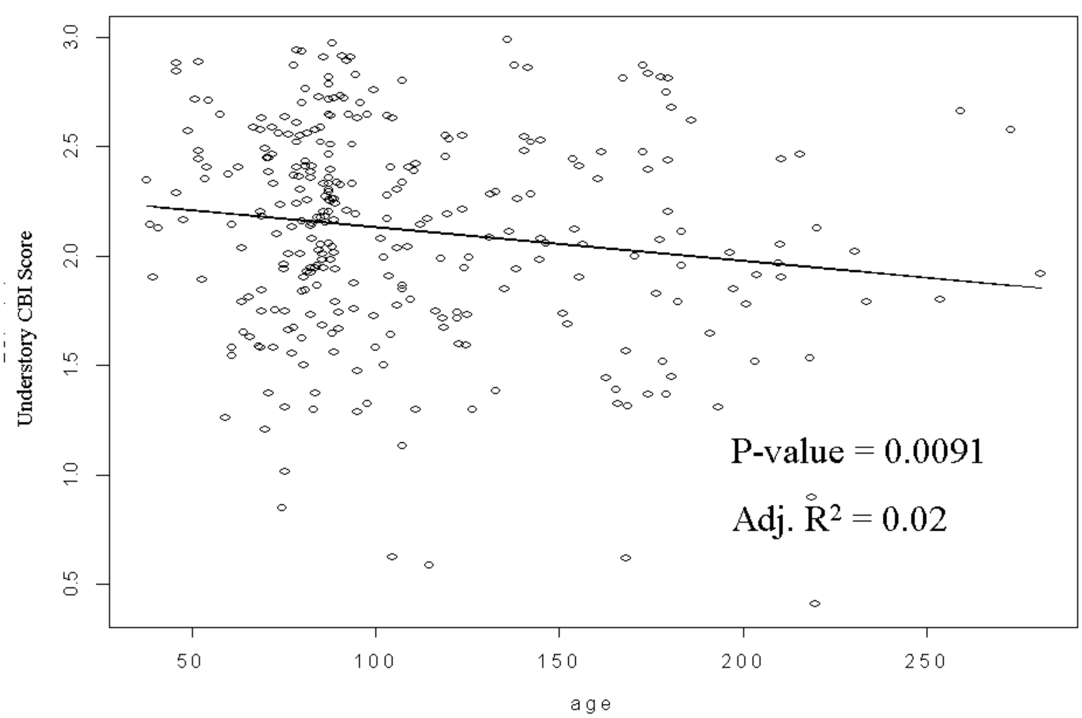

Figure 3 – Relationship between understory CBI burn severity score and stand age.

These results are consistent with those of other examinations of burn severity to both CBI and Normalized Burn Ratio using data from Interior fires in Alaska (Kasischke et al. 2008, Murphy et al. 2008, Verbyla 2008), though they differ from Allen and Sorbel

(2008) who documented significant relationships between CBI and differenced NBR on fires from the less extreme fire seasons in 2001-2003.

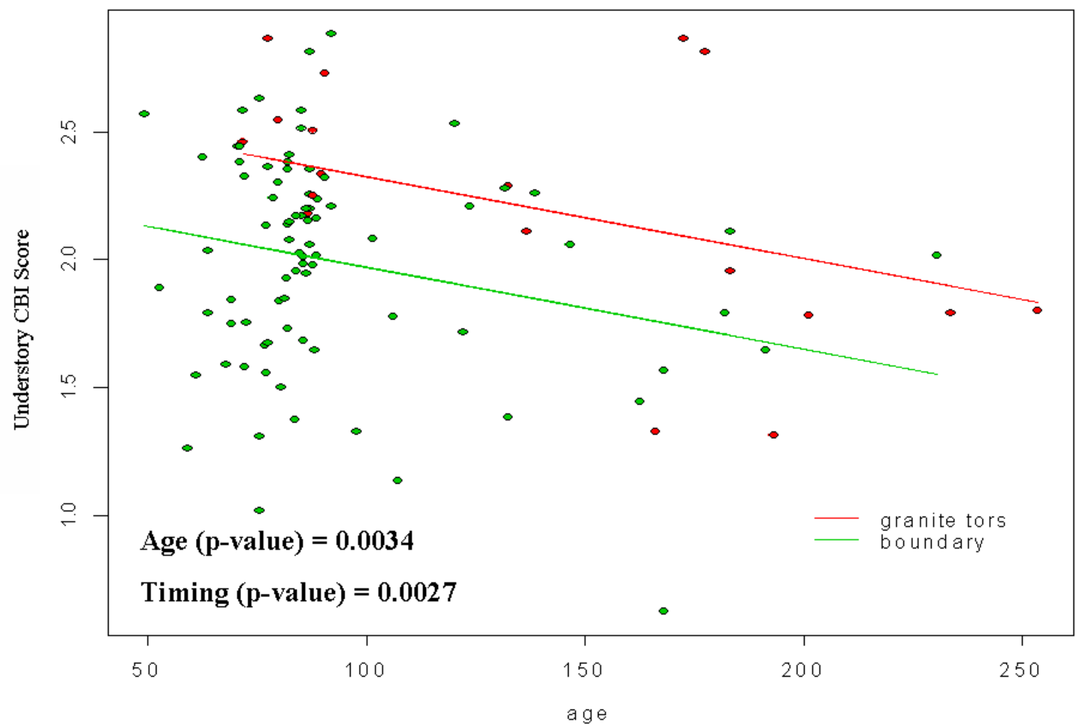

Figure 4 – Relationship between understory CBI burn severity score, stand age, and timing of burn. Boundary fire (green) represents an early-season burn and Granite Tors fire (red) represents a late-season burn.

<u>*Predicting the Impact of Future Climate Changes*</u>

Results from statewide simulations identify consistent trends in projected future fire activity and vegetation response. The simulation results strongly suggest that boreal forest vegetation will change dramatically from the spruce dominated landscapes of the last century. Although individual simulations identify a range of potential responses between the different climate scenarios, all model results show a shift in landscape dominance from conifer to deciduous vegetation within the next 50 years.

The ALFRESCO model simulations suggest a general increase in fire activity through the end of this century (2099) in response to projected warming temperatures and less available moisture. Changes in the projected cumulative area burned suggest the next 20-30 years will experience the most rapid change in fire activity and the associated changes in vegetation dynamics. Future fire activity suggests more frequent large fire seasons and a decrease in magnitude and periodicity of small fire seasons.

Increased deciduous dominance on the landscape will contribute to a probable change in the patch dynamics between vegetation types and age. The large regions of mature unburned spruce will likely be replaced by a more patchy distribution of deciduous forests and younger stages of spruce. The simulation results suggest that this change will occur over the next few decades, in response to simulated increases in fire activity, and will then reach an equilibrium stage where the patch dynamics may self-perpetuate for many decades if not centuries. In spite of the shift towards less flammable age classes and towards deciduous species, the simulation results indicate that there will be more frequent fires burning; resulting in an overall increase in acres burned annually. These two results appear to drive the simulated change in landscape dynamics where increased landscape flammability, driven by climate change, modifies landscape-level vegetation (i.e., fuels) distribution and pattern, which in turn feeds back to future fire activity by reducing vegetation patch size (i.e., fuel continuity).

New Developments in the Boreal ALFRESCO Model

Several improvements have been made to the Boreal ALFRESCO model that have improved the ability of the model to predict changes in fire regimes, stand age and vegetation under different climate scenarios.

Downscaled historical and future projection data: The simulation design for this project utilizes climate observations and projections that have been assessed and downscaled by the UA Scenarios Network for Alaska Planning (SNAP; www.snap.uaf.edu).

Incorporation of monthly data: Boreal Alfresco now runs on monthly time steps which help capture seasonal variation. The model was driven by spatially explicit datasets of observed and projected monthly temperature and precipitation – March through June monthly average temperature and June and July total precipitation. Based on future projections we expect climatic effects alone to result in substantial increases (as much as 50%) in landscape flammability across climate scenarios

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By calibrating the model to provide a robust simulation of the known stand age distribution across the landscape we identified strong relationships between climate and annual area burned that could be used to create a reference condition landscape for Alaska. This reference condition landscape illustrates how the boreal forest structure could look without the influence of human activity.

Incorporation of NLCD data: The new National Land Cover Database (NLCD) map for Alaska (2001) represented the first seamless existing land cover data set at a 30 m x 30 m resolution for Alaska since a 1 km x 1 km resolution classification was derived from the Alaska Very High Resolution Radiometer (AVHRR) data (1990)**.** By using the NLCD data, we created a new 1 km resolution vegetation grid for Alaska. The finer resolution NLCD data, improved the ability to identify pixels with patchy pockets of vegetation types and assign them to their appropriate ALFRESCO vegetation category based on the majority of the pixels within the 1 km square. For example, using AVHRR areas of woodland black spruce were misclassified as tundra but could be reclassified as black spruce in the new revised vegetation layer.

The revised NLCD data layer also was used to corroborate the modeling results that indicate that the boreal forest is shifting from a spruce-dominated landscape to a deciduous-dominated landscape.

Our U.S. Fish and Wildlife Service stakeholders requested that we attempt to run Boreal ALFRESCO at a 30 meter resolution since that is a typical resolution for refuge landscape management. Although detailed outputs and analyses were not completed, we were able to run the Kanuti National Wildlife Refuge simulation area using a 30 meter resolution landscape. These output values were used to provide a reference landscape as FWS worked to develop an FRCC assessment for the refuge.

ALFRESCO simulated fire regimes and VDDT: We performed some preliminary comparisons between reference conditions simulated by VDDT and conditions simulated by ALFRESCO. We used ALFRESCO to explore regional differences in simulated fire regime across interior Alaska (where > 97% of total area burned in Alaska occurs). We defined four distinct subregions (Figure 5) and then based on historical reconstruction simulations for the period 1900-2000 quantified the probability of burning across subregions (Figure 6). Preliminary simulation results suggest as much as a 4-fold difference in average burn probability between regions, which based on prior research is primarily a function of differences in regional climate and vegetation distribution. These results warrant the possible exploration and development of additional regionally specific PNVG models.

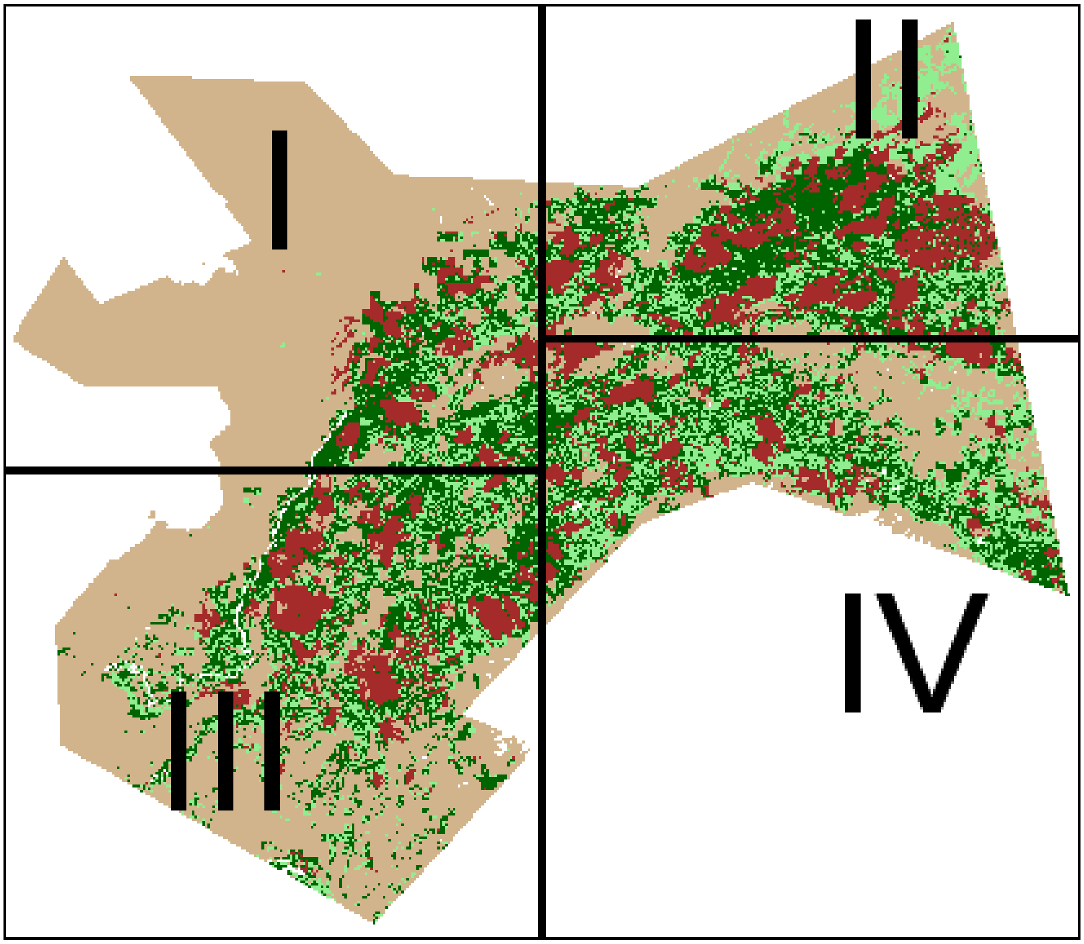

Figure 5. Map of interior Alaska showing four subregions and associated vegetation distribution (lt. brown = tundra; dk. Brown = early successional deciduous; lt. green = white spruce; dk. green = black spruce).

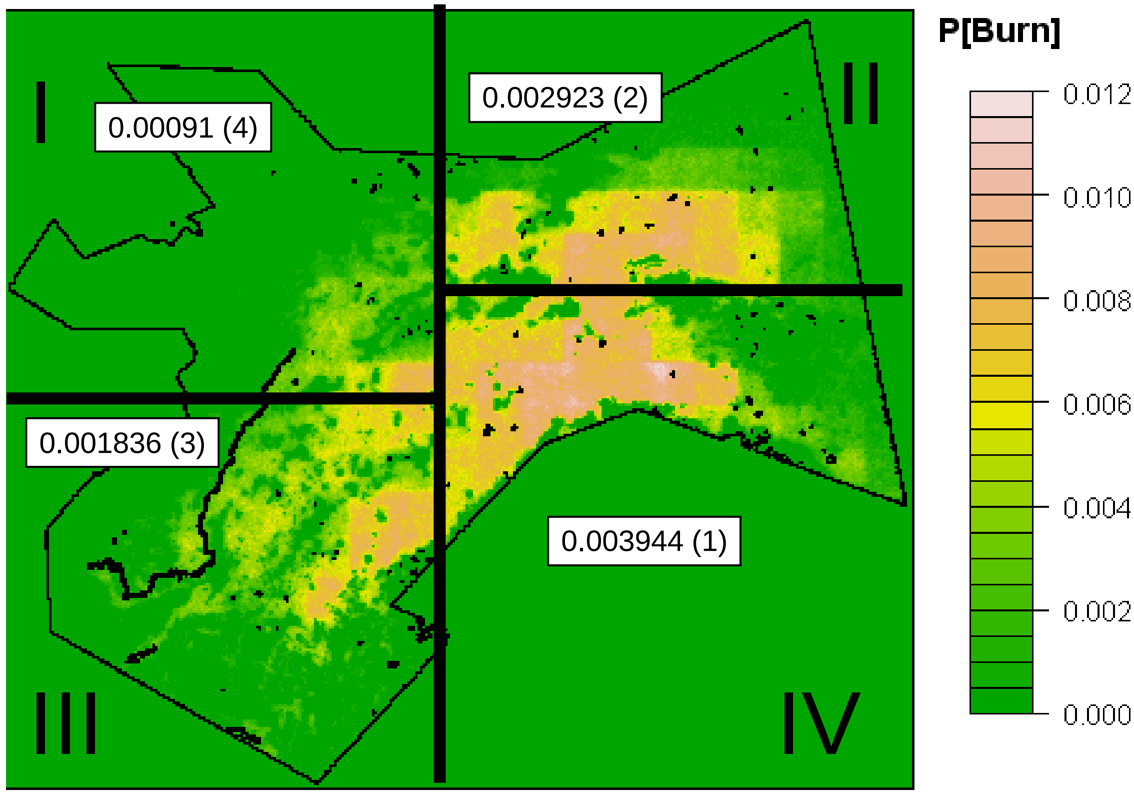

Figure 6. Map indicating average regional burn probability across all species across 100 replicates. An integrated regional probability is indicated in the boxes and rank is indicated in parentheses.

We then compared VDDT's simulated reference conditions to ALFRESCO's simulated reference conditions by subregion. We identified small differences in estimated reference conditions by ALFRESCO except for black spruce in region IV – the region with the highest probabilities of burning. We also provided preliminary estimates of future (2099) reference conditions in response to different IPCC climate models and emissions scenarios. In all cases the differences between VDDT and ALFRESCO were substantial. These results further suggest a closer look at VDDT model parameterizations is warranted. We must note that ALFRESCO is simply another model and its results are subject to further investigation as well. We should also point out that ALFRESCO is based on significant empirical relationships and has been thoroughly tested and analyzed in Alaska over the past 7 years. There are other fundamental differences between VDDT and ALFRESCO that are likely responsible for much of the differences identified in the comparison – primary among them are ALFRESCO's explicit incorporation of climate and the spatially explicit nature of the vegetation dynamics (e.g., complex spatial relationships between available fuels, realized climate, and ignition source).

Management Implications

The ALFRESCO model simulations suggest a general increase in fire activity through the end of this century (2099) in response to projected warming temperatures and less available moisture. Changes in the projected cumulative area burned suggest the next 20-30 years will experience the most rapid change in fire activity and the associated changes in vegetation dynamics. Future fire activity suggests more frequent large fire seasons and a decrease in magnitude and periodicity of small fire seasons. Large differences do exist among climate scenarios providing multiple possible futures that must be considered within the context of land and natural resource management.

Increased deciduous dominance on the landscape will contribute to a probable change in the patch dynamics between vegetation types and age. The large regions of mature unburned spruce will likely be replaced by a more patchy distribution of deciduous forests and younger stages of spruce. The simulation results suggest that this change will occur over the next few decades, in response to simulated increases in fire activity, and will then reach an equilibrium stage where the patch dynamics may self-perpetuate for many decades if not centuries. In spite of the shift towards less flammable age classes and towards deciduous species, the simulation results indicate that there will be more frequent fires burning; resulting in an overall increase in acres burned annually. These two results appear to drive the simulated change in landscape dynamics where increased landscape flammability, driven by climate change, modifies landscape-level vegetation (i.e., fuels) distribution and pattern, which in turn feeds back to future fire activity by reducing vegetation patch size (i.e., fuel continuity).

Decisions made by fire and land managers during this current period of rapid change, will influence the structure and pattern of vegetation across the boreal forest in Alaska. Fire managers should consider how land management objectives may be affected by the predicted changes to natural fire on the landscape. The Boreal ALFRESCO model can be used to simulate how changes in fire management may change the potential future landscape, it can also be used to assess how particular vegetation age classes (i.e., deciduous forest 10-30 years old) that may represent habitat conditions for important wildlife resources may be affected by the fire, vegetation and climate interactions predicted into the future.

Recent Findings and Ongoing Work

We have conducted simulations over Interior Alaska with both Boreal ALFRESCO and a biogeochemistry model,TEM (Terrestrial Ecosystem Model ; UAF colleagues McGuire and Euschkirchen) using several scenarios of climate change in the 21st Century. We have coupled the output of fire disturbance from ALFRESCO to drive TEM in order to evaluate the sensitivity of carbon dynamics to fire disturbance simulated by ALFRESCO. We have also used the results of these simulations to evaluate how changes in forest composition associated with fire disturbance may influence summer surface energy exchange of Interior Alaska during the 21st Century. We are currently integrating the effects of how changes in snow cover influence surface energy exchange at the shoulder seasons with the effects of how changes in forest composition influence surface energy exchange during the summer.

Future Work

This project and our previous JFSP project have developed a modeling framework and collaborative network between UAF and the fire management community that has acted as a catalyst to leverage additional research project, ideas and collaborations. There are several areas of future work we hope to pursue through a variety of funding sources. These research areas focus on (1) ecosystem feedbacks to the climate system, (2) dynamic coupling of disturbance-succession processes (ALFRESCO) and biogeochemistry (TEM), and (3) decision support tools for federal and state agency use related to understanding and planning for climate change and associated changes to ecosystems and disturbance regimes.

Deliverables

We have provided all deliverables identified in our proposal to our cooperators (see table below). These include: (1) GIS data layers and associated spreadsheets for all field data related to burn severity; (2) preliminary report of analysis of burn severity data including multiple working meetings between cooperator and listed collaborators; (3) annual cooperator and collaborator meetings to present project results and obtain feedback; (4) annual reports to JFSP; (5) VDTT parameterization and associated FRCC information transfer with cooperator and collaborators; (6) held small tech transfer workshops to test ALFRESCO software and receive feedback; (7) two multiple-day tech transfer workshops (Anchorage in February 2008 and Fairbanks in March 2008) to introduce managers to ALFRESCO software including software and dataset transfer; (8) submitted a high-profile manuscript to the journal Nature (currently in review; see manuscript section below); (9) submitted and published several additional manuscripts to peer-reviewed journals (see manuscript section below); and (10) summarized our research project, findings, and deliverables in this final report.

Tech transfer activities include the completion and update of a web-supported hosting (see www.snap.uaf.edu/downloads/boreal-alfresco and www.snap.uaf.edu/downloads/datasets-boreal-alfresco) of the ALFRESCO software and associated datasets.

Deliverable	Description	Delivery Date
Study Sites Map	GIS data layer identifying plot locations, burn perimeters, etc.	Fall 2005
Annual Report	Project status report to JFSP and agency partners.	Spring 2006
Cooperators Meeting	Presentation of fieldwork, model development, etc; request feedback from collaborators.	Spring 2006
Tech Transfer Workshop	First workshop to initiate model testing and manager input.	Spring 2006
Study Site Data Delivery	Provide preliminary results of fieldwork to specific NWRs and NPs	Fall 2006
FRCC Information Transfer	Initialize discussions on manager requested FRCC support and methodology.	Fall 2006
Annual Report	Project status report to JFSP and agency partners.	Spring 2007
Cooperators Meeting	Presentation of fieldwork, model development, etc; request feedback from collaborators.	Spring 2007
Tech Transfer Workshop	Second workshop to test and calibrate model.	Spring 2007
FRCC Information Transfer	Provide VDDT parameterization data sets to Alaskan managers task with FRCC compliance.	Spring 2007
Study Site Data Delivery	Provide final results of fieldwork to specific NWRs and NPs	Fall 2007
FRCC Information Transfer	Provide improved VDDT parameterization data sets to Alaskan managers task with FRCC compliance.	Fall 2007
Cooperators Meeting	Presentation of fieldwork, model development, etc; request feedback from collaborators.	Spring 2008
Journal Articles	Write and submit series of peer-reviewed journal articles.	2006- 2009
Tech Transfer Workshops	Two workshops to train and implement Boreal ALFRESCO model.	Spring 2008
Final Report	Final project report to JFSP and agency partners	Fall 2009

Refereed Manuscripts

D.H. Mann, T.S. Rupp, M. Olson, and P.A. Duffy. 2009. Aging stands and warming climate drive Alaskan boreal forests over an ecological threshold. Nature. Submitted.

E. EUSKIRCHEN, A.D. MCGUIRE, F.S. CHAPIN III, and **T.S. RUPP**. 2009. The changing effects of Alaska boreal forests on the climate system. Canadian Journal of Forest Research. Submitted.

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RUPP, T.S., X. CHEN, M. OLSON, and A.D. McGUIRE. 2007. Sensitivity of simulated land cover dynamics to uncertainties in climate drivers. Earth Interactions. 11(3):1-21.

Acknowledgements

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