Interactions between fire and carbon cycle in the boreal zone of Siberia

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- Wei Min Hao, US Forest Service, Missoula, MT, USA
- Galina Ivanova, SFI, Krasnoyarsk, Russia
- Elena Kukavskaya, SFI
- Douglas McRae, NRCAN-CFS (retired), Ontario, Canada
- Evgenii Ponomarev, SFI
- Amber J. Soja, National Institute of Aerospace, Hampton, VA, USA
Background

- Wildland fire affects some 10 to 20+ million ha of boreal forest and forest-steppe annually—mostly in Russia.
- Changes in these fire patterns have potential for global effects.
- There is great spatial and temporal variability in vegetation, fuels and burning conditions.
- Fuel consumption and emissions vary widely within and between ecosystems.
- Accurate estimates of impacts of fire on carbon cycle in require many different types of information to eliminate major sources of error.
- Data and models must be integrated across temporal and spatial scales.
The FIREBEAR (Fire Effects in the Boreal EurAsian Region) project—1998 to present

- Goals:
  - Build collaborative relationships
  - Increase global awareness of Russian science
  - Increase participation of Russian scientists globally
  - Foster opportunities for young scientists
  - Better understand the role and effects of fires in Russia in a global context.

- Collaborate on remote sensing of fires in Asian Russia
- Experimental burns in Scots pine and mixed conifer/larch forests-variations in behavior and effects
- Integrate experimental data with remote sensing and with weather data
- Study interactions between fire and logging
- Better understanding of variability of fire and effects in time and space
  - Fire emissions
  - Fire behavior
  - Ecosystem effects, fire regimes
  - Management impacts
  - Carbon and fire/climate interactions
What have we learned?

- Remote sensing data have improved accuracy of burned area estimates for Russia. Data from 1996-2002 are from the receiving station in Krasnoyarsk (Anatoly Sukhinin).
- Historically, official data on burned areas in Russia were substantial underestimates.
- There are large interannual variations in burned area.
- Variations are not synchronous across the boreal zone, or within Eurasia.
Geographical patterns of fire vary annually

Mapping and classification systems affect estimates of burned area by vegetation type

Proportion of burned area in each ecosystem type for Siberia from 2002 to 2011 according to (a) GLC-2000, (b) GlobCover-2009, (c) MODIS Land Cover Collections 4 and (d) 5, and (e) the Digitized Ecosystem Map of the Former Soviet Union.

This study illustrates how critical accurate mapping of vegetation is to any estimates of emissions or fire effects on a regional scale.

Kukavskaya et al., (2013) CJFR
We are trying to refine remote sensing estimates of number of wildfires vs. agricultural fires, and their effects on burned areas. The goal is to correct estimates of burned areas based on accuracy of satellite detection for fires of different categories.

1 – category of «ordinary» wildfires;
2 – short-lived fires (mostly agricultural and very small)
3 – large scale wildfires

Courtesy of Evgenii Ponomarev
Influence of short-duration fires on burned area estimates

Fires that were identified only during one satellite overpass during 1996 — 2012 made up 45 to 65% of total fires. Their burned area has been estimated to be up to 30% of the annual total.

Based on SPOT and LANDSAT imagery, most of these fires are 1-day agricultural burns, and their area has historically been overestimated because they are much smaller than the 1km nominal hot spot pixel of AVHRR or MODIS.

Courtesy of Evgenii Ponomarev
USFS & Sukachev Institute of Forest (SIF) MODIS Burned Area Algorithm vs. Landsat

Landsat Scene: September 18, 2008

Courtesy Wei Min Hao and Evgenii Ponomarev
Fire chronology—central Siberia Scots pine

Fire return interval: 25-35 years
Landscape-scale fire return interval: ~50 years

Data from Galina Ivanova
The wide range in fire behavior in these forests leads to highly variable emissions and potential impacts on carbon cycle in stands of similar structure, composition and fuel loads.

Fuel consumption from our experimental surface fires on dry pine sites varied from 1 to 2.8 kg/m² depending largely on burning conditions.

Because of the variability in burn severity, especially in Scots pine forests, we have been developing models to relate fire weather and fuels to fuel consumption and emissions.

Such models will enable predictions of potential burn severity and emissions over large areas.
Potential Fire Feedbacks to Climate—An Example
Fire severity in Scots pine varies widely

Scots pine forest before, immediately after, three, and eight years since fire of (I) moderate- and (II) high-severity fire. After moderate-severity fire trees were alive and composition of herb/shrub layer did not change; high-severity fire resulted in almost total tree mortality and in colonization by grasses.
Recovery of ground fuel loading after fires of low, moderate and high severity.

Relationship between ground fuel load one year after fire and fire severity index (FSI).
Experimental surface fires

Rate of spread: 2.5 m/min
Fireline intensity: 620 kW/m

Rate of spread: 4.9 m/min
Fireline intensity: 2259 kW/m

Rate of spread: 5.6 m/min
Fireline intensity: 5220 kW/m

Data and photos from Douglas McRae
Relationships derived from experimental fires in dry Scots pine forests

- FWI and the Russian PV-1 moisture index correlate well with depth of calculated fuel consumption (based on prefire and postfire sampling).

- We also show strong relationships between FWI and depth of burn and between depth of burn and consumption of ground fuel (litter and humus layers).

- These are clearly ecosystem-specific. The gray and open points are for more mesic types of pine forests.

McRae et al. manuscript in preparation
Weather-based fire hazard indices can relate well to distribution and severity of fires in Siberia:

<table>
<thead>
<tr>
<th>Fire Weather Index</th>
<th>Carbon emissions t/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 to 10</td>
<td>4.1 to 7.7</td>
</tr>
<tr>
<td>10 to 15</td>
<td>7.7 to 10.0</td>
</tr>
<tr>
<td>15 to 23</td>
<td>10.0 to 13.7</td>
</tr>
<tr>
<td>23 to 40</td>
<td>13.7 to 21.4</td>
</tr>
</tbody>
</table>

Canadian Fire Weather Index (FWI) in part of central Siberia for 6-15 June 2003. High FWI values are associated with areas of high fire activity. Estimates of potential fuel consumption are based on data from experimental fires in Scots pine. Active fires from MODIS over the same period are shown in red on the right.

FWI map and data: Doug McRae. Remote sensing data: Anatoly Sukhinin
Burn severity affects soil respiration

- After even low-severity surface fires in Scots pine and larch forests, soil respiration decreases significantly.
- Recovery to prefire levels may take several years.
- Fire severity was higher on Plot 2 than on Plot 1.

Post-fire soil respiration in Scots pine (Baker and Bogorodskaya, AGU 2010)
Analysis and classification of fire scars

Classification of Landsat imagery based on correlation with postfire disturbance and tree mortality.

12 test sites in the Angara river region

30 test sites in the southern pines

Angara region

Southern pines
We classified burn severity into five classes based on field sampling of tree mortality on 49 burned areas. Class I represents the highest severity, Class V the lowest severity. (Ponomarev and Buryak, unpublished)

<table>
<thead>
<tr>
<th>Severity class</th>
<th>Total area, ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>3978</td>
</tr>
<tr>
<td>Class II</td>
<td>9630</td>
</tr>
<tr>
<td>Class III</td>
<td>77765</td>
</tr>
<tr>
<td>Class IV</td>
<td>25184</td>
</tr>
<tr>
<td>Class V</td>
<td>138091</td>
</tr>
<tr>
<td>Fire by treeless</td>
<td>58644</td>
</tr>
</tbody>
</table>
Fuel loads in different forest types

by tree species

Fuel loading, t/ha

European part of Russia
Siberia
Central Siberia

Ivanova, Kukavskaya, Tchebakova, unpublished
Fuel loads in pine stands of central Siberia by ground cover

Ivanova, Kukavskaya, unpublished
Fuel loading vs. fuel depth in drained peats in Krasnoyarsk region

Depth-of-burn: 0.4 – 0.6 m
Carbon emissions: 650 – 950 t/ha

Kukavskaya and Ivanova, unpublished
Interactions between fire and logging

- Fuel consumption in fires on logged sites is typically twice that in fires on unlogged sites (Kukavskaya et al. submitted).
- We can estimate GHG and aerosol emissions from fuel consumption data. (Baker, Hao, Samsonov (IJWF 2012), and others).
Development of long-term (30-yr) remote sensing data sets on fire in Russia

Data gap

September 2002 GAC composite

MODIS

September 9, 2002

AVHRR LAC

Don Cahoon and Brian Stocks, unpublished
Modeling Fire Behavior-Emissions with the CanFIRE Model

- Remotely Sensed Data
  - Fuels Database
    - Fuel Types
    - Fuel Load
  - Final burn area (AVHRR, MODIS)
  - Daily fire spread (hot spots)

- Daily Weather
  - FWI System
    - Burning Conditions
      - Fire-induced C Pool Changes And Emissions

Bill de Groot, NRCan, Canadian Forest Service
Burning Conditions

Fuels (load, type)

Fire behaviour, fire effects projections
Russian Study Area
Preliminary Comparison of Russian and Canadian Boreal Fire Size

Adapted from de Groot et al., 2012, A comparison of Canadian and Russian boreal forest fire regimes, Forest Ecology and Management
Summary

- Forest and steppe fires are widespread disturbances in Siberia that may have important feedbacks with climate.
- Variability in behavior and effects of fire is high—both spatially and temporally.
- To understand and predict global/regional effects of fire we must understand processes, estimate effects at stand and landscape levels, and quantify changes over time.
- We have developed both intensive (field-based) and extensive data on many aspects of fire, fuels, fire effects on a range of undisturbed and disturbed sites, and effects of fire weather on fuel consumption for Siberia.
- We are still working to refine some of the important data-bases and models.
- We will integrate this information through the CanFIRE model to model fire and fire effects across Siberia, and to project effects of climate on changing fire regimes.
- Well worth the time and energy to build international collaborations.
Collaborating Organizations:

Russian Forest Service
- Forestry Committee and Leshozes, Krasnoyarsk Region
- Forest Protection Airbases, Krasnoyarsk Region
- Avialesookhrana headquarters, Pushkino, Moscow region

Russian National Academy of Science, Siberian Branch
- V.N. Sukachev Institute of Forest, Krasnoyarsk
- Institute of Chemical Kinetics and Combustion, Novosibirsk

Universities
- Siberian Technological University
- St. Petersburg Forestry University
- University of Arizona

US Forest Service
- Rocky Mountain Research Station
- Northern Research Station

International Programs
- Natural Resources Canada, CFS
- Great Lakes Forestry Centre
- National Institute of Aerospace

Coordination with other NASA, ISTC and CFS-funded research
Thank You

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