Climate Change and Wildfires[1]

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Abstract

Wildland fire regimes are primarily driven by climate/weather, fuels and people. All of these factors are dynamic and their variable interactions create a mosaic of fire regimes around the world. Climate change will have a substantial impact on future fire regimes in many global regions. Current research suggests a general increase in area burned and fire occurrence but there is a lot of global variability. Recent studies of future global fire weather under different climate change scenarios using several General Circulation Models are reviewed. A widespread increase in future fire weather severity was found over almost all the earth with increasing fire season length occurring in many regions, particularly at northern latitudes. In the boreal forest region, which represents about one-third of global forest cover, increased area burned over the last four decades has been linked to higher temperatures as a result of human-induced climate change. This trend in the boreal region is projected to continue as fire weather severity and fire intensity will sharply rise by up to 4-5 times current peak values by the end of the century. Many national fire management organizations already operate at a very high level of efficiency, and there is a very narrow margin between suppression success and failure. Under a warmer and drier future climate, fire management agencies will be challenged by fire weather conditions that could push current suppression capacity beyond a tipping point, resulting in a substantial increase in large fires.

Keywords: General Circulation Models, IPCC climate change scenarios, fire weather severity, fire intensity, fire management

Introduction

Wildland fires burn 330-431 M ha of global vegetation every year (Giglio and others 2010). About 86% of wildland fire occurs in tropical grassland and savannahs, and 11% in forest (Mouillot and Field 2005). There is charcoal evidence that global fire

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has increased since the last glacial maximum about 21,000 years ago, with increased spatial heterogeneity during the last 12,000 years (Power and others 2008). During the last millennium, the global fire regime appears to have been strongly driven by precipitation, and shifted to an anthropogenic-driven regime during the Industrial Revolution (Pechony and Shindell 2010). In the last few decades, there is evidence of greater area burned and increasing fire severity in many different global regions (Pyne 2001, FAO 2007, Bowman 2009). There are varied reasons for regional increases in wildland fire activity, but the primary factors are fuels, climate-weather, ignition agents, and people (Flannigan and others 2005, 2009b). In future, fire regimes are expected to be temperature-driven (Gillett and others 2004, Pechony and Shindell 2010), with warmer conditions and longer fire seasons leading to increased area burned and fire occurrence (Flannigan and others 2009b). However, a review of global research papers showed mixed results for fire severity and intensity (Flannigan and others 2009a). In the boreal forest region, which represents about one-third of global forest cover, fire records document increased fire activity in recent decades (Stocks and others 2003, Kasischke and Turetsky 2006) due to increased temperature (Westerling and others 2006). Under current climate change scenarios, global temperature increase is expected to be greatest at northern high latitudes (IPCC, 2007). For that reason, the boreal forest region is anticipated to experience the earliest and greatest increases in wildland fire activity under future climate change. The purpose of this paper is to summarize recent research on future global fire regimes, resulting impacts on fire behavior in circumpolar boreal forests, and implications for fire management.

Future global fire regimes

In a recent study of future global wildland fire (Flannigan and others 2013), the potential influence of climate change on fire season length and fire season severity was examined by comparing three General Circulation Models (GCM) and three possible emissions scenarios (nine GCM-emission scenario combinations). The GCMs used in the study were: 1) THE CGCM3.1 from the Canadian Centre for Climate Modeling and Analysis, 2) the HadCM3 from the Hadley Centre for Climate Prediction in the United Kingdom, and 3) the IPSL-CM4 from France. The models were selected to provide a range of expected future warming conditions. There are four emission scenario storylines (A1, A2, B1, and B2) that set out distinct global development direction to the end of this century (IPCC, 2000). The Flannigan and others (2013) study used the following three scenarios: A1B, representing a world of very rapid economic growth with global population peaking by mid-century, rapid development of efficient technology, and a balanced use of fossil fuel and non-fossil fuel sources; A2, representing a world of increased population growth, slow economic development, and slow technological change (business-as-usual scenario); and B1, representing the same population as A1, but more rapid change in economic structure, and moving towards service and information technology.

The GCM-emission scenarios were used to calculate fire weather conditions during the next century. Fire weather data (temperature, relative humidity, wind speed, 24-hr precipitation) were used to calculate daily component values of the Canadian Forest Fire Weather Index (FWI) System (Van Wagner 1987). Fire season length was calculated using a temperature approach, with the start of the fire season defined as three consecutive days of 9°C or greater, and the end of the fire season by three consecutive days of 2°C or lower. Fire severity was calculated using the Daily Severity Rating (DSR), which represents the increasing difficulty of control as a fire grows (Van Wagner 1970) and is a simple power function of the Fire Weather Index component of the FWI System. In the Flannigan and others (2013) study, changes in fire severity were measured using the Cumulative Severity Rating (CSR), which was the sum of DSR values during the fire season divided by the fire season length. In this way, the CSR was a seasonal length-scaled version of the DSR. Changes in future fire season length and CSR were summarized by decade as anomalies from the 1971-2000 period (results were only presented for mid-century and end of century).

Figures 1 and 2 from the Flannigan and others (2013) study show examples of CSR for the HadCM3 model and the A2 scenario for 2041-2050 and for 2091-2100. These examples (Figures 1 and 2) are representative of all the GCMs and scenarios maps that show a significant world-wide increase in CSR especially for the northern hemisphere. With these increases, we expect more area burned, increased fire occurrence, and greater fire intensity that will result in more severe fire seasons and increased fire control difficulty.

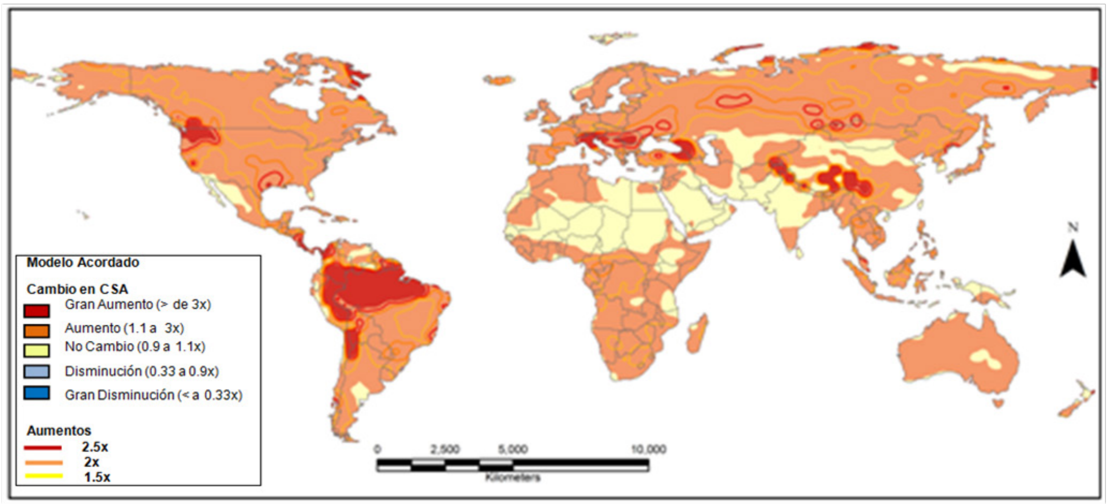

Figure 1—Cumulative Severity Rating anomalies for the HadCM3 A2 scenario for 2041-2050 relative to the 1971-2000 base period.

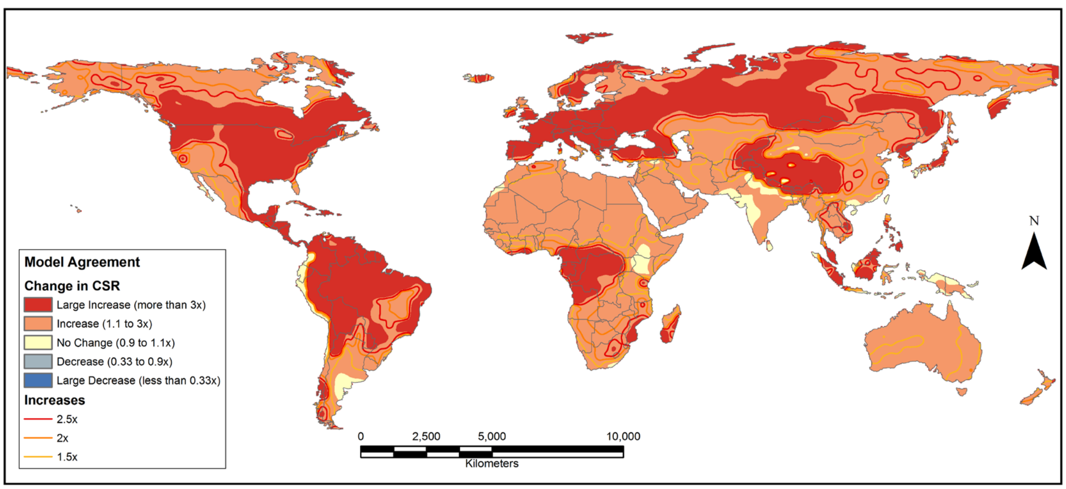

Figure 2—Cumulative Severity Rating anomalies for the HadCM3 A2 scenario for 2091-2100 relative to the 1971-2000 base period.

Future boreal fire regimes

There are several studies that indicate an increasing trend in area burned across the North American boreal zone during the last several decades (Podur and others 2002, Kasischke and Turetsky 2006) that is closely aligned with an increasing temperature trend, and is a result of human-induced climate change (Gillett and others 2004). A steadily increasing temperature trend is expected to continue at northern latitudes as climate change progresses. Fire regimes of the northern circumpolar boreal forest are changing rapidly and will continue to do so, and may serve as an early indicator of potential change in other global fire regimes. The boreal forest covers 1.35 B ha, representing about one-third of global forest cover (Brandt 2009, FAO 2001). There is an average of 9 M ha (ranging 4–18 M ha) burned annually in the boreal forest region (Giglio and others 2010). A change in boreal fire regimes can have substantial impact on atmospheric greenhouse gasses because the boreal zone is the source of 9% (182 Tg C yr^{-1}) of global wildland fire C emissions (van der Werf and others 2010).

Over 70% of the boreal forest is in Eurasia, with the remainder in North America. Although the boreal forest is primarily represented by *Pinus, Picea, Larix, Abies, Populus* and *Betula* spp. across the entire forest region, there is a distinct difference in continental fire regimes. This dichotomy in fire regimes is due in great part to differences in forest composition and tree species morphology, and the influence of those characteristics on fire regime. The major difference between the two continents is that the North American boreal forest is dominated by *Picea* and *Abies* (44% by area) and *Pinus* (22%), which have highly flammable foliage and either a low branching habit (*Picea*, *Abies*) or a relatively low live crown base height (*Pinus*) that promote crown fires. In northern Asia, the boreal forest is dominated by Larix (30%), which has foliage with high moisture content, and relatively tall-growing *Pinus* (28%) species, which have a higher live crown base height; both of these factors substantially reduce the occurrence of crown fire in northern Asia.

A recent modeling study comparing boreal fire regimes in western Canada and central Siberia (de Groot and others 2012a) indicates that there are many more large (>200 ha) fires occurring in northern Asia than North America. Therefore, there is a much higher annual area burned rate, and shorter mean fire return interval in northern Asia (1.89 M ha per 100 M ha of forest land; MFRI=53 years) than in western North America (0.56 M ha per 100 M ha of forest land; MFRI=180 years). However, the average large fire size in western North America (5930 ha) is much larger than in northern Asia (1312 ha). Most fires in boreal North America occur as crown fires (57%), which appears to be limited by the total amount of coniferous cover (63% of the study area of de Groot and others 2012a). In northern Asia, only 6% of large fires occurred as crown fires in the de Groot and others (2012a) study, due to two-thirds of the study area being covered by non-crowning fuel types (*Betula, Larix, Populus*) and higher average live crown base heights for crown fire-susceptible species (*Pinus sibirica, Pinus sylvestris*). As a result, North American fire regimes are typically dominated by infrequent fast-spreading crown fires of very high intensity, and northern Asia fire regimes are characterised by relatively frequent surface fires of moderate to high intensity. Although there is a higher C emissions rate (t/ha) in North American boreal fires due in part to greater crown fuel consumption, there is a much higher total C emissions from wildland fires in the Asian boreal (128 Tg C $year^{-1}$, vs

54 Tg C $year^{-1}$ in North America) due to a much higher annual area burned rate and a larger total forest area.

A follow-up study by de Groot and others (2012b) examined the impact of climate change on these circumpolar boreal fire regimes. Future boreal fire regimes were simulated with the CGCM3.1, HadCM3, and IPSL-CM4 GCMs and the A1B, A2, and B1 scenarios, using the same procedures as Flannigan and others (2013). The resulting fire weather data and FWI System parameters were used in the Canadian Fire Effects Model (CanFIRE; de Groot 2006, 2010) to simulate future expected fire behavior and C emissions. The results showed that fire weather severity increased across the circumpolar boreal region, and that the DSR and head fire intensities also increased, although conditions were slightly more extreme in North America. All of these parameters indicate that there will be greater difficulty in controlling future wildland fires across the boreal forest. All three GCMs showed general agreement in long-term trends of increasing fire weather severity and fire behaviour activity, but the Hadley and IPSL models in particular, indicated future burning conditions that far-exceed current conditions. By the end of the 21st century, all GCM and scenario combinations indicated that average monthly head fire intensities will exceed airtankers suppression capability in most months of the fire season (April to September) across the boreal region; the IPSL and Hadley models indicate that this suppression threshold will be surpassed in every month from April to October. The results of the de Groot and others (2012b) study, combined with the increasing fire season length in the boreal region found by Flannigan and others (2013) and other studies suggesting that annual area burned could increase 2–5.5 times in boreal North America (Flannigan and others 2005, Balshi et al, 2009) and increased fire activity in Russia (Dixon and Krankina 1993, Stocks and others 1998), indicate that there will be a huge increasing demand on fire management in the future, regardless of climate change scenario.

Climate change and fire management

Current climate change models are in agreement that there will be increased fire weather severity in the future. This is anticipated to increase both fire occurrence and severity, resulting in larger fires and more area burned, which raises serious doubts over the ability of fire management agencies to effectively mitigate future fire impacts. Forest fire management agencies currently operate with a very narrow margin between success and failure when suppressing fires, and a warmer and drier climate would result in more fires escaping initial suppression efforts and growing large (Stocks 1993). In addition, given competing fiscal demands, governments would be unlikely to provide funding increases necessary to maintain current effectiveness levels.

In a study within the boreal region, McAlpine (1998) suggested that increased frequency of drought years and extreme climatic events, in combination with longer fire seasons, would increase fire activity and area burned in Ontario, Canada. Minimizing the increases in area burned associated with climate change would require significant increases in fire management expenditures. Simulation studies using the Ontario initial attack system (McAlpine and Hirsch 1998) showed that reducing the number of escaped fires from current levels would require a very large investment in additional resources, and that incremental increases in fire suppression resources result in diminishing gains in initial attack success. Wotton and Stocks (2006) used Ontario's initial attack simulation system in combination with scenarios of expected fire occurrence and fire weather to show that a doubling of current resource levels would be required to meet a modest increase of 15% in fire load (which is based on number of fires and difficulty of control). More recently, Podur and Wotton (2010) expanded this work, combining GCM-derived scenarios of future fire weather with a fire growth and suppression model in Ontario. Results indicated a 2-fold to 5-fold increases in area burned over the next century, driven by more frequent fire weather conducive to large fire growth and an increasing number of fires escaping initial attack. The recent development of the Canadian Wildland Fire Strategy (CWFS), approved by federal, provincial, and territorial governments (CCFM 2005), is in direct response to the growing consensus that climate change-driven forest fire and forest health issues, along with diminishing fire management capacity and an expanding wildland urban interface, will combine to create unprecedented fire effects across Canada in the near future. Under this scenario, maintaining current levels of fire protection success will be economically and physically impossible, as well as ecologically undesirable. A new accommodation with fire, in which fire assumes its natural role across more of the Canadian landscape, seems a likely outcome of this confluence of factors.

The substantial increases in CSR predicted globally across climate change scenarios by the end of this century are truly noteworthy for wildland fire managers. Increases of up to 300% in CSR, particularly in the northern circumpolar region, will place unprecedented demands on fire suppression resources. Some of the CSR increase is due to longer fire seasons (about 20-30 days); however the DSR on low and even moderate days (the most frequent days in the fire season) is quite small relative to DSR values on high and extreme days, and thus the vast majority of the increase is due to the increase in potential fire intensity and subsequent control difficulty. Fire suppression action most often fails during high intensity crown fires (Stocks and others 2004), and the climate change scenarios of this study indicate that this type of fire behavior will occur with greater frequency in the future. Many countries of the world operate highly efficient fire management organizations that have a high fire control success rate. However, climate change may cause a disproportionate increase in uncontrolled fires because many fire management organizations already operate at near to optimum efficiency; thus any further increase in fire control difficulty will force many more fires beyond a threshold of suppression capability (cf Flannigan and others 2009b, Podur and Wotton 2010). Perhaps we are already experiencing what is to come with recent disastrous fires in Australia in 2009 and 2012, Russia in 2010 and in the USA in 2011 and 2012. Increased wildland fire on the landscape in the future will force fire management agencies to re-assess policy and strategy. All wildland areas cannot be protected from fire, and many high value areas that are managed with a policy of fire exclusion will be threatened by wildfire.

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