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PCIC SCIENCE BRIEF: OBSERVED INCREASES IN EXTREME FIRE WEATHER DRIVEN BY HUMIDITY AND TEMPERATURE

Over the past few decades there has been an increase in the number of large wildfires in many regions, including Canada. The extreme fireweather that drives these fires is projected to increase in many areas. Wildfires have had substantial impacts across British Columbia, destroying homes, displacing communities and blanketing large areas of the province in smoke that greatly reduces air quality. Better understanding the extreme fire weather that drives wildfires can help us to understand the future risks that they pose. A paper published in *Nature Climate Change* uses reanalysis data to examine extreme fire weather and the conditions that drive it over the 1979-2020 period. This work shows that temperature and relative humidity are driving observed global trends of increased fire weather. Here we discuss what these results tell us about changes to fire weather in our province and across Canada.

Introduction

Wildfires are a natural part of the Earth system that have shaped ecosystems for as long as vegetation has been present on our planet's surface, for more than 400 million years[1]. Fire is tied to the lifecycles of certain plants[3] and can clear the ground of decaying organic matter, allowing land organisms to access soil and soil organisms to more easily access nutrients above the soil. At the same time, wildfires can have multiple impacts on human communities, destroying homes and displacing populations, polluting drinking water, destroying timber stocks and reducing air quality as wildfire smoke blankets the landscape. The after effects of fire on the landscape can alter the soil's ability to hold moisture, leading to debris flows and mudslides.

Globally, while fire season lengths have likely increased the area burned by wildfires each year has seen a slight decline over the past few decades, due to less savannah and grassland area burning, partly as a result of changes to rainfall patterns and partly as a result of savannahs being converted into agricultural land[2]. However, this decrease is not uniform and at smaller scales the pattern can be quite different. Canada has seen an increase[4] in the area burned since the 1970s and projections suggest that this will increase still further by the end of the century[5].

The wildfires that are responsible for most of the area that is burned regionally are the small percentage of fires that occur under what are termed extreme fire conditions. These are conditions under which wildfires are most likely to occur and spread rapidly. They are characterized using a variety of indices made up of variables such as air temperature, precipitation, wind speed and relative humidity[6].

Wildfires in British Columbia (BC) can and have displaced tens of thousands of residents, with more than a hundred evacuation orders being issued in some years. The BC communities of Lytton and Monte Lake were destroyed by wildfires. The cost of fighting wildfires in BC varies yearly and runs in the hundreds of millions of dollars, with hundreds of millions more in insured and uninsured damages in some years.

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1. The first evidence of wildfire appears in the fossil record near the end of the Silurian period, about 420 million years ago, in the form of early plant fossils preserved as charcoal. For more information on this, see Glasspool, Edwards and Axe (2004).
2. For more information on the human influence on declining burn areas, see Andela et al. (2017). For more information on how shifting precipitation patterns are affecting fire patterns in Africa, home to much of the world's grasslands, see Wei et al., 2020.
3. For example, certain species of pines, such as Lodgepole pines, found in BC, have a set of cones that are sealed with a strong resin such that the cones open when the resin is melted by the heat present in fires. Fire reduces the forest canopy that blocks sunlight to the forest floor and this allows for younger, smaller trees to grow.
4. For more information on the number of wildfires and the total area burned each year, see Tymstra et al. (2020) and the Canadian National Fire Database, at: https://cwfis.cfs.nrcan.gc.ca/ha/nfdb.
5. For more information on changes to fire occurrence and annual area burned, see Boulanger, Gauthier and Burton (2014).
6. The amount of moisture that air can "hold" is a function of temperature. (Note that this is a simplification. The amount of moisture in a volume of air is given by Dalton's Law and a full treatment is outside the scope of this Science Brief.) Relative humidity is a measure of the amount of water vapour in the air, expressed as a percentage of the maximum amount of water vapour that the air could possibly hold at a given temperature.

Having a better understanding of trends in extreme fire weather and the specific meteorological variables that are most important in driving wildfires would help the scientific community to assess their confidence in and better interpret future projections of fire weather, which can, in turn, inform wildfire management practices. Writing in the journal *Nature Climate Change*, Jain and colleagues (2022) bring together satellite fire data[7], data on global biomes[8] (areas characterized by their wildlife, soil, vegetation and climate) and reanalysis data[9] to examine trends in extreme fire weather and the meteorological conditions responsible for driving them over the 1979-2020 period.

Trends in Extreme Fire Weather

Jain et al. use three indices in their analysis of fire weather: the Initial Spread Index[10] (ISI), Fire Weather Index[11] (FWI) and vapour pressure deficit[12] (VPD). The FWI and ISI are part of the Canadian Fire Weather Index System (CFWIS), which is a standard approach for the quantification and estimation of fire weather. In particular, the authors examine extreme fire weather, which they define as the 95th percentiles of these indices. They examine global trends in regions with significant burnable biomass (some areas with high aridity and low biomass, such as North Africa, are excluded are excluded).

The authors found that, globally, values for extreme FWI increased by about 14% and extremes of both ISI and VPD increased by about 12%. Considering only regions in which trends were positive, these become about 32%, 30% and 21%, respectively. Significant positive trends in extreme FWI, ISI and VPD showed similar spatial patterns (Figure 1). The strongest trends for each were in regions of western North America, South America, Africa, Western Europe and Eastern Australia. While positive trends for FWI and ISI were present in just over a quarter of burnable global land area, significant positive trends in VPD were present over a larger area, across just over 45% of the burnable land area. Significant positive trends were present over Western North America and the southern half of British Columbia. Jain and colleagues also found that areas with negative trends in all variables were much sparser, covering just under 3% of the global burnable land area, and found mainly in India and Southeast Asia. Tropical, subtropical and temperate biomes had the greatest percentage of significant increasing trends in extremes of FWI, ISI and VPD. Boreal biomes also had significant increasing trends, but these were smaller in size and significance while polar biomes showed significant positive trends in VPD only, across just under 40% of the burnable area. Southeastern British Columbia also showed increases in all three extreme fire weather indices.

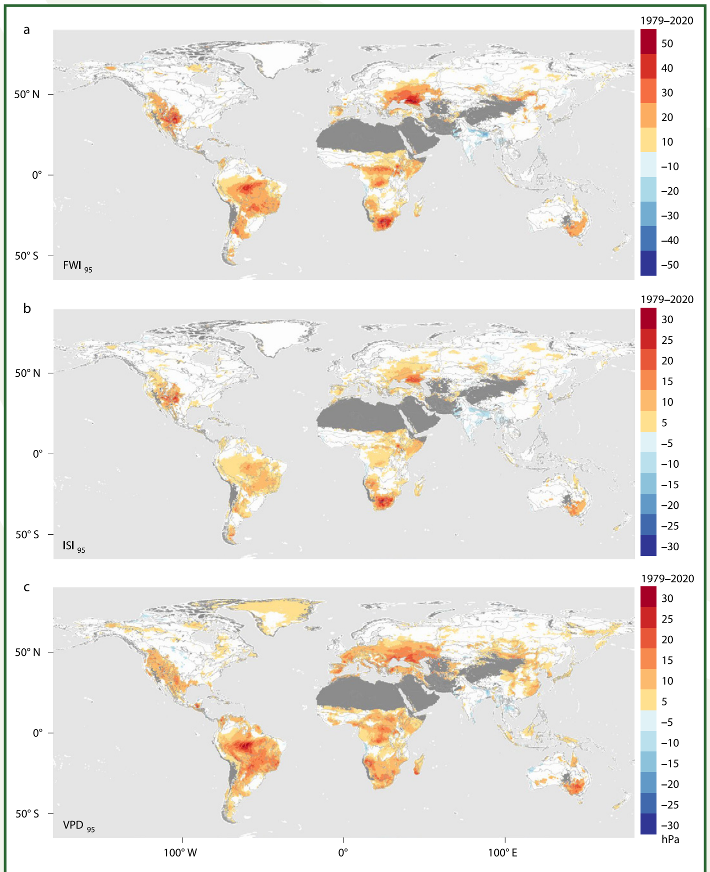

Figure 1: Trends in Fire Weather (from Jain et al., 2022). This figure shows significant trends in extremes (95th percentiles) of annual FWI (a), ISI (b) and VPD (c). Values are as indicated by the colour bars on the right. White indicates areas in which there are no significant trends, dark grey indicates areas without appreciable burnable biomass and light grey lines denote the boundaries of biomes.

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7. The authors use data from the Global Fire Atlas, which is online, here: https://www.globalfiredata.org/fireatlas.html.
8. The authors use data from the World Wildlife Fund's *Terrestrial Ecosystems of the World* (Olson et al., 2001).
9. A reanalysis is a representation of the historical climate that is created from historical observations that are "assimilated" into a global weather forecast model that is run in a hindcast mode. The fifth version of the European Reanalysis product (ERA-5) was used. For more on ERA5, see Hersbach et al. (2020).
10. The Initial Spread Index gives an indication of the rate at which fire can be expected to spread. It is calculated using information about wind conditions and the moisture content of the available fuel sources.
11. The Fire Weather Index gives an indication of the risk of occurrence of wildfire.
12. Vapour Pressure Deficit is the difference between the maximum amount of moisture that air can hold (at which point it is saturated and past which point any additional moisture would begin to condense out) and the actual amount of moisture present in the air.

The authors also found that the final decade of the period that they analyzed, 2011-2020, contains the eight most extreme years for FWI and ISI and the nine most extreme years for VPD (Figure 2). This period also includes seven of the warmest years on record and record-breaking fire seasons in western USA, Siberia, Australia and the Amazon. This period also contains the extreme 2017 and 2018 fire seasons in British Columbia.

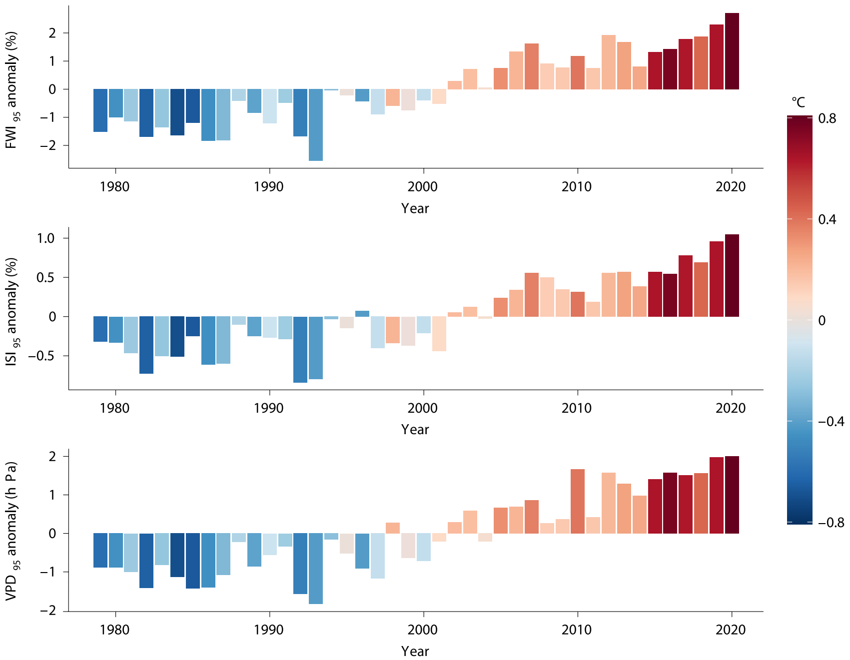

Figure 2: Anomalies in global extreme fire weather metrics (from Jain et al., 2022).

This figure shows anomalies in the annual global means of extreme (95th percentile) FWI (top panel), ISI (middle panel) and VPD (bottom panel) over fire seasons during the 1979-2020 period. The colours of the bars indicate the annual global mean land-surface temperature anomalies for the corresponding years, with values as shown in the colour bars on the right. All anomalies are relative to the 1979–2020 period.

Temperature and Relative Humidity Drive Fire Weather Extremes

Jain and colleagues bring together reanalysis data[10] with global fire and vegetation data to examine how extreme fire weather has been changing as estimated by fire weather indices. Their results show a world in which extreme fire weather is increasing overall, with significant regional variability. With these results established, they turn to the question of what is driving these increases in extreme fire weather.

The authors consider the effects of temperature, precipitation amount, relative humidity, wind speed and VPD on extremes of ISI and FWI. They find that relative humidity, temperature and VPD were the primary drivers for extreme FWI, while precipitation amount and wind speed played much less of a role (Figure 3). Relative humidity, temperature and VPD were drivers for extreme FWI for about 75%, 40% and 62% of the grid cells with significant trends, respectively, whereas the values for precipitation amount and wind speed were both about 11%. The values for extreme ISI were very similar, at about 42%, 82% and 59% for relative humidity, temperature and VPD, and about 13% and 12% for precipitation amount and wind speed.

The authors then tease apart the individual effects of temperature and atmospheric moisture content, as represented by dew point temperature[13]. This is important because RH and VPD are correlated with and depend, in part, on temperature. (Warmer air can be thought of as being able to "hold" more moisture, hence affecting RH and VPD.) In the earlier part of the authors' analysis, they investigate the effects of temperature, RH and VPD on the fire weather indices, but this might not tell the whole story, without an analysis of atmospheric moisture. They first noted that significant positive trends for temperature and dew point temperature were found across about 74% and 44% of global burnable land area, respectively. Across these areas both temperature and atmospheric moisture content are increasing. Negative values for temperature were found over less than 1% of the burnable area and negative values for dew point temperature were found across about 12% of the burnable area. The authors then consider pairs of trends in these two variables and find that two combinations in particular account for most of the observed trends.

First, locations with positive temperature and dew point trends made up about 68% of all observed trends. This was the case for North America, the Eurasian Boreal area and India. Second, areas with increasing temperature and decreasing dew point, including the Amazon, South Africa and the western US, accounted for just under a third of all trends. The other two combinations accounted for only a couple of percent each. The authors find that increases in extremes of FWI, ISI and VPD generally occur where tem-

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[13] The dew point temperature is the temperature at which air would have a relative humidity of 100%, past which point it could no longer hold any additional water vapour and water would begin to condense out.

perature trends are greater than dew point trends[14] and that these occurred in about 99% of positive trends in FWI and ISI extremes and about 91% of VPD extremes. Perhaps unsurprisingly, the strongest trends occurred where regions were getting warmer and dryer, with increasing temperatures and decreasing dew point temperatures.

It is worth nothing that, while the authors do perform an analysis that attributes changes in extreme fire weather to changes in temperature and relative humidity, their analysis does not explicitly attribute changes in extreme fire weather to anthropogenic climate change.

Summary: Temperature and Relative Humidity Drive Extreme Fire Weather, Projections Suggest Increasing Fire Weather Severity

The continued warming in the climate due to anthropogenic greenhouse gas emissions has influenced and is expected to continue to influence wildfires, with effects varying regionally. Globally, we have seen a likely increase in the length of wildfire seasons, but a slight decrease in area burned, due to less burning in Savannah and grassland areas. Future projections suggest an increase in fire season severity across most of the world's burnable land areas. These projections suggest that Canada is likely to see an elevated fire risk due to anthropogenic climate change as the fire season grows longer, and a number of fire metrics such as fire risk, area burned, the number of fires and the number of days with extreme fire weather present (termed, "spread days") all increase. The work of Jain and coauthors builds on our understanding of wildfire and is of particular interest because of its focus on extreme fire weather, which is responsible for the largest wildfire events.

Jain et al. find that trends in temperature and relative humidity are driving the extreme fire weather that they examine, as represented by ISI and FWI. They also find that increases in FWI, ISI and VPD occur most often in regions where temperature trends are greater than dew point trends—that is, regions where increases in temperature are larger than increases in moisture, or where temperature is increasing but areas are getting dryer.

The authors show an increase in extreme fire weather for all three indices across southern British Columbia, an area where increasing temperature is outpacing increasing moisture as represented by dew point temperature. The authors also attribute noon RH and noon temperature as drivers of extreme ISI and FWI in the southeastern portion of the province.

This work underlines the importance of rising temperatures and relative humidity in the occurrence of extreme fire weather, and is consistent with attribution work on on wildfire risk conducted at PCIC. These studies, led by PCIC, detected an anthropogenic influence on extreme fire risk in a region in Western Canada[15] and on the 2017 extreme fire season[16]. Understanding the key drivers of fire weather will help the scientific community to better understand how extreme fire weather will change in the future. This understanding, in turn, will be helpful for informing fire management plans.

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[14] It is also worth nothing that earlier research has suggested that, while increasing temperatures can lead to an increase in rain, which makes the fuel for forest fires more moist, the resulting increases in the moisture of fuel are generally outweighed by the drying caused by increased transpiration from plants and evaporation due to the increasing temperatures. For more on this, see Flannigan et al. (2016).

[15] For more on this, see Kirchmeier-Young et al. (2017).

[16] For more on this, see Kirchmeier-Young et al. (2019).