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Global wildland fire season severity in the 21st century ☆

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ABSTRACT

We used Cumulative Severity Rating (CSR), a weather-based fire danger metric, to examine the potential influence of climate change on global fire season severity. The potential influence of climate change on fire season length was also addressed. We used three General Circulation Models (GCMs) and three emission scenarios to calculate the CSR and fire season length for mid-century (2041–2050) and late century (2091–2100) relative to the 1971–2000 baseline. Our results suggest significant increases in the CSR for all models and scenarios. Increases were greatest (more than three times greater than the baseline CSR) for the Northern Hemisphere at the end of the century. Fire season length changes were also most pronounced at the end of the century and for northern high latitudes where fire season lengths will increase by more than 20 days per year. The implications from this study are that fire seasons will be more severe in future and that conventional fire management approaches may no longer be effective.

1. Introduction

Wildland fire is a widespread and critical aspect of the earth system (Bond and Keeley, 2006). Estimates of annual area burned range between 300 and 450 Mha (van der Werf et al., 2006) which is comparable to the size of India. Over 80% of the global area burned occurs in grasslands and savannas, primarily in Africa and Australia but also in South Asia and South America. Globally fires are frequent over most of the earth except in areas of sparse vegetation (e.g., North Africa) and near the poles (Mouillot and Field, 2005). Wildland fires are a continuous and global feature with fire occurring all year long in the northern or southern or both hemispheres. We do not know how many fires are started each year but human activities are responsible for the vast majority; lightning is the other common ignition cause for wildland fires. Many billions of dollars are spent on fire management and fire suppression every year.

Fire activity is strongly influenced by four factors: fuels, climate-weather, ignition agents and people (Flannigan et al., 2005). Fuel amount, type, continuity, structure, and moisture level are critical elements of fire occurrence and spread. For fires to spread there needs to be fuel continuity; some suggest that at least 30% of the landscape needs to have fuel for a fire to spread (Hargrove et al., 2000). This is important in many drier parts of the world where a certain amount of precipitation is required prior to the fire season for plant growth to provide sufficient fuel buildup that allows continuous fire spread on the landscape (Swetnam and Betancourt, 1998; Meyn et al., 2007). Fuel structure can also be important in fire dynamics. For example, understory trees and shrubs in a forest can act as ladder fuels that carry a surface fire up into tree crowns and thereby generate a faster moving and much more intense fire. Although the amount of fuel, or fuel load, affects fire activity because a minimum amount of fuel is required for fire to start and spread, fuel moisture largely determines fire behaviour, and has been found to be an important factor in the amount of area burned.

Weather and climate – including temperature, precipitation, wind, and atmospheric moisture – are critical aspects of fire activity (Flannigan and Harrington, 1988; Swetnam, 1993). Some examples that highlight the role of weather and climate include Cary et al. (2006) who found that weather and climate best explained the amount of area burned using landscape fire models, as compared with variation in terrain and fuel pattern. Carcaillet et al. (2001) found that climate was the key process triggering fire over the eastern boreal forest during the Holocene. Prasad et al. (2008) found that mean annual temperature and average precipitation of the warmest quarter of the year were among the variables that best explained fire occurrence in southern India.

The global climate is warming and this may have a profound and immediate impact on wildland fire activity. Some suggest that wildland fire activity has already increased due to climate change.

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Gillett et al. (2004) suggest that the increase in area burned in Canada over the past four decades is due to human-caused increases in temperatures. Flannigan et al. (2009a) in a review of global wildland fire activity found numerous research papers that suggests area burned and fire occurrence will increase with a warmer climate and fire seasons will be longer. The results were more mixed with respect to fire severity and intensity with some studies suggesting increase and some suggesting no changes or decreases. The objective of this paper is to examine future global fire season severity using the Daily Severity Rating (DSR) of the Canadian Forest Fire Danger Rating System (CFFDRS). These results provide insights into future fire intensity, which is important in terms of fire management. For example, as average fire intensity increases, wildfire suppression resource requirements will exceed available resource levels with greater frequency, resulting in greater area burned. Additionally, we will calculate future fire season length for the globe as an additional indicator of future fire management challenges since longer fire seasons will translate into more fire starts and more opportunities for fires to escape control.

2. Data and methods

This study used components of the Canadian Forest Fire Weather Index (FWI) System. The FWI System is used by many countries around the world, and the FWI component itself (of the FWI System) is commonly used as a general indicator of fire danger and fire intensity at the landscape level (Van Wagner, 1987). The FWI System is a weather-based system that models fuel moisture using a dynamic bookkeeping system that tracks the drying and wetting of distinct fuel layers in the forest floor. There are three moisture codes that represent the moisture content of fine fuels (Fine Fuel Moisture Code, FFMC), loosely compacted organic material (Duff Moisture Code, DMC) and a deep layer of compact organic material (Drought Code, DC). The drying time lags for these three fuel layers are 2/3 of a day, 15 days and 52 days respectively for the FFMC, DMC and DC under normal conditions (temperature 21.1 °C, relative humidity 45%). These moisture indexes are combined to create a generalised index of the availability of fuel for consumption (Buildup Index, BUI); the FFMC is combined with wind to estimate the potential spread rate of a fire (Initial Spread Index, ISI). The BUI and ISI are combined to create the FWI which is an estimate of the potential intensity of a spreading fire. The daily severity rating (DSR) is a simple power function of the FWI intended to increase the weight of higher values of FWI in order to compensate for the exponential increase in area burned with fire diameter (Williams, 1959; Van Wagner, 1970).

The FWI was designed as a scaled analogue of Byram (1959) fireline intensity. Fireline intensity is used operationally in many jurisdictions around the world to evaluate the potential effectiveness of different resources to contain and control wildland fire for the environmental conditions on a given day. It was recognised early in the development of fire danger rating that the appropriate scale of operationally useful fire danger indexes (i.e. the FWI) did not reflect the difficulty of control or work required for suppression of a fire under given conditions (Williams, 1959). The Daily Severity Rating (DSR) was conceived to indicate fire suppression difficulty in the Canadian danger rating system and is essentially a simple power function of the FWI (with an exponent of 1.77). With this scaling, the DSR is intended to reflect the non-linear increase in difficulty of control as the fire grows (Van Wagner, 1970) and as such is the index used when seasonal summaries of fire severity are generated.

Typically, the average DSR over an entire fire season (the Seasonal Severity Rating, SSR) is used to provide a general summary of the potential difficulty of fire control over an entire season. It is used when regionally contrasting potential fire control difficulty for seasons over multiple years. A simple seasonal average, however, may not be the best relative indicator of changes in control difficulty in scenarios where a trend to a lengthening of the fire season exists. In such scenarios, increased number of days of high and extreme potential suppression difficulty may be obscured in the average by increased number of days overall; days which, in the shoulders of the season, are likely to be more benign. For this study, to try to capture the changes in control difficulty across fire seasons with potentially changing lengths, we chose to rely on the sum of DSR values over the season as our indicator of fire season severity (the Cumulative Severity Rating, CSR). In a region with an unchanging fire season duration, SSR and CSR are essentially the same (CSR simply being SSR unscaled by the number of days in the fire season). By not scaling the CSR by season length, however, it provides what can be thought of as a weighted count of number of severe days in the fire season, and thus will be a better indicator of the absolute numbers of challenging (in terms of fire

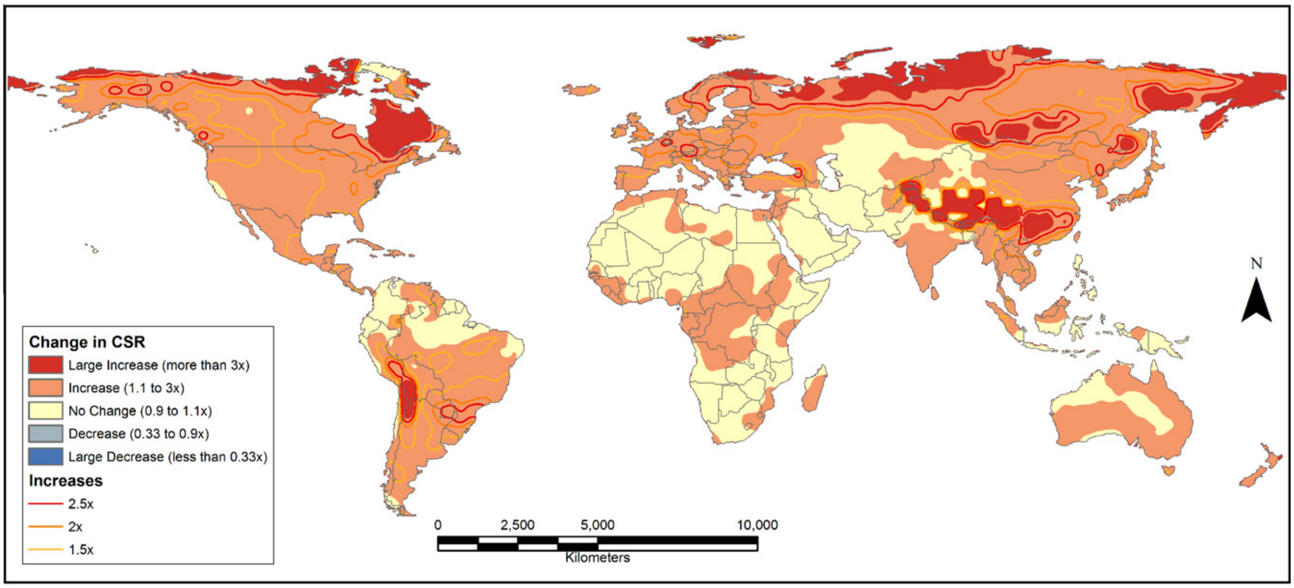

Fig. 1. CSR anomalies for the IPSL-CM4 A2 for 2041–2050 relative to the 1971–2000 base period.