Will fire danger be reduced by using Solar Radiation Management to limit global warming to 1.5°C compared to 2.0°C?

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Key Points:

- High fire danger is generally decreased at 1.5°C compared to 2.0°C, but there are regional variations and some regions show an increase
- The highest decrease in high fire danger is 3.8 on the McArthur scale, but in some regions of USA and Asia fire danger is increased by 5.5
- The number of days of high fire danger is decreased by up to 30 a year with Solar Radiation Management and increased by 31 days in parts

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Abstract

The commitment to limit warming to 1.5°C as set out in the Paris Agreement is widely regarded as ambitious and challenging. It has been proposed that reaching this target may require a number of actions, which could include some form of carbon removal or Solar Radiation Management in addition to strong emission reductions. Here we assess one theoretical solution using Solar Radiation Management to limit global mean warming to 1.5°C above pre-industrial temperatures, and use the McArthur fire danger index to evaluate the change in fire danger. The results show that globally fire danger is reduced in most areas when temperatures are limited to 1.5°C compared to 2.0°C. The number of days where fire danger is 'high' or above is reduced by up to 30 days per year on average, although there are regional variations. In certain regions, fire danger is increased, experiencing 31 more days above 'high' fire danger.

Index Terms and Keywords

1630 Impacts of global change

1631 Land/atmosphere interactions

3305 Climate change and variability

3390 Wildland fire model

7914 Engineering for hazard mitigation

1 Introduction

As climate change brings hotter, drier conditions to many parts of the world, fire danger is likely to increase in some areas. Fire is one of the most important disturbances globally, impacting vegetation, hydrological cycles, atmospheric chemistry, and the carbon cycle, as well as having socio-economic impacts through loss of life and property (Hantson et al, 2016). Studies have previously attributed fire events to anthropogenic climate change, such as the Californian fires of 2014 (Yoon et al, 2015), showing that climate change has already increased the likelihood of fire occurrence in some areas. Other studies have shown that global fire risk may change under different emissions scenarios (e.g. Gonzalez et al, 2010; Settele et al, 2014; Betts et al, 2015), showing in general an increase in fire danger with higher levels of climate change above 2°C in the future, and a shift towards a more climate-driven fire regimes (Pechony and Shindell, 2009). However there is inhomogeneous response, and in some areas fire risk may decrease with climate change in the future (Mortiz et al, 2012).

At the Conference of Parties meeting in Paris in 2015 (COP21), for the first time nations across the world committed to limit global mean warming to 2.0°C, and to “pursue efforts to limit warming to 1.5°C” (United Nations, 2015) in an attempt to limit the negative impacts of climate change. Work is now ongoing to understand how this more ambitious climate goal might be achieved, and the potential costs, benefits and impacts of a 1.5°C verses a 2.0°C world. It will also be important to fully understand the impacts of the methods used to achieve this in order to make informed choices moving forwards.

For a high probability of stabilising temperatures at 1.5°C, it will be necessary to reduce greenhouse gas emissions substantially and rapidly (Millar et al, 2017). It is also suggested that this will require net negative emissions by the end of the century or sooner (Rogelj et al, 2016), or alternative means of limiting warming. These could be achieved through deployment of geoengineering solutions, either by removing carbon dioxide from the atmosphere (Carbon Dioxide Removal, CDR) for example through Bioenergy Carbon Capture and Storage (BECCS) (Fuss et al, 2014, Smith et al, 2016), or by reducing the incoming solar radiation through Solar Radiation Management (SRM) (Vaughan and Lenton, 2011; Kravitz et al, 2013). However, these technologies are mostly untested, and the impacts of employing such methods of mitigation are not well understood.

One option for SRM could be in the form of stratospheric aerosol injection of sulphur dioxide (SO_2) (Crutzen et al, 2006). Relatively small amounts of SO_2 injection would be required (Keith et al, 2010), and this would have reasonably quick effects on reducing global temperatures. However, it has been noted that this could alter regional climate patterns (Haywood el al, 2013) and hence could modify fire regimes. Here we perform the first assessment of the potential impact on global patterns of fire danger using SRM to limit global warming to 1.5°C, compared to a 2.0°C achieved solely through limiting the rise in greenhouse gas concentrations.

It should be noted that once injected, SO_2 emissions would need to be repeated every year to maintain temperature reduction, and if stopped, the temperature would rise sharply up to pre-SRM levels (Jones 2013), unless greenhouse gas concentrations levels were simultaneously reduced. SRM may therefore allow some additional time for reducing greenhouse gas emissions, but is viewed as an unsuitable replacement for such reductions in the long-term (Keith et al, 2015). It has been shown that this termination effect would be particularly severe in high emission scenarios such as RCP8.5, and consequently it is impracticable to consider the use of SRM in this context (McCusker et al, 2014). This study therefore focuses on the potential impact of employing SRM together with strong mitigation efforts using the Representative Concentration Scenario (RCP) 2.6 (van Vuuren et al, 2011). It should also be noted that there are a number of other potential hazards of SRM which should be taken into consideration, including negative impacts on stratospheric ozone (Keith et al, 2010), hydrology and regional climate (Trenberth and Dai, 2007), nutrient cycles, and vegetation loss resulting from sulphur deposition (Crutzen, 2006), and continued ocean acidification (Robock, 2008). These additional impacts are outside the scope of this paper.

2 Methods

Here we use a theoretical SRM geoengineering scenario to model the potential impacts of fire risk on a global scale at 1.5°C compared to 2.0°C. We use output from the Earth System Model HadGEM2-ES (Collins et al, 2011; Jones et al, 2011) at a spatial resolution of 1.875° x 1.25°, driven by concentrations following the strong mitigation scenario RCP2.6, and in a second experiment set up a new run of RCP2.6+SRM is initialised at 2020 and run to the end of the 21st century with SO_2 injected continuously and uniformly into the stratosphere at a height of 16-25km in 4 member ensemble simulations. In the model, the SO_2 oxidises to form a sulphate aerosol which reflects incoming solar radiation and creates a cooling effect on the climate, simulating the effect of SRM in order to keep climate warming to 1.5°C. The results are then analysed in terms of potential fire impacts. We use the McArthur Forest Fire Danger Index (FFDI) to compare fire danger for both scenarios RCP2.6 and RCP2.6+SRM, using the mean from the 4-member ensemble runs. A period of 10 years 2061-2070 is chosen to represent the future state, as the decade at which maximum warming occurs in the RCP2.6 scenario. We also compare the results to the present day fire danger, where present day is taken as the period 2006-2015.

The assessment of fire danger is a way of determining the risk of fire occurrence and impact in a region, in terms of ignition, rate of spread, ability to control, and potential impact, based on a number of input variables (de Groot et al, 2015). The McArthur FFDI (McArthur, 1967; Noble et al, 1980) was designed for use in Australia but it can be used for assessing global fire danger, (Golding and Betts, 2008; Betts et al, 2015) and uses meteorological conditions to calculate the risk of fire occurrence in the following equation:

$$\boldsymbol{FFDI = 1.25 * D * exp\left[\frac{T - H}{30.0} + 0.0234 * V\right]}$$

Where D = drought factor, T = Temperature (ºC), H = humidity (%), and V = wind speed (km hr^{-1}). The drought factor (D) is calculated as follows:

$$\boldsymbol{D = \frac{0.191 * (SMD + 104) * (N + 1)^{1.5}}{3.52 * (N + 1)^{1.5} + P - 1}}$$

Where P = precipitation (mm day^{-1}) and N = number of days since last rain. Here we use varying soil moisture from the Earth System Model to calculate the soil moisture deficit (SMD) compared to the field capacity at a depth of 1m to account for varying ecoregions, based on Holgate et al (2017). Soil moisture is calculated based on inputs and outputs of precipitation, snowmelt, evapotranspiration and drainage. The land surface scheme is based on MOSES-2 (Essery et al, 2003), but further improved to include sub-gridscale soil moisture variability (Clark and Gedney, 2008; Martin et al, 2011).

This fire danger system is used operationally in high fire-risk areas such as across Australia as a way of providing early warning for dangerous fire events (de Groot et al, 2010). It provides a way of managing the resources needed for fire management and suppression, and underpins evacuation plans for national safety.

Here we use daily input data to calculate the FFDI. We first present the change in key meteorological variables, temperature and precipitation (Figure 1). We use the 90th percentile of daily maximum temperature to understand the extremes that contribute to fire danger, and the mean change in precipitation to understand the overall pattern of change. We then assess the change in the 90th percentile of fire danger between the RCP2.6 and RCP2.6+SRM scenario compared to present day, and explore how regions experiencing ‘high’ fire danger may change with each scenario (Figure 2). The results of these analyses are presented by Giorgi region (Giorgi and Francisco, 2000) (Figure 3).

3 Results

Compared to present day climate, the temperature increases globally in the future under scenario RCP2.6 (Figure 1, panel a) as expected. However, this increase is not homogenous; the mean change shows greater warming in the northern high latitudes (Figure S3 in the Supplementary Materials), and at the 90th percentile the regions in central and eastern USA and NE Asia show minimal to negative change. With the application of SRM, overall the temperature decreases compared to RCP2.6, however the same regions (USA and NE Asia) show an increase in temperature (Figure 1, panel c). There are also regions where the change between RCP2.6 and SRM is approximately 0, such as across Scandinavia.

The change in mean precipitation is even more heterogeneous. Across the northern hemisphere the change is mostly an increase in precipitation with RCP2.6 compared to present day (panel b). Across the southern hemisphere, the change is mostly a decrease in precipitation with particularly strong drying across Brazil, except for two regions that show an increase in precipitation (east Brazil and south Brazil / Uruguay). With deployment of SRM, the results show a decrease in precipitation in many areas compared to RCP2.6, including central and eastern USA and NE Asia (panel d). However some regions show an increase in precipitation compared to RCP2.6, including Central America, a band across Brazil, central Africa, West Asia, and most of Australia. Most of the Sahara region shows no noticeable change.

We assess how the 90th percentile of fire danger may change with RCP2.6 and RCP2.6+SRM (Figure 2) to understand if more areas are exposed to high fire danger in the future due to these meteorological changes. We also calculate how many days where the fire danger is ‘high’ or above changes between scenarios, to understand if regions become vulnerable to dangerous fires more often.

In the present day, the Sahara, Middle East, and parts of west and central Australia show 'severe' fire danger (Figure 2, panel a), which also corresponds to the highest number of days above 'high fire danger (panel b).

Compared to present day fire danger, RCP2.6 shows an increase in the 90th percentile of fire danger across most regions globally, with the highest change of 8 (panel c). The areas most affected by increased fire danger in this scenario include South America, Europe, Arabia and western Australia. Interestingly, there are also regions that decrease in fire danger in this scenario, such as USA and NE Asia, with the largest change of -5. These regions correspond to reduced temperatures and increased precipitation with RCP2.6 (Figure 1, a and b). The number of days where fire danger is 'high' or above is also mostly increased in RCP2.6 compared to present day (panel d), with the highest change across Southern Africa, Australia and South America, and a maximum increase of 62 days per year on average (619 days across the 10 year period). A similar pattern of decreased fire danger in the USA and NE Asia can be seen in both the change in the 90th percentile of fire danger (panel c) and the change in number of days above 'high' FFDI (panel d). Panel (d) also shows a decreased number of days of high fire danger across East Brazil.

Compared to present day fire danger, RCP2.6+SRM also shows an increase in fire danger for most regions in the future (Figure 2, panel e), although this is generally less than in the RCP2.6 scenario. However, the two regions (USA and NE Asia) that showed a decreased danger in the RCP2.6 scenario do not show as much of a decrease with SRM, and in fact some parts of these regions show higher danger with SRM in both the 90th percentile and the number of days above 'high' FFDI. Parts of Central America and western Asia show a marked decrease with SRM.

Overall the 90th percentile of fire danger is reduced with the application of SRM, but there are some regions that show the opposite trend (Figure 2, panel g). NE Asia and the USA show an increase in the 90th percentile of fire danger reached with RCP2.6+SRM compared to RCP2.6, with a maximum increase of 5.5. This is partly due to a decrease in fire danger seen in the RCP2.6 scenario compared to present day that is not as marked with SRM (Figure 2, panel c and e). Most other regions show a decrease, with the highest reduction being 3.8. In some areas there is no clear change, such as across western South America, and the northern high latitude regions. The change in number of days above high fire danger with SRM shows a similar increase in fire danger across NE Asia, and America compared to the RCP2.6 scenario (Figure 2, panel h). These regions show a maximum of 31 more days at 'high' fire danger on average per year at 1.5°C compared to 2°C. Again the general global trend is a decrease in the number of days of high fire danger in the RCP2.6+SRM scenario compared to RCP2.6 with a maximum reduction of 30 days per year on average, although some areas show no obvious change including central Asia.

The results show that where mean temperature reduction with SRM is minimal (Figure S3 panel b), and where the 90th percentile of temperature change shows an increase compared to RCP2.6 (Figure 1c), together with a marked reduction in precipitation (Figure 1d), there is increased danger of fire for two key regions. These regions may be exposed to higher fire danger for longer periods under an SRM scenario compared to RCP2.6.

Considering the Giorgi regions, Figure 3 shows that in most regions overall fire danger is increased in the future under both scenarios. The largest difference in 90th percentile fire danger is in Northern Australia (NAU), where application of SRM decreases the danger overall. Southern Australia (SAU) and Central Asia (CAS) also show among the highest decreases. Other regions show small changes, such as Alaska (ALA). In some cases the fire danger is reversed, with SRM causing increased fire danger at the 90th percentile compared to RCP2.6. In East Asia (EAS), Eastern North America (ENA) and Central North America (CNA) the highest fire danger increases with application of SRM, which supports the findings in Figure 2. A similar trend is seen in the number of days where fire danger is high or above. This is usually lower in the SRM scenario compared to RCP2.6, but in the same regions it is increased (EAS, ENA, CNA). In some cases the overall fire danger is changed to negative with SRM, including Central Asia (CAS), Central America (CAM), and West North America (WNA).

4 Discussion

The results presented here have shown that in general, meteorological fire danger increases in the future (Figure 2 and Figure 3), even in a scenario of strong climate change mitigation. Here we have compared the highest mitigation scenario from the IPCC Representative Concentration Pathway scenarios, RCP2.6 which limits committed warming to 2.0°C, with an even stricter mitigation target of 1.5°C achieved through implementation of SRM. If we were to compare this with a business as usual scenario, RCP8.5, we would likely see a significant difference in fire danger globally and regionally, with global temperatures expected to reach approximately 5.5°C above pre-industrial in this high emission scenario (Settele et al, 2014; Betts et al, 2015). This could also result in different patterns of increase / decrease in fire frequency and probability, for example Mortiz et al (2012) show a reduction in fire across the tropics with future high emissions scenarios in a range of global climate models. We have compared these two mitigation scenarios here to determine if there is a difference in fire danger, if so by how much, and if this the same everywhere in the world. The results have shown that the highest fire danger, the 90th percentile of the distribution, has shifted so that more regions globally experience higher fire danger in the future under RCP2.6 compared to present day (Figure 2c). Regions may also experience prolonged exposure to higher levels of fire danger in the future (Figure 2d). However, fire danger does not increase homogenously, and some areas show decreased fire danger (some parts of USA and NE Asia). These regions would experience higher fire danger with implementation of SRM, partly due to the decrease seen in the RCP2.6 scenario. These areas show the smallest decrease in temperature, and are vulnerable to decreased precipitation and humidity with SRM (Figure 1 and Figure S3 and S5). A decrease in precipitation as seen here may be partly due to circulation changes caused by lower temperatures, and research has also shown a direct impact of aerosols on the hydrological cycle and transport of latent heat, leading to a reduction in precipitation (Trenberth and Dai, 2007). This has direct implications for the use of aerosols in SRM methods. This highlights an important message, that although temperature could be decreased globally by using geoengineering methods such as SRM, the impacts are not felt evenly across the world. This spatial heterogeneity in fire danger response underlines the importance of conducting a thorough assessment of potential impacts when considering new geoengineering technology, as there may be unintended and unanticipated consequences on both a regional and global scale.

The McArthur Index is useful in providing an indication of fire danger as it includes a number of meteorological variables as well as a drought index. However, it is worth noting that it was designed and calibrated for Australian vegetation (de Groot et al, 2006), and therefore its applicability outside of this region is less certain, where other species may have a different tolerance and resistance to fire (Golding and Betts, 2008). Moreover, there will be some bias in the fire index as a result of using model input data instead of observations. To ensure the results were not dependent on the fire index used, we also assessed the mean response with the Angström Index (Chandler et al, 1983) (see Supporting Material). The Angström Index is a very simple fire index using only two variables, temperature and relative humidity. The index gives very similar results, with global mean fire danger increasing in the future, and the RCP2.6+SRM scenario generally showing a smaller increase in fire danger than the RCP2.6 scenario. Similar regions also show an increase in fire danger with SRM in both the McArthur and the Angström Index. However, the largest difference in the mean fire danger in the McArthur FFDI is in Australia, whereas the largest difference in the Angström Index is in Europe, both reflecting the regions they were designed for. Many fire indices were initially designed for other regions, such as the National Fire Danger Rating System (NFDRS) in America (Bradshaw et al, 1983), and there may therefore be some small variations in the extent of the change using different fire indices.

It should also be noted that both indices used here provide an indication of fire danger given certain meteorological conditions, and do not take into account the availability of fuel or ignitions. For a full assessment of fire prediction using fuel, flammability and ignition, a land-surface or Earth System model including fire disturbance is required. This said, the inclusion of additional inputs introduces greater uncertainty, and fire indices are therefore useful in providing a simple guide of how fire conditions may change in the future with climate change, and give an indication of how different temperature scenarios are likely to affect fire danger. They are also used operationally to manage fire danger, with the McArthur Index being used frequently in high fire-risk areas in Australia to manage dangerous fire events (de Groot et al, 2015).

5 Conclusions

This study has shown that there is a noticeable change in the fire danger with RCP2.6+SRM compared to RCP2.6. In most areas this change is a reduction in fire danger, with a maximum decrease of 3.8 in the 90th percentile, and 30 fewer days per year on average of high fire danger. However, the changes are not homogenous and there are regions where the fire danger is increased due to reduced precipitation and minimal temperature reduction with the implementation of SRM, in particular parts of NE Asia and the USA, and also due in part to the reductions seen in the RCP2.6 scenario which are not seen in the RCP2.6+SRM scenario. The maximum increase due to SRM is 5.5 on the McArthur FFDI and 31 more days of above ‘high’ fire danger per year on average. Considering the Giorgi regions, the greatest difference between the scenarios is in Australia and central Asia. In some cases the overall fire danger is changed to negative with SRM, including Central Asia (CAS), Central America (CAM), and West North America (WNA).

These results highlight the importance of thoroughly assessing all of the potential impacts on a regional scale when considering geoengineering options, to rule out any potential unintended consequences that may be caused by large scale geoengineering. The changes to key impact metrics need to be evaluated thoroughly in order to weigh them against the potential costs and risks of mitigation options such as this. The method of geoengineering chosen here also does not address CO_2 levels by itself, and additional mitigation methods would need to be simultaneously employed to reduce emissions. While it has been shown that there would be some benefits from this method of SRM in the form of an overall reduction in meteorological fire danger, the negative impacts of SRM also need to be carefully considered, and more work is needed to fully understand the potential impacts across a range of variables.

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Acknowledgments, Samples, and Data

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McArthur FFDI: http://dx.doi.org/10.5285/70ac55eb85344c3bb2239ed2d7b7575d

Angström Index: http://dx.doi.org/10.5285/75a7e567fe2342a493663a7a085d015e

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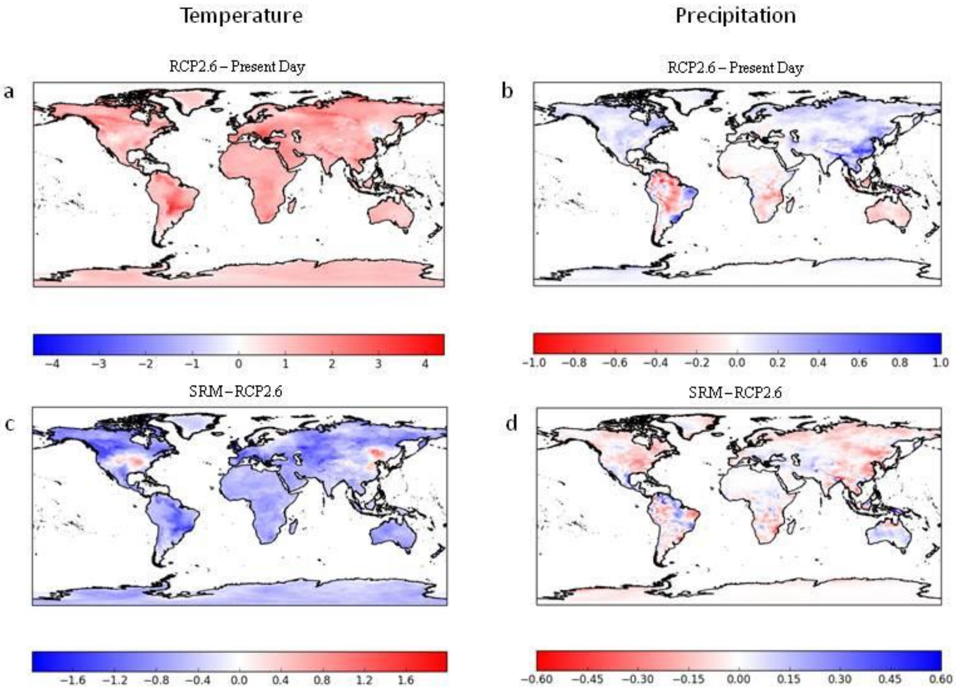

Figure 1. Change in daily climate variables: 90th percentile of daily maximum temperature (°C) at 1.5m (left column), and mean precipitation change (mm/day) (right column). Upper row shows RCP2.6 (2061-2070) minus present day (2006-2015). Lower row shows the change with SRM, calculated as change in RCP2.6+SRM (2061-2070) from Present Day (2006-2015) minus change in RCP2.6 (2061-2070) from Present Day (2006-2015).

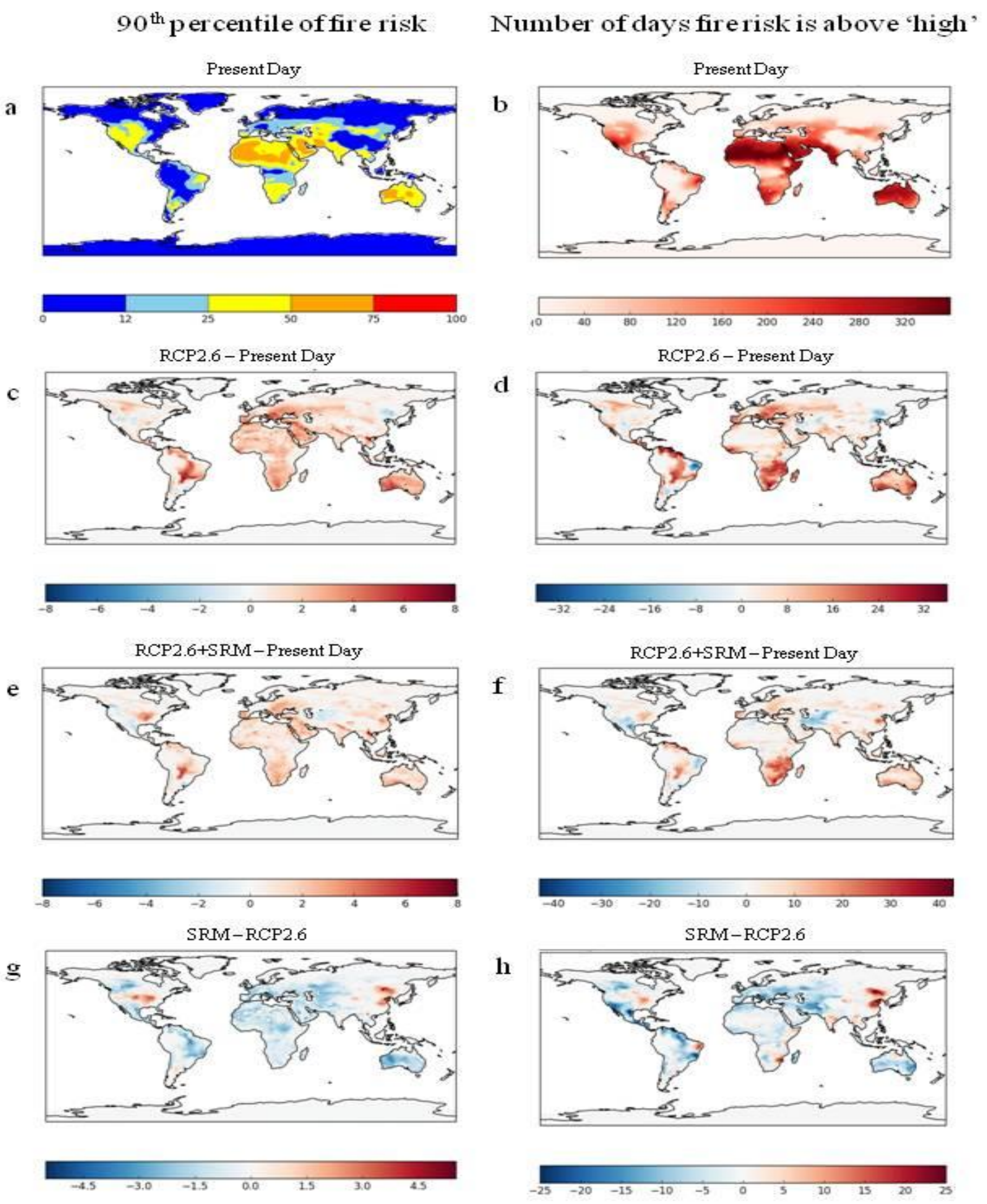

Figure 2. 90th percentile of fire danger (left column) and number of days where fire danger is 'high' or above on the McArthur scale (right column) averaged over 10 years. Top row shows present day (2006-2015). Second row shows the change in RCP2.6 (2061-2070) minus Present Day (2006-2015). Third row shows the change in RCP2.6+SRM (2061-2070) minus Present Day (2006-2015). The bottom row shows the change in fire danger with SRM, calculated as change in RCP2.6+SRM (2061-2070) from Present Day (2006-2015) minus change in RCP2.6 (2061-2070) from Present Day (2006-2015). Panel (a) uses the McArthur FFDI scale categories as follows: 0-11 = Low-moderate fire danger; 12-24 = High fire danger; 25-49 = Very high fire danger; 50-74 = Severe fire danger; 75-99 = Extreme fire danger; 100+ = Catastrophic fire danger.

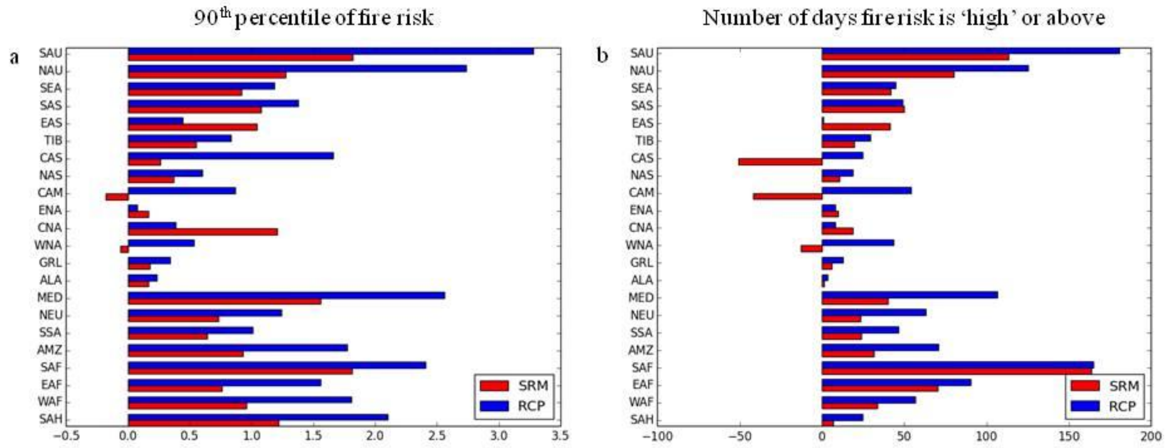

Figure 3. Graph of change in McArthur FFDI from 2061-2070 compared to present day (2006-2015), for 90th percentile of fire danger (a) and number of days at 'high' fire danger or above (b). Red bars represent the RCP2.6+SRM scenario, blue bars represent RCP2.6 scenario. Full list of Giorgi regions can be found in the Supplementary Material.