

**FROSTFIRE Synthesis Workshop
21-23 March 2000**

**The Role of Fire in the Boreal Forest
and its Impacts on Climatic Processes**

Meeting Abstracts

Compiled by L.D. Hinzman

**The University of Alaska Fairbanks
INE/WERC Report No. 00.03**

<http://www.uaf.edu/water/publications/hreports.html>



FROSTFIRE Synthesis Workshop¹

21-23 March 2000

21 March 2000 Tuesday

8:00 8:30 Continental Breakfast
8:30 8:45 Terry Chapin Welcome, Introduction, and Charge
8:45 9:05 Eric Kasischke Alaskan Fire Regime
9:05 9:25 Sam Sandberg Fuels and Fire Behavior
9:25 9:45 Hiroshi Hayasaka Fire Behavior
9:45 10:05 Cathy Cahill and Rich Collins Plume Analysis
10:05 10:25 Break
10:25 10:45 Masami Fukuda Permafrost and Remote Sensing
10:45 11:05 Terry Clark Remote Sensing of Frostfire
11:05 11:25 Dave Valentine and Rich Boone Soil Carbon Balance
11:25 11:45 Larry Hinzman Hydrology, Permafrost and Nutrient Transport
11:45 12:00 Discussion
12:00 1:00 Lunch
1:00 1:20 Scott Rupp Vegetation Dynamics
1:20 1:40 Terry Chapin Vegetation Feedbacks to Climate
1:40 2:00 Dave McGuire Ecosystem Modeling
2:00 2:20 Randi Jandt Fire Management
2:20 2:40 Break
2:40 5:00 Poster Session

¹ This workshop was sponsored by a grant from the Japanese New Energy and Industrial Technology Development Organization.

22 March 2000 Wednesday

8:30 General discussion of plans for meetings and publications

Hinzman: American Geophysical Union annual meeting (December 2000)

Sandberg: Journal of Wildland Fire

Chapin: Journal of Geophysical Research

Ottmar: Management Reports

Chapin: Data Archival

Involvement of non-FROSTFIRE Scientists?

9:30 Working groups to develop list of JGR/JWF papers and AGU talks

CO₂ feedbacks to climate

C budget of fire

Regional C budget

Nitrogen effects on the carbon cycle; fire effects on N budgets

Fire effects on DOC, DIC, and stream outputs of C and N

Surface energy exchange; feedbacks to regional climate

Fire effects on permafrost

Surface energy balance

Hydrologic responses to fire

Remote sensing: regional extrapolations of fire effects

Detection of changes in of fire frequency

Detection of fire severity

Detection of permafrost response

Fire effects on vegetation trajectory

Fire behavior and management

Climate and vegetation effects on fire behavior

Fire prediction and management

Role of human activities in Alaskan fire regime

10:00 Coffee Break

10:30 Working groups discuss synthesis topics and data needs for these syntheses

12:00 Lunch

1:00 Report to whole group with list of papers and synthesis outlines

2:00 Working groups develop explicit plans and schedules for data exchange and synthesis papers; write a one paragraph summary of "the story" that each synthesis paper will tell.

4:30 Report to group as whole about synthesis plans

7:00 Poster Session and Reception

23 March 2000 Thursday

8:30 Discussion of cross-topic synthesis, develop themes and outlines

Examples:

Climate-fire-vegetation interactions

Role of fire in the changing boreal carbon cycle

Past and future changes in boreal fire management

Video?

What else?

10:30 Report to whole group

1:00 Plans for future research

2:00 Wrap-up and future planning

3:00 Writing

Chemical Composition and Lidar Measurements of Frostfire Smoke

Cahill, Catherine F. and Collins, Richard L.

A size and time resolved aerosol sampler ran for 24 hours starting at 0900 ADT July 9, 1999. The sampler was located in the Caribou-Poker watershed. These measurements have revealed a size distribution that is significantly narrower than the typical log-normal size distribution used in models. Although the composition of the smoke samples varied during this period the mass distribution remained approximately constant. Lidar measurements were conducted at the Davis Science Center, Poker Flat Research Range, approximately 8 km from the burn site. Zenith soundings of the troposphere were made near local midnight on the nights of the 7th, 9th, 10th, 11th and 23rd of July. During the fire period smoke was detected up to heights of 2.5 km above the lidar site. The scattering associated with the smoke was up to 10 times greater than that of the clean atmosphere at heights of 1.5 km.

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Fire Effects on the Diurnal Patterns of Energy, Water and CO₂ Exchange of Black Spruce in the Growing Season

Chambers, Scott D; Durant, Michelle L; Chapin, F. Stuart III

We used tower based climate and eddy-covariance measurements to characterize the summertime energy, water and CO₂ exchange over a black spruce stand in the Caribou Poker Creek Watershed before and after a prescribed burn in 1999. We also made similar measurements over 12 other recently burned (0-15 years previously) black spruce stands throughout interior Alaska. Although fire reduced stand albedo by roughly 0.04, we observed a slight reduction in net radiation at the surface. We also observed an increase in the relative partitioning of net radiation into sensible and ground heat fluxes due to the lack of transpiring vegetation. Peak daytime CO₂ emission following the prescribed burn was approximately half the magnitude of the peak daytime uptake before the fire. Chamber measurements of soil CO₂ flux over the freshly burned surface were in good agreement with the eddy-covariance net-ecosystem exchange measurements. Several years after fire successional species dramatically increase the stand albedo and relative partitioning of net radiation into latent heat flux at the expense of sensible heat flux. Consequently the atmosphere is locally cooler, moister with poor vertical mixing.

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Remote IR Sensing and Analyses of Frostfire Data

Clark, Terry, L.; Radke, Larry; and Coen, Janice

Airborne measurements using both an Inframetrics IR video camera and NASA's ERDAS were used aboard NASA's Navajo Piper to observe the prescribed burns. Results from the image analyses will be presented showing characteristics of three crown fires. These will be shown using computer generated videos. One of the major problems associated with rendering high speed IR imaging is the successful registration of the images. The wind buffeting plus yaw, roll and pitch of the aircraft introduce large motions which must be extracted before any coherent frame to frame information can be processed. The talk will show progress made on the image registration. Some examples from the ERDAS view of the fire will also be presented showing the multi-channel visible through IR view of the fires.

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Fire history of the C4 and P6 basins of the Caribou-Poker Creeks Research Watershed, Alaska

Fastie, Christopher L.

I reconstructed the history of forest fire in the C4 and P6 basins of the Caribou-Poker Creeks Research Watershed using dendrochronologically dated fire scars and recruitment dates of black spruce and birch trees. The dates of 5 stand-destroying fires since 1896 were recorded in 63 fire-scarred black spruce trees. Recruitment dates (from the innermost annual ring of basal cores or sections) of more than 300 spruce and birch from 20 sampling locations record tree establishment following fires.

In 1902, a stand-destroying fire affected about 20 ha of black spruce forest in the P6 basin. Today, this area on the ridge north of the watershed again supports black spruce. In 1925, a fire destroyed the forest throughout about 75 ha, or 15 of the P6 basin, on a south-facing slope which now supports a stand of paper birch. The area outside of this basin affected by these fires is unknown. Most of the P6 basin (about 80) has not been affected by a stand-destroying fire since about 1800.

In 1896, a stand-destroying fire affected at least 60 ha of black spruce forest in the upper reaches of the C4 basin. In 1909, a fire burned a smaller area of black spruce forest along the ridge at the northern margin of the C4 basin. In 1924, a stand-destroying fire burned the entire C4 basin except for the areas affected by the 1896 and 1909 fires. Except for trees in areas burned in 1896 and 1909, most of the trees that were alive in the C4 basin before the 1999 experimental burn recruited after 1924. Immediately prior to the 1924 fire, the south-facing slope of the C4 basin was systematically logged, as evidenced by widespread stumps which were cut with an ax prior to being charred. Age structures of black spruce suggest that many of the trees killed by fires or logging between 1896 and 1924 had established after fires in the early 19th century.

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Entrapment of Smoke in a Nighttime Temperature Inversion

Ferguson, Sue A.; Ruthford, Julia; Nagel, David; Moore, Mark; and Sandberg, David V.

Then managing smoke from wildland biomass fires, much effort has been placed on lofted trajectories that may influence human health, regional haze, scenic vistas, and effects on incoming radiation. It has been found, however, that neutrally-buoyant smoke from the smoldering phase of a fire causes significant impact to nearby homeowners and highway visibility. Even with relatively low concentrations, the smoldering smoke that settles into valleys and basins at night creates such a nuisance that prescribed burning programs are significantly affected, and in some cases even terminated. To help understand the patterns of smoldering smoke in boreal forests and to build tools that can help manage such smoke, we designed a series of observations during the Frostfire experimental burn.

We launched a tethered balloon from a site near the outflow of the basin. The balloon carried sensors that measured wind speed and direction, dry bulb and wet bulb temperature, carbon monoxide, and passive particle concentration. Launches began around midnight and continued every ½ to 2 hours until about 8 am for 5 nights following ignition. In addition to the balloon-mounted instrumentation, a ground-based weather station and carbon monoxide sensor operated continuously at the balloon site. Also, two vacuum-powered nephelometers continuously recorded particle concentrations; one from the balloon site and the other about 2 km down valley in the marsh.

The observations showed a strong diurnal cycle of about 12 hours duration in which a vertical temperature inversion each night caused particles and gases to concentrate near the ground while weak surface winds transported the trapped smoke down valley. Also, smoke tended to concentrate in the warm sector of the atmosphere, near the top of the inversion, especially at times when burning occurred at places above the inversion. The layered concentrations of smoke and lack of vertical mixing affect transport patterns and resulting impacts on local visibility and health. Because the strength, duration, and consistency of the nighttime inversion is comparable to locations at lower latitudes, algorithms to predict the structure of nighttime inversions may be globally consistent. We used the Frostfire observation data to show that reasonable approximations of nighttime smoke distributions can be made from a simple algorithm of topographic features.

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In-situ Measurements of Moss Moisture

Ferguson, Sue A.; Rorig, Miriam L.; Bluhm, Andrew; and Sandberg, David V.

The moisture content of material on a forest floor can play a significant role in its potential for fire ignition and resulting severity, especially in boreal ecosystems that contain deep layers of moss. To better understand the effect of weather and permafrost on moss moisture, we fixed in place several time delay reflectometer (TDR) moisture sensors, at 5cm and 10cm depths within the Frostfire experimental burn site. This allowed us to monitor the pattern of drying and wetting at each location over time. Spatial heterogeneity, structural bias, and variable porosity prevented proper sensor calibration. Therefore, we could not determine actual moisture content or compare the magnitude of values between sites. At times, however, manual moisture measurements were available from co-located sites. The volumetric and gravimetric samples compared favorably with the TDR sensor values and allowed modest calibration.

Several interesting patterns in moss moisture were observed with the in-situ moisture sensors. For example, accelerated drying occurred shortly after the permafrost depleted. There was a strong diurnal pattern in moss moisture that was greatest at sites closest to the surface. Although diurnal patterns in moss moisture closely followed air humidity patterns, longer period drying trends in the moss were observed at times when the air humidity was rising, indicating a threshold dryness that retards the ability of moss to absorb new moisture. Also, rewetting after precipitation appeared to depend on the precipitation amount and rate, much like the rewetting characteristics of a dry sponge. At times, no increase in moss moisture was observed after a light precipitation event. Other times moisture increases were delayed by hours following sustained rainfall. At the time of the Frostfire ignition, the moss moisture was at its lowest for the season.

More work is needed to determine if in-situ sensors can offer meaningful information from one season to the next. Also, more data are needed to determine if observed drying trends following permafrost depletion are common, whether a threshold of dryness that retards remoistening can be quantified, and whether diurnal changes in moisture are significant enough to alter the timing of planned ignitions. The promise of in-situ moisture sampling is encouraging and, in the future, may afford more accurate planning of prescribed burning and better prediction of wildfire potential.

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Forest Fire Impacts to Active Layer Characteristics

Fukuda, Masami

During the FROSTFIRE experiment in 1999, the active layers at the site were impacted by fire both directly and indirectly. The author conducted on-the-spot investigations before and after the fire experiment. Thermal conductivity of active layer was measured by means of portable conductivity meter at various locations. The water contents and density were also obtained by TDR moisture sensors. Sampled soil material was heated up to 800°C to obtain the organic material content. Ground temperatures were monitored at 35 locations at 50cm depth by HOBO-type data loggers. During the fire, a rapid increase of temperature was detected at C4 site. The ground surface temperature was estimated to be about 270°C and duration of heating was 5 hours. The heating period was not long enough to cause a rapid temperature rise in active layer directly through conduction. This increase of ground temperature was induced by percolated melt water downward in active layer. The amount of organic materials in active layer greatly affects the thermal conductivity of active layer. A mineral soil with less organic material yields high thermal conductivity. The uppermost layer of active layer was covered by moss and other organic matter and may be burned during fire to varying severity. Loss of organic content results in higher thermal conductivity and quicker temperature response than un-burned layers. In the years following the fire, the active layer becomes thicker at a burned site than in a control site.

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Forest Fires in Alaska Observation Results Near FROSTFIRE Site

HAYASAKA, Hiroshi

This paper describes results of FROSTFIRE, a forest fire experiment carried out in July 1999 and also surveys results of the Donnelly Flats forest fire in June 1999 from the point of view of forest fire behavior. An investigation of the Donnelly Flats forest fire site found that the main burnt matter were branches with needles of black spruce and mosses and lichen which cover the ground. On the basis of these results, a vegetation investigation was carried out before the FROSTFIRE experiment. The following items were measured to obtain fuel information: weight of branches with needles of two black spruce trees and the thickness of mosses which covered the surface around the trees. Annual ring of two black spruce trees is also analyzed. Several thermocouples were placed on a tree to measure temperatures during the fire. Thunderstorm observations by video camera from the Poker Flat mountaintop recorded multiple lightning strikes. After the storm, three plumes from forest fires were observed in different directions and the probability of ignition of forest fires by the lightning is discussed. Map of lightning location is used to clear characteristics of lightning. The combustion calculations using mean tree densities of black spruce and mean thickness of mosses estimate the quantity of CO₂ released in forest fires in Alaska.

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Chemistry of Burning the Forest Floor

Harden, Jennifer W., Manies, Kristen L., Fries, Terry L.

Field observations of fire severity and fuel consumption can potentially be used to estimate mass losses of C, N, S, and other elements based on pre-burn and post-burn chemical data. Also, based on elements conserved in the soil during a burn, we can potentially back-calculate fire severity and fuel consumption from the distribution of elements in the ash layer. We collected volumetric pre-burn and post-burn samples using a variety of field methods at sites where USFS collaborators measured burn severity. We analyzed samples for C, N and their stable isotopes, major elements, and trace elements using a variety of spectrographic and gravimetric techniques. In black spruce/feathermoss sites at Helmer's Ridge and at the Lower Black Spruce sites, we found that (1) soil/forest floor layers vary significantly in C/N ratios, ^{13}C , and ^{15}N values owing to depth dependence of moss content, root content, and decomposition stage, (2) the C and N isotopes of the burned forest floor reflect mainly the chemistry of the uppermost unburned or charred layer; this suggests little or no isotopic fractionation occurred during the burn. (3) in samples where 80 to 90 of our sample was consumed, 80 of C and 70 of N were volatilized by the fire, with C and N losses generally increasing with fire severity (4) inorganic elements were concentrated in the uppermost charred layer, and variation in weight fraction appears to be related to fire severity.

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Long-range Transport of Gaseous and Particulate Materials by Forest Fire

Hatsushika, Hiroaki; Kim, Yong-Won; Yamazaki, Koji

The Forest Fire at Delta Junction was occurred from 10 June, 1999. After 1 month, the Frostfire Experiment was done between July 8th to 15th at Little Pokar Creek in the suburb of Fairbanks. The experiment was scheduled in the site for investigating the impacts of Forest Fire on the boreal ecosystem and the feedback to the climate system. The objective of this study is to simulate how and whereto the gaseous and particulate materials are transported by using trajectory calculation. The dataset used in this study is ECMWF/TOGA objective analysis (4times per day, 0.5x0.5 degree gridded, 15 P-levels) data during the period from June 10 to 22 and from July 8 to 19 in 1997. We could estimate the distribution of particles under certain conditions, such as size of particles and with or without wet deposition. Small particles have the possibility to be transported to the Arctic sea-ice region, while large particles are rapidly deposited near and inland the Alaska region. We need to investigate the behavior of emitted particles in more detail, because the particles affect directly and indirectly to environment of Arctic region.

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Ectomycorrhizae and Succession in a Boreal Forest Watershed

Helm, Dot J.

Ectomycorrhizae (EM) are symbioses between plant species and certain fungi in which the fungi help the plant absorb nutrients and moisture from the soil while the plant provides the fungi with an energy source (carbon). Individual plants may support many species of ectomycorrhizal fungi (EMF). The early- and late-stage hypothesis of EMF succession suggests that these EMF may vary with the age of the roots and the substrates. Early-stage EMF would be found on young roots, most likely in mineral soils. Late-stage EMF would be found on older roots and more likely in organic substrates. Since lethal temperatures of fire may extend only a few centimeters into the soil, the EMF in the mineral soil may be the most likely to survive and form refugia for post-fire colonization. In a severe fire, these EMF may now be near the surface. Additionally, in lightly burned sites, some of the EMF may survive in organic layers and also provide inoculum for post-fire succession. Changes in composition of EMF communities have been studied previously across fire chronosequences in boreal forests, but they did not have pre- and post-fire data. Frostfire has provided a unique opportunity to document EM succession on permafrost and non-permafrost sites.

In this study, soil/litter cores have been taken in proposed-burn and control sites in the black spruce (permafrost) and hardwood (non-permafrost) vegetation types by horizon both before and after the fire. Roots are washed, the dominant EM morphotypes are described according to characteristics of the mantle, emanating hyphae, and hyphal strands, if present. Mycorrhizal community composition on the root systems is quantified by the percentage of root tips colonized by each morphotype. The changes in EM communities over time can be documented and compared with the pre-burn EMF communities.

The poster presents some of the EM found before the fire. After the fire some EM were found within millimeters of charred root remains. What actually happens during succession remains to be documented.

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FROSTFIRE: Disturbance in an Alaska Boreal Forest

Hinzman, Larry D.; Chapin, Terry; Sandberg, David; Fukuda, Masami; Yoshikawa, Kenji;
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FROSTFIRE was a landscape-scale prescribed fire experiment conducted during the summer of 1999 on the Long Term Ecological Research site north of Fairbanks, Alaska, in the Caribou-Poker Creeks Research Watershed. It burned over 900 acres. The objective of this research is to develop a predictive understanding of the major classes of feedbacks from boreal fire to climate, as a basis for improved understanding of the changing role of the boreal forest in the Earth system. Boreal forests account for about a third of the carbon sequestered in terrestrial ecosystems, so changes in their functioning or distribution could create important feedbacks to the climate system. Changes in the extent of forest cover could alter regional energy budgets enough to amplify or nullify the expected rapid climatic warming at high latitudes, depending on whether the area of forest expansion into tundra is greater or less than deforestation associated with wildfire and logging. Warming could cause boreal forests to change from accumulating carbon to being a net source if warming increases fire frequency or decomposition. The rate of change in boreal forests is governed by fire frequency and severity, with important immediate and long-term effects on carbon and energy flows. Currently, global models of vegetation change assume a constant disturbance regime. Fire's effects are not adequately incorporated in these models of high-latitude climate feedbacks. Forty percent of the area currently covered by boreal forest may change to a different biome, and the species composition may change in much of the remainder. Unless we improve our understanding of the causes and consequences of fire regime, it will be difficult to develop credible models of the role of boreal forest in climate feedbacks. FROSTFIRE will improve our understanding of the role of fire in the Alaskan regional system.

Forest fires have an immediate effect upon the surface energy and water budget by drastically altering the surface albedo, roughness, infiltration rates, and moisture absorption capacity in organic soils. In permafrost regions, these effects become part of a process of long term (20 to 50 years) cumulative impacts. Burn intensity may largely determine immediate impacts and long-term disturbance trajectories. As transpiration decreases or ceases, soil moisture increases markedly, remaining quite wet throughout the year. As the insulating quality of the organic layer is removed, permafrost begins to thaw near the surface and warm to greater depths. Within a few years, it may thaw to the point where it can no longer completely refreeze every winter, creating a permanently thawed layer in the soil called a talik. After formation of a talik, soils may be able to drain internally throughout the year and may become quite dry. The local plants and animals must continuously adapt to the changing soil thermal and moisture regimes.

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The Effect of Wildfire on Insect Communities in Interior Alaska.

Hjältén, Joakim; Atlegrim, Ola; Rexstad, Eric

Introduction: Today most scientists agree that fire is a very important natural disturbance agent in most terrestrial ecosystems. However, our knowledge regarding the effect of fire on the flora, and especially the fauna, is still limited (Lyons et al. 1978, Mushinsky and Gibson 1991, Holliday 1992, Whelan 1997). Fire and insects are often synergetic components of many northern boreal ecosystems (McCullough et al. 1998). An increased understanding of the ecology of fire-insect interactions is essential if we want to develop strategies to maintain both biological diversity and forest production in northern forest ecosystems. Besides benefiting certain invertebrates, fire might change interactions between invertebrates present in the forest ecosystems.

The aim of this study is to determine the effect of fire on the insect community (with special emphasis on coleopterans) in different forest types. Furthermore, to determine if the low density of ants in Alaskan boreal forests results in different composition and relative abundance of the invertebrate community and if differences in post-fire succession between Alaska and Scandinavia also can be explained by low ant abundance.

Preliminary results: Not all the Coleopterans collected has yet been identified. However, the first crude sorting has been conducted, dividing the material into the following categories, coleopterans not including rove beetles and carabids, carabids, rove beetles, dipterans, spiders, aphids and ants. No detailed analyses of the material has been conducted but the general patterns based on the pit fall material are as follows:

- Large differences in the community structure of coleopterans in burned and control areas
- Two to three fold increase of carabids in the burned areas Ten fold decrease of rove beetles in burned areas
- Six to ten fold increase of Coleopterans, not including carabids or rove beetles beetles, in burned areas.
- Five to ten fold increase of homopterans in burned areas
- In addition to this, there were also big differences between the forest types, both with regard to initial densities of different arthropod groups and the effect of fire on the arthropods.
- No wood ants were found, instead the ant community is instead composed mainly by carpenter ants (*Camponotus*), red ants (*Myrmica*) and ground ants (*Lasius*).
- Nest density of the dominating ants seems to be higher in Alaska compared to Scandinavia.
- Several of the relationships between ants and other invertebrates in Alaska are contradictory to the ones found in Europe.

Discussion: The general patterns of changes in the insect community following fire is similar to results reported from Fennoscandia (Mauna and Rutanen 1994, Hjältén Unpubl.). However, more interesting is response of functional groups of insects to fire and the effect of fire on diversity of insects on different spatial scales. But these questions can not be answered before all insect species have been identified. There seems to be great differences between Alaska and Scandinavia with respect to the composition of ants. Wood ants dramatically influence invertebrate abundance in Scandinavian forests. In Alaskan forests this influence seems to be different due to the dominance of other ant species, and might indicate other indirect effects of ants in the forest ecosystem, such as effect on invertebrate herbivory.

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Applied Fire Management at BLM Alaska Fire Service: Examples of Data Use in Decision-Making

Jandt, Randi

There are three general levels of decision-making for a fire management agency. (1) On-scene at a wildfire or when implementing a prescribed burn, incident commanders, burn bosses, and firefighters make the most urgent and immediate decisions: concerning expected fire behavior, tactics, and personnel/public safety. (2) A second level occurs at the headquarters, where decisions about which fires or land units should receive priority for resource allocation and, given current conditions, will fires threaten resources in those units. (3) Planning decisions about strategy to manage future fire on large land areas, or around communities are made by consortiums of neighboring land managers and fire control personnel well before the season. These levels of decision-making use a variety of different data types and sources. For example, on-scene decisions require weather and fuel measurements and good models to predict consumption, rates of spread, flame heights. We need more accurate models to allow us to bring our prescribed fire treatments closer to the “edge” of urban interface: where most of the need (and the risk) resides. Successional data for a variety of vegetation types and burning conditions has many gaps, which we need to close as we attempt to fine-tune burn prescriptions in order to meet the goals of land managers for wildlife forage, berry production, and stand conversion. Fire planning efforts require the perspective of long-term and cumulative ecological effects.

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Influence of Permafrost on Groundwater Nutrient Inputs in Sub-Arctic Streams

Jones, Jeremy B.; Petrone, Kevin C.; Hinzman, Larry D.

The influence of permafrost on groundwater nutrient inputs was investigated in three sub-basins in central Alaska. Hydrologic inputs from soils versus deeper ground water to the stream surface were determined using an end-member mixing-model. In the high-permafrost catchment (53.2 of basin underlain by permafrost), most surface discharge was derived from soils (81 of surface flow), whereas in the two lower-permafrost catchments (3.5 and 19 underlain by permafrost) considerably less surface water was from soils (33 and 63 of surface discharge). Nitrate concentration was nearly eight-fold higher in deeper ground water than soil water (258 ugN/L versus 34 ugN/L), whereas dissolved organic carbon (DOC) concentration was greatest in soil water (35 mgC/L versus 7.6 mgC/L). Coupled to this variation in subsurface flows and chemistry, nitrate was greatest in streams draining the two lower-permafrost watersheds averaging 566 and 633 ugN/L. In the high-permafrost catchment nitrate concentration was nearly 50 lower averaging 305 ugN/L. DOC concentration, in contrast, was over 50 lower in the lower-permafrost watersheds averaging 4.3 and 7.1 mgC/L than in the high-permafrost watershed with 14.5 mgC/L. Permafrost appears to govern subsurface nutrient inputs into sub-arctic streams by regulating the interaction between ground waters and soil versus deeper subsurface environments.

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Seasonal Change in the Needle Photosynthetic Capacity and Concentration of Nitrogen in Eight Species of Spruce

Kayama, Masazumi; Kitaoka, Satoshi; Okuyama, Satoru;
Matsuda, Kyo; Koike, Takayoshi; Fukuda, Masami

The genus *Picea* is a typical tree species in northern hemisphere. Among this genus, Black spruce (*Picea mariana*) is a major species distributes on permafrost region. This region has been affected by frequent forest fires. To estimate the growth capacity of Black spruce which regenerated after forest fires, seasonal change in the photosynthetic capacity and concentration of nitrogen in needles were measured. Moreover, these abilities were compared among the eight spruce species, which were planted on the same stand in The Tomakomai Experiment Forest where volcanic ash were covered. We selected eight spruce species as follows; four spruce species were native to Japan, three species were originated from north America and the rest was European species. Even though different geographical origin, specific niche occupancy should be reflected from its growth characteristics. Maximum photosynthetic rate of species of the northern part of America showed little change until October. Concentration of nitrogen in the needles decreased with needle aging. However, decrease in the nitrogen concentration of old aged needles on Black spruce was little as compared with the new needles.

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Biomass Burning and Carbon Release during Fires in Alaskan Boreal Forests

Kasischke, Eric S.

Patterns of biomass burning and pyrogenic carbon release in Alaskan boreal forests were studied by comparing data collected in adjacent burned and unburned stands. While the majority of the data were collected from the organic mats of mature black spruce forests, a limited amount of data were collected from aboveground vegetation and organic mats in mature aspen, white spruce, black spruce and willow/black spruce forests. The results of the study showed that patterns of burning varied amongst the different forest types, with levels of carbon release ranging between 14 t ha⁻¹ (aspen forests) to nearly 40 t ha⁻¹ (black spruce forests). The amount of carbon present in the organic mats of the black spruce forest sites was highly variable (24.6 to 146.6 t ha⁻¹), as was the carbon released during fires (11.1 to 76.1 t ha⁻¹ or 12.9 to 88.9). The amount of carbon present in the organic mat of black spruce forests was significantly correlated with slope position and the percent carbon consumed in the organic mats by fires in black spruce forests was correlated with slope position and time of the fire during the growing season.

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Effect of Forest Fire on the Fluxes of Trace Gases in a Boreal Ecosystem, Interior Alaska

KIM, Yongwon and TANAKA, Noriyuki

The experimental burn so called "Frostfire" was scheduled in the Caribou-Poker Creeks Research Watershed (C4 area) for a study on the potentially massive effects on regional warming and the rapid changes of carbon balance in boreal forest ecosystems during July 8-15, 1999. The experiment was carried out black spruce forest on north-facing slope that had a strong association with permafrost that was distributed patchy and was formed at 30 cm underlying the moss layer. The birch forest was located on south slope. We used the dark and light chambers that one was specified 30 cm diameter and 10 cm high, and the other was 20 cm diameter and 8 cm high. The purposes of this study is 1) to estimate the fluxes of CO₂, CH₄ and N₂O for the pre- burning in black spruce and deciduous birch forests and for the post-burning in black spruce, 2) to measure the net respiration rate of moss layer in black spruce, 3) to understand the role of forest fire for the variations of trace gases, finally 4) to understand the relationship between the fluxes and soil temperature that plays a part in influencing factor on these fluxes.

As the result of this study, the forest fire was found to remarkably decrease soil CO₂ and N₂O emission rates by 40 % and 60 % with light chamber and 50 % and 10 % with dark one, and atmospheric CH₄ oxidation to soil by 10 % and 30 % with light and dark chambers between pre- and post-burning for 1999. We will discuss on the more results in Frsotfire Synthesis Meeting.

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**Interpretation of Remotely Sensed Data on Black Spruce and Paper Birch
Communities in Alaskan Boreal Forest From Their Physical Characteristics
Enhanced by Fire:
Preliminary Results on Componential Spectral Characteristics**

Kushida, Keiji; Fukuda, Masami

We measured spectral characteristics of black spruce (*Picea mariana*) and paper birch (*Betula papyrifera*) communities elements such as forest floor and leaves to analyze relationships between remotely sensed data and forest structural characteristics in Caribou-Poker Creeks Research Watershed (CPCRW). Remote sensing technique is necessary as a tool for monitoring boreal forest functions and changes including forest fire influences. There are many radiative transfer models of vegetation canopies (for examples, Asrar, 1989; Myneni et al., 1989), however, little field measurements of spectrum of boreal forest elements except for studies by Daughtry (1989) or BOREAS Project (Williams, 1991; Sellars et al., 1997). This is one of the reasons why we can hardly apply radiative transfer models to interpret satellite data. In this research, We obtained leaf and forest floor spectral characteristics of paper birch, black spruce, and partially burnt black spruce communities in CPCRW. As a result of SAIL radiative transfer model calculation with these measured values, we proposed charts to interpret atmospherically corrected Landsat TM data of the communities from LAIs, forest floor types, and leaf spectral characteristics.

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Soil carbon and nitrogen storage of forest soils. -Before fire in CPRW, and in a burnt and a unburnt stand in Delta Junction-

Matsuura, Yojiro

Soils of birch-spruce stands in CPRW had relatively low storage of carbon, ranging from 4.7 to 5.4 kg C/m². Carbon in forest floor were varied site to site, ranging from 2.2 to 4.7 kg C/m². Soil C/N ratio of birch-spruce stands were approximately 11. On the other hand, soils in spruce dominant stands with shallow permafrost table had much carbon storage in forest floor, ranging from 5.3 to 8.9 kg C/m². Spruce dominant forest soil showed high C/N ratio above 20. A burnt and a unburnt forest soil were examined to estimate carbon release by forest fire occurred in Delta-Junction during last June 1999. According to preliminary survey, about 3 kg C/m² were lost during forest fire. Total soil carbon storage and soil C/N ratio did not change so much during the fire.

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The Role Of Fire Disturbance, Climate, and Atmospheric CO₂ in the Response of Historical Carbon Dynamics in Alaska From 1950 To 1995: A Process-Based Analysis with The Terrestrial Ecosystem Model

McGuire, A. David; Meier, Rose A.; Zhuang, Qianlai; Macander, Matthew; Rupp, T. Scott; Kasischke, Eric; Verbyla, David; Kicklighter, David W.; and Melillo, Jerry M.

To evaluate how historical C storage in Alaska may have been influenced by fire disturbance, climate changes, and changes in atmospheric CO₂ between 1950 and 1995, we conducted simulations with the Terrestrial Ecosystem Model (TEM). We conducted three simulations that included responses of C storage to: CO₂ only (S1), CO₂ and climate (S2), and CO₂, climate, and fire disturbance (S3). To estimate the relative influences of CO₂, climate, and land use on simulated responses of C storage, we assumed that responses of the S1 simulation represent the CO₂ response, the difference between the responses of the S2 and S3 simulations represent the climate response, and the difference between the responses of the S3 and S2 simulations represent the response of fire disturbance. Between 1950 and 1995, the S3 simulations of TEM indicate that C storage in Alaska increased 2.1 10¹² g (Tg) C yr⁻¹, with tundra responsible for approximately 40, boreal forest responsible for approximately 45, and maritime conifer forest responsible for approximately 15 of the C storage. The partitioning of effects indicate that increasing atmospheric CO₂ was responsible for enhancing C storage 3.5 Tg C yr⁻¹, that climatic variation was responsible for a loss of 0.3 Tg C yr⁻¹, and that fire disturbance was responsible for a loss of 1.1 Tg C yr⁻¹. The effect of atmospheric CO₂ on carbon storage in enhancing C storage, which was very sensitive to assumptions in TEM about changes in vegetation C:N ratios associated with increasing CO₂, continues throughout the period of the simulation. Approximately 65 of the effect of increasing atmospheric CO₂ was concentrated in tundra, about 30 in boreal forest, and about 5 in maritime conifer forest. The simulations with TEM indicate a substantial degree of inter-annual variability in the effect of climatic variation on state-wide C storage. The effect of climatic variation over the period differed among vegetation types in the state, in that it was responsible for a loss of 0.9 Tg C yr⁻¹ in tundra, but an increase of 0.4 and 0.2 Tg C yr⁻¹ in boreal forest and maritime conifer forest, respectively. There was also substantial inter-annual variability in the effect of fire disturbance on state-wide C storage, as the effect of fire disturbance includes emissions associated with fires as well as the effects of post-fire C dynamics on C storage. Tundra and boreal forest each accounted for approximately half of the losses associated with fire over the period, while the effect of fire on C storage of maritime conifer forest was negligible. The results of the simulations with TEM suggest that increasing atmospheric CO₂, climatic variation, and fire disturbance play substantial roles in the historical C dynamics of Alaska. Furthermore, the simulations suggest that effects of tundra and boreal forest on historical C storage in Alaska have been similar in magnitude, but that effects of increasing CO₂ and climatic variation on C storage in tundra and boreal forest is not similar in magnitude. Finally, the simulations suggest that fire disturbance plays a major role in the dynamics of tundra C storage at large spatial scales in Alaska.

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Infrared Fire Behavior Data for FROSTFIRE

McRae, Douglas J., Stocks, B.J.;Jin, Ji-zhong

The Canadian Forest Service flew an AGEMA 570 infrared camera in a Bell 206 helicopter at FROSTFIRE (9 July 1999) to assist in the quantification of fire behavior on this particular research burn. Since infrared wavelengths are not obscured by smoke, fire documentation is not hindered and can be conducted safely from above the fire. Infrared data were captured as single digital images taken at different intervals during the burn, and continuously onto HI8 videotape. Analysis of the digitized images can provide documentation of various fire behavior characteristics (e.g., fire growth, rates of spread, fire temperatures, residence times, reaction intensities and spotting distances). In addition, images can be useful to verify specific events related to the fire, such as the timing and rate of ignition line creation.

Data was collected on FROSTFIRE for two time periods (4:39:41-5:03:33 and 6:15:13-7:56:52). The break in sampling was caused by the need to ferry the helicopter to Fairbanks for refueling. Sampling ceased when the pilot reached his daily maximum flying time, as he was involved in the morning briefing for pilots. Preliminary image examination shows excellent documentation of the actual fire growth.

Software to post-process the digitized images has been developed to allow images to be computer corrected to the proper scaling to overcome aircraft inconsistencies (e.g., altitude, pitch, etc.), for proper multiple image alignment, scaling, and for data interpretation. We have just received map data for FROSTFIRE, which will allow us to scale our images and to complete the final analysis. Unfortunately, the combination of slow spread rates of the fire and the high flight altitude (required to obtain coverage of the fire area) resulted in a large pixel size (12x12 feet) which will create problems in accurately determining fire behavior characteristics such as rates of spread. This problem is often inherent in infrared documentation of slow spreading fires, as the large pixel size, in conjunction with movement between consecutive images (i.e., shift of fire even within the same pixel due to pixel size), caused by the instability of the aircraft itself, hinders the precise location of specific points of the fire. In some cases, the fire could appear to retreat because of this error. However, the present infrared images will permit a good record of ignition times and spread patterns across the FROSTFIRE site. In addition, it will provide documentation of the most active portions of the fire at any time.

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Satellite Remote Sensing of Smoke Particle Emission from Boreal Forest Fire

OHTA, Sachio; HASEGAWA, Shuichi; MURAO, Naoto and SHAW, Glenn E.

The boreal forest fire frequently occur in the Arctic and release a large amount of smoke particles, mainly soot and organic matter, in addition to carbon dioxide. The smoke particles scatter and absorb the solar radiation to change radiation budget in the Arctic, which is called the direct effect of aerosols on climate. In addition, water soluble organic aerosols in the smoke probably cause an increase in cloud reflectivity through an increase in the number concentrations of cloud droplets. The increase in cloud reflectivity greatly affects the arctic climate.

In this research, we estimate emission of smoke particles by using satellite radiance data. Assigning size distribution and the complex indices of refraction for the smoke particles, and the land surface reflectivity, we can calculate upward radiation at top of the atmosphere by solving radiative transfer equations in the visible region. We, then have to determine the surface reflectivity in the boreal forest and the complex indices of refraction of the fire smoke particles. At Poker Flats Rocket Range we determine the surface reflectivity by measuring the direct solar radiation by a sun-photometer, the scattering coefficient by an integrating nephelometer, and the absorption coefficient by an absorption photometer. By using above results, we can calculate the radiance at top of the atmosphere. By comparing the calculated radiance with one measured by satellite, we can determine the land surface reflectivity. We also observe concentrations of chemical species of aerosols at Poker Flats Rocket Range. Chemical characterization is taken for the aerosols measured at Poker Flats Rocket Range in 1999-2001 and those measured at Ester-Dome in 1991-1992. In July 1991 forest fire occurred near Ester-Dome. Based on the chemical characterization, we determine the complex index of refraction of aerosols in normal condition and that of smoke particles in the forest fire. In the scene for the forest fire plumes, by using the size distribution and complex index of aerosols in addition to the land surface reflectivity, we can, thus, obtain the distribution of aerosol optical thickness. Integrating the optical thickness in transect of the fire plume, we, thus, estimate the emission of forest fire smoke particles.

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Predicting Forest Floor Reduction at Frostfire and Other Fires in Alaska

Ottmar, Roger D.; Vihnanek, Robert E.; Bluhm, Andrew A.; and Sandberg, David V.

Introduction--Wildland fire is a major disturbance agent that has shaped the biotic landscapes throughout time. The amount and duration of the heat determined by the availability of the fuels to consume is the ultimate driving force that causes a widespread range of environmental responses and social political consequences. Since the majority of consumable biomass in boreal forest ecosystems is generally contained in the forest floor, the ability to predict its ignition potential and consumability will be a critical requirement to predict fire effects. A study was initiated in 1990 to begin collecting forest floor reduction data and to develop a forest floor consumption algorithm that will be implemented into Consume 3.0 (Joint Fire Science Program 1999) for use in the boreal forest types. The objective of this study is to test the algorithm using the measured data from the Large Black Spruce and Upper Black Spruce Frostfire sites.

Methods--Six prescribed burns during 1990, 1992, and 1993 were monitored for forest floor reduction in the boreal forest type in Alaska. The units were 1) Deshka 1 (D1) located in a mix of black spruce and white spruce near Palmer, Alaska; 2) Chisana 1, 2, 3, 4 (CH1, 2, 3 & 4) located in a mix of black and white spruce near Tok, Alaska; and 3) Bonanza Creek (BC) located in a white spruce stand which had been clearcut logged near Fairbanks, Alaska. In addition, forest floor reduction was measured at two sites for the Frostfire Project in 1999. The Large Black Spruce (LGBS) site was located in the bottom of Little Poker Creek with relatively large diameter black spruce. The Upper Black Spruce site was on Helmers ridge in a stand of relatively small diameter black spruce.

Eighteen permanent plots were positioned in a grid across each unit. To measure the preburn and remaining forest floor depths, 16 welding rod pins were located on two perpendicular axes centered on each plot center. The pins were inserted into the forest floor with the pin head level with the surface. After the fire, each pin was located and a measurement was collected from the top of the pin to the consumed forest floor layer. This represented total forest floor reduction. A trowel was used to dig to mineral soil and a second measurement was taken from the top of the pin to mineral soil. This represented total forest floor depth before the burn. Multiple regression statistics (SASS) were used to develop predictive equations for the reduction of forest floor fuels from the 6 burns monitored in 1990-1993. The independent variables collected from LGBS and UPBS sites at Frostfire were input into the algorithm to evaluate its predictive capability.

Results--Forest floor preburn depths for the units used to develop the algorithm ranged from 3.2 inches at the BC burn to 7.4 inches at the CH1 research burn. The 10-hour fuel moisture content ranged from a low of 9 percent at CH4 to 16 percent at CH1. Forest floor reduction observed varied by only an inch between units. Average forest floor depth was 7.9 and 7.1 inches respectively for Frostfire LGBS and UPBS sites. The 10-hour fuel moisture content was 19 percent for both Frostfire units and forest floor reduction was measured at 3.1 and 2.4 inches for LGBS and UPBS respectively.

After completing regression analysis using the measured data from the six 1990-1993 research burns, the best predictive equation, $Y=4.946-0.1796X_1+0.1112X_2$ ($r^2=0.94$) used 10-hour fuel moisture (X_1) and pre-burn forest floor depth (X_2) as independent variables. Graphs of the residuals and observed forest floor reduction (inches) versus predicted forest floor reduction (inches) resulted in a fairly linear pattern around zero for the residuals and reasonable agreement between predicted and observed values. The algorithm under-predicted the LGBS unit by 0.6 inches and the UPBS unit by 0.1 inch.

Discussion--The forest floor reduction predictive equation developed for the boreal forest types relies on the 10-hour fuel moisture content and preburn forest floor depth. The 10-hour fuel moisture relates to the ignitability of the forest floor. The preburn forest floor depth relates to the inherent relationship between forest floor reduction and preburn depth. Intuitively, the algorithm seems sound, however, detailed forest floor type and forest floor moisture content over time will need to be thoroughly analyzed to determine the forest floor moisture threshold at which this algorithm will adequately operate. The Frostfire data should assist us in completing the algorithm development. The algorithm did a good job at predicting forest floor reduction measured at the Frostfire UPBS site. This area was ignited with a helicopter with a relatively uniform head fire advancing across the unit. The algorithm under-predicted the forest floor reduction for the Frostfire LGBS unit by over 0.5 inches. As additional analysis is completed and new data points are collected, the algorithm will be adjusted to be more robust for sites in Alaska.

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FROSTFIRE Biomass Consumption- Carbon Pools

Ottmar, Roger; Sandberg D.V.; Bluhm, Andrew

Pre-burn biomass, post-burn biomass and biomass consumption is presented for the experimental burn in the C4 watershed in the Caribou-Poker Creeks Research Area. Data was collected from a total of 226 plots, located systematically (200m x 200m grid, i.e. 'dispersed' plots) and 126 plots distributed in 7 selected forest stands (18 plots/unit, i.e. 'intensive' plots) throughout the watershed. Before the burn, each plot was classified by forest type (according to Viereck, et. al. 1992) and the various biomass components (i.e. carbon pools) were measured. Following the burn, all plots were revisited to assess the forest types that burned with what severity. Six of the ten forest types burned and approximately one-third of both the dispersed and the intensive plots burned. Total pre-burn biomass was divided into seven fuelbed components (i.e. carbon pools); 1) trees, 2) saplings, 3) seedlings, 4) tall shrubs, 5) understory vegetation, 6) woody fuels, and 7) forest floor material. Fire severity was then assessed for these components, either on an individual stem or area basis, and was estimated using classes to the nearest 10. Three fire severity classes were used for the vegetation components; 1) 'Green'- no consumption of foliage, 2) 'Brown'-foliage discolored or desiccated, may be black, brown, or wilted, and 3) 'Black'-foliage consumed. Three additional fire severity classes were used for the forest floor material component; 1) 'Unburned'- no consumption, 2) 'Skiffed'-scorched or consumed upper forest floor layer, consumption is the result of, and limited to, the flame front, and 3) 'Cooked'- consumption extends into lower forest floor layers; consumption occurs during or within a couple of hours after the fire or may occur several hours or even weeks after the fire. Post-burn biomass/consumption was calculated by applying consumption coefficients based on the severity classes to pre-burn biomass. Consumption of the woody fuel component was determined by direct measures of pre- and post-burn biomass. Furthermore, to determine the quantity/effect of charred biomass in carbon pools, post-burn woody fuel, forest floor surface material, and duff biomass was divided into separate 'charred' and 'uncharred' categories. These results will be combined and synthesized with other data and incorporated into a GIS database to provide a watershed-level impact of the burn on boreal forest carbon pools.

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Nitrogen and Carbon Dynamics of Storm Runoff in Three Sub-Arctic Watersheds: The Influence of Fire and Permafrost

Petrone, Kevin C; Hinzman, Larry D; Boone, Richard D.

Biogeochemical cycling in the boreal forest landscape is driven by physical, chemical and biological properties that are regulated by permafrost and the fire disturbance regime. We measured stream concentrations of dissolved organic carbon (DOC), and nitrate (NO₃⁻) in three watersheds underlain by 3 permafrost (LoP), 18 permafrost (Burn) and 53 permafrost (HiP) during two storm events in July and September 1999. The storm hydrograph for the September event was separated using a two-end member mixing model. In the intermediate (18) permafrost watershed, we report the effects of a prescribed burn that took place in July 1999. Post-fire observations for storm events in July and September 1999 show positive relationships between DOC and discharge for all basins. The increase in DOC during storms was greatest in HiP, moderate in the burn, and smallest in LoP. The NO₃⁻ response was variable across all basins. There was a negative relationship between NO₃⁻ and discharge in LoP and a positive relationship in HiP. Our results show that DOC and NO₃⁻ concentrations are influenced by permafrost. Nitrate and DOC increased in HiP despite a larger contribution of "new" water (low in NO₃⁻ and DOC) to the stormflow peak. Nitrate was leached in the active layer of HiP, but diluted by rain water or NO₃⁻ depleted soil water in LoP. In the burn basin, the immediate fire effect is shown by a non-linear response of NO₃⁻ to increased flow in the post-fire rain event in July. This hysteresis indicates that burned soils in the contributing area for stormflow may have reached the stream. The long-term effect of the prescribed fire will be driven by changes in the active layer depth due to removal of the insulative moss layer on the forest floor. Future stormflow analyses will include isotope tracers to identify sources of carbon and nitrogen to stream chemistry.

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Fire Danger Indexes and Fuel Condition in Alaska

Rorig, Miriam L. Ferguson, Sue A. and Sandberg, David V.

The Canadian Forest Fire Danger Rating System (CFFDRS) and the National Fire-Danger Rating System (NFDRS) were developed to assess and predict wildfire danger in the forests of Canada and the United States. In addition, the fire weather index components of these systems are used to model fuel conditions for prescribed fires, an application for which the indexes have not previously been tested. Meteorological and fuel moisture data from the Frostfire experimental burn were used to evaluate the ability of the indexes to determine fuel condition in black spruce and hardwood boreal forests. The burn plan for Frostfire called for FFMC between 88.5 and 92, DMC between 59 and 71, and DC between 300 and 475 during the summer of 1999. The FFMC reached its acceptable range 6 times, twice in each month of May, June, and July. The pattern of FFMC coincided with fuel-stick moisture measurements. The DMC rose above 60 on two separate occasions, June 11-15 and July 11-15, while the DC rose above 300 in mid July and stayed relatively high through early August. Wildfires occurred in June, coinciding with maximum values of FFMC and DMC, and when fuel-stick (30 cm above the surface) and moss (5 cm below the surface) moistures were at a minimum. The DC also showed a local maximum at this time but reached a value only of 225, well below the threshold where deep burning and smoldering were expected. The Frostfire prescribed fire occurred in early July, when moss and fuel-stick moisture again reached a minimum and all three CFFDRS indexes were within the accepted threshold values. Although the DC stayed high for another month, and FFMC continued to peak at times, the DMC fell sharply after July 16, coinciding with a sharp rise in the moisture of moss, and no additional fire ignition was observed. A secondary peak in DC that occurred on August 4th, however, seemed to coincide with some enhanced smoldering in the Frostfire burn area.

Although the NFDRS is designed to model a different type of fuel complex than that found in interior Alaska and not used in planning Frostfire, the 1000-hr index clearly indicated the June dry period when wildfires occurred and the July dry period when the Frostfire prescribed fire occurred. Also, like the DMC, the 1000-hr index showed a significant increase in moisture after rains began in late July. The 100-hr index additionally showed dry periods in May, which coincided with a brief minimum in fuel-stick moisture, and August, which was associated with a peak in DC and observed Frostfire smoldering. The 1-hr and 10-hr indexes were much less conclusive. They followed relative humidity very closely, which exhibited a number of minimums throughout the summer but neither index showed distinctively unique conditions that coincided with the wildfire and prescribed fire events.

The results indicate that the FFMC and 100-hr index can be reasonable indicators of fuel-stick moisture but by themselves cannot explain necessary conditions for fire in Alaska. The FFMC was designed to be an indicator of ease of ignition and flammability, and therefore does not model seasonal trends. The DMC and 1000-hr are better indicators of relative readiness for burning because they are more indicative of fuel consumption. These indexes exhibited the only two peaks that coincided directly with fire activity. The DC did well to track the gradual drying of moss layers, reaching a maximum when the moss moisture reached its minimum in mid July, but the DC also indicated a similar magnitude of dryness in early August. The DC is an indicator of smoldering in the deep duff layers, and in fact there was enhanced smoldering at this time. The moderate moss layers (5-10 cm), however, showed a significant increase in moisture, and therefore this peak in DC may have been a false indicator of moisture content.

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FROSTFIRE Burn Severity Estimates from Ground-Based Observations

Sandberg, D.V.; Ottmar, Roger; Bluhm, Andrew; Vihnanek, Robert

Burn severity estimates are presented for the experimental burn in the C4 watershed in the Caribou-Poker Creeks Research Area. The results are presented for the two types of plots (“Intensive” and “Dispersed”) established in the watershed. For a detailed description of the plot types, sample sizes, and measurement protocol, refer to the poster titled, “FROSTFIRE Biomass Consumption- Carbon Pools” by Ottmar, Sandberg, and Bluhm. Burn Severity is assessed separately for each vegetation component and for the forest floor. Table 1 describes mean severity estimates for burned plots located systematically throughout the watershed (i.e. ‘dispersed plots’), by fuelbed component and forest type. Across all forest types, approximately 13 (range 0 to 42) of the forest floor was unburned, 52 (range 10 to 80) was lightly burned (‘skiffed’) and 35 (range 12 to 80) was severely burned (‘cooked’). Burn severity of the crowns for canopy trees (both conifers and hardwoods) was approximately 43 unburned (i.e. ‘green’), 39 scorched (‘brown’), and 18 consumed (‘black’). For seedlings and shrubs approximately 16 of the crown was green, 59 was brown, and 25 was black. Forest types displayed a wide range of burn severities. For example, in the conifer woodland forest type, only about half of the forest floor area burned, and there was almost no crown consumption, while in the open mixed forest type, nearly all of the forest floor burned and the majority of the crowns were consumed. Table 2 describes mean vegetation severity estimates for plot located in specific stand types/units (i.e. ‘intensive plots’), by biomass component and unit. Of the seven units, only three were burned and included in the analysis. Because severity was estimated in an individual stem basis, it could be divided not only by trees, saplings, seedlings, and shrubs, but also by species and live/dead status. Across all units, conifer trees, saplings, and seedlings burned more severely than hardwoods and dead trees burned more severely than live trees. For tall shrubs, these trends were not observed; all species, status combinations had between 32 and 43 crown consumption. As with forest types, the units displayed a wide range of burn severities. The Birch unit experienced the least amount of consumption; there was less than 50 consumption for all biomass components. However, the upper-slope Black Spruce unit was severely burned; consumption ranged from 53 to 100 for all biomass components. These results are available for each plot in the watershed and are summarized by forest type and fuelbed component. They are also stored in a GIS data layer in order so that summaries can be compiled for any subset of the watershed.

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FROSTFIRE Fuel and Fire Characterization Sampling Design and Plot Locations

Sandberg, D.V.; Ottmar, Roger; Vihnanek, Robert; Bluhm Andrew

FERA used a hierarchical sampling design to provide 1) intensive sampling of fuels and fire effects in each key forest type and 2) a systematic grid of dispersed plots to characterize the entire watershed. Data and observations taken from each layer in the hierarchy are used to infer characteristics of the other data layers. The intensive site design provides for seamless inclusion in FERA's database and models of fire effects in the boreal forest and other ecosystems, while the dispersed plot layout is optimized to provide ground truth for Thematic Mapper imaging and other remote sensing. Seven intensive plots were located in the watershed, each with eighteen subplots. Each fuelbed component (trees, saplings, shrubs, understory vegetation, woody fuels, surface vegetation, forest floor) was characterized according to its effect on the fire environment and its importance as a carbon pool. Mature trees were measured individually, while lower vegetation was characterized in smaller subplot areas. We used a standard protocol developed by FERA to characterize fuelbeds in Alaska and develop models to predict fire severity. Two hundred and twenty-six (226) dispersed plots are located on a 200-meter grid across the entire watershed. Vegetation and fire severity was classified on an area basis, and measurements taken of the dead biomass near each plot center. A subset of forty-four (44) plots ("dispersed intensive") involved more quantitative sampling of vegetation and the forest floor. All plots are located by GPS coordinates for future monitoring. We used a sampling protocol adapted from one commonly used to ground-truth remote sensing products. This design should provide individual results from the FrostFire experiment and future research in the research watershed to be placed in context with the totality of the characteristics observed.

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Frostfire: GIS and Remote Sensing Applications

Sandberg, David V.; Alvarado, Ernesto; and Ottmar, Roger D.

The Fire and Environmental Research Applications Team (FERA) is developing temporally and spatially explicit forest floor, vegetative, fire behavior, and fire severity data layers using ground inventory data, aerial stereo photography, infrared scanner imagery, and Landsat TM imagery. The robust collection of data will allow the analysis of the FROSTFIRE experiment at several time and spatial scales.

The finest spatial data was collected before the fire on a grid of 160 intensive and 226 dispersed ground plots designed to study fuelbed and vegetation characteristics. Those plots were re-measured after the fire to re-characterize vegetation, determine ground fire severity, and estimate effects on carbon pools and emissions. The second spatial data scale was gathered from aerial stereo photography taken on June 5 and 11. The prefire aerial photography (1 inch=500 feet) was used to produce an enhanced map of vegetation types currently existing in the C4 watershed. The map includes 11 vegetation types and smaller patches that will allow us to map the vegetation mosaic across the watershed. Post fire aerial stereo photography was taken on August 4. Post fire aerial photos were interpreted and digitized to produce a fire severity map that includes 5 classes. This will allow detailed analysis of the relationships between vegetation type, fire behavior, and fire severity.

During the fire, a USDA Forest Service aircraft equipped with infrared sensors scanned the watershed several times. Real-time fire behavior was characterized with remote sensing in collaboration with a USDA PSW Station/NASA project. The project produced 24 infrared images that cover all the active flaming and residual smoldering at flight time. The FROSTFIRE research watershed is also part of a Landsat TM validation project. The FERA team is collaborating with the USDA FS Intermountain Fire Sciences Laboratory at Missoula, MT to develop methods and protocols for mapping fuels and fire hazard across multiple scales using Landsat TM imagery.

Finally, FERA is developing methods and protocols to consistently analyze FROSTFIRE results across multiple spatial scales. These FROSTFIRE results will assist FERA scientists to better understand the fire process across multiple ecosystems ranging from the boreal forests in Alaska to the tropical forests in Brazil.

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FROSTFIRE: Severity Map from Aerial Photography

Sandberg, D.V. (1); Alvarado, Ernesto (2); Bluhm, Andrew (1); and Morse, Richard

FERA has developed a fire severity map based on interpretation of aerial stereophotography at a scale 1"=500 ft. A map of pre-fire forest types was developed too. The pre-fire photos were taken between on June 5 and June 11, the post-fire were taken on August 4, 1999. The post-fire patches were digitized and assigned to one of the five burn severity classes that can be visually assessed from stereo pairs. The fire severity classes are based on the canopy condition observed on the post-fire photos.

The blackened class corresponds to a crown fire for the entire patch, only stems left, all foliage was consumed; the Scorched class corresponds to a crown fire on the entire patch, foliage still attached to the branches but scorched brown; the mixed class shows a pattern of scorched brown crowns with live green crowns intermixed, with more brown than green crowns; and the Green Lit class includes patches mostly live crowns with very few scattered dead trees or no signs of fire as evaluated from the stereo photos. The Green No Lit class corresponds to the area of the watershed that was outside of the ignition area.

As part of the analysis of pre and post aerial photography, a forest type map was also developed. The forest types were photo-interpreted by the FERA technical personnel in charge of the ground sampling. Special attention was put to match what was observed on the aerial photos with field experience and knowledge of Viereck's vegetation classes. Eleven forest types were classified within the boundaries of the fire line.

Further work will include the study of the burn severity in relation to pre-fire fuelbed characteristics, vegetation patterns, slope and aspect, fuel moisture, observed fire behavior from infrared imagery, and weather observations during the fire. A spatial analysis will be performed to correlate the ground fire severity measured from FERA's intensive and dispersed sampling plots. Data from this experiment and others in Alaska are being used to formulate a system to predict fire severity in boreal forests.

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Isotopic Composition of Carbon Dioxide from a Boreal Forest Fire

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The isotopic composition of carbon dioxide released from terrestrial ecosystems contains information regarding its source. We collected air samples from the smoke plume during the Frostfire main burn and in the smoldering phase that followed and determined the ^{14}C , ^{13}C and ^{18}O signature of the carbon dioxide. Using Keeling plots to determine the isotopic signature of the carbon dioxide derived from the burned biomass, we estimated a $\delta^{14}\text{C}$ value of +210 per mil and a $\delta^{13}\text{C}$ value of -27 per mil. The ^{13}C signature was consistent between the main burn and the smoldering phase, whereas the $\delta^{18}\text{O}$ signature was more variable, ranging from -30.4 per mil in the main burn to -39.5 per mil in the smoldering phase. The ^{13}C signature of the carbon dioxide was consistent with the values for live vegetation, while the ^{14}C signature indicated that carbon released during the fire was stored in the ecosystem, on average, for 12 years. The ^{18}O signature reflected a combination of atmospheric oxygen and water contained in plants and soil, indicating that oxygen exchange may have occurred between carbon dioxide and water during combustion.

In addition to carbon dioxide released directly by the fire, we also measured the isotopic signature of carbon dioxide respired by soil in black spruce forest before and after the experimental burn. The isotopic signature reflects the contribution of organic matter decomposition and plant root respiration to the soil carbon dioxide flux. We intend to continue measuring soil respiration fluxes and isotopic signatures following the fire in unburned forest, and burned forest where vegetation is prevented from recolonizing. From these measurements, we will quantify the net release of carbon by decomposition in the years following the fire, and determine the source of organic matter that drives this post-fire carbon flux.

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The Effects of Fire on Soil Solution Chemistry in Discontinuous Permafrost Forest Basin in Interior Alaska

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Hinzman, Larry D.; Boone, Richard D.

The wild fire has been an important role on hydro-biogeochemical cycles in discontinuous permafrost region located in interior Alaska. The fire will affect the quality and quantity of the chemistry of surface soil and moss environment. We observed soil solution chemistry in organic and mineral topsoil at C4 basin in Caribou- Poker Creek Research Watershed (CPCRW) to determine the effect of a fire on the nutrient dynamics from soil to stream. We installed the suction and plate lysimeters below the moss layer and Ah horizon at the burned and control site in 1998 summer. We are collecting the solution samples before and after the experimental fire, during autumn rain events and melting period to measure the concentration of dissolved organic carbon, dissolved inorganic carbon, NO₃, NH₄, PO₄ and other major inorganic elements in soil solution. The initial condition and some results of soil solution will be presented in the upcoming workshop.

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Ground Temperature Regime after Wildfire in Boreal Forests of Interior Alaska

Romanovsky, V.E.; Yoshikawa, K.; Hinzman, L.D.; and Bolton, W.R.

Intensive forest fire research was conducted in the Caribou-Poker Creeks Research Watershed (CPCRW), located 48 km north of Fairbanks, Alaska, in the summer of 1999. These results are compared to another fire in interior Alaska to establish the applicability of this study to the other site. The thermal conditions in a pre- and post-burn black spruce forest were monitored in this experiment. One purpose of this study was to detect the short-term changes in the ground temperature regime after wildfire in boreal forests of Interior Alaska. To contribute to this understanding, we examined the relationship between temperature and moisture content both in the seasonally frozen and seasonally thawed active layers. Two fires, occurring in 1996 and 1999 in CPCRW, have been examined for this study. The active layer thickness or freezing rate of the seasonally frozen layer responds to the surface moss layer thickness. The thickness of the remaining (partially burned) moss layer was very important in controlling the thermal condition of the mineral soil after the fire. Removing the moss layer dramatically changes the thermal conditions. Snow depth and soil water content were not significantly different in the first winter (first freezing period at the 1999 site). However, ground conditions change to higher water content and warmer soil temperatures after several years in the 1996 burned site. The pre-burn thickness of the moss (fiberic) layer was 16 cm at the 1999 study site. Fire destroyed this layer completely and the upper part of the peat layer (8 cm) was also destroyed. The loss of this low thermal conductivity insulative material amplified the ground temperature fluctuations. The temperatures in mineral soil at the 1999-burned site were warmer in autumn and colder in winter compared to the same depth at the reference undisturbed site. While the ground surface temperature (one centimeter below the ground surface) at the 1999 burned site was significantly warmer (by 2 to 5 °C) during the freeze-up period (between October 10, 1999 and January 1, 2000) than at the reference site, the freeze-up at the 1999 burn site occurred one month earlier (January 2, 2000) than at the reference site. These measurements have helped develop a more comprehensive understanding of fire impacts and recovery in permafrost regions of boreal forests.

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Modeling the Response of Boreal Forest to Climatic Warming: Understanding the Interactions Between Vegetation, Climate, and Disturbance Regime in Interior Alaska

Rupp, T. Scott; Starfield, Anthony M.; Chapin, III; F.S.

Variations in regional fire regime are highly sensitive to changing climate and vegetation pattern. Simulating the response of terrestrial ecosystems to climatic warming involves complex interactions between climate, disturbance, and recruitment across the landscape. This dynamic linkage is manifest in the Alaskan boreal forest where climate, vegetation composition, and fire regime have all varied considerably in the last 10,000 years. In the boreal forest, successional changes in vegetation strongly influence disturbance probability, and disturbance type and severity largely determine successional trajectory. Historically there have been strong vegetation effects on fire regime, demonstrating the importance of temporal and spatial vegetation pattern across the landscape. We developed a spatially explicit landscape model (ALFRESCO) that integrates effects of climate, vegetation, fire, and topography to simulate changes in regional patterns of fire and vegetation in response to a changing climate. Model simulations suggest rapid changes in disturbance regime and vegetation within the boreal forest in response to changes in climate. Fire and vegetation are connected by a negative feedback, in which early successional post-fire vegetation is less flammable than late successional vegetation. Fire-induced changes in vegetation led to a more homogenous landscape dominated by early successional deciduous forest. These results suggest that the higher albedo deciduous forest dominance would have a negative feedback to climate warming due to changes in albedo and energy partitioning, and landscape pattern would influence disturbance dynamics, which feedback to regional carbon dynamics.

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Response of boreal forest soil CO₂ efflux to experimental wildfire (Frostfire) in an interior Alaska watershed

Valentine, David W.; Boone, Richard D.

We assessed the response of mid-day net soil CO₂ flux (respiration-photosynthesis) under two contrasting vegetation types to an experimental wildfire of moderate intensity as part of the Frostfire project. In 1998 and 1999, late growing season soil CO₂ effluxes in three unburned replicate sites under mixed hardwood (MH; *Betula papyrifera* and *Populus tremuloides*) averaged 110-150 mg C m⁻² h⁻¹. These rates were 2-3 times higher than under closed canopy black spruce (CBS; *Picea mariana* and mixed shrubs). Growing season soil temperatures at any given depth were higher in MH than in CBS sites owing to an insulating moss layer, and peak correlations between CO₂ efflux rates and soil temperatures occurred closer to the soil surface in MH than in CBS sites. In July 1999, the moderately intense fire killed all vegetation and thinned the CBS moss layer by an average of 5.5-6.5 cm. The fire halved soil CO₂ effluxes from MH sites and reduced soil CO₂ effluxes from burned CBS sites slightly but significantly ($p < 0.05$). Decreased CO₂ efflux probably resulted from fire-induced cessation of root respiration in both sites. The thinning of the CBS moss layer both reduced insulation and eliminated moss and herb photosynthesis; both may have contributed to offsetting respiration declines.

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Approaches to Understanding the Effects of Wildfire on Interior Alaskan Vegetation Trajectories

Williams, Cynthia L.; Foote, M. Joan

Our Frostfire research is based on the premise that boreal vegetation change is mediated by species-specific responses to disturbance. Much of the response of individual species to wildfire can be understood by identifying the smaller scale processes and specific thresholds influencing species distributions immediately post-fire. In this poster we introduce and outline some of our syntheses of the pertinent biology, literature, and longitudinal studies of the effects of wildfire on interior Alaskan forests. We are using four primary organizational approaches: 1) principles of plant growth and morphology, 2) comparative life histories, 3) environmental effects, and 4) longitudinal studies. In this poster we diagram intra-annual life history characteristics of dominant tree species, contrast the growth and replacement responses of major species to ground fires of different severities, and outline fifteen fire regime scenarios based on an integration of the four approaches. We conclude from longitudinal studies of post-fire vegetation trajectories that: 1) Trajectory of overstory vegetation following fire is usually dominated by the mix of species that establish during the first four post-fire years. 2) Fire severity has specific species-specific threshold effects on site recovery. 3) Species specific responses and thresholds needed for modeling vegetation response to fire have not yet been extracted from existing datasets. 4) Major changes in vegetation trajectories are most likely when these thresholds are reached. In this poster we summarize our ongoing syntheses of Joan Foote's published and unpublished studies of post-fire vegetation trajectories in Alaska in order to refine modeling algorithms describing patterns and rates of vegetation change after fire, and to identify specific thresholds causing major changes in vegetation dynamics.

Our Frostfire sites and sampling strategy were chosen to strengthen our ongoing analyses toward the following goals: 1) to identify for major species the relative survival, regeneration, and seed production thresholds in existing spatial and temporal fire severity gradients, 2) to quantify for major species the regeneration potential as a function of on-site, neighborhood, and regional presence and seed sources, 3) to distinguish the effects of early post-fire herbaceous and shrub layer composition and regeneration on subsequent canopy composition and cover, and 4) to distinguish whether post-fire vegetation trajectories follow a repeatable set of alternative pathways (perhaps linked to a few overriding environmental determinants), or whether vegetation response is more varied (perhaps with a greater number of determining factors).

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Duff Moisture Dynamics in the Frostfire Prescribed Burn Unit

Wilmore, Brenda; Sandberg, David V.; Fox, John D. Jr.

Duff Moisture Dynamics in the Frostfire Prescribed Burn Unit Brenda L. Wilmore, John D. Fox, Jr., and David V. Sandberg In the fire prone Alaskan Interior the feathermosses are the predominant fire carrier. It is the moisture content profile of the moss mat that determines if and how much of the feathermoss fuel is available for combustion. The Canadian Forest Fire Danger Rating System (CFFDRS) Fire Weather Index (FWI) attempts to model the moisture content profile of the forest floor with three fuel moisture codes. To enhance understanding of how the feathermoss mat might be incorporated into the FWI fuel codes, weekly bulk density and moisture content samples were collected from four stand types within the Caribou-Poker Creek watershed from May through July of 1999. The stand types included a riparian black spruce (LGBS), a ridge top black spruce (UPBS), a north slope black spruce (SLBS), and a birch stand (BIR).

The feathermoss mat in all of the four stands was composed of *Hylocomium splendens*. and/or *Pleurozium schreberi*. Four distinct layers (live moss, dead moss, upper duff, and lower duff) were observed within the moss profile in all of the stands. Each layer exhibited distinctly different bulk density and moisture content dynamics. The bulk density of each given layer tended to be similar across stand types. Despite the homogenous forest floor there was great variability in moisture content in each given layer within and across stand types. This had a significant effect on which areas of the watershed burned during the Frostfire ignition and smoldering phases.

The FWI showed strong correlations with moisture contents of the different layers. The Fine Fuel Moisture Code was best correlated with the live moss layer. The Duff Moisture Code was best correlated with the dead moss layer. The Drought Code correlated well with both the upper and lower duff layers although the correlation was generally stronger with the lower duff layer. This indicated wetting and drying trends are being adequately modeled by the FWI fuel moisture codes. However, the variation in moisture content between sites and the large range of burn depths observed in the Frostfire burn unit suggest that the moisture content prediction capabilities of the FWI fuel moisture codes still need refinement for precise burn prescription development.

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Effects of Fire Perturbation on the Morphology of Ectomycorrhizae in Association with Black Spruce (*Picea Mariana*) in a Boreal Forest in Interior Alaska

Woodgate, Wayne A; Dexter, Kyle RK; Laursen, Gary A

Pre-burn ectomycorrhizal infection in Black spruce (*Picea mariana*) was evaluated for the criterion of hyphal presence, weft or mantle thickness, hyphal color, wall thickness, and the presence of clamp connections to assess potential changes in mycorrhizae due to quantifiable effects of fire perturbation in interior Alaska. It is hypothesized that the biodiversity of post-fire ectomycorrhizae will change morphologically due to reduced aboveground vegetation, fewer epigeous fungal sporocarps, a greater number of soil borne Zygomycetes, and fungi associated with pyrophyllitic sclerification. Four plots (two coniferous and two mixed deciduous) in the Caribou-Poker Creek watershed were established as control and experimental study sites. They were sampled for mycorrhizae and sporocarps three times each for two years prior to the Frostfire controlled burn to establish a baseline database. A single post burn sample was the only one taken due to the lateness of ignition and the phenology of fungal fruit body appearance in Interior Alaskan boreal forests. An analysis of mycorrhizal spruce roots collected pre- and post-burn demonstrates one hundred percent (100) infection. A large proportion (82) of the constituent ectomycorrhizae had smooth, thin walled and hyaline hyphae; other roots sampled (9) had thick walled, dark, and faintly ornamented hyphae (believed to be that of *Cenococcum*) and some samples (9) had both types on the same histological section. Of the roots with thin walled hyaline hyphae, 24 had clamp connections. The presence of different ectomycorrhizal morphotypes is indicative of the different mycorrhizal species of higher fungi forming these associations. The baseline data will be used to assess disturbance affects of fire on mycorrhizae associated with Black spruce in interior Alaskan boreal forests.

Variations of Surface Water, Energy and Carbon Exchange Associated With Boreal Forest Fire

Wu, W.; Lynch, A. H.; Chapin, F. S. III

Influence of vegetation re-growth associated with boreal forest fire on surface water, energy and carbon fluxes is investigated using a column climate system model. First, the response of several vegetation types which are most likely to occur at some point after fire is investigated under the same atmospheric environment. The results show substantial variations in surface water, energy and carbon exchanges due to changes in land cover induced by fire. Second, two multi-decadal model simulations were conducted to examine long-term surface flux variations after fire. The control experiment specifies a cool climate mixed forest for the whole period, the sensitivity experiment considers a typical vegetation succession after-fire scenario, in which the surface type varies from a charred surface immediately after fire, followed by shrub, to deciduous forest, and then to black spruce forest in the last two decades. In Comparison to the control experiment, we found that 1) air temperature and soil temperature became warmer after fire, and soil temperature was more responsive; 2) soil generally became drier; 3) variations in precipitation mostly occurred in short term, while changes in evaporation occurred both in short and long terms; and 4) Ecosystem carbon uptake were generally decreased throughout the experiment, so that the sink role of ecosystems became weaker. These changes are due to the decrease in albedo and increase in leaf area index in the years following a fire.

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Short- and Long-Term Impacts of Wildfire on the Thermal Regime and Soil Moisture Content in the Boreal Forests of Interior Alaska

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The purpose of this study is to investigate the short and long-term impacts of wildfire in the boreal forests of Interior Alaska. Our working hypothesis is that wildfire affects the short- and long-term ground thermal regime and soil moisture content in different ways with substantially different responses. The short-term effect of wildfire results in increased ground temperature and soil moisture content, while the long-term effect is an increased ground temperature and decreased soil moisture content. The magnitude of change (both short- and long-term) in ground temperature as well as soil moisture content is proportional to fire severity. The active layer thickness or thawing rate of the seasonal frost layer is mainly a function of the surface albedo, the ground surface temperature, and soil moisture content. Fire severity controls the thickness of the remaining (partially burned) organic layer, which in turn controls the thermal condition of the mineral soil.

Several natural wildfires (which occurred in the 1920s, 1954, 1994, 1996, and 1999) in Interior Alaska have been examined for this study. At each location, we examined the relationships between active layer thickness, ground temperature, soil moisture content, and burn severity. We found that as the active layer thickness was not significantly different between lightly burned and unburned areas, the soil thermal regime and the vegetation structure were not dramatically altered by the mild burning. However, the severely burned sites had higher soil moisture contents and warmer soil temperatures following the wildfire. In the decades following a fire, the severely burned sites have progressively become dryer and warmer resulting in major changes to the vegetation type and soil structure. The pre- and post-fire active layer thickness and fire severity were measured at sites burned in 1994, 1996, and 1999. The pre-burn thickness of the organic layer was estimated from the adjacent non-burned areas. Between the burned and non-burned areas, the surface temperature, surface soil moisture content, ground temperature, soil moisture content at the organic layer/mineral soil interface, and active layer depth were measured every 3 meters. At the 1996 burn site, a ground temperature and soil moisture transect was established between the burned area and the adjacent non-burned area. The soil structure, ground temperature and soil moisture content were examined in black spruce and aspen forests at the 1954 burn site. These measurements have helped develop a more comprehensive understanding of the fire impacts and recovery in permafrost regions of the boreal forests.

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Modeling Permafrost and Carbon Dynamics in an Old Black Spruce Ecosystem

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We coupled the modified Goodrich model, a one-dimensional finite difference soil thermal model with moss and organic layers in the soil profile, to the Terrestrial Ecosystem Model (TEM) for the purpose of simulating monthly soil temperatures at different depths in high latitude ecosystems. In this version of TEM, soil biogeochemical processes are influenced by soil temperatures in the top 20 cm of the soil. We evaluated the performance of this model for an old black spruce ecosystem at the Bonanza Creek LTER site where simulations successfully used mean monthly air temperature for estimating soil temperature at different depths in the soil. To test the applicability of this model for black spruce ecosystems in other regions in North America, we compared simulated and field-based soil temperatures, gross primary production (GPP), ecosystem respiration (RESP), and net ecosystem production (NEP) in an old black spruce (OBS) ecosystem in the northern study area (NSA, northern Manitoba, Canada) of the Boreal Ecosystem Atmosphere Study (BOREAS). We simulated monthly soil temperatures, GPP, RESP, and NEP for the NSA OBS site from 1975 to 1997 using climate data from Thompson, Manitoba, and compared these estimates to field-based estimates available between 1994, 1995, 1996, and 1997. Model estimates of soil temperature are highly correlated to measurements at 5, 10 and 20 cm depths ($R^2 = 0.96, 0.98, \text{ and } 0.96$, respectively). Model estimates for GPP and RESP are highly correlated with the field-based estimates ($R^2 = 0.92, 0.94$ for GPP and RESP, respectively). The slope of the regression between field-based and simulated GPP is approximately 1.00 (0.96); the intercept of the regression (-2.87) is not significantly different from 0. In contrast, the slope of the regression between field-based and simulated RESP (0.77) is less than 1.00, and the intercept (11.34) is significantly different from 0. Although the simulated seasonal pattern of NEP generally matched the field-based data, the correlation was lower ($R^2 = 0.40$). These analyses indicate that the soil thermal model of TEM provides good estimates of monthly soil temperature in the upper soil profile of black spruce forests in both Alaska and Northern Manitoba. Additionally, this version of TEM is useful for simulating carbon fluxes at an eddy correlation tower in Northern Manitoba.

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Modeling Soil Temperature of Alaskan Black Spruce Forests

Zhuang, Qianlai; Romanovsky, Vladimir E.; and McGuire, David A.

Modeling soil temperature is important for estimating carbon dynamics of boreal forests. In black spruce forests, soil temperature depends on the properties of snow cover, moss, organic soil, mineral soil and air temperature. Traditionally, soil temperature has been modeled using daily air temperature at a fine time step (for example, 0.5 hours). For application to large spatial scales, it would be useful to run a soil temperature model using monthly air temperature data at a coarse time step (for example, 12 hours). To evaluate this possibility, we modified the Goodrich model, a one-dimensional finite difference model, by integrating a moss layer into the soil profile of black spruce forests. We applied the modified model to a black spruce stand in Bonanza Creek Experimental Forest, a Long Term Ecological Research (LTER) site. We ran the model with four combinations of input data and time step: (1) using daily snow cover and air temperature data and running the model at 0.5 hours time step; (2) using daily snow cover and air temperature data and running the model at 0.5 days time step; (3) using monthly snow cover and air temperature data and running the model at 0.5 hours time step; and (4) using monthly snow cover and air temperature data and running the model at 0.5 days time step. For all simulations, the slopes of the regression between simulated and observed temperature are approximately 0.9 at depths of 23cm, 32cm, 42cm, and 52cm below the soil surface. Similarly for all simulations, the slopes of the regressions between simulated and observed temperature integrated over the top 23cm of the soil are approximately 0.95. These simulations indicate that it is possible to use mean monthly air temperature and a 12-hour time step to estimate soil temperature at different depths of the soil and throughout the top layer of the soil, which is an important area for soil biogeochemical processes. Our next step is to couple the soil temperature model with a monthly biogeochemical model, the Terrestrial Ecosystem Model (TEM).

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