Does Fire Affect Climate?
Fire Effects on Regional and Global Climate

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Alaska Human-Fire Interactions Symposium, August 15, 2006
Interactions of Boreal Forest Ecosystems with the Earth’s Climate System

Regional Climate

Global Climate

Water and energy exchange

Impacts

Exchange of radiatively active gases (CO$_2$ and CH$_4$)

Delivery of freshwater to Arctic Ocean

Boreal Forest Ecosystems
Terrestrial responses to warming in the Arctic that influence the climate system. Responses of permafrost on the left are coupled with functional (physiological) and structural biotic responses on the right either directly (arrows B and D) or through mediating processes of disturbance and land use (arrows C and E). Functional and structural biotic responses are also coupled (arrow A). Response pathways are identified at three time scales (seconds to months, months to years, ad years to decades).

How might fire regimes contribute to radiative forcing?

Two of the major contributors:

1. Changes in ecosystem metabolism (e.g., respiration and photosynthesis) can lead to cooling/heating through changes in greenhouse gas concentrations.

2. Fire contributes to changes in surface albedo. How long do these changes in surface albedo persist following fire? That is, what is the cooling effect of fire in the long term?
Question to ask:

How do changes in the fire regime of the boreal forest influence:

(1) ecosystem metabolism, and
(2) albedo

in terms of radiative forcing (e.g., heating or cooling) to the atmosphere?
Upland black spruce fire chronosequence in Delta Junction, Alaska (64ºN)

Photos: J. Randerson
Responses of boreal forests to fire disturbance in Bonanza Creek

![Graph showing the responses of boreal forests to fire disturbance in Bonanza Creek. The graph plots NPP (gC m^{-2} yr^{-1}) and RH over time (Year) from 0 to 225 years. The NPP line shows an initial increase, a peak, and then a decrease, while the RH line remains relatively constant.]
Responses of boreal forests to fire disturbance in Bonanza Creek

Net Carbon Flux to Ecosystem = NPP - RH - Fire Emissions
Terrestrial Ecosystem Model couples biogeochemistry & soil thermal dynamics

Soil temperature

Vegetation type; Snow pack; Soil moisture

atmospheric carbon dioxide

gross primary production

respiration $R_A$

decomposition $R_H$

litterfall production

Vegetation

Labile Nitrogen

exchange

Structural Nitrogen

uptake

Nitrogen input

Net exchange/mineralization

Inorganic Nitrogen

uptake

Nitrogen lost

Carbon

Net exchange/mineralization

Litterfall production

Soil and Detritus

Carbon

Net exchange/mineralization

Nitrogen

Prescribed Temperature

Snow Depth

Moss Depth

Organic Soil Depth

Mineral Soil Depth

Upper Boundary Conditions

Heat balance surface

Heat Conduction

Snow Cover

Moss & litter

Frozen Ground

Moving phase plane

Soil Temps. at Different Depths

Soil Thermal Model (STM; Zhuang, McGuire, & Romanovsky)
CO$_2$ Concentration

Climate (Cloudiness, Temperature, Precipitation)

Fire regime (Severity, History, FRI)

TEM Carbon Pools (Vegetation & Soil)

NPP

$R_H$

Fire Emissions

NECB
We conducted a simulation in which we allowed fire frequency to increase across the boreal forest region by 1% per year so that annual area burned was approximately doubled by between 2000 and 2100 across the boreal forest.

Some of our simulations indicated that the boreal forest region lost 1000 g C m$^{-2}$ during the 21$^{st}$ Century. This is equivalent to approximately a “local area” forcing of 3 W m$^{-2}$.

However, at the global scale this effect will only influence atmospheric concentrations of CO$_2$ by a few ppm.

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Photos: J. Randerson
For how long does higher albedo persist following fire?

How does an increasing fire cycle affect albedo in the long run?
Changes in surface albedo at the Delta Chronosequence

Grey line = Recent burn
Black line = Control

Liu et al., 2005
Randerson et al. (in review):

report measurements and analysis of a boreal fire near Donnelly Flats, integrating the effects of greenhouse gases, ozone, aerosols, black carbon deposition on snow and sea ice, and post-fire changes in surface albedo. The net effect of the fire was to increase radiative forcing during the first year ($33 \pm 31 \text{ W m}^{-2}$ of burned area). Over the first 80 years after fire, however, the net effect of all agents was to decrease radiative forcing ($-2.3 \pm 2.2 \text{ W m}^{-2}$) largely due to sustained increases in surface albedo.

However, a reduction in fire return interval from 100 years to approximately 80 years will decrease radiative forcing by only about $0.2 \text{ W m}^{-2}$ across the landscape.
Conclusions

• It is clear that an integrated analysis of the responses of ecosystem metabolism and ecosystem structure (albedo) is necessary to estimate the effect that fire may have on climate. The degree to which the climate system is vulnerable depends on the rate at which the fire regime changes as this has consequences for both the rate of carbon loss as CO$_2$ and the rate of conversion of conifer forests to deciduous forests.

• Fire seasons like the ones we experienced in 2004 and 2005 released substantial amounts of CO$_2$ to the atmosphere and will have lasting impacts on albedo over the next century. Will these large fire years lead to local cooling?