"Connecting diverse wildland fire, emissions, air quality and modelling communities."

Welcome to the Fall Issue of the Canadian Wildland Fire and Smoke Newsletter. It has been a very busy season for many of us, both on the wildland fire/emergency management side and the smoke modelling, forecasting, and health side of things. The Canadian fire season may have started off slowly with a tangible lack of early season mayhem (especially here in Alberta) compared to 2016 but things picked up drastically nationally and internationally as the season progressed.

It ended up being another Canadian (and global) wildfire season plagued by evacuations, communities at risk, lost structures and most unfortunately, lost lives. We saw late season wind events create some interesting and trying situations in the southern areas of the prairie provinces. Around the world there were numerous broadcasts of horrific scenes, peoples homes burning, and even worse, people trapped within the infernos.

I am sure many of our readers are looking forward to the "down season", if you can call it that with the paperwork that follows these kinds of events. We hope that as you sit down to read this newsletter you enjoy reading and reflecting on the stories and articles our cohort of volunteer authors so kindly provided. We hope that you too will consider submitting an article to our newsletter in the future.

-Karen Blouin, Associate Editor

In this issue:

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"Connecting diverse wildland fire, emissions, air quality and modelling communities."

The 2017 Canadian Wildfire Season

by Mike Flannigan

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While this short update focuses on Canada, I would be amiss not to mention the devastating and deadly wildfires throughout the world in 2017. Early in the year, Chile had a record breaking year for fire activity. Then deadly fires hit Portugal and South Africa. Also, fires in New Zealand (Port Hills), Greenland and Ireland made the news. Most recently the wildfires in California have been the deadliest ever in the state and will be the costliest globally with losses likely in the many billions of dollars. Lastly, deadly fires in Spain and Portugal (again) were driven by strong winds associated with an Atlantic Hurricane (Ophelia).

In Canada, the fire season started off slowly but that changed dramatically in early July in BC with around 220 fire starts between July 6-8th and many of these fires were near communities. Many of these communities were evacuated and some structures were lost. In BC, it was a very long, hot, dry and smoky summer. The area burned for BC was the highest ever recorded with over 1.2 million hectares. That is head-and-shoulders above the previous record of 857,000 ha in 1958 which is also head-and-shoulders above the 3rd most active year of 1961 with 482,000 ha burned. (Figure 1). Significant fire activity also influenced the Northwest Territories, Saskatchewan and Manitoba. The direct fire management expenditures in Canada this year will probably exceed 1 billion dollars. Four of the last 5 years in Canada have experienced area burned exceeding 3 million hectares for the first time in our historical record. The one year that did not exceed 3 million hectares was 2016, the year of the Fort McMurray fire. The Fort McMurray fire was the costliest wildfire on record globally, although it will likely will be surpassed by the October 2017 California wildfires. Recent research (Kirchmeier-Young et al. 2017) suggests that extreme fire risk in areas like Northern Alberta has increased by 1.5 to 6 times due to climate change. What will 2018 bring?

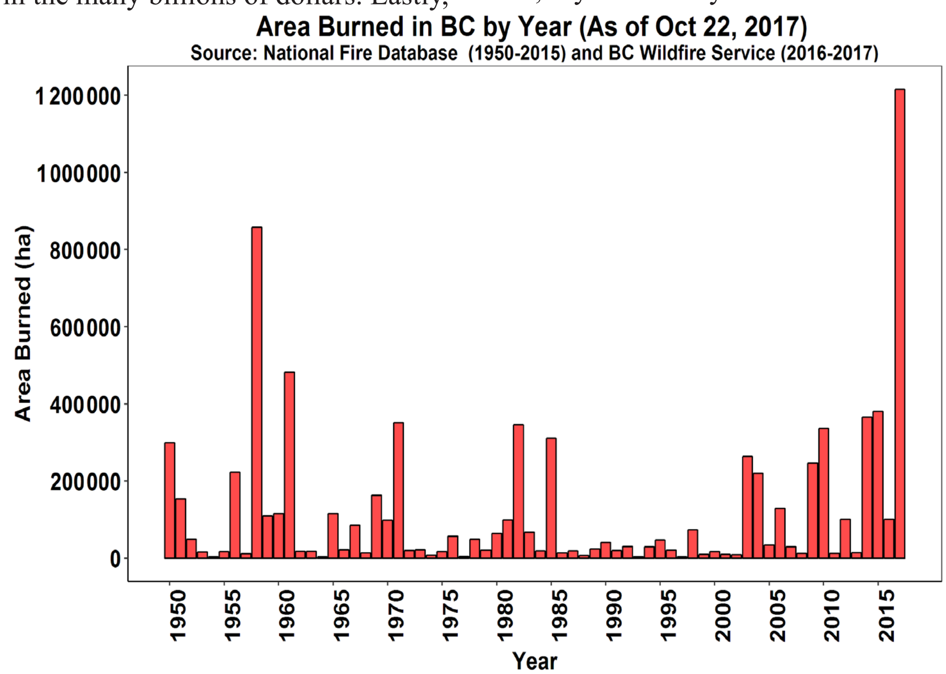

Figure 1: Annual area burned in British Columbia (total area burned for 2017 as of October 22, 2017). Figure created by Xinli Cai, Canadian Partnership for Wildland Fire Science.

References

Kirchmeier-Young, M.C., Zwiers, F.W., Gillett, N.P., and Cannon, A.J. (2017) Attributing extreme fire risk in Western Canada to human emissions. Climatic Change 144(2): 365-379.

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Appropriate response—Ontario's strategic approach to wildland fire

by Colin McFayden[1] and Den Boychuk[2]

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Ontario Ministry of Natural Resources & Forestry, Aviation Forest Fire and Emergency Services

Abstract

This article is an informal discussion of the "appropriate response" aspect of the Ontario Ministry of Natural Resources and Forestry's Wildland Fire Management Strategy and possible future application as part of the wildland fire response in Ontario.

What is appropriate response in Ontario? The Ontario Ministry of Natural Resources and Forestry (MNRF) is continuing to evolve in its approach to fire management where fire managers have more flexibility to decide where to limit or allow area burned according to each fire's circumstances. This is part of a risk-based approach or "appropriate response". This moves Ontario further from a culture of automatic fire exclusion over a large portion of the province.

What pushed us to update the Ontario fire management strategy? Like most other fire agencies, Ontario has been under increasing pressures related to climate change, expansion of wildland interface, and wildland firefighting capacity, including interagency staff and equipment sharing requests to meet peak demands in western provinces through interagency sharing agreements.

In addition to our fire protection role, the Ontario Ministry of Natural Resources and Forestry also manages the resources and assets of Crown land for a range of biological, social and economic goals. Ontario's Fire Management Strategy recognizes that fire is a natural ecosystem process that provides benefits through its contribution to the natural functioning of wildlands and provides other positive impacts such as improving resource values and removing hazardous fuels such as storm- or insect-damaged stands.

Canada has experienced more catastrophic fires in the recent years, e.g., Kelowna, British Columbia, Slave Lake and Fort McMurray, Alberta. In Ontario, a fire near Timmins in 2012 had the potential to be one such catastrophic fire. Hundreds of people were evacuated from surrounding areas and a state of emergency was declared for the city of approximately 43,000. In 2016, a fire near Kenora caused the evacuation of several cottage subdivisions. But it's not just the fires in close proximity to communities that cause widespread disruptions. A large fire in a remote area can result in shut down of industrial operations and evacuations of downwind communities due to smoke from many kilometres away.

Figure 1: 2017 Wildland fire near a community airport

Why move away from fire management zones? The previous fire management strategy did accommodate appropriate response, but generally as an exception rather than the rule. It delineated specific fire management zones, where response decisions usually followed the predetermined direction for each zone, i.e., full response in 3 of 5 zones. Consistently following the zone direction can lead to possibly inefficient decisions, like suppressing a fire on a forested island where there is little risk of escape or damage to buildings, or suppressing fires toward the end of the fire season when fire risk was limited. Conversely, a predetermined decision to not suppress a small fire in a remote area with high fuel and weather indices could lead to a need to initiate suppression later in the season on a much larger fire, leading to significantly higher suppression costs. While fire managers could deviate from the predetermined response in a particular zone (e.g., when a fire escapes initial attack or there are not enough suppression resources), most suppression actions followed the initial zone direction. With the exception of some fire management plans within provincial parks the general focus was suppression centric.

How did Ontario arrive at appropriate response? Initially, we explored other options for a strategic approach, including a more detailed zonation with smaller fire exclusion areas. These were deemed as impractical or too high-risk for implementation. To help the program move towards better use of fire while managing total costs, risks, and opportunities, the idea of assessing each fire and determining whether to limit or allow areas to burn according to local conditions was found to be a better approach than managing by zones. This approach is analogous to precision agriculture (irrigate, fertilize, and spray only where and when needed according to local conditions, rather than on entire fields on a predetermined schedule). The idea was to limit or allow the right fire, in the right place and the right time.

How does Ontario decide how to respond to each fire? The protection of human life and safety remains the overriding priority. Another long-standing guiding principle for fire management decision-making is wildland fire economics, the historical development and principles of which were reviewed by Simard (1976). In principle, a response should be designed to minimize the expected total cost plus net loss of wildland fire, accounting for constraints such as public and worker safety, risk, and many other factors. Using wildland fire economics explicitly, however, is not yet possible because we can't yet quantify the values of the many negative and positive impacts of wildland fire in a satisfactory way. Instead, we use naturalistic decision making and work with our stakeholders to assess the magnitude of the positive and negative impacts and costs. Regarding the utility of impacts, costs, and risks, in practise, we weigh the protection of resources and assets relatively higher than the suppression costs.

As stated earlier, the previous strategy used a coarse-scale top down approach, where the desired response objective was predetermined for large zones, and then implemented for individual fires. In contrast, the current strategy uses a finer-scale bottom up approach, where the desired response objective is determined for individual fires at the time according to the specific situation, and then implemented if it can be done according to the current conditions of capacity and fire behaviour.

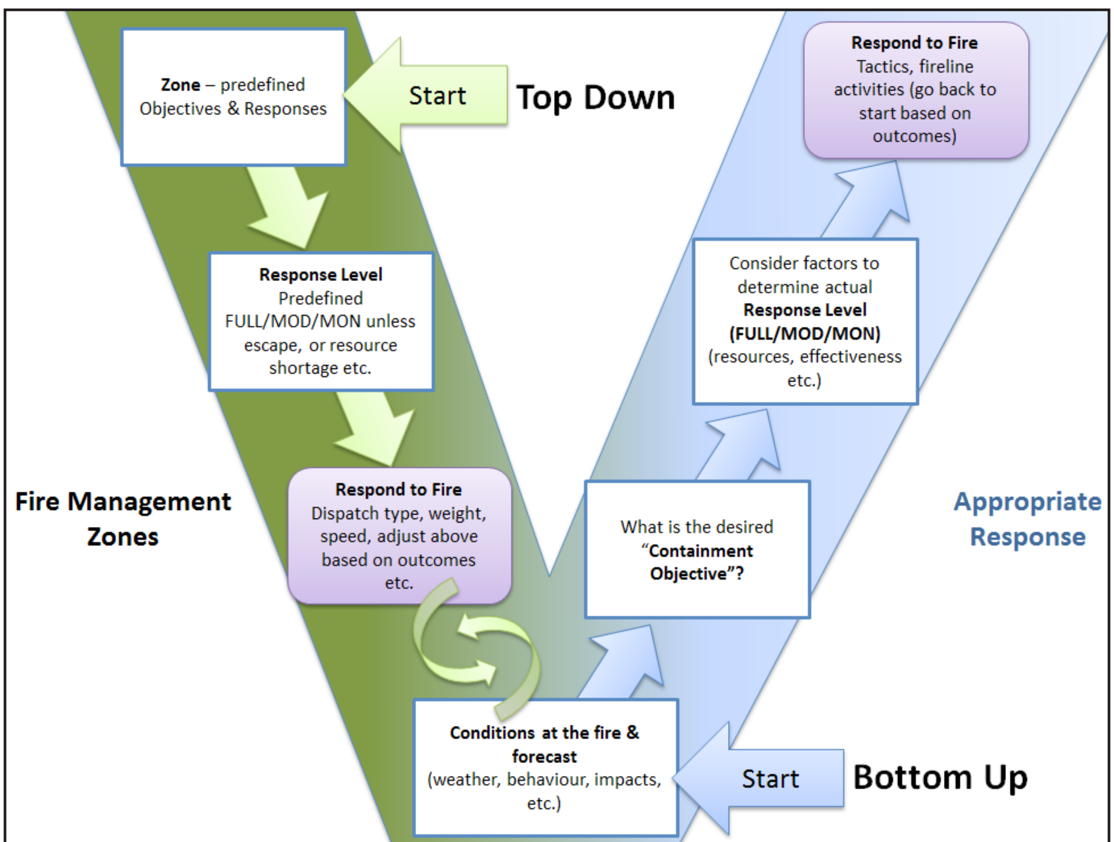

Figure 2:Top down vs. bottom up strategic approach

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Challenges with appropriate response: Dealing with uncertainty is an unavoidable part of fire management. Thinking long term in fire management is difficult and always comes with a great deal of uncertainty. Weather and other factors that drive fire occurrence and behaviour are highly variable and difficult to predict. Decision makers have made and continue to make good decisions despite uncertainty.

Response decisions are also not set in stone. Frequent re-assessment of the situation and decisions takes place to allow for adjustment of response actions as actual conditions unfold. It is important, however, to make the initial response decision carefully because suppressing a fire unnecessarily is expensive, and suppressing a fire once it gets larger can be even more expensive. A change in response actions later in the life of a fire doesn't necessarily mean that the earlier decision was incorrect, only that new information became available or the conditions changed. One can have good decisions with either good or bad outcomes as well as poor decisions with either good or bad outcomes.

The fire objective and response lexicon commonly used in Ontario (and nationally) does not meet the needs of the appropriate response approach (e.g. Full, Modified, and Monitored response). That terminology lumps various elements of objectives, actions, and tactics into broad categories that suit most, but not all situations. These terms become inadequate under the appropriate response strategy where each component of the process must be understood, such as desired containment objective, actual response direction, and tactics used. This is needed for real-time fire situational awareness and for after action review and analysis. The current terminology was designed to describe what has been done, rather than both what was desired to be done and what was actually done, along with the reasons for any difference. For example, less suppression might have actually been done because of limited capacity, extreme fire behaviour, or low fire behaviour toward the end of the season. More specific terminology is needed for real-time fire situational awareness and for after action review and analysis.

Daily preparedness planning requires decisions about the numbers, types and alerts of firefighting resources based on anticipated fire occurrence and fire behaviour. Fire management zones prescribed which areas needed to be resourced for suppression and which did not. Under an appropriate response strategy, the location and likelihood of fire suppression can shift over time according to the fire weather and the lateness of the season, so we must decide daily the extent of the area to resource.

Current and future decision support: Ontario recognizes the importance of developing decision support tools that suitably trained and experienced staff can draw upon to help make decisions under uncertainty. Collaborating with the Canadian Forest Service, University of Western Ontario, University of Toronto, and the University of Alberta, Ontario is developing the next generation of decision support tools to assist with these challenges. Through these collaborative efforts we are looking at ways to improve fire occurrence prediction, detection, daily initial attack resource deployment, long-term fire weather forecasting, probabilistic fire growth modelling, large-fire management; response cost modelling, and impact modelling.

Ontario also continues to work on a new fire objective and response lexicon that adequately describes the elements of appropriate response for clarifying decision alternatives and facilitating situational awareness and analysis.

To help with daily preparedness planning, preliminary models have been developed by Ontario:

- daily spatial fire occurrence prediction,
- daily containment objective indicator, and
- an indicator of response speed and weight

These are landscape level models designed to aid preparedness planning, i.e., where to position resources each day.

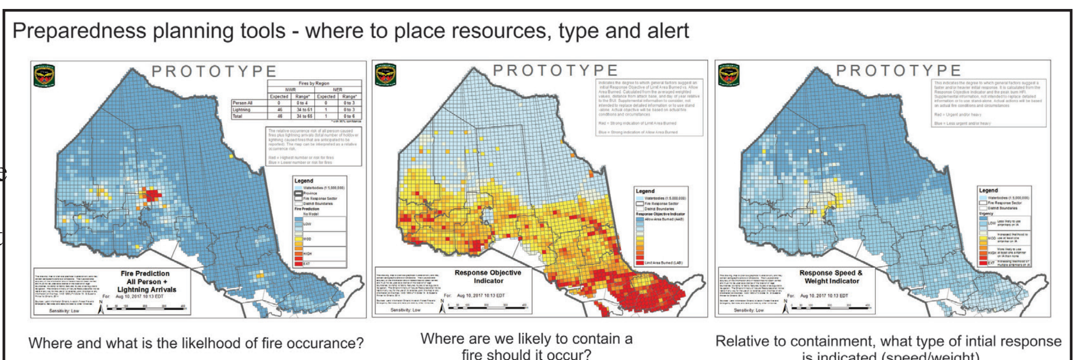

Figure 3: Preparedness tools

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Summary:

Mike Wotton and Mike Flannigan summarized the need for appropriate response in their 2017 article in which they stated "appropriate response … necessitates accepting more risk with the end goal of preventing major losses." And in order to implement appropriate response "Canadian wildfire managers cannot be expected to risk manage these new challenges with the same old tools."

The gains will be made in those situations where a fire (or many fires) could be managed to achieve the positive impacts while firefighting resources are used on the critical fires. For example, in 2017 where Ontario had 191 fires totalling approximately 91,000 hectares in size being monitored, a large portion of our FireRanger crews were sent west to assist in British Columbia over the season.

With a strategy of appropriate response, Ontario maintains its commitment to public safety, reduces unwanted fire loss and disruption, and facilitates opportunities for fire to play its natural role in maintaining healthy wildland ecosystems.

For more information on fire management in Ontario go to https://www.ontario.ca/page/forest-fires

Acknowledgements:

The authors would like to thank Dan Leonard, Fire Response Specialist with the Ontario Ministry of Natural Resources and David Martell, Faculty of Forestry, University of Toronto, for their comments and suggestions. Photograph taken by Dennis Gilhooly.

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Figure 4: CL-415 airtanker

Congratulations Brian Stocks!

2017 IAWF Ember Award

for Excellence in Wildland Fire Science awarded to

Brian Stocks, B.J. Stocks Wildfire Investigations Ltd.

Brian Stocks (center) holding his Ember Award with two members of Stocks Nation, Amber Soja (left) and Nancy French (right). In case you are having trouble reading their shirts, they say "Stocks Nation, Making Wildland Fire Science Great Again"

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Building a Blueprint – a renewed future for wildland fire science in Canada

By Stacey Sankey

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In 2016, the Canadian Council of Forest Ministers (CCFM) reviewed and renewed its commitment to the *Canadian Wildland Fire Strategy* (CWFS)[1]. Originally signed in 2005, the CWFS created an innovative, modern vision for wildland fire management in Canada, focused on creating resilient communities, an empowered public, and healthy forest ecosystems. Recognizing significant progress has been made over the past decade to fulfill CWFS objectives, the 2016 document ("*Canadian Wildland Fire Strategy: A 10-year Review and Renewed Call to Action*")[2] identified new priorities toward full strategy implementation. Among the identified priorities were calls to enhance horizontal collaboration and integration and to increase investments into innovation.

In response to these two specific recommendations, a new pan-Canadian initiative is underway. The "Blueprint for Wildland Fire Science in Canada" (Blueprint) is envisioned as a strategic, comprehensive, and collaboratively built plan aimed at growing Canada's wildland fire science capacity (resources, investments, collaborative opportunities, and partnerships) to ensure Canada is well prepared for the changing nature of fire in our forests and on the landscape.

The Challenges

Like many areas around the world, Canada is experiencing increases in extreme wildland fire behaviour. Driven largely by the impacts of climate change, bigger and more intense fires are stretching our fire management and operational response abilities beyond existing capacity. They are also creating bigger, more potentially damaging and dangerous situations for forest-based communities, infrastructure, and economies.

At the same time, over a period of about 40 years, Canadian investments into wildland fire science and technological (S&T) innovations have been steadily decreasing as governments, academia, and funding agencies deal with tighter budgets, competing priorities, and broader mandates. Taken together, these factors have created a 'perfect storm' of increasing fire complexity, decreasing fire research capacity, and more forest-based values placed at risk.

The Blueprint

The Blueprint is being developed by a team of partners, representing provincial, territorial, Indigenous, academic, and non-government sectors, and led by Natural Resources Canada's Canadian Forest Service (CFS). The final product will serve to facilitate coordinated, integrated growth and application of wildland fire science in Canada, providing:

- an overview of research capacity gaps and needs (including fire behaviour and ecology, fire management and operations, human dimensions and economics of fire and mitigation, risk assessments, and the integration of Indigenous traditional knowledge and experience);
- identification of shared national priorities;
- options for research resourcing; and
- recommendations on opportunities for multi-organizational collaboration and partnerships.

Outreach activities to gather input and expertise from researchers and stakeholders across the country will be essential to ensuring the Blueprint's relevancy and, ultimately, its success. This outreach process is now underway and will continue into 2018, with a final document to be completed by June 2018.

If you would like more information on the Blueprint for Wildland Fire Science in Canada initiative, or are interested in being a contributor, please contact project manager Stacey Sankey (stacey.sankey@canada.ca) or 780-435-7346.

> *"Canada's capacity in fire response has been built on past investments in science, decision analysis and practical technology application. From aircraft design to suppression systems to computer-based fire behaviour predictions the investment in science and the university trained people who carry out such work has consistently diminished. The problems of the future will not be resolved by relying on the science of the past nor will they be resolved without focused programs in government and universities."*
> - from The Canadian Wildland Fire Strategy: A 10-year Review and Renewed Call to Action

Footnotes

[1] More information on the CWFS can be found on the CCFM website: http://www.ccfm.org/english/coreproducts-cwfs.as

[2] The Canadian Wildland Fire Strategy. A 10-Year Review and Renewed Call to Action

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Return to Flame: Reasons for Burning in Lytton First Nation, British Columbia

By Michael Lewis[1], Amy Christianson[2] and Marsha Spinks[3]

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Abstract

Land and fire managers alike are increasingly moving beyond policies that often favoured fire suppression to policies that allow, and may even initiate, small- to medium-scale, variable-intensity fires as a course of better forest and land management and a means to achieve any number of stand-specific economic or cultural outcomes. In light of this policy regression, it is unknown to what extent the traditional Nlaka'pamux lands have seen a return to Indigenous fire use as a tool. Tribal Elders and select members of the Lytton First Nation participated in a series of interviews focusing on Indigenous fire use in the region. Fire use continues on the traditional lands of the Lytton First Nation. However, the scope has decreased, both in size and applications, and, although burning continues to follow traditional rationales, several of these rationales (e.g., foodstuff amelioration) have become less common. Debris control and hazard abatement are now the predominant motivators for fire use.

Management and Policy Implications

The outcomes of this study can be considered highly applicable in the framework of community-led fire-based landscape management in moderately populated areas with a historical precedent. As with any form of ecological management, several purely ecologically beneficial outcomes can be expected:

- Overall forest health improvement in ponderosa pine (Pinus ponderosa) and Douglas-fir (Pseudotsuga menziesii) stands, with increased age heterogeneity and improved pathogen and insect resistance in both.
- Improved grazing areas for native, established, and domesticated ungulate species: moose (Alces alces), bighorn sheep (Ovis canadensis), mule deer (Odocoileus hemionus), elk (Cervus elaphus canadensis), and domesticated cattle (Bos taurus).
- Restoration of the Bunchgrass biogeoclimatic zone is needed for species-at-risk, such as burrowing owl (Athene cunicularia), western rattlesnake (Crotalus oreganus), and sage thrasher (Oreoscoptes montanus), or extirpated species, and control of invasive or undesirable species.

From a socio-cultural perspective, reinstatement of variable-intensity burning may hold several beneficial outcomes for the valley's Indigenous communities including greater protection from high-intensity wildfires, increased natural production of socially and culturally valued plants and foodstuffs (edible plants), and increased opportunities for tradition-based education on ecosystem management, burning of common areas, and support for community cohesion.

This article is based on an upcoming publication in the Journal of Forestry.

Marsha Spinks of Lytton First Nation conducting a spot burn in the community to reduce fuel in the understory. (Photograph courtesy of author)

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Edmonton smoked by BC wildfires, July 19-20, 2017 - a case study

By Dan McLennan and Al Pankratz

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Introduction

According to the government of British Columbia, the summer of 2017 was the worst fire season in recorded history as determined by area burned with over 1.2 million hectares (12000 sq km) consumed by wildfire [http://bcfireinfo.for.gov.bc.ca/hprScripts/WildfireNews/Statistics.asp] (see Figure 1). Several hundred homes were consumed by flames and tens of thousands of people were ordered to evacuate due to nearby fires. Some communities in central BC experienced weeks of extremely high smoke concentrations. Major population centres in the Lower Fraser Valley as well as the city of Vancouver were affected for a number of days by dense smoke which resulted in air quality advisories as well as exceedances of the Canadian Air Quality PM2.5 standards. The fires and smoke created widespread economic disruption as tourists' plans were cancelled or altered due to closed facilities and driving restrictions. Nearby provinces and states also experienced significant smoke episodes as prevailing winds carried the smoke over the northwestern US and western Canada. This article explores one such episode which affected Edmonton, Alberta on July 19th and 20th of 2017.

Wildfire smoke episodes are not new to Edmonton. Given the right direction of prevailing winds, Edmonton can be immediately downwind of BC, Washington state, the Northwest Territories, northern Alberta and northern Saskatchewan. It is rare that a summer goes by without at least one smoke episode affecting the central areas of the province of Alberta. In fact, two previous smoke inundations were discussed previously in the Canadian Wildland Fire and Smoke Newsletter (CWFSN, Spring 2016 and Spring/Summer 2011 issues), both with similar source regions (central BC) to the 2017 episode. Other similarities shared between this event and one discussed in the 2016 Spring CWFSN article are the occasional periods of high PM10/PM2.5 ratios driven by significant increases to PM10 compared to PM2.5.

Meteorology

The meteorology affecting BC and Alberta from July 17-20 was typical of summertime. A cold front had passed southeastward through Alberta on the 17th and 18th and in its wake, a very weak and ill defined surface high pressure gradient

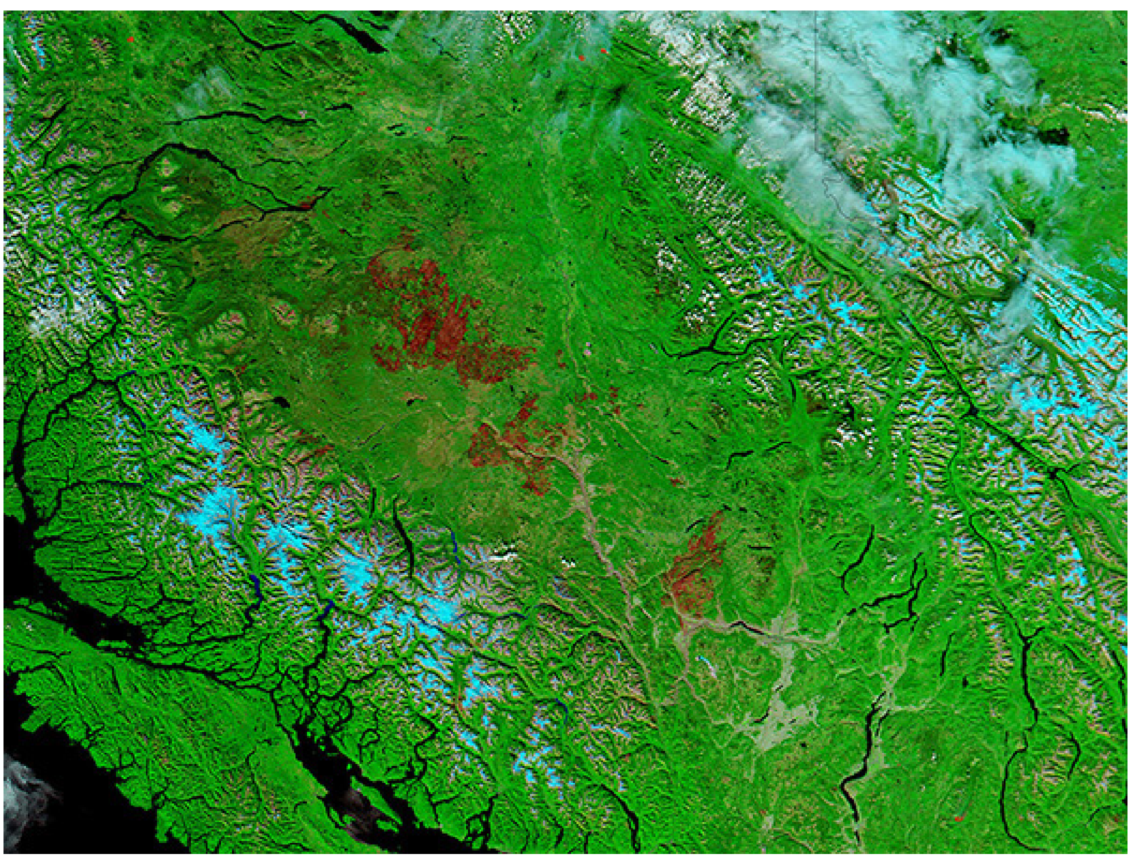

Figure 1. 1.2 million hectares of burn scars (shown in red) after the 2017 BC fire season. Image courtesy Jeff Schmaltz, MODIS Land Rapid Response Team, NASA GSFC.

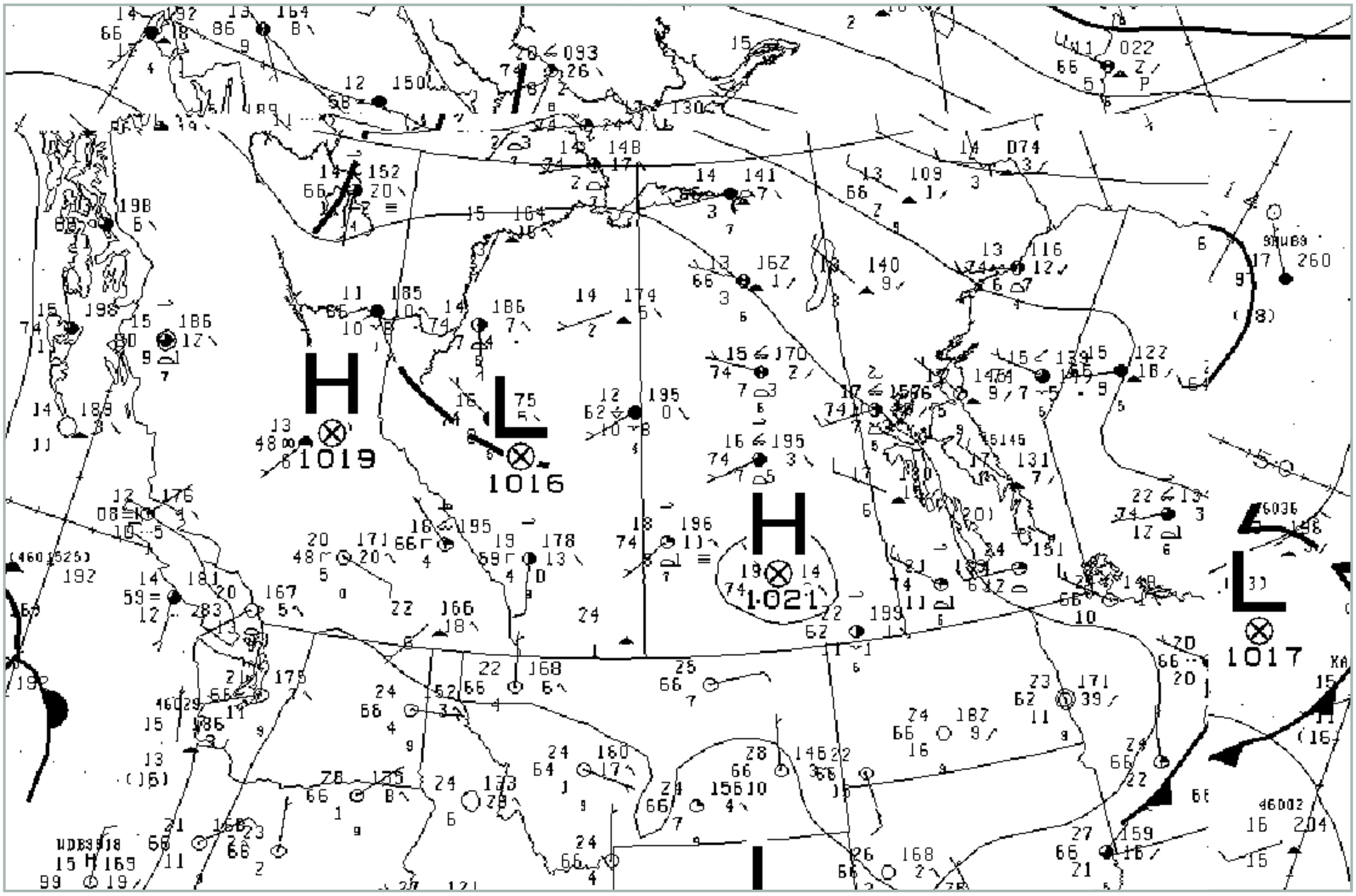

Figure 2. Surface analysis, 1800 UTC July 18, 2017.

became established at the surface. No major synoptic systems affected BC during the period of interest. There the primary weather-maker over central and southern areas was a roughly north-south thermal trough resulting from temperatures in the upper twenties to low thirties Celsius (Figure 2). Aloft, a gentle 20-30 knot westerly flow predominated through the first thousand meters above the mountaintops (Figure 3).

July 18th proved to be the warmest day of the four over southern BC and the most conducive to fire growth, as illustrated by a six hour period of crossover conditions at Williams Lake. Crossover occurs when the relative humidity is numerically less than the temperature and is used as a rule of thumb by fire weather forecasters to indicate conditions that are favourable for fire growth. The two numbers are not strictly comparable, but the scales for each happen to line up in such a way that this crossover seems to correspond well to extreme burning conditions. The meteorology was therefore in place to support the lofting of large amounts of smoke from central BC into a moderate westerly flow and into west central Alberta.

Fuel and Burning Conditions

Fuel and burning conditions were optimal due to the hot and dry conditions which were perfect for evaporating fuel moisture. In addition, extensive dead coniferous (gray phase) trees were present as a result of the devastating effects of insect infestations over the previous decades. Figure 4 shows the areas where mountain pine beetles were observed between 1999 and 2012. With regards to this particular study, the area in question likely had almost 100% pine mortality. Trees killed by the beetles burn in a similar way to the C-3 fuel type (mature jack or lodge-pole pine) but with the addition of a heavy slash load at the surface, making for a vigorous surface fires that are able to sustain themselves for a long period of time. Large amounts of smoke would result from widespread availability of coarse woody debris that was down, dry, and ready to combust.

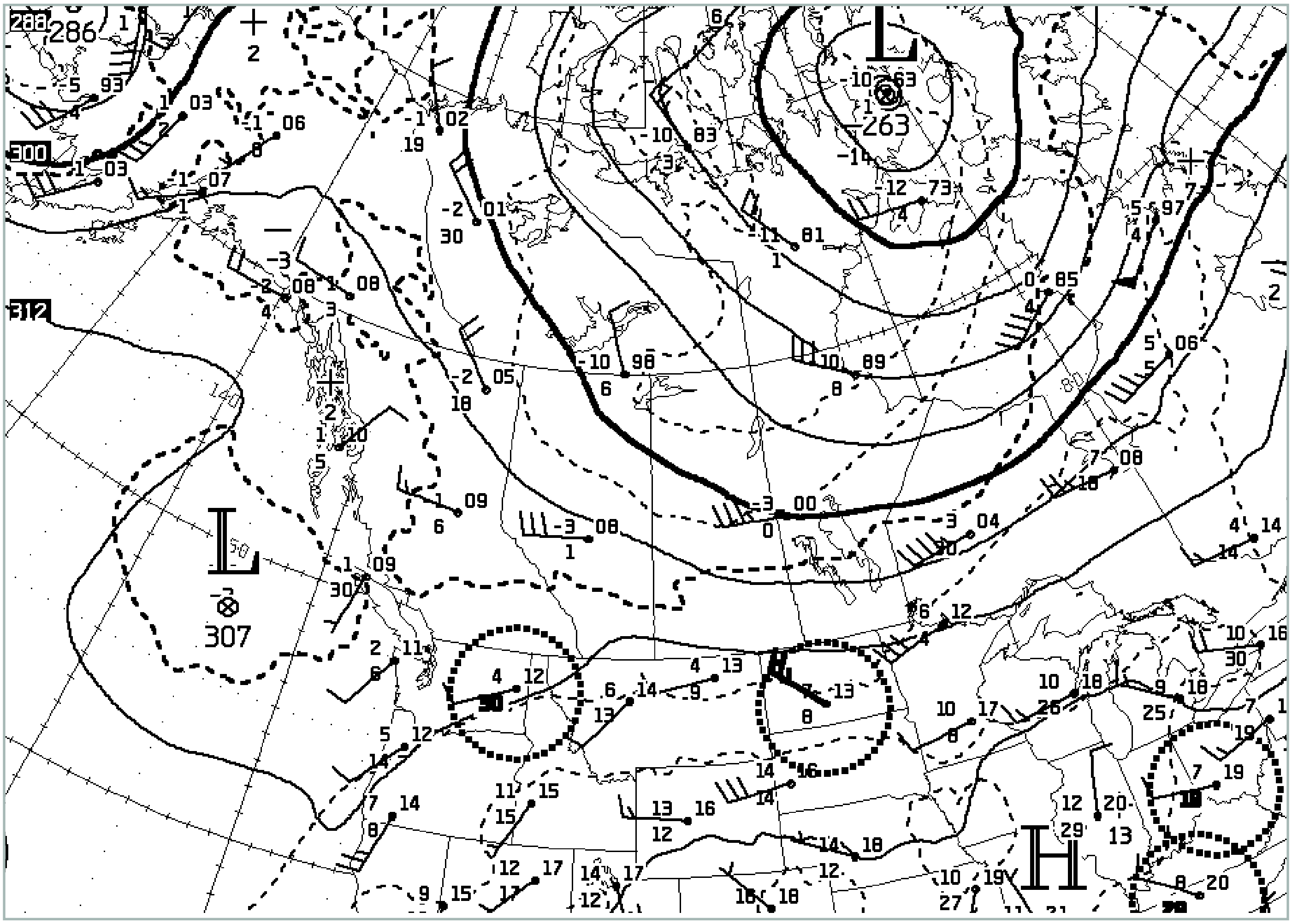

Figure 3. 700 mb upper air analysis – 1200 UTC 18 July 2017

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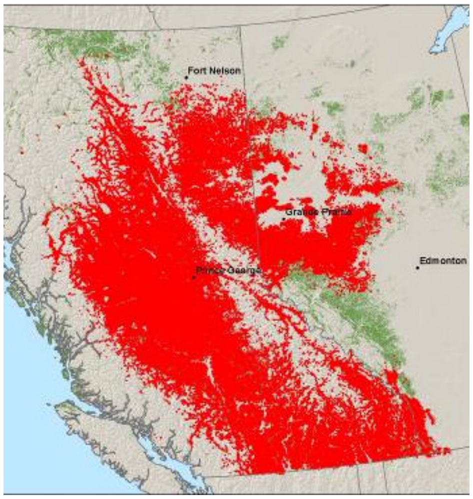

Figure 4. Areas in red affected by mountain pine beetles between 1999 and 2012. Map courtesy Natural Resources Canada, [http://www.nrcan.gc.ca/forests/fire-insects-disturbances/top-insects/13397, accessed 16 Oct, 2017]

Figure 5. Extensive smoke in south-central British Columbia on 18th July, 2017. Note dark tan plume tops below center indicating pyrocumulus clouds and likely crown fires.

Pyro-convection

MODIS satellite imagery for the afternoon of the 18th (Figure 5) shows extensive areas of smoke over south central BC, as well as an intriguing area of pyro-convection located near Williams Lake. Portions of the pyro-towering-cumulus (pyro TCU) are dark, indicative of a hot, turbulent, high-volume fire probably consuming larger fuels likely due to crowning. The crown fraction burned (CFB) index of the CWFIS associated with this area had frequent values in the 80-100 range, supporting this diagnosis. Such convective plumes would be quite capable of pushing smoke up above the mountain tops and into the westerly flow.

Forecaster Response

This event was well handled by Environment and Climate Change Canada (ECCC) forecasters. The BlueSky Canada and Canadian Meteorological Centre's smoke models predicted the movement of smoke into

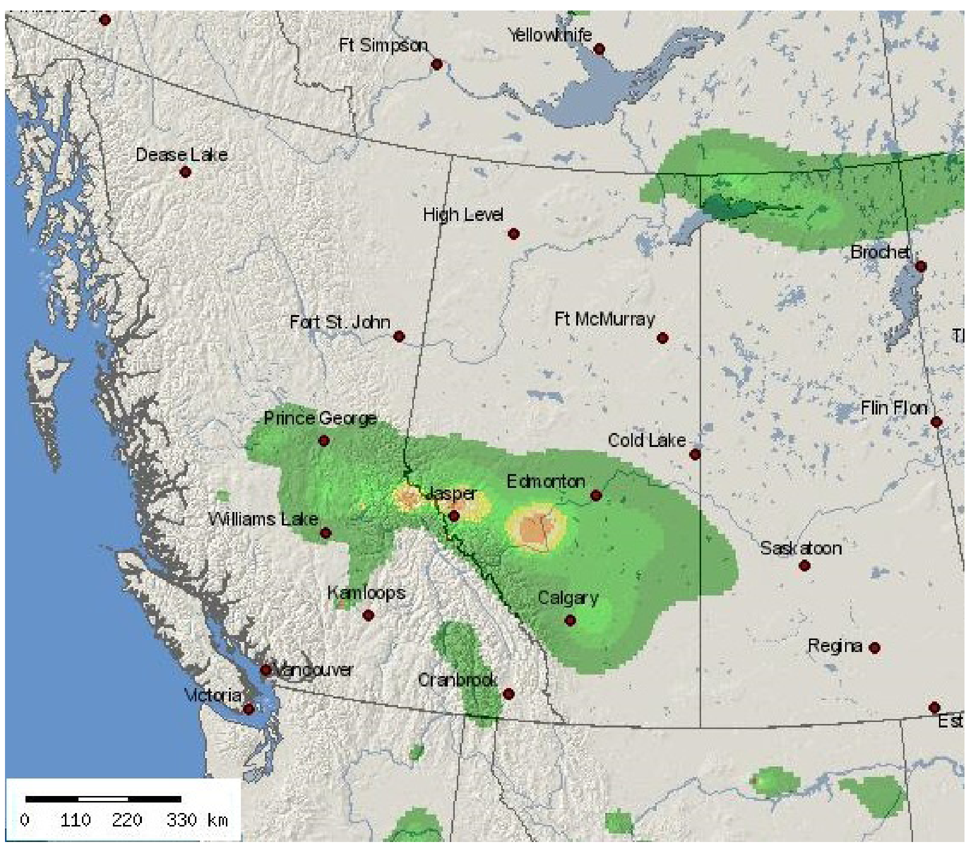

Figure 6. BlueSky Canada smoke prediction for July 19th at 12 noon.

central Alberta (see Figure 6), albeit with underdone concentrations. An alert message was issued at 4 AM on Tuesday the 18th, warning about dense smoke in the Red Deer, Hinton, and Edmonton areas for Wednesday July 19th, with AQHI values reaching 10 on that day. Subsequent alerts estimated that the smoke would remain until Thursday afternoon or evening. Figure 7a shows the visual conditions in Edmonton on the morning of the 20th prior to clearing that afternoon. Figure 7b shows the same view one day later once some of the smoke had cleared.

Air Quality Measurements and Analysis

Environment and Climate Change Canada's Air Quality Science Unit operates a Grimm Environmental Dust Monitor 180. It is an optical particle counting instrument capable of providing one minute data for PM1, PM2.5 and PM10. Thanks to quick deployment by ECCC technicians and timely predictions by the Meteorological Service of Canada's forecasters, the instrument was set up in the Air Quality Science Trailer to capture the predicted smoke event in Edmonton. Smoke began to be detected in Edmonton on July 19th 2017 around 06:00 MST as demonstrated by the jump in PM10 data in Figure 8. PM10 increased initially, stagnated at a similar level for a few hours, then steadily increased throughout the day. In the early hours of the 20th, PM10 levels dropped before increasing again between 04:00 and 08:00. There was a similar trend in PM2.5 on the 19th, but it was delayed from the initial onset of elevated PM10 by 7 hours. This is evident in tracking the red PM10/PM2.5 ratio line in Figure 8. From the initial onset of smoke until 14:00 on the 19th, the ratio of PM10 to PM2.5 is greater than 2, then from 15:00 to 03:00 on July 20th, the PM10/PM2.5

Figure 7a. Look hard – downtown buildings are just barely visible above the treeline at left center (July 20, 2017 08:20 MST).

Figure 7b. The same view a day later (July 21 07:20 MST).

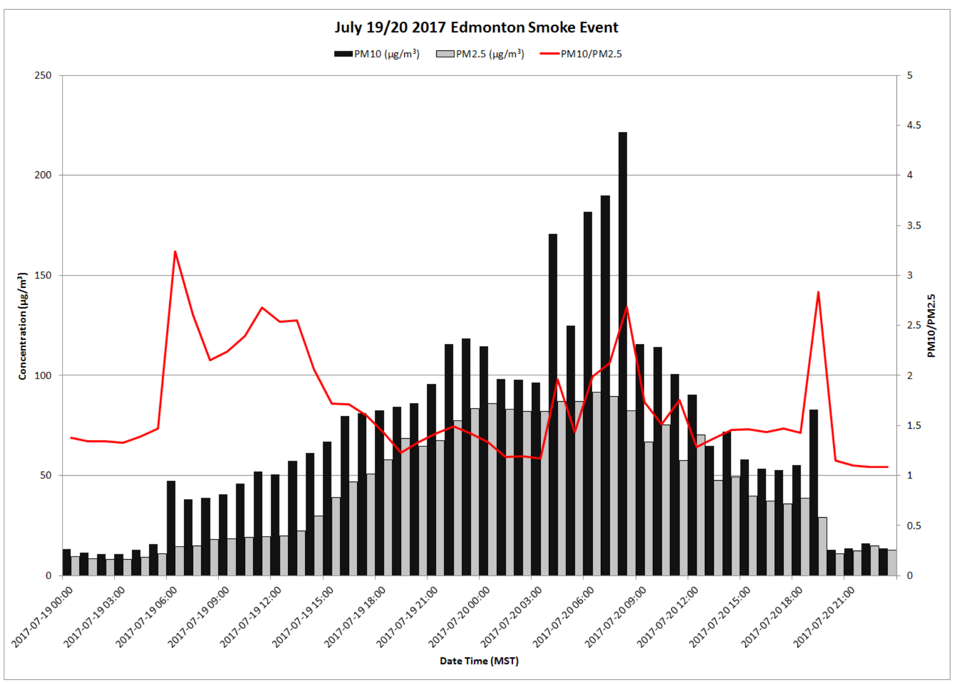

Figure 8. Trends in PM10, PM2.5, and PM10/PM2.5 for July 19/20, 2017

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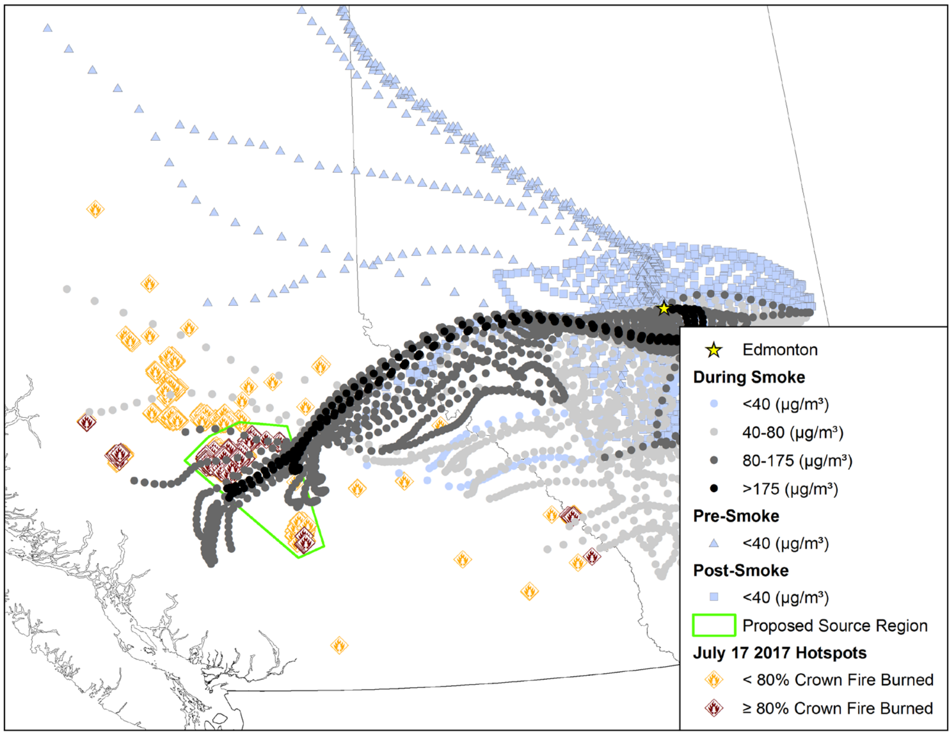

Figure 9. Back trajectories arriving in Edmonton from July 18, 19:00 to July 21, 06:00 MST, and their associated PM10 concentration

ratio dropped to lower levels, followed by a second 5 hour period where the highest concentrations of PM10 (221µg/m^3) were observed, increasing disproportionately to PM2.5 and again increasing the PM10/PM2.5 ratio.

In an attempt to determine possible underlying factors affecting the smoke that arrived in Edmonton, we used NOAA's Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model. Back trajectories were generated for air parcels arriving at Edmonton every hour from July 18 19:00 to July 21 06:00 MST. HYSPLIT was set to have parcels arrive at a height of 50 m and to follow the history of those parcels back to 60 hours prior to arrival time. The back trajectories were then color coded based on arrival concentration, and grouped by shape depending on whether they arrived before, during, or after the observed smoke period (see Figure 9). Active fire and fire hotspot data was extracted from the Canadian Wildland Fire Information System's (CWFIS) Interactive Map and plotted along with the HYSPLIT trajectories. As mentioned previously, CWFIS indices such as CFB percentage were obtained as part of the hotspot data and included in the GIS analysis. Hotspot data was extracted for various days around the 17th of July, but it was decided to use the 17th as it best represented the range of times when the back trajectories were over central BC, and because there were few differences in hotspot locations from day to day at this scale.

Figure 9's back trajectories show the position of air parcels every hour in their history. Dark gray and black colours indicate the highest arrival concentrations of PM10 in Edmonton. Most back trajectories associated with the highest PM10 concentrations arrived in Edmonton after passing over or near hotspots with a high CFB index, which leads us to suspect these fires as the primary sources of high PM10 smoke. The region outlined in green highlights the most likely culprits in our analysis.

In an attempt to determine if a particular fire or region could be the source of the high ratio smoke events, Figure 10 was created with the point to raster feature of ArcView's ArcMap. Each cell is a 0.25 by 0.25 decimal degree square. In Figures 10a and 10b, the squares are colour-coded based on the average arrival concentration of back trajectories contained in each cell for PM10 and PM2.5 respectively. The scales are standardized on both figures so that equal concentrations are represented by the same color. We note in both the PM10 and PM2.5 plots the higher relative concentrations around the proposed source region, and the band of high concentration trajectories arcing from the proposed source region almost up to the Alberta elbow, then going south and east of Edmonton before circulating back to the city. 10c shows the average PM10 values divided by the average PM2.5 values. The ratio ranges extend above 2, but for the purpose of this plot, anything above 2 is shaded red. In looking at Figure 10a, b, and c together, you can see that the areas in red along the British Columbia border and over south central Alberta have high ratios as a result of moderate PM10 and low PM2.5 values. These regions are associated with the initial arrival of elevated PM10 and the high PM10/PM2.5 ratio. As there are no hotspots in Alberta, the smoke was not created there but is simply the path in which the smoke had taken to reach Edmonton, these paths when looked at far enough in the past are from the BC fires. To determine where the high PM10 – high PM10/PM2.5 source region was, the PM10/PM2.5 ratio plot was multiplied by

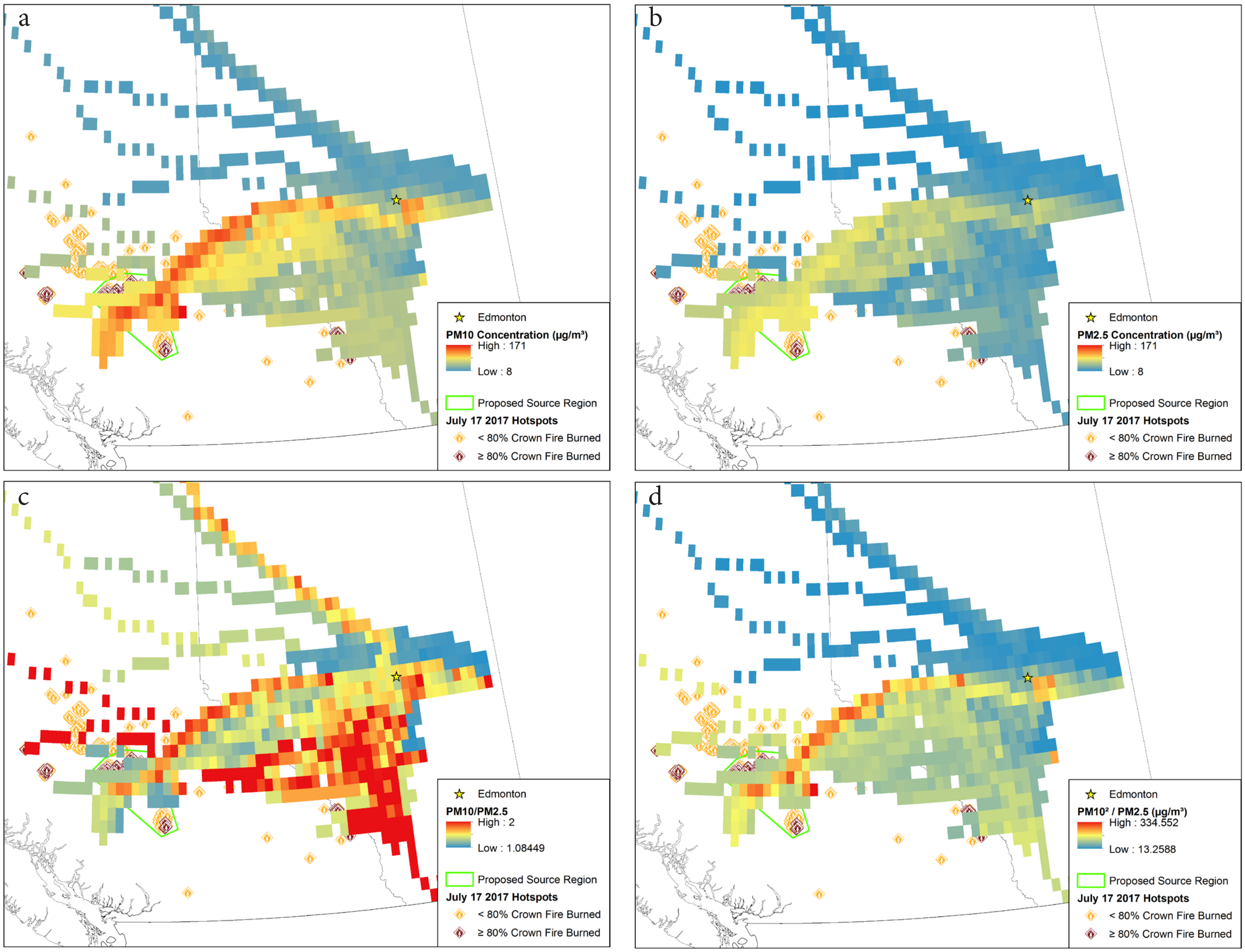

Figure 10. Grid cells are colour coded based on average arrival concentrations at Edmonton for all trajectories within the grid cell. a) shows PM10, b) shows PM2.5 ,c) shows the PM10/PM2.5 ratio, and d) shows the PM10/PM2.5 ratio multiplied by PM10 to emphasize the cells containing the trajectories of the highest concentration air parcels arriving in Edmonton.

the PM10 concentration to give us a weighted ratio in Figure 10d. What we see here is a clear indication that the high concentration/high ratio event comes from the proposed source region, and that the pyrocumulus plumes associated with the high CFB fires likely played a role in these high concentration/high ratio events.

We also did a temporal analysis of the back trajectories in an attempt to determine when the source of the smoke was created. We extracted the dates and times of trajectories within 0.5 decimal degrees of a hotspot or active fire, and the trajectories' PM10 concentration and PM10/PM2.5 ratio when it arrived at Edmonton (Figures 11 and 12). It is important to note that if a back trajectory was within range of multiple hotspots, it was still only counted once in this analysis. There are two periods of time with numerous trajectories within proximity of the fires – one short, one long as noted by the two peaks in Figure 11. The first period centered on July 17 03:00 was comprised of PM10 concentrations < 80 $\mu g/m^3$, and PM10/PM2.5 ratios almost exclusively greater than or equal to 2. Looking at Figure 12 these points are spread out and range across central to eastern British Columbia. The longer second period in Figure 11 from July 17 16:00 to July 18 14:00 was comprised primarily of PM10 concentrations > 80 $\mu g/m^3$ and the occurrence of PM10/

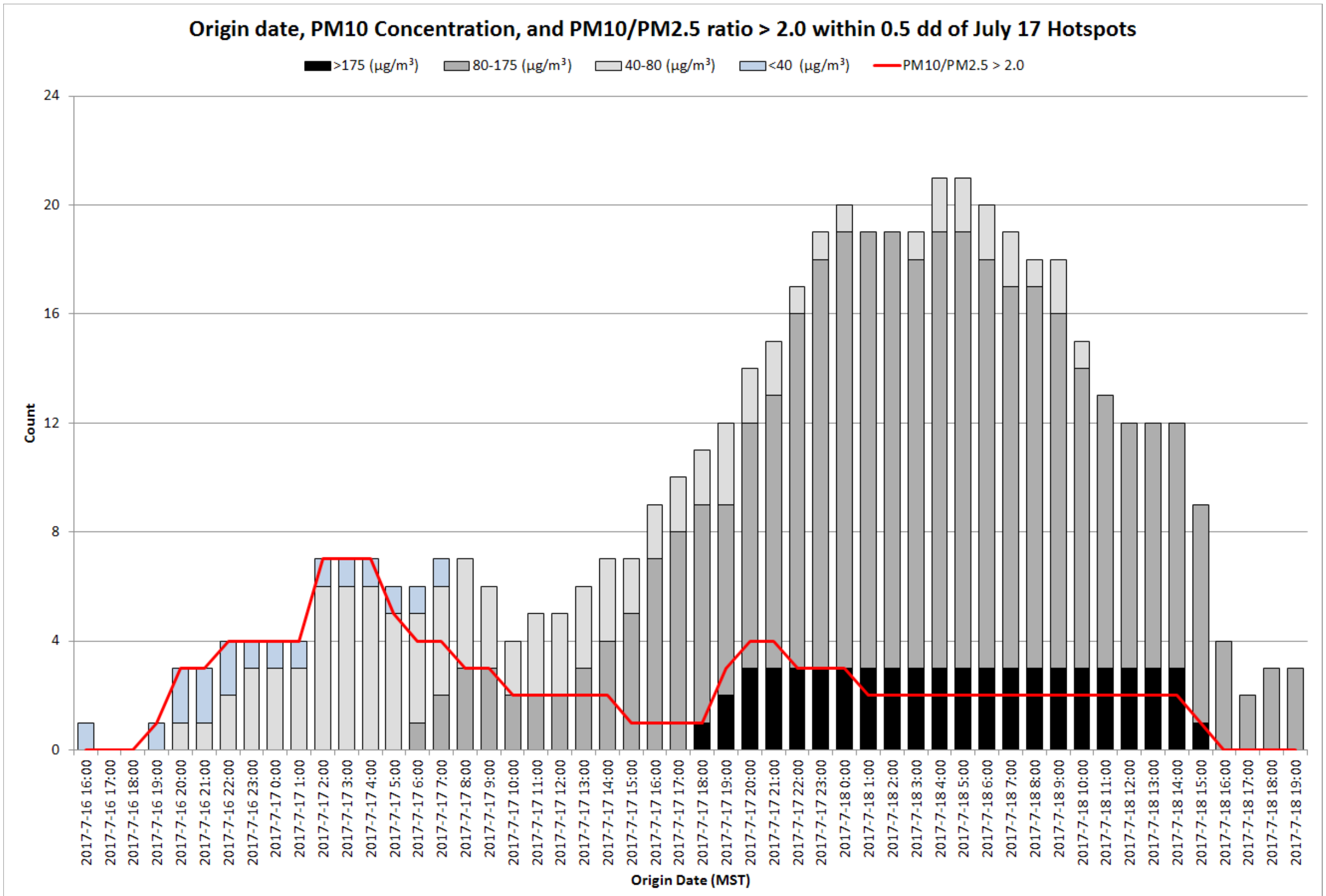

Figure 11. Date and time of back trajectories within 0.5 decimal degrees of active fires/hotspots and associated arrival concentration at Edmonton.

PM2.5 ratios ≥ 2 is spread out over the longer period as well. When looking at these points on Figure 12, we see tight clustering in the proposed source region and convergence as it slowly starts to arc north east towards the Alberta elbow. This second period tells us that July 17 18:00 to July 18 15:00 is most likely to be the source time of the high PM10 concentration – high PM10/PM2.5 ratio smoke event.

Conclusions

We used back trajectories to trace the source regions of the smoke responsible for a high concentration particulate matter episode in Edmonton

on July 19 and 20, 2017. Our analysis led us to conclude that the primary sources were fires burning in the south central portion of British Columbia on July 17th and 18th. Examination of satellite imagery during those days suggests the presence of pyrocumulus clouds. That information taken together with the high Crown Fraction Burned indices in the area lead us to hypothesize that the periods of high PM10 concentration and high ratios of PM10 to PM2.5 within the smoke that arrived at Edmonton were due to the phases of the fires in BC during which crown fires and pyro-towering-cumulus clouds were forming and injecting large amounts of particulate matter into the layer a kilometer or so above the mountain tops. Over the course of the next 24-36 hours, that smoke was carried by a moderate westerly flow across the continental divide after which it descended and fumigated a large portion of central Alberta for approximately 36 hours.

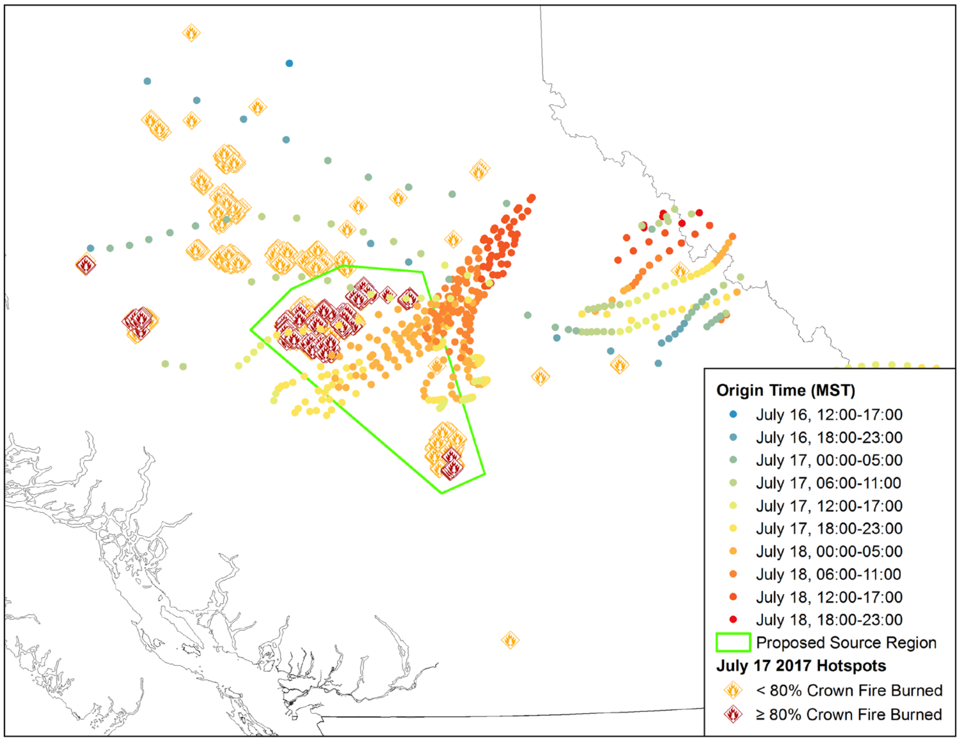

Figure 12. Temporal analysis map indicating the times at which the trajectories were in the locations plotted.

"Connecting diverse wildland fire, emissions, air quality and modelling communities."

Gradual landscape anthropization and its effect on the pyrogeography of Alberta

By François-Nicolas Robinne

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Context

Our planet is undergoing a pervasive global environmental crisis causing a series of profound socio-ecological changes. The main driver of this crisis is humankind, which its ever growing population associated with a highly consumerist lifestyle entrains deep changes in land-cover and land-use (Moran and Kanemoto 2016). Referred to as landscape anthropization, it commonly translates into significant changes in the local fire regime, sometimes even bringing fire in areas naturally not fire-prone. The commonly accepted model states than an increase in human pressure is linked to an increase in the density and frequency of human-caused ignitions along with a reduction of the average fire size and of the total cumulated area burned (Guyette et al. 2002). However, due to the diversity of socio-ecological systems on Earth, this conceptual model may not apply everywhere.

The boreal forest of Canada is undergoing critical land-cover and land-use changes due to a rapid industrial development relying on the accessibility to natural resources (Pickell et al. 2015). This development led to the formation of an ecological frontier (Héritier 2009), a large-scale transitional space under human development. As shown in many publications, such a dynamic affects boreal ecosystems in several ways, including fire regimes, although to a magnitude that has yet to be fully understood. In a recent publication for the International Journal of Wildland Fire, entitled "Anthropogenic influence on wildfire activity in Alberta, Canada" (Robinne et al. 2016), my co-authors and I focused our effort on the provincial-scale impact of expanding human activities. We introduced the concept of "human-wildland interfaces" (HWI), a term more inclusive than" "wildland-urban interface" which does not apply to farmlands and industrial activities. We wanted to investigate the influence of landscape anthropization on the pyrogeography of the province of Alberta, with the hypothesis that the ecological frontier would mark a transition between natural and anthropogenic fire regimes (Fig.1).

Method and Results

We built multivariate regression models for the 1980-2010 time period to predict the total area burned (TAB) by fires >200 ha in a~215,000 ha hexagonal units covering the forested parts of the province and then compared it to official records from the Canadian National Fire Database. We first created a biophysical model based on four commonly-used biophysical variables (e.g., precipitation, temperature) and we then tested 14 anthropogenic variables (e.g., population density, distance to buildings), one at a time, and checked for the gain in the model's predictive power. The biophysical model explained ~40% of the variance in TAB. The three anthropogenic variables adding for most of individual explanatory power were the distance to the transportation network (+ 7.9%), the Human Footprint Index (+6.5%), and the density of the energy distribution network (+5.5%).

We also assessed spatial variations in the effect of the anthropogenic variables we tested using partial dependence analysis, a procedure that can isolate the individual effect of a chosen variable in a given model. The response of TAB was far from being uniform. Instead of the monotonic decrease in area burned, several variables showed a humped relationship, with an initial increase in TAB with distance then shifting to a decreasing trend over 20 to 50 km linear distance. A provincial-

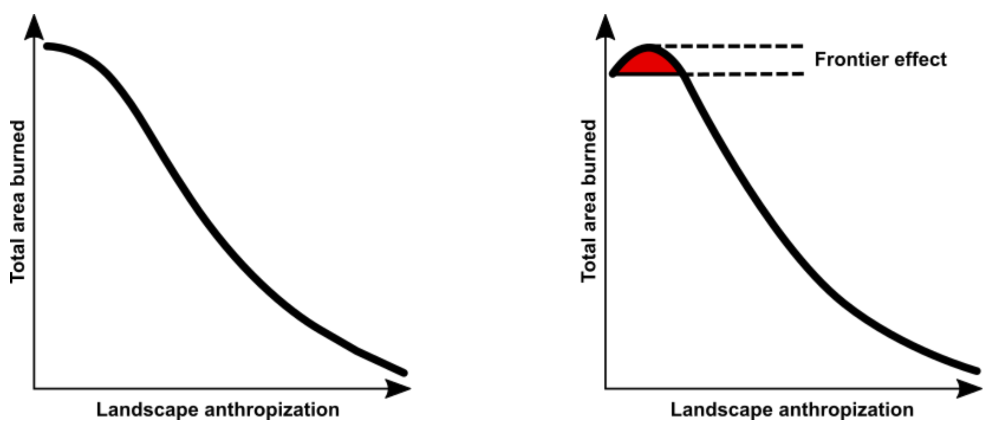

Figure 1: On the left, the theoretical human-fire relationship commonly accepted; on the right, our "frontier" hypothesis stating that the presence of an ecological frontier leads to an increasing area burned during the initial stage of landscape anthropization.

scale representation of human influence (Fig.2) highlighting the ecological frontier (i.e., intermediate human influence) generally showed overestimations of the area burned (Max. ~21,000ha) where human influence already impedes fire spread. But it also displayed several clusters of underestimations representing twice the size of the total overestimated area (~876,000 ha underpredicted).

Discussion

Our results showed several non-linear relationships between area burned and anthropogenic factors; further underlining the complexity of the human-fire interactions in North-American forests (Parisien et al. 2016). As expected, areas under high human pressure displayed lower area burned due to higher landscape fragmentation and better defensibility. However, the ecological frontier displays a total area burned higher than predicted by the model, as what could be the result of the intermix of a low density of human-wildland interfaces within a flammable homogeneous landscape. We were surprised to see no effect of seismic line disturbances on the fire regime. Temporal and spatial scales could be responsible for this absence of signal, as well as the lack of details as to the age and design of those industrial features. It is also possible that weather conditions leading to massive fires, typical of the boreal fire regime, offset landscape fragmentation at this scale.

We argue that such results should push toward a better representation of the different types of interfaces existing in the boreal forest (Johnston 2016). The diversity of land-use and land-cover changes in the economic development context of Alberta justifies such an endeavour. The ecological frontier can be qualified as a particular “roadshed”

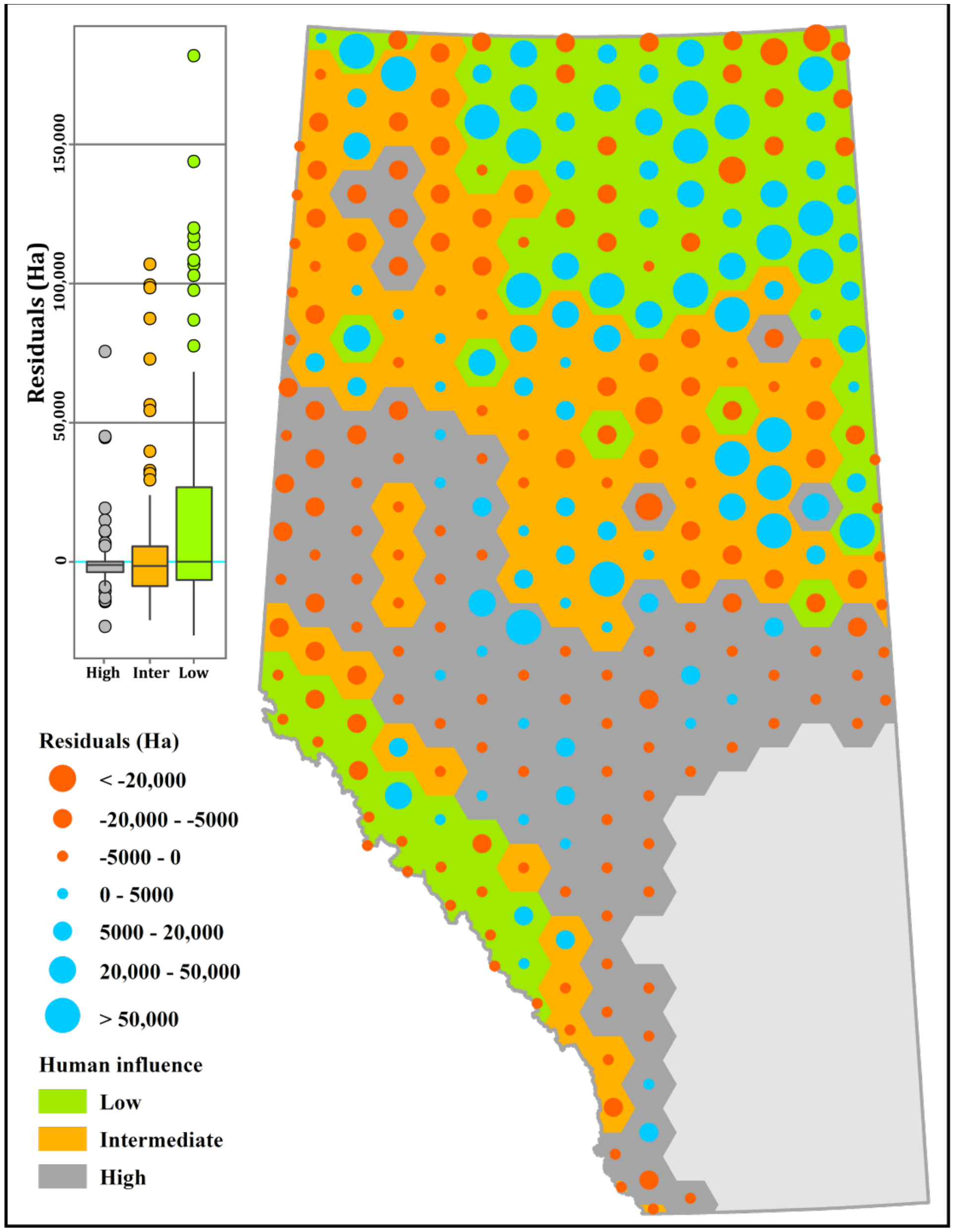

Figure 2: Map of the classified model residuals according to the regional human influence levels, determined as a function of linear distance to road. The ecological frontier is essentially represented by the orange band extending northward, with a north-west–south-east general orientation. Blue dots represent model underpredictions, whereas red dots represent overpredictions. The boxplot provides an overview of the statistical distribution of residuals according to each human influence level.

characterized by low-density but penetrating transportation network acting like “fuses” and favouring the overlap of human and natural ignitions in a highly fire-prone homogeneous landscape (Narayanaraj and Wimberly 2012). As landscape anthropization will progress, one can expect future records of area burned to quickly decrease and mix with the traditional human-fire relationship model.

The approach presented in this study could be improved by the use of spatial data with a finer temporal grain, which are unfortunately inexistent in a digital format for most of the anthropogenic variables we used. Also, testing for the response of other fire regime metrics such as ignitions density or fire frequency could certainly provide further insights to our understanding of the mutating regional pyrogeography. Nevertheless, our work offers a nuanced vision of the shifting mechanism from a natural to an anthropogenic fire regime proposed by Guyette et al. (2002), with a particular applicability to regional-scale frontier dynamics linked to natural resources exploitation. This approach could therefore prove useful in other parts of the world's forests facing similar industrial pressures (e.g., Siberia, Amazonia, Indonesia).

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Interpolating daily precipitation to improve fire danger rating in Alberta, Canada: which methods are best?

By Xinli Cai

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In Canada, wildfire is suppressed when it threatens human life, infrastructure, and valuable resources. Accurately predicting fire danger is challenging, but is essential for effective suppression. Among the factors used to determine fire activity, weather is considered the best predictor of daily fire danger and fire activity (Flannigan et al 2005). Canadian scientists have worked on integrating weather information into fire danger rating since the 1920s, resulting in the development of the Canadian Forest Fire Weather Index (FWI) System (Van Wagner 1987). The FWI System is a strictly weather-based system that relies on local noon observation of temperature, relative humidity, and 10-m open space wind speed, as well as 24-h accumulated precipitation to produce six main output indexes representing fuel moisture and potential fire intensity in a standard pine forest stand. The six indices of the FWI System have been widely used by Canadian fire management agencies to support their daily decision-making process.

Fire weather variables are recorded at the fire weather stations, which are sparsely distributed in the boreal forest. Thus, the fire weather variables have to be interpolated into areas where weather stations are unavailable. Currently, daily precipitation is one of the key challenges of fire weather interpolation because summer precipitation often results from highly localized convective storms and thunderstorms. Studies have shown that the current fire weather interpolation methods (i.e., inverse distance weighting and thin-plate splines) may be insufficient to address the spatial variability of daily precipitation using the current fire weather station network (Flannigan and Wotton 1989, Flannigan et al 1998). More sophisticated geostatistial methods such as ordinary kriging and regression kriging may result in better estimates of daily precipitation and need to be evaluated for better fire weather interpolation.

The second approach of estimating precipitation is to use the gridded precipitation products directly, such as radar precipitation (Flannigan et al 1998). Environment and Climate Change Canada (ECCC) have developed the Canadian Precipitation Analysis (CaPA) System (Mahfouf et al 2007), a data assimilation system that produces gridded precipitation analysis in near-real time at a 10 km resolution over North America. Recently, the CaPA System successfully integrated radar composite data into the analysis, which resulted in a significant improvement of the CaPA System.

To find the best approaches of estimating daily precipitation and improve the accuracy of fire danger rating in areas between weather stations, we evaluated the currently available precipitation estimating methods (i.e., multiple interpolation methods and the CaPA System), and examined the sensitivity of interpolation methods to weather station density.

Overview of the methodology

This study used fire weather station observations from Alberta Agriculture and Forestry (AAF) and the CaPA System outputs from ECCC (Figure 1), which were collected in the forested portion of the province of Alberta, Canada, during the 2014-2016 fire seasons.

Based on previous studies, we selected six interpolation methods (Table 1) to compare with the CaPA System. A leave-one-out cross-validation procedure was used to generate precipitation estimates for interpolation methods, whereas the 24-h precipitation accumulates from the CaPA System were directly extracted to the valid AAF stations. Precipitation estimated from the interpolation methods and the CaPA System, in combination with the AAF daily observations of temperature, relative humidity, and wind speed, were used to calculate the indexes of the FWI System.

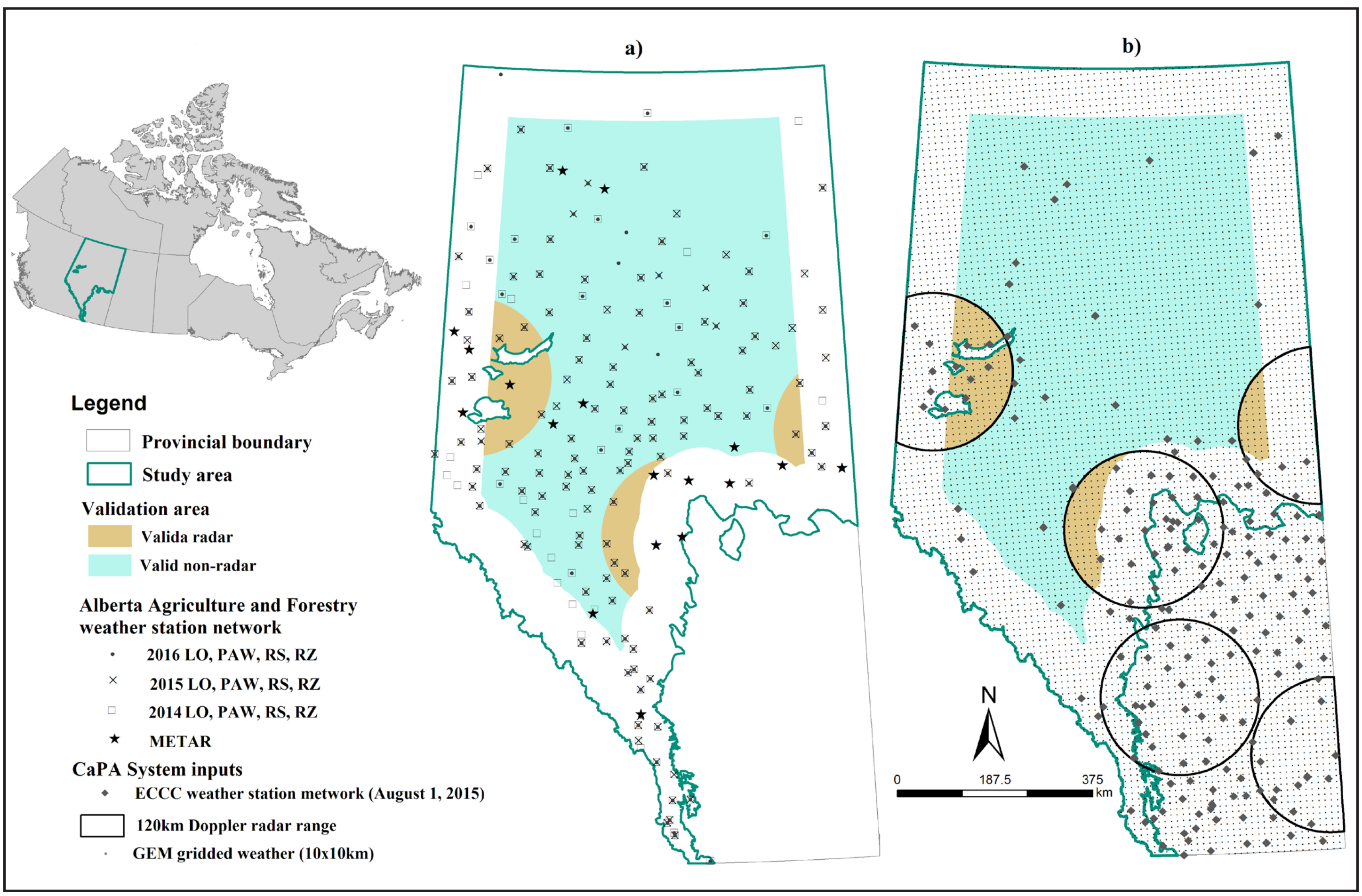

Figure 1 (a) Alberta Agriculture and Forestry weather station network and (b) inputs of the Canadian Precipitation Analysis (CaPA) System.

The average errors of the estimates of precipitation and the FWI System indices were quantified by the mean absolute error and mean error. The ability of the candidate methods in estimating effective precipitation of the fuel moisture codes were quantified by categorical equitable threat score and frequency bias index using the following bins: (0, 0.5); (0.5, 1.5); (1.5, 2.8); (2.8, ∞) mm. A bootstrap confidence interval (n=1000) was computed to identify the statistical difference between the methods, and a stationary block bootstrapping method (Politis and Romano 1994) which takes into account the spatial and temporal autocorrelation of the data was applied.

Finally, we performed a sensitivity analysis to examine how the weather station density affected the performance of interpolation methods. The sensitivity analysis was performed by randomly sampling (n=100) 10%, 25%, 50%, 75%, and 90% of the fire weather stations in our study area using a 6-step procedure. Details of this procedures are available in Cai (2017).

Type of the methods	Methods	Transformation of daily precipitation[1]	Abbreviation
Gridded product	Canadian Precipitation Analysis System	–	CaPA
Non-geostatistics	Inverse distance weighting[2]	–	IDW
	Thin-plate spline smoothed[3]	–	TPS-S-SRT
		square root	TPS-S-SRT
	Thin-plate spline non-smoothed[4]	–	TPS-NS
		square root	TPS-NS-SRT
Univariate geostatistics	Ordinary kriging[5]	–	OK
		square root	OK-SRT
Multivariate geostatistics	Regression kriging with elevation as a covariate[6]	–	RK(elev)
		square root	RK(elev)-SRT
	Regression kriging with CaPA as a covariate[6]	–	RK(CaPA)
		square root	RK(CaPA)-SRT

[1] Square root transformation was applied to the precipitation observations before the interpolation, and a back-transformation was applied to the resulted estimates.
[2] A power parameter of 2 was used for the function of inverse distance as this is the currently procedure used in fire weather interpolation by the Canadian Wildland Fire Information System (Natural Resource Canada 2008).
[3] A spline surface was fitted with the constraint of smoothing that is optimized by minimising the generalized cross-validation.
[4] A spline Surface was fitted using the exact observations.
[5] A spherical model was used to build the semi-variogram.
[6] Regression kriging first built a linear regression of the observations and the covariate; then a semi-variogram was built with the spherical model using residuals of the regression.

Table 1. Precipitation estimating methods evaluated in this study.

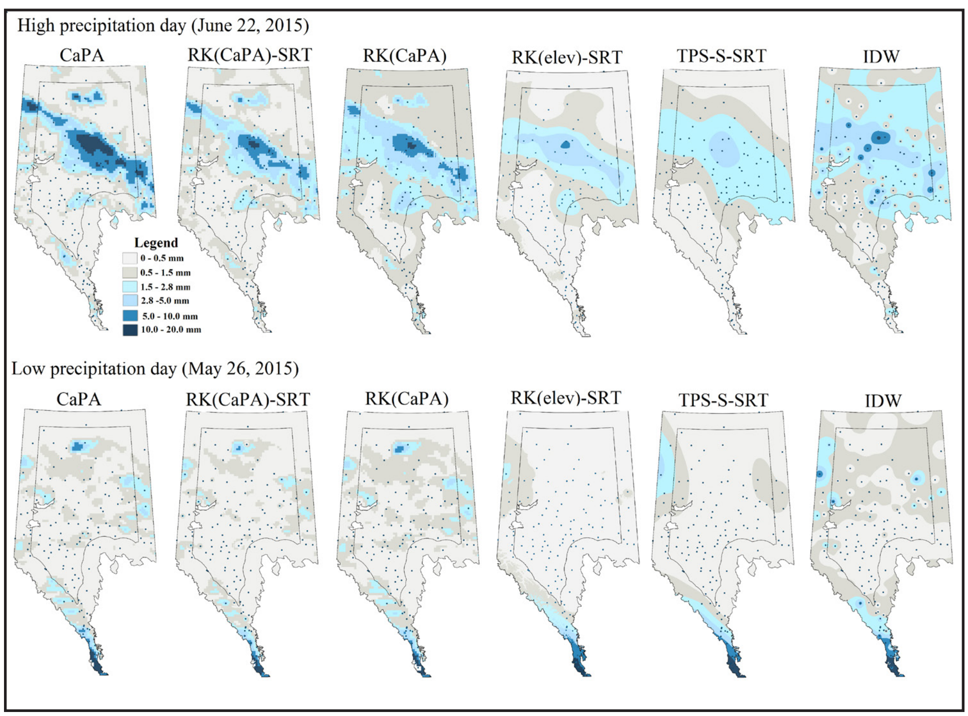

Figure 2 Examples of the 24-h precipitation estimated using the top performing methods and current operationally used methods (IDW) on a light precipitation day (May 26, 2015) and a rainy day (June 22, 2015). Each dot represents an AAF fire weather station.

Results

This study shows that the CaPA System was only a mid-tiered method (7th of 12) in estimating precipitation in Alberta, except in areas within a 120 km Doppler radar range, where the CaPA System performed the second best. Regression kriging with CaPA System as a covariate was the best performing method regardless of the radar coverage. Figure 2 shows that RK(CaPA)-SRT and RK(CaPA) captured precipitation events identified by both the CaPA System and the fire weather stations, resulting in a less smoothed precipitation map compared to other interpolation methods. However, IDW produced precipitation maps with the unrealistic "bullseye".

Figure 3 shows that all the top performing methods underestimated a significant precipitation event (~40mm) at the beginning of the fire season, resulting in an overestimation to FWI System indices. The Fine Fuel Moisture Code (FFMC) recovered quickly after a few dry days, while the estimates of Duff Moisture Code (DMC) and Drought Code (DC) remained overestimated for the duration of the fire season due to their longer drying time lags of 12 and 52 days, respectively. The CaPA System mostly underestimated the precipitation event, resulting in the most overestimated DC. In contrast, the RK(CaPA) generated the most accurate DC estimates.

Sensitivity analysis showed that all the interpolation methods had improved performance in estimating precipitation as weather station density increased (Figure 4). For precipitation, FWI and FFMC, the CaPA System was the best performing method when weather station density was ≤ ~0.5 / 10 000 km2; RK(CaPA)-SRT became the top performing methods for station density above the threshold. For DMC and DC, RK(CaPA) was always the top performing methods regardless of weather station density.

Discussion: which methods are best?

In this study, some of the most commonly used daily precipitation estimating methods were evaluated to improve the fire danger rating in the province of Alberta. We found that regression kriging with the CaPA System as a covariate showed the best performance in estimating precipitation and FWI System indexes in Alberta. Although the CaPA System was only a mid-tired method; it provided

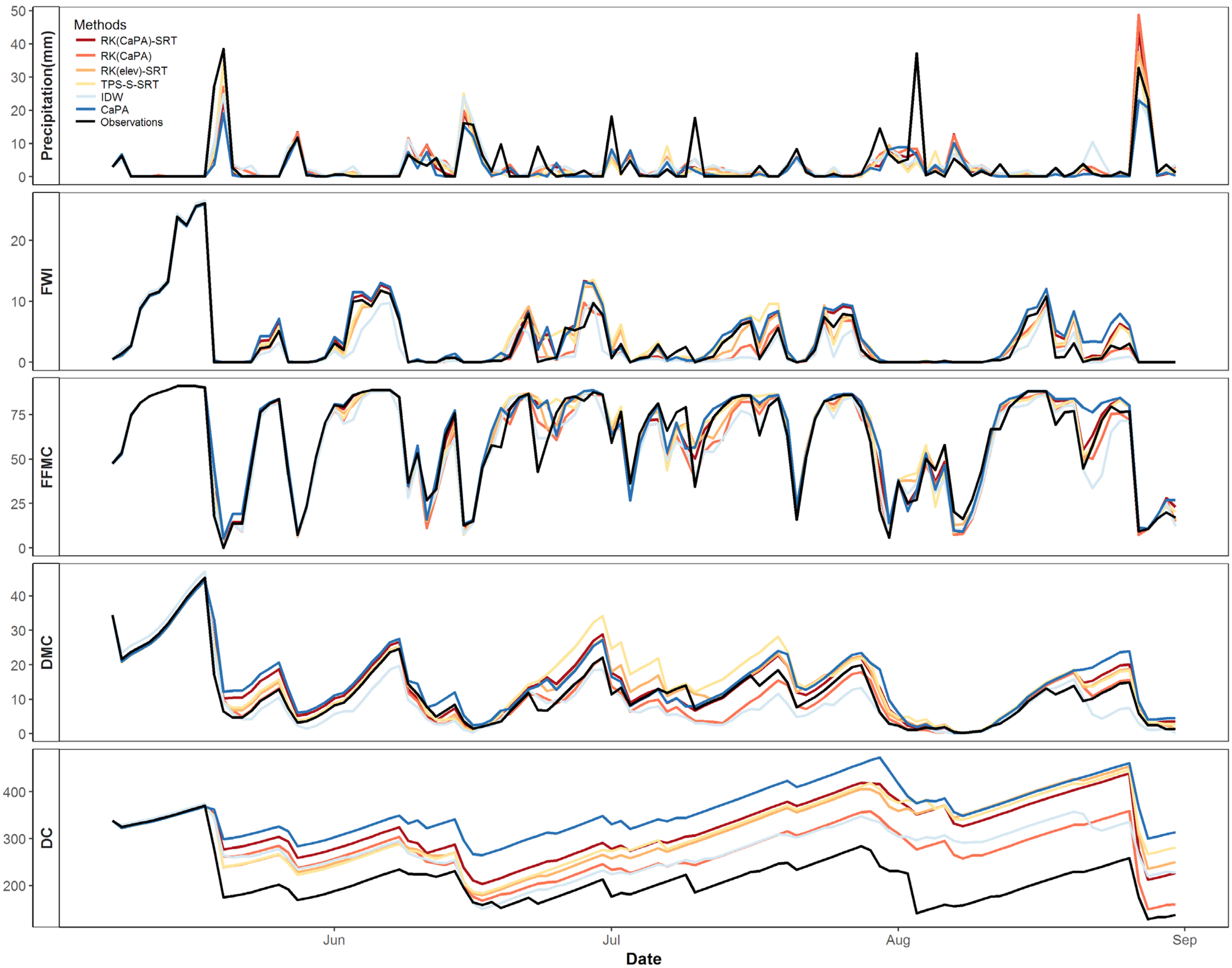

Figure 3 Time series plots of observations versus predictions for precipitation and the derived FWI System indices for the top performing methods and current fire weather interpolation method (IDW) used by CWFIS at Whitemud lookout tower in 2016 (116 days). Whitemud lookout tower is within the 120km Doppler radar range.

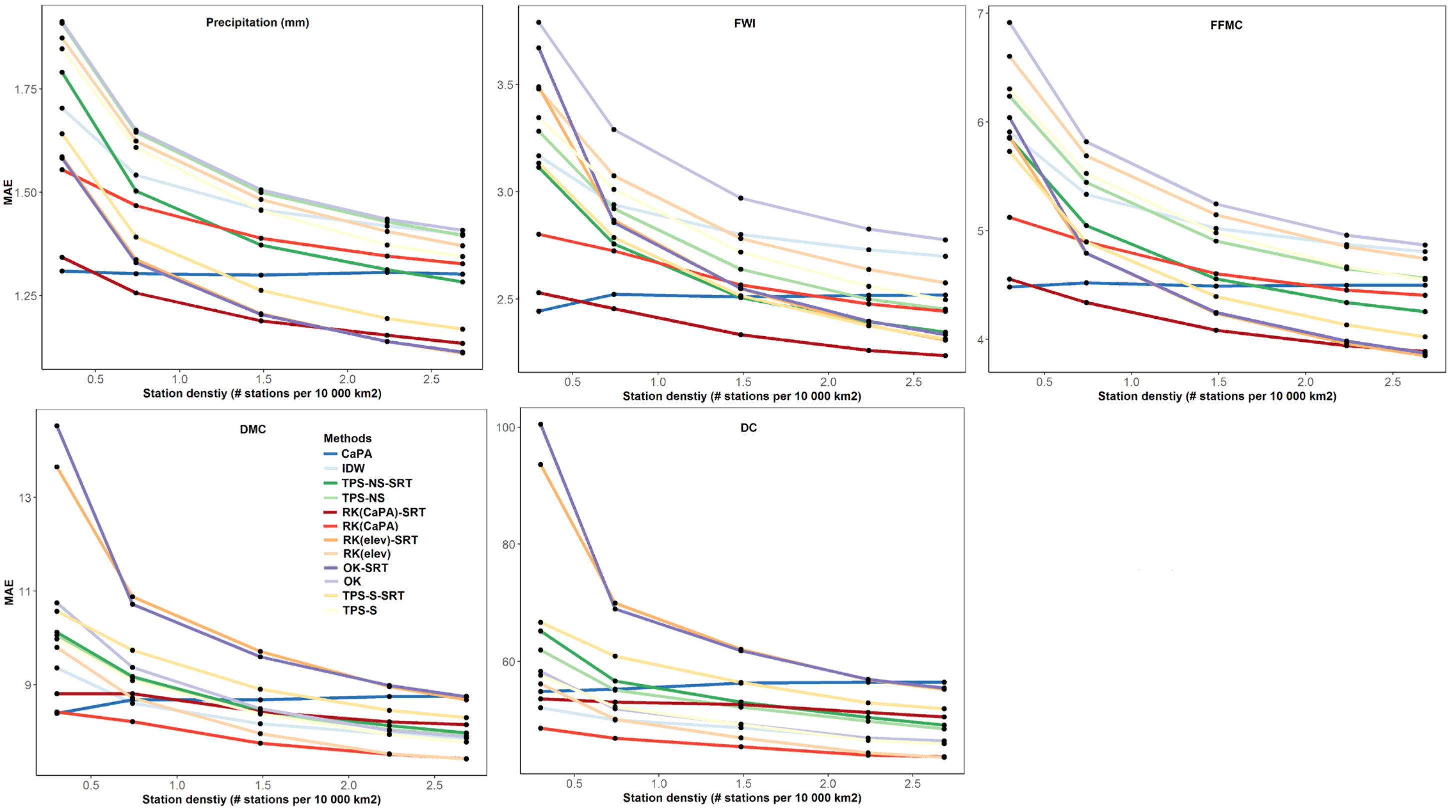

Figure 4 Mean Absolute Error (MAE) of precipitation and FWI System estimates for the weather station density sensitivity analysis. Dots are the mean of MAE values resulted from the random resampling (n=100) and are averaged for the years from 2014 – 2016 for each weather station density scenario.

valuable additional information in regression kriging other than elevation. As a result, both RK(CaPA)-SRT and RK(CaPA) could capture the convective precipitation events in areas with lower fire weather station density (e.g. northern part of the study area as shown in Figure 2). The second group of top performing methods included TPS-S-SRT, RK(elev)-SRT, and OK-SRT, but there was no significant difference between these methods. The current fire weather interpolation method used by CWFIS, namely IDW, was found to be the second worst interpolation method. Therefore, we recommend the used of regression kriging with the CaPA System as a covariate to gain a better estimates of fire danger.

Our research suggested that the direct use of the CaPA System was not optimum for fire danger rating in Alberta, which is different from a previous study that showed the CaPA System improved the accuracy of fire danger rating in Ontario (Hanes et al 2017). In our study, ECCC station network density was only 1.13 / 10 000 km^2, but AAF weather station network was 3.1 / 10 000 km^2, which may explain why CaPA System was outperformed by the geostatistical methods. In addition, our sensitivity analysis showed that if the fire weather station density was below the threshold of ~0.5 / 10 000 km^2, the CaPA System became the best performing method, which is the case in the Hanes et al (2017) study.

We tested only one gridded precipitation analysis for fire danger rating. Other gridded precipitation products such as the Global Precipitation Measurement and Precipitation Estimation from Remote Sensing Information using Artificial Neural Network could be evaluated for more accurate fire danger rating. Additionally, the performance of regression kriging with alternative gridded precipitation products as covariates could also be evaluated in the future.

Conclusion

The primary goal of this study was to select a robust precipitation estimating method to improve the fire danger rating in the province of Alberta. Our study showed that regression kriging with the CaPA System as a covariate was the best performing method and produced significantly better estimates of precipitation and FWI System indexes compared to the current fire weather interpolation method (IDW). Regression kriging is a relatively new method for fire weather interpolation. The addition of regression kriging to the field of fire management and research will result in more accurate fire danger rating and improve the daily decision-making process for better resources allocations and pre-planning. Furthermore, this study was the first to examine the sensitivity of interpolation methods to fire weather station density for precipitation, which will help inform fire managers and researchers in selecting the best precipitation estimating method for fire danger rating.

This article is a summary of a thesis completed in 2017 (Cai 2017).

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Global Fire EWS

A Global Early Warning System for Wildland Fire

The Global Fire Early Warning System (EWS) provides 1-10 day forecasted FWI System data based on the Canadian Meteorological Centre's (CMC) Global Deterministic Forecast System (GDPS). Global Fire EWS' 0.24 x 0.24 degree resolution provides a means of comparing fire danger between countries, continents and biomes. To enhance the weather-based FWI system, multiple basemaps and active fire hotspots are available within the system to present additional perspectives on terrain, vegetation, proximity to populations, and visible smoke and cloud. The Global Fire EWS is processed and presented on Canada Wildfire's network at the University of Alberta in collaboration with Natural Resources Canada and multiple international partners.

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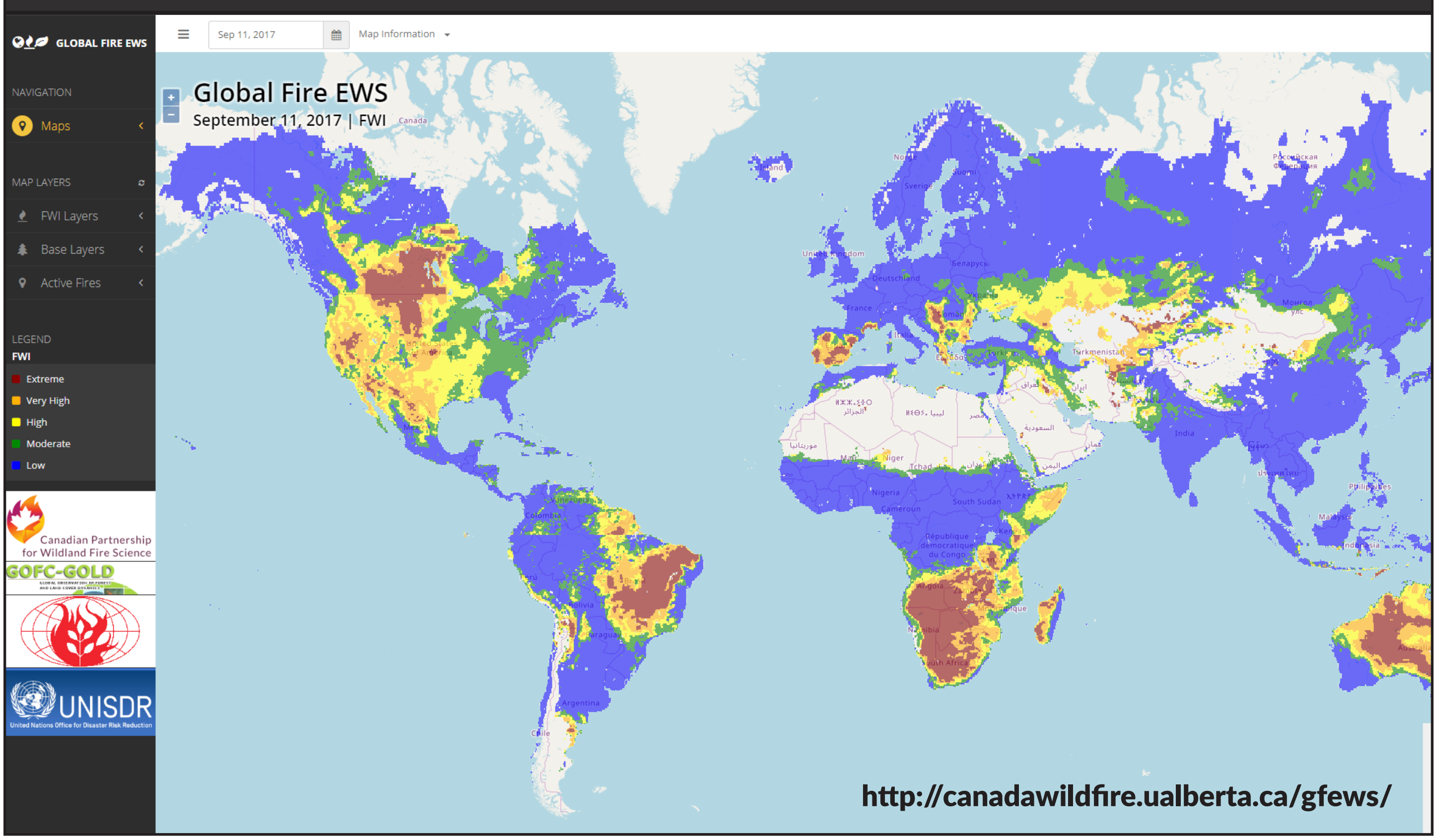

"Connecting diverse wildland fire, emissions, air quality and modelling communities."

An early warning system to forecast the close of the spring burning window from satellite-observed greenness

By Paul D. Pickell, Nicholas C. Coops, Colin J. Ferster, Chris W. Bater, Karen D. Blouin, Mike D. Flannigan, and Jinkai Zhang. Contact: Dr. Paul D. Pickell, Post-Doctoral Fellow, University of British Columbia, paul.pickell@forestry.ubc.ca

Introduction

In the Boreal forests of North America it is anticipated that climate warming will result in increases in fuel availability and fire severity, however the effects of increasing human activity from urbanization and resource extraction remain unclear. More than two-thirds of human-caused fires in Alberta occur during the spring burning window, a period of increased ignition and fire spread potential between snow melt and the onset of leaf growth. Previous research has shown that the moisture content in fine fuels is a critical indicator of human-caused fire activity. Observations from the satellite MODIS provide a unique opportunity to observe and monitor fuel moisture from growing vegetation, since healthy leaf area has a strong relationship with spectral greenness indices and leaf moisture. We investigated the relationship between fine temporal changes in satellite-derived greenness and the beginning and end of the spring burning window as quantified by human fire ignitions in Alberta's Forest Protection Area. The developed relationships of the spring burning window can provide near real-time fuel moisture information to fire managers for allocating fire suppression resources and planning prescribed burns.

Methods

The historical wildfire database contains attributes for each fire ignition including date and source. Human-caused fire activity was modeled by converting human fire ignition counts to fire days, defined as any day of the calendar year when one or more human-caused fire ignitions are reported. Next, the MODIS satellite captures cloud-free red and near infrared wavelengths at 8-day increments that allows for accurate tracking of vegetation phenology. The MODIS images were mosaicked to cover the entire province of Alberta and used to estimate greenness using the normalized differenced vegetation index (NDVI). We defined green-up as the date when NDVI reached the half of the maximum for the year (Figure 1), which was then mapped across the region. We tested the ability to forecast the spring burning window throughout each annual season. This was achieved by simulating the availability of MODIS observations throughout each year and using the average greenness values for unobserved dates. The greenness curves that emerged were then used to estimate the green-up date for the cumulative set of annual satellite observations. A network of

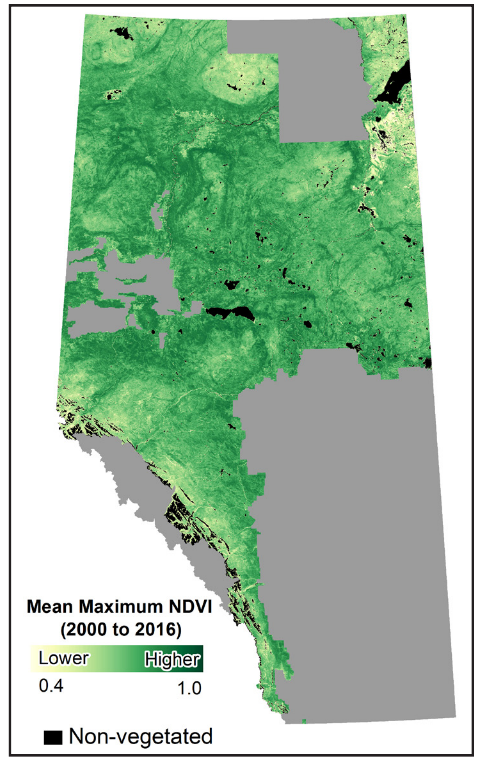

Figure 1. Mean maximum greenness as expressed by the Normalized Vegetation Differenced Index (NDVI) for years 2000 to 2016 within the Fire Protection Area of Alberta.

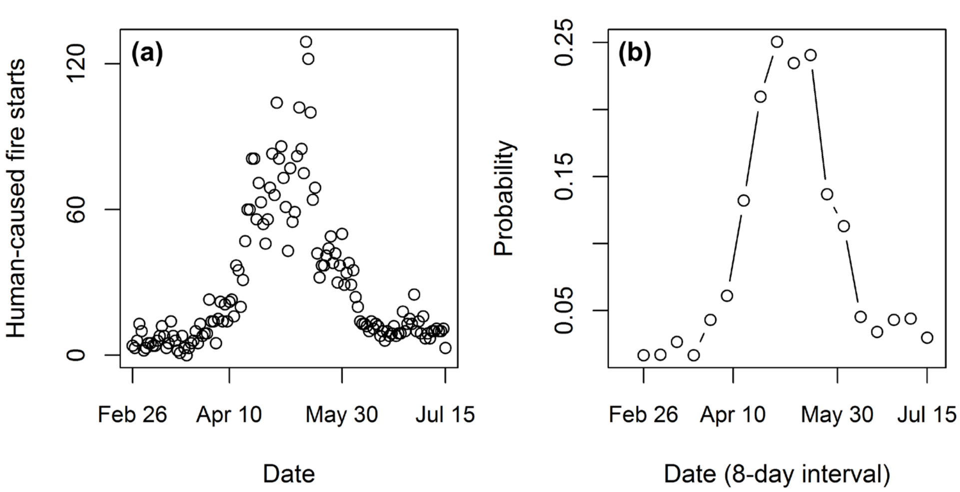

Figure 2. (a) Total number of human-caused fire starts by day-of-year from 2000-2014. (b) Probability of a human-caused fire day modelled as a binomial process by 8-day intervals corresponding to the frequency of satellite observations of greenness.

16 phenological cameras was installed in situ in three natural sub-regions during the growing season for 2009-2011 and 2013. The cameras acquired five photos daily. From these images we show examples of forest condition on the dates that we predict high probability of a human-caused fire day based on the aforementioned green-up model.

Results

Human-caused fire activity during the years 2000 and 2014 peaked between April and May (Figure 2). Vegetation green-up varied from year-to-year within each natural sub-region (Figure 3). The earliest observed green-up day-of-year occurred on April 5, 2015 in the Montane and Upper Foothills natural sub-regions. The latest observed was on June 14, 2002 in the Alpine natural sub-region. Human-caused fire activity was concomitant with satellite-observed green-up. The median green-up for all years was April 30, compared with May 8 for human-caused fire ignitions. The mean absolute error (days) for the forecasted green-up day of year decreased in all natural sub-regions, as more observations were made available throughout the season (Figure 4). A 10-day window of accuracy was not achieved until later in the season for the other natural sub regions (Figure 4). Phenological camera observations in mixedwood stands showed leaf-off conditions had the same timing as peak human-caused fire activity (early May). In a coniferous site in the Alpine natural sub-region, changes in greenness were subtler and consequently fine fuel moisture content was less obvious.

Discussion

Globally, northern Boreal forests are seeing an increase in industrial activities that have transformed historically remote Boreal forests into anthropogenically-modified landscapes with increased risks for human-caused fire ignitions. The economic and social costs associated with fire suppression are very high in the early months of the fire season and the variability of fire-fighting costs from year-to-year increases uncertainty for fire managers. Thus, a cost-effective early warning system is critical to mitigating these socioeconomic costs. With the rapid increase in fire suppression activities, the fire statistics demonstrate that the spring burning window remains the most dangerous part of the year with respect to loss of life and infrastructure. The ability of fire ignitions to quickly

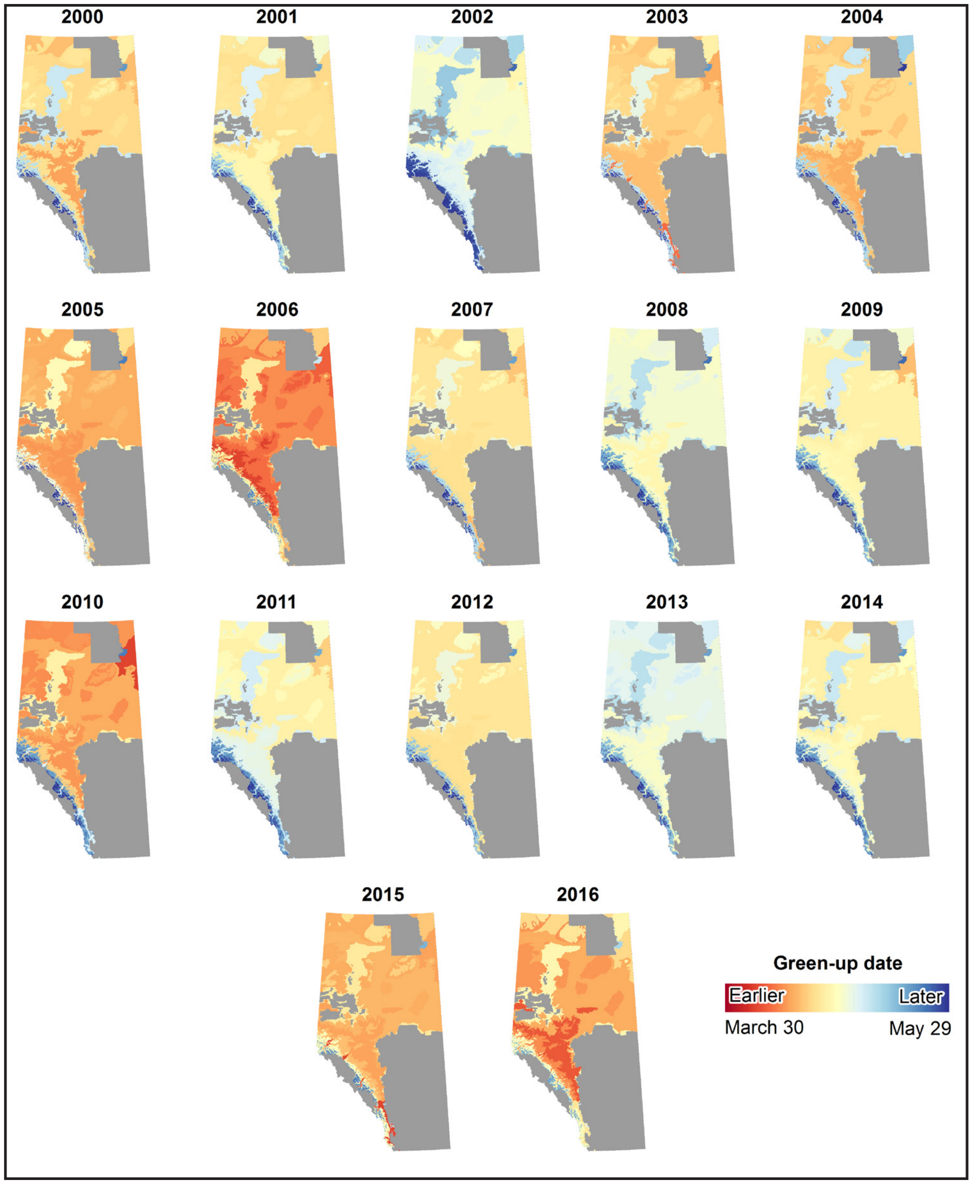

Figure 3. Green-up date for each natural sub-region modeled from half-maximum greenness for all years. Earlier dates represent earlier than average green-up and later dates represent later than average green-up relative to the entire wildfire protection area for all years (April 29).

spread in early spring is attributed to a dip in foliar moisture and the drying of fine fuels, leading to increased fire frequency, area burned, and fire size during springtime. Historical and contemporary fire records show that the spring burning window results in increased fire activity between May and June which coincide with changes in vegetation phenology. Simulation of the phenological curves from the end of winter to the end of vegetation green-up provides key evidence that vegetation greenness may be used as a reliable proxy for fine fuel moisture content. Satellite-observed greenness data are processed continuously and could serve as an early-warning system, which offers potential benefits to fire resource allocation.

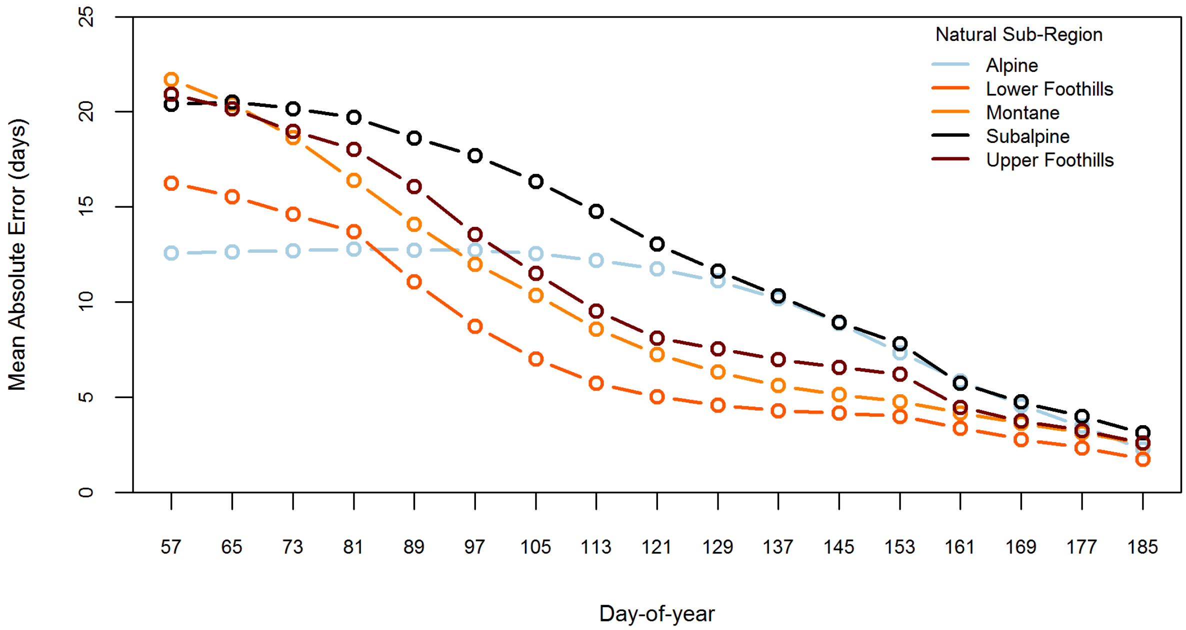

Figure 4. Forecasting the green-up day-of-year was simulated for each year by successively adding greenness observations to the mean greenness curve and calculating the mean absolute error within each natural sub-region.

This article is based on a recent publication by the authors in Nature Scientific Reports (link).

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Congratulations on your Retirement Ray!

On the evening of November 6th, 2017 FPInnovations celebrated Ray Ault during his retirement send-off. The celebration was held in Edmonton and was attended by a large number of government agencies, companies and past and present FPInnovations staff. Those in attendance included personnel from: AAF, NWT, YT, CIFFC private industry the University of Alberta and the Canadian Partnership for Wildland Fire Science

Ray was the first person hired in 2001 to lead the then newly founded wildfire research group and has been credited with growing the program to include many of Canada's leading wildfire agencies, companies and universities. During his 17 year career with the group Ray has managed the program, built national and international relationships and encouraged collaboration aimed at providing practical wildfire solutions to its membership and the greater wildfire community.

The night was capped off by a special presentation from retired Alberta ADM Cliff Henderson who was instrumental in starting and supporting the fire group. Each person in attendance provided a few words, either in the form of a story or as a tribute to Ray. Common themes highlighted Ray's enthusiasm, passion, and unique ability to communicate and bring people together. Ray, although sorely missed, leaves the program on solid footing to expand and move forward.

Some of the faces of FPInnovations' Wildfire Operations Research Group, past and present, at Ray's retirement send off.

"Connecting diverse wildland fire, emissions, air quality and modelling communities."

Canadian Partnership for Wildland Fire Science Second Biennial Wildfire Science and Technology Retreat

By Dan Thompson, Forest Fire Research Scientist, CFS, Northern Forestry Centre, daniel.thompson@canada.ca

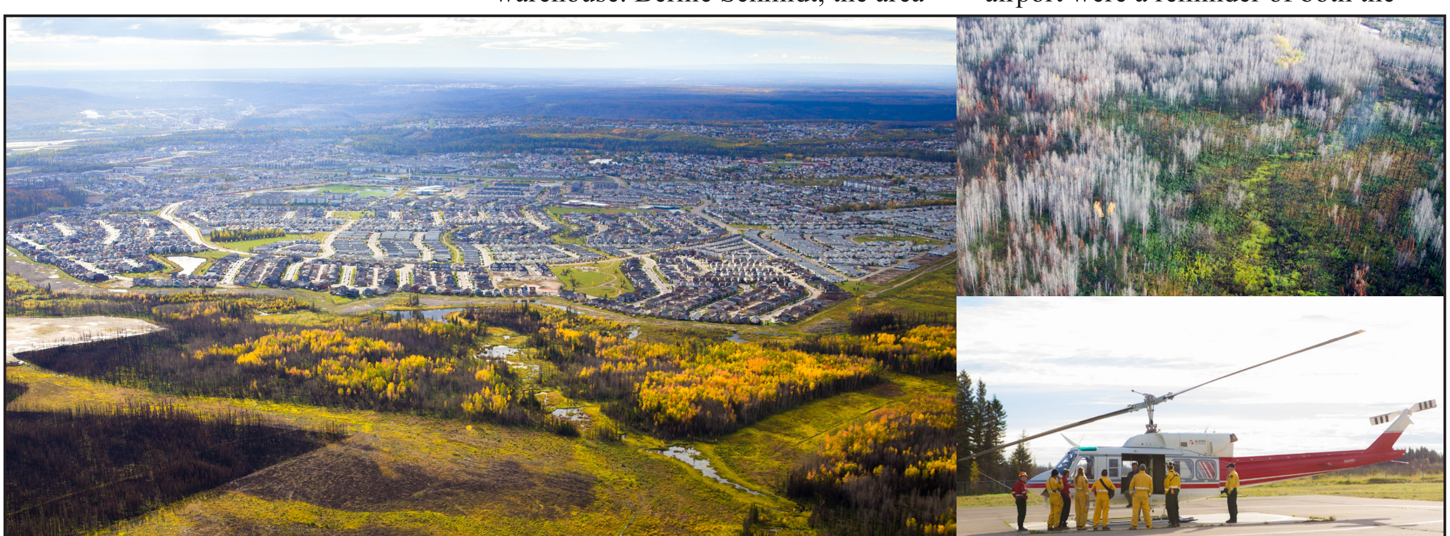
Connecting wildfire researchers, academics, students, and wildfire management staff

Held September 17-19 , 2016

Building on the success of the 2014 Partnership retreat held in Jasper and Hinton, the 2016 Partnership retreat focused on the Fort McMurray area and the Horse River wildfire that impacted the community earlier that year. The trip included students and faculty from the University of Alberta (UA), as well as staff from Alberta Agriculture and Forestry (AAF), the Canadian Forest Service (CFS), and FPInnovations. Broadly, the goal of the trip was for the attendees to learn first-hand the impacts of the destructive Horse River wildfire on the community of Fort McMurray, its infrastructure, and the surrounding forest ecosystems.

The group was treated to a tour of the Fort McMurray water treatment facility where they were taught about the work needed to keep the treatment plant up and running during the wildfire.

The first stop on the trip was the city water treatment facility operated by the Regional Municipality of Wood Buffalo. The facility provided uninterrupted water flow for fire suppression efforts in the city during the Horse River wildfire. Staff explained the long and stressful hours as the fire entered the community, and the personal and professional challenges in providing over double the normal supply of water to satisfy firefighting efforts. Next, attendees received a tour of the airport grounds and wildfire warehouse. Bernie Schmidt, the area Wildfire Manager, provided a detailed overview of the wildfire. He detailed the challenges in attempting to manage a complex incident spanning both a wide forest area and a major population centre. Tours of the rapidly-regenerating steep hillsides near the airport were a reminder of both the



The attendees were treated to an aerial tour of the area where they noted the patchy nature of the burn mosaic.

intense nature of the fire, as well as the adaptive capacity of the boreal forest to recover from the natural disturbance of wildfire.

An aerial tour of the fire provided by AAF revealed large tracts of forest within the fire's perimeter that were left unburned or burned very lightly, a testament to the patchy nature of rapidly moving fires.

Following the aerial tour of the fire, the group visited a household on the north end of the city. Despite not losing their home, the citizens relayed the impacts of the evacuation on themselves, their family, pets, and fellow community members. The role of social media in both the evacuation process itself and as a way of assisting the recovery effort was an interesting highlight.

Lastly, the group visited a wetland drained in the early 1980s that was impacted by the fire. Drainage dramatically increased tree growth, leading to increased fuels and deep and persistent peat smouldering that required intensive effort with heavy equipment to extinguish. Experimental drainage areas such as this were highlighted as windows into the future fire potential of wetland ecosystems under a warmer and drier future fire regime.

The common message throughout the diverse groups visited was the room for constant improvement on the fire preparedness, response, and recovery phases, especially given the extreme fire conditions the community encountered in May of 2016. Lessons learned from Fort McMurray will surely be useful in the future as we learn and continue to live with fire.

The group visited a wetland drained in the early 1980s to the south of Fort McMurray and discussed the impacts of the wildfire on wetland ecosystems and vice versa.

PARTNERSHIPS, COLLABORATIONS, AND SHARED EDUCATION

Attendees:
Greg Baxter (FPInnovations)
Xinli Cai (UA)
Rodrigo Campos (UA)
Piyush Jain (UA)
Ginny Marshall (CFS/UA)
Brett Moore (AAF)
Kimberly Morrison (UA)
François Robinne (UA)
Bernie Schmidt (AAF)
Dan Thompson (CFS)
Cordy Tymstra (AAF)
Hugh Wallace (UA)
Ellen Whitman (UA)

Special Thanks to the 2016 Planning Committee:
François Robinne (UA)
Dan Thompson (CFS)
Cordy Tymstra (AAF)

Photos courtesy of Xinli Cai; Written content provided by Dan Thompson, Canadian Forest Service, Northern Forestry Centre

"Connecting diverse wildland fire, emissions, air quality and modelling communities."

Congratulations to the Wildland Fire Canada 2016 award winners!

The 2016 J.G. Wright Award for outstanding contributions to wildland fire research was awarded to (tie) Marty Alexander and Peter Kourtz

Dr. Marty Alexander (left) and his wife of 41 years, Heather (right).

Peter Kourtz accepting his award.

The 2016 H.W. Beall Award for outstanding contributions to innovation in wildfire management was awarded to Peter Fuglem

Peter Fuglem accepting his award.

The inaugural CIFFC Operational Award was awarded to Brian Simpson

Brian Simpson

The inaugural WFC Student Ignition Award was awarded to Rachel Reimer for her presentation titled The fire within: gender and leadership in wildland fire

Rachel Reimer (right) with WFC2016 co-chair Kendrick Brown (left).