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"Connecting diverse terrestrial, emissions, air quality and modelling communities."

Fire Emissions in Central Siberia

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Introduction

Wildfires in the Russian boreal forest zone are estimated to typically burn 12-14 million hectares (ha) annually [Cahoon et al. 1994; Conard and Ivanova 1997; Conard et al. 2002; Dixon and Krankina 1993; Kasischke et al. 1999]. Boreal forests contain about 21 percent of global forest area and 28 percent of global forest carbon [Dixon et al. 1994], yet data on the extent and impacts of fire in these forests related to actual burning conditions are scarce and often contradictory. While seemly very remote, smoke from Siberian biomass burning can easily reach North America via long range transport, and can at times constitute a significant amount of the pollution present in the Arctic (Amber et al. 2008).

Fire is a highly variable phenomenon [Countryman 1972]. Depending upon burning conditions, the emissions from a fire can have a wide range of total gas and aerosol amounts as a result of variable consumption of biomass fuels. Another aspect of fire is its variation in intensity. If a fire is intense enough it can inject smoke to high altitudes, which benefits long-range emission transportation. To better understand fire in central Siberia, the Russian FIRE BEAR (Fire Effects in the Boreal Eurasia Region) Project was created as a forest fire research study to provide answers to basic questions on the management of fuels, fire and fire regimes, with the goal of enhancing carbon storage and forest sustainability in ways that minimize negative impacts of fire on global environment, wood production and ecosystem health [McRae et al. 2006]. Improved understanding of the extent and severity of fires and of factors affecting fire behavior, as well as the effects of fire on carbon storage, air chemistry, vegetation dynamics and structure, and forest health and productivity is essential for an improved understanding of the impacts of these fires.

Figure 1. A typical view of a dry site Scots pine forest growing close to 60° N latitude in central Siberia. Note the lack of conifer vegetation between the ground and the tree crowns, which would have acted as a ladder fuel for initiating a crown fire if present.

This paper highlights some of the findings on fire emissions from the FIRE BEAR Project, which has been on-going since 1999. The discussion will center on data obtained from burning 200x200 m experimental plots on Scots pine (Pinus sylvestris)/ lichen (Cladonia sp.)/ feather moss (Pleurozeum schreberi) forest sites in the Krasnoyarsk Region of central Siberia. One site was 200 km northwest of where the Angara River empties into the Yenisey River, while two sites were near the Angara, 200 km east of this confluence. Study site latitudes ranged from 58 to 60 degrees north. Even this far north, these central Siberian forests support a commercially viable timber harvest (Fig. 1). Similar latitudinal locations in Canada are mostly above the treeline or support only dwarf-sized trees. Study sites were multi-aged forests, with the oldest trees dating back to 1550. At the Yartsevo site, fires (dominated by early summer surface fires), occurred an average of once every 29 years between 1550 and 1956, the dates of the first and last recorded fires on the site. However, this does not consider the extensiveness of fires at different spatial scales [Swetnam and Baisan 1996]. Only twelve fires were recorded on at least 30 percent of the trees (including the 1550 date). The average mean interval between these fires was 36.9 years. Larger, landscape-scale fires recorded on at least 50 percent of the sample trees occurred 8 times (once every 58 years) over the same period [McRae et al. 2006].

Methodology

The research team set up a complete fire weather station on site for calculating the fire danger based on both the Russian Moisture Code [Vonsky 1975] and the fuel moisture codes and fire behavior indices of the Canadian Forest Fire Weather Index System [Canadian Forestry Service 1987; Van Wagner 1987]. These daily fire danger values are used as independent variables to portray burning conditions in models that were created to estimate expected fire behavior and fuel consumption. Biomass of all ground, surface, and aerial (tree) fuels was sampled before and after burning. The differences allowed the team to estimate the fuel or biomass consumption. This information was used to estimate total emissions for each fire. Experimental fires were carried out in June and July, which correspond to the main fire season for this region. Plots were burned under a wide range of fuel moisture and weather conditions to observe effects on fire behavior, fire severity, emissions, and other ecological factors. Protective firelines, ignition, and suppression were the responsibility of the Russian Aerial Forest Protection Service (Avialesookhrana) fire management personnel. All experimental plots were burned using line ignition along the windward side to quickly create equilibrium fire behavior that mimicked wildfires under similar burning conditions [Johansen 1987; McRae 1997].

Figure. 2. A Russian researcher using a filter probe held over an active portion of a fire to collect aerosols. A pump with a known flow rate collects smoke samples through the probe and deposits them onto filters for later analysis (apparatus on wheels to the left side of the image).

To measure patterns and speed (rates) of fire spread, electronic timers similar to those of Blank and Simard [1983] were used. These timers were buried at grid points in a 25x25-m sampling grid laid across each plot. Using times from 3 timers, an algorithm [Eenigenburg 1983] can be used to estimate direction and rate of spread of a fire. For several fires, researchers were fortunate to be able to estimate rates of spread using an infrared camera that was flown aerially over the fire [McRae et al. 2005]. Combining rate of spread and fuel consumption values allows the estimation of fireline intensity [Byram 1959], which can be used to estimate fire column height or potential injection altitude of the smoke into the atmosphere.

Carbon emission factors, in units of grams produced per kg of fuel burned for carbon dioxide, carbon monoxide, and methane, were determined using both ground and aerial emission sampling. The canister samples collected were analyzed in the laboratory for these gases and other hydrocarbons [McRae et al. 2006]. In addition, ground and air particulate sampling (Fig. 2) was carried out to enable quantitative determination of chemical elements comprising the aerosol particles [McRae et al. 2006, Samsonov et al. 2006].

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Results and discussion

All test fires were surface fires (Fig. 3) due mainly to the absence of ladder fuels that allow a fire an opportunity to shift from the surface to the crown of a tree. In fact, during a typical year in Russia, 80% of all fires are reported to be surface fires [Belov 1976; Furyaev 1996]. Total fuel consumption ranged from 1.0-3.2 kg/m^2, depth of burn into the organic forest floor ranged from 3.3-6.6 cm, rates of spreads ranged from 0.6-16.9 m/min, and fireline intensities ranged from 185-14,530 kW/m. Fire scenarios ranged from situations where personnel could easily approach and cross over the active fireline to ones where the fire was impossible to approach due to safety concerns (e.g., heat, fast fire spread).

Carbon (C) released by the fires (assuming that carbon comprises approximately 50 percent of the dry fuel consumed - [Levine and Cofer 2000]) ranged from 4.8 to 16.1 tonnes (t) C ha^{-1} depending upon the fire severity. This range of carbon release accurately reflects the variability of fire behaviour and fuel consumption experienced at actual fires throughout a normal fire season. It is this variability, along with the exact characteristics of individual fires, that emission modellers find difficult to incorporate into their simulations for a particular forest type. By combining data from experimental fire sites with regional weather data, the team has developed regression models that link fire emissions with both the Canadian and Russian Forest Fire Danger Rating Systems (Fig. 4). This

Figure 3. Images showing the typical range in Scots pine fire behavior on a dry site in central Siberia for a) a low-intensity (620 kW/m); b) a moderate (2259 kW/m); and c) a high-intensity (5220 kW/m) surface fire. Only the latter surface fire was severe enough to cause mortality of all trees on the site. The multiple fire whirls that were observed on the latter fire are good indicators of a high-intensity fire.

approach holds significant promise as a way of combining fuel and weather data with remote sensing-based fire severity estimates to calculate carbon sequestration and emission.

Emission factors of CO were between 98 g/kg and 135 g/kg, and the average emission factors of CH_4 and CO_2 for these fires were approximately 8 and 1650 g/kg, respectively. These data indicate a significant release of greenhouse gases (carbon dioxide and methane), from fires in central Siberia, given the total amount of biomass consumed annually. The emission factor value ranges are similar to those found for wildfires burning in pine forests in the western United States [Babbit et al. 1994] and for North American boreal and temperate forests [Cofer et al. 1996].

The data indicate significant emissions of a wide range of aerosols in smoke [Samsonov et al. 2006; McRae et al. 2006], which have the potential to significantly affect both regional air quality and atmospheric chemistry and radiation fluxes. More specifically, in a typical year, where $12 \times 10^6 – 14 \times 10^6$ ha burn in Russia, we estimate that $3 \times 10^6 – 10 \times 10^6$ t of particulate matter may be emitted into the atmosphere [Samsonov et al. 2006]. About 90-95% of the particulate matter consists of fine smoke particles in the size range of 0.1- 5 mm in diameter. Such particles can strongly affect both the scattering and absorption of solar radiation in the atmosphere resulting in a decrease in the amount of solar energy which is able to reach the Earth's surface. Entrained aerosols include soil particles that have accumulated prior to the fire as dust on vegetation or on the surfaces of litter and ground fuels. This appears to be the primary means by which fire emissions acquire a significant quantity of chemical elements typically found only in soils (e.g., iron, calcium, aluminum, silicon, etc.).

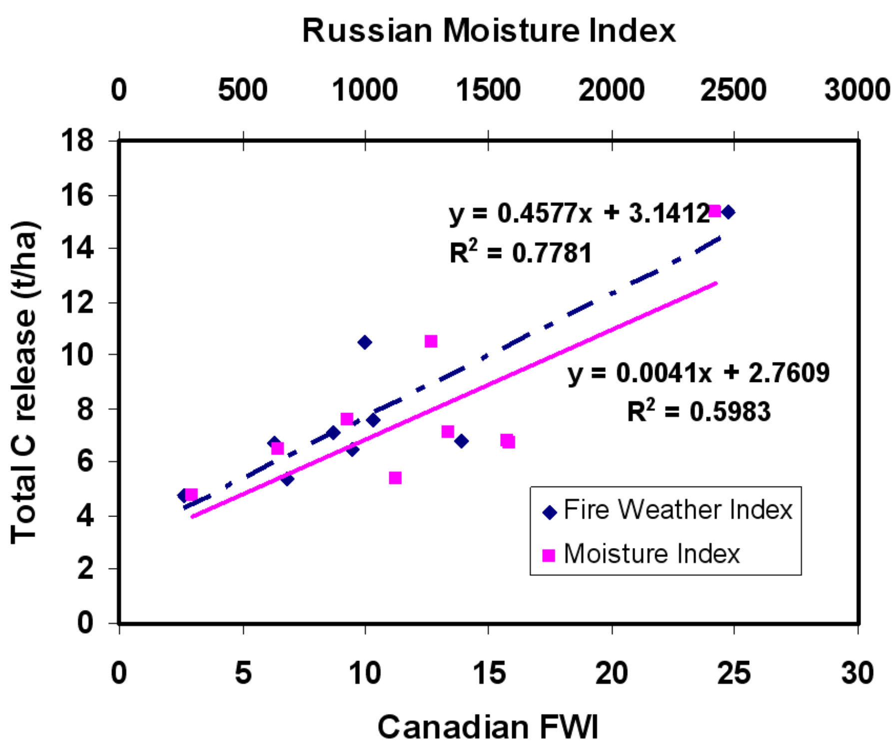

Figure 4. Models illustrating the relationships between carbon release from our experimental fires and Fire Weather Index (FWI) values of the Canadian Forest Fire Weather Index (Canadian, Forestry Service 1987) and the Russian Moisture Index (Vonsky et al. 1975).

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