OPERATIONAL WILDFIRE MAPPING WITH SENTINEL-2 AND LANDSAT IN BRITISH COLUMBIA

Ashlin Richardson[1], Devona Hay[1], Neal McLoughlin[1], Morgan Crowley[2], Sasha Nasonova[1], Alexandre Bevington[1]

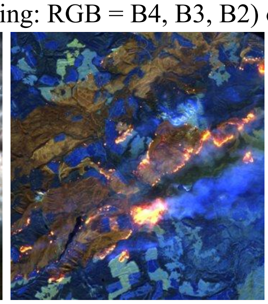
[1]BC Ministry of Forests, PO BOX 9502, STN PROV GOVT, Victoria BC V8W9C1 Ashlin.Richardson@gov.bc.ca
[2]Canadian Forest Service, 1219 Queen Street East, Sault Ste. Marie, ON, P6A 2E5 Morgan.Crowley@canada.ca

ABSTRACT

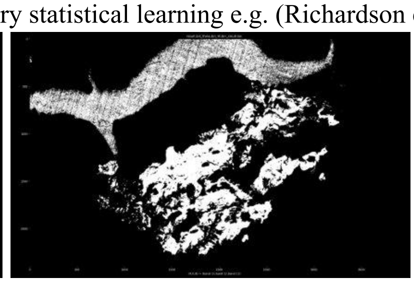
We outline a 2022 operational trial of satellite fire perimeter mapping in British Columbia using ESA Sentinel-2 data, augmented by USGS/NASA Landsat data. In the trial the BCWS (BC Wildfire Service) Predictive Services unit generated over three hundred "low latency" fire polygon updates which were then vetted by BCWS's Geospatial Services Team, showing that Sentinel-2 is effective for timely (delivery in under twelve hours from capture) fire mapping, even of small or unknown fires, as well as mapping fires under smoke cover. Front-line staff on high-profile incidents in 2022 recognized the products' value. Moreover, increasing extreme weather event potential (White et al, 2023) supports furthering the exploitation of Remote Sensing to improve situational awareness.

In 2022, BC Wildfire Service used Sentinel-2 spaceborne multispectral data from ESA with two objectives: monitoring progression of remote fires where active suppression was not occurring, and improving situational awareness. The result was improving the frequency and fidelity of fire mapping updates, including for fires being actively suppressed. A short-wave based (i.e. non-thermal) infrared method (Wooster et al, 2021) was used, illustrated here with September 10, 2022 imagery of the Battleship Mountain wildfire (G72150) and outlined in steps one to five below.

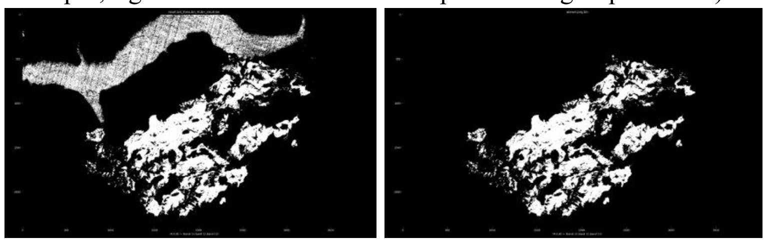
1. Prepare Sentinel-2 (select bands B12, B11 and B9) or Landsat data (spectrally interpolate to simulate Sentinel-2's bands B12, B11 and B9). Cloud-penetration and sensitivity to active fire motivate selecting the three longest wavelengths (Right: false color encoding: RGB = B12, B11, B9). For comparison (Left: true color encoding: RGB = B4, B3, B2) over the same area.

2. Classify fire with a simple rule (e.g. the "band math" expression: B12 > B11 && B12 > B9) whose output is shown to the right below (false color encoding: RGB = B12, B11, B9 on the left). Alternatively if this fails, can use rudimentary statistical learning e.g. (Richardson et al, 2010).

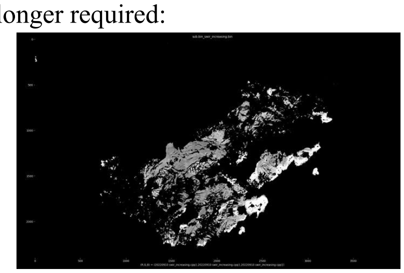


.

3. False positives are scrubbed manually using a GUI tool such as GIMP (below left: “band math” expression output; right: result scrubbed for false positives e.g. liquid water):

.

4. Convert the raster result of the “band math” expression to polygon using a Python script, then use QGIS to overlay and compare with existing publicly available BCWS perimeter data.
5. Submit polygon in KMZ format for Subject Matter review by BCWS’s Geospatial Services.

Currently a new fire classification rule, the “band math” expression “B12 / B9 > 1.1” is being investigated to reduce false positives due to water in solid, liquid or gas state. The new rule is shown below, multiplied by B12 so that brighter spots in the map reflect higher fire intensity. In this example, scrubbing of false positives is no longer required:

.

Acquisition frequency and data latency were the most significant issues. The effect of fire smoke on classification accuracy will be discussed. The authors are grateful for infrastructure support provisioned by NRCan’s Emergency Geomatics Service team, which is anticipated to improve this application’s latency by several hours, for use in the 2023 fire season. Continued development of this initiative will contribute towards Knowledge Exchange (KE) and readiness activities for Canada’s upcoming WildfireSat mission. Please see (McFayden et al 2023) for more details.

Keywords— Fire Mapping, Sentinel-2, Landsat, SWIR, Fire intelligence, Situational awareness

REFERENCES

White, R.H. et al. 2023. “The unprecedented Pacific Northwest heatwave of June 2021”, *Nature Communications,* Vol. 14 (Article Number 727): doi: https://doi.org/10.1038/s41467-023-36289-3

Wooster, M.J. et al. 2021. “Satellite remote sensing of active fires: History and current status, applications and future requirements”, *Remote Sensing of Environment,* Vol. 267 (No. 15): doi: https://doi.org/10.1016/j.rse.2021.112694.

Richardson, A. et al 2010. “Unsupervised nonparametric classification of polarimetric SAR data using the K-nearest neighbour graph”. Paper presented at IGARSS 2010. doi: https://doi.org/10.1109/IGARSS.2010.5651992

McFayden, C.B. et al 2023. “Canadian Fire Management Agency Readiness for WildFireSat: Assessment and Strategies for Enhanced Preparedness”, *MDPI Fire,* Vol. 6 (No. 73). doi: https://doi.org/10.3390/fire6020073

INVESTIGATING SPACEBORNE L-BAND POLARIMETRIC SAR FOR OPERATIONAL WILDFIRE MAPPING IN BC

Ashlin Richardson[1], Lucio Mascolo[2], Subhadip Dey[3], Armando Marino[4], Hao Chen[5], Sasha Nasonova[1], Andre Beaudoin[5]

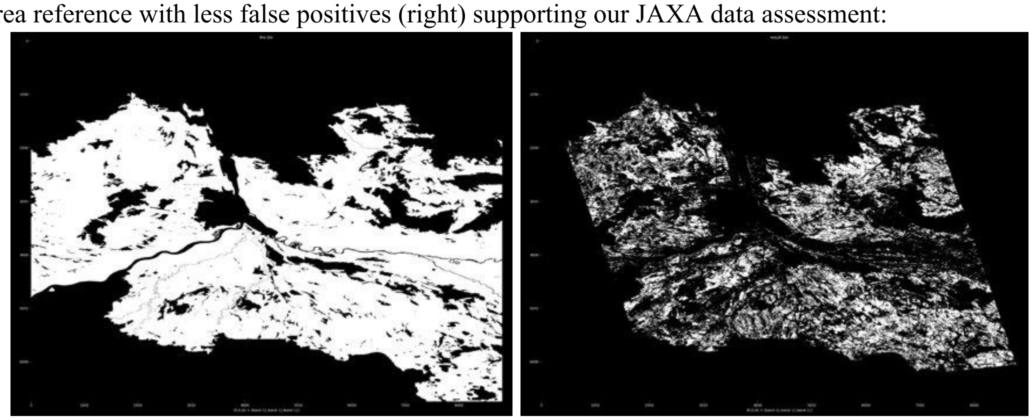
[1]BC Ministry of Forests, PO Box 9502, Stn Prov Govt, Victoria BC V8W9C1 Ashlin.Richardson@gov.bc.ca
[2]Global Change Unit, Imaging Processing Laboratory, University of Valencia, PO Box 22085 E-46071 Valencia, Spain lucio.mascolo@ua.es
[3]Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur, Kharagpur 721302, India sdey2307@gmail.com
[4]Department of Biological and Environmental Sciences, University of Stirling, Stirling FK9 4LA, UK armando.marino@stir.ac.uk
[5]Canadian Forest Service, 506 Burnside Rd W, Victoria, BC V8Z 1M5 hchen@canada.ca

ABSTRACT

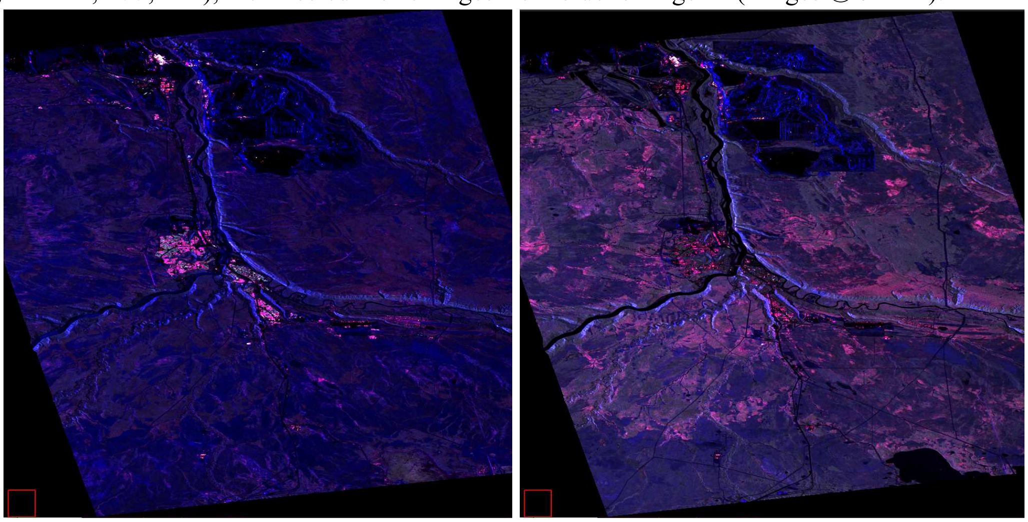
This paper investigates L-band Polarimetric Synthetic Aperture Radar (PolSAR) data to support optical fire and burn severity mapping (Tanase et al, 2015) under cloud cover (Goodenough et al, 2011) for the reason that L-band data are more sensitive to tree branches, stems and biomass when compared with C-band systems like Radarsat-2/RCM and Sentinel-1. Moreover Quad-Pol (QP) data are higher dimensional and improve the potential to discern between different types of materials, including but not limited to the ability to correct ionospheric distortion affecting L-band. Due to scarcity of ALOS-2/PALSAR-2 data over British Columbia in the QP mode, we chose the 2016 Horse River fire affecting Fort McMurray, Alberta Canada to study operational potential of L-band QP SAR using several methods, as we expect wider QP data availability in future.

There are two time series of ALOS-2 QP data available over Fort McMurray, with distinct but overlapping footprints. Whereas (JAXA, 2016) and (Plank et al 2019) analyse the series in which Fort McMurray appears slightly East of the footprint centre, we analyse the other series where Fort McMurray appears closer to the footprint centre, by classifying the burned area to help prepare for using L-band ALOS-4/PALSAR3, ROSE-L or NISAR missions in operational fire mapping scenarios in BC. Finally, as L-band SAR missions may not provide large coverage in QP mode yet, we hedge our bets and apply Dual-Pol (DP) methods of (Mascolo et al, 2021) providing physical polarimetric interpretation accessible from both DP and QP acquisition modes.

Due to the challenge posed by fire perimeter data's operational orientation, October 3, 2016 Landsat data classification was used along with existing CNFDB fire perimeter data (left), to create a burned area reference with less false positives (right) supporting our JAXA data assessment:


.

The 20150404 (pre) and 20160528 (post) images were initially classified using PolSAR parameters e.g. Coherency (T) elements (Goodenough et al, 2011) using only *k*NN with *k*=1 and very few positive and negative samples (N=20 training pixels for a raster of millions of pixels). E.g. using T22 only as in (JAXA, 2016) accuracy was 77% overall. For T11, T22, and T33 channels 80% accuracy was obtained. Moreover, there was 75% accuracy using T22 of post image only. Finally, 75% accuracy was found by classifying DP parameters (Mascolo et al, 2021) for post image only. So we expect to report much higher classification accuracy in the full paper by using Machine Learning (ML) algorithms, plus substantially more training samples. Finally, additional info gained from five other images available on the same footprint, such as with coherent change detection as in (Lehrbass et al, 2018) will be reported. Below the April 4th, 2015 (left) and May 28th, 2016 (right) images are visualized with Coherency matrix (T) parameters (encoded as R,G,B = T22, T33, T11); the affected area changes from blue to magenta (images © JAXA):


.

In conclusion, preliminary results showed operationally interesting information retrieval to be expanded and interpreted with detailed physical modelling in the full paper. Thanks to JAXA for ALOS-2/PALSAR-2 data provided under EORA3 for our project “BC Wildfire Service – Predictive Services Unit – Fuel Type Layer Project”.

Keywords— Radar, Polarimetric SAR, Fire mapping, ALOS-2, Wildfire, Fort McMurray

REFERENCES

Tanase, M.A., Kennedy, R., and Aponte, C. 2015. “Radar Burn Ratio for fire severity estimation at canopy level: An example for temperate forests.” *Remote Sensing of Environment,* Vol. 170: pp: 14-31. doi: http://dx.doi.org/10.1016/j.rse.2015.08.025.

Goodenough, D. G., Chen, H., Richardson, A., Cloude, S., Hong, W., and Yang., L. 2011. “Mapping fire scars using Radarsat-2 Polarimetric SAR Data.” *Canadian Journal of Remote Sensing,* Vol. 37 (No. 5): pp. 500-509. doi: https://doi.org/10.5589/m11-060.

JAXA EORC, 2016. “ALOS-2/PALSAR-2 Observation Results on Wildfire in Canada”, JAXA Website, last modified January 21, 2016, https://www.eorc.jaxa.jp/ALOS-2/en/img_up/dis_pal2_can-forest_fire_20160509.htm.

Plank, S., Karg., S. and Matinis, S. 2019. “Full-polarimetric burn scar mapping - the differences of active fire and post-fire situations.” *International Journal of Remote Sensing,* Vol 40 (No. 1): pp 253-268. doi: https://doi.org/10.1080/01431161.2018.1512768.

Mascolo, L., Cloude, S.R., Lopez-Sanchez, J.M. 2021. "Model-based decomposition of dual-pol SAR data: application to Sentinel-1." *IEEE Transactions on Geoscience and Remote Sensing,* Vol 60. doi: https://doi.org/10.1109/TGRS.2021.3137588.

Lehrbass, B., and Decker, V. 2017. “Natural Resources Canada’s Response to the Fort McMurray Wildfire.” Paper presented at EO Summit 2017, Montréal, Québéc, June 2017.

Using Multi-Temporal Remote Sensing to Improve Provincial Harvest Monitoring

Sasha Nasonova[1], Christopher Butson[1], Mike Fowler[1], Hunter Gleason[2], and Ashlin Richardson[3]
…..
[1]Forest Analysis and Inventory Branch, B.C. Ministry of Forests, 1520 Blanshard Street, Victoria, B.C, V8W 3K, Sasha.Nasonova@gov.bc.ca, Christopher.Butson@gov.bc.ca, Mike.Fowler@gov.bc.ca
[2]Environmental Monitoring and Analysis Branch, B.C. Ministry of Environment, 1011 4th Ave, Prince George, B.C, V2L 3H9, Hunter.Gleason@gov.bc.ca
[3]B.C. Wildfire Service, B.C. Ministry of Forests, PO BOX 9502 STN PROV GOVT1520, Victoria, B.C, V8W 9C1, Ashlin.Richardson@gov.bc.ca

ABSTRACT

The Forest Analysis and Inventory Branch (FAIB) of British Columbia's Ministry of Forests is responsible for the inventory and continuous monitoring for growth and disturbance of nearly 60 million ha of forested land. The standard forest inventory program - vegetation resources inventory (VRI) predominately uses aerial photography and ground sampling to estimate forest cover attributes such as height, species composition, diameter at breast height (dbh), volume, and trees per ha. Since the VRI is used to inform annual allowable cut determinations made by the province's Chief Forester, it is necessary to project annual forest growth and make annual updates to the VRI to account for stand replacing disturbances (i.e. harvest and wildfire). When it comes to harvest monitoring, the province relies heavily on licensee reporting of harvest activities. However, these data can be temporally imprecise, with reported disturbance start and end dates not always representative of when harvest activities took place. Additionally, the submission and integration of the information into the provincial database can be delayed by up to 18 months due to the large of volume of data and submission deadlines.

Traditionally, FAIB has relied on two-date change detection during the summer season to identify harvested areas throughout the province. However, this approach can be data intensive and provides an incomplete picture of harvest activity because individual scenes are used, with any missed harvest captured in the following year. Annual time-series methods that leverage cloud-based data and algorithms such Landtrendr (Kennedy et al., 2010) have shown considerable improvement, capturing more harvest area than two-date change detection. However, similarly to the two-date change detection, harvest activity that occurred in the late fall/winter months is assigned to the subsequent year (i.e. harvest that occurred in November 2021 will be assigned a harvest year of 2022). Though this is acceptable for updating the VRI, as we are more interested in harvest extent than exact timing, recently it has become apparent that timely and accurate disturbance dates are necessary for supporting forest management decision making. As a result, we investigated a number of sub-annual, time-series change detection methods including Continuous Change Detection and Classification (CCDC), Breaks for Additive Season and Trend (BFAST), and simple tracking of spectral indices within individual forested areas of interest (Verbesselt et al., 2010; Zhu & Woodcock, 2014). Using, CCDC and provincial permit data we have successfully produced quarterly harvest maps, allowing us to improve our understanding of harvest timing throughout the province.

This work serves as an update on the harvest monitoring activities of the Forest Analysis and Inventory Branch of British Columbia's Ministry of Forests. With the wider availability of cloud-based data and tools such as Google Earth Engine, introduction of new platforms (e.g. Landsat-9), combined with increased need for sub-annual monitoring, substantial gains have been made in the uptake of satellite multispectral imagery and time-series algorithms for forest inventory. However, harvest tracking in near real-time remains a priority for the organization, and we will discuss opportunities and potential challenges for this work.

***Keywords*—** forest inventory, British Columbia, multispectral, time-series, disturbance, change detection

REFERENCES

Kennedy, R.E., Yang, Z. and Cohen, W.B., 2010. "Detecting trends in forest disturbance and recovery using yearly Landsat time series: 1. LandTrendr - Temporal segmentation algorithms". *Remote Sensing of Environment*, 114(12), pp.2897-2910.

Verbesselt, J., Hyndman, R., Newnham, G., and Culvenor, D. 2010. "Detecting trend and seasonal changes in satellite image time series". *Remote Sensing of Environment*, 114, 106-115. DOI: 10.1016/j.rse.2009.08.014.

Zhu, Z. and Woodcock, C.E., 2014. Continuous change detection and classification of land cover using all available Landsat data. *Remote Sensing of Environment*, 144, pp.152-171.

KNOWLEDGE EXCHANGE AND ASSESSING WILDFIRE MANAGEMENT AGENCY READINESS FOR WILDFIRESAT

Colin B. McFayden[1], Matthew Coyle[2], Emily S. Hope[1]; Den Boychuk[3]; Lynn M. Johnston[1]; Ashlin Richardson[4]; Meghan Sloane[1]; Alan S. Cantin[1]; Joshua M. Johnston[1] and Timothy J. Lynham[1]

…..

[1]Natural Resources Canada, Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON, Canada

[2]Government of the Northwest Territories, Department of Environment and Natural Resources, Forest Management Division, Fort Smith, NT, Canada

[3]Ontario Ministry of Natural Resources and Forestry, Aviation Forest Fire and Emergency Services, Sault Ste Marie, ON, Canada

[4]British Columbia Ministry of Forests, Wildfire Service, Victoria, BC, Canada

ABSTRACT

Responding to the many challenges wildland fire managers face, the Government of Canada is designing and launching a new wildfire monitoring satellite system, WildFireSat. WildFireSat is the first public satellite monitoring system designed in conjunction with frontline fire managers in Canada, responding directly to their needs (Johnston et al., 2020). Currently under development, the satellite mission has an anticipated launch targeted for 2029. The data products from WildFireSat are anticipated to be transformational for operational situational awareness and decision-making. WildFireSat will provide unprecedented, daily, near real-time strategic intelligence on all active wildfires across the country. The resulting intelligence products will be timed to provide agencies with the information needed to make critical decisions at key points during the planning process (Canadian Forest Service, 2023).

Experience tells us that having new information available does not always mean there will be uptake (McFayden et al., 2022). Preparing ahead of launch will allow fire management agencies to better position themselves to benefit from WildFireSat. In this presentation we discuss (1) knowledge exchange in fire management, (2) an assessment of the readiness of Canadian fire management agencies to integrate WildFireSat, and (3) guidance for reducing readiness gaps. This will be a joint presentation with presenters from the WildFireSat mission team and the Government of the Northwest Territories.

WildFireSat is unique in that the resulting information system will be tailored to the needs of fire management across Canada; this will require engaging in knowledge exchange (KE) with fire management agencies. We view KE as an overarching process where knowledge is collaboratively created, shared, and transformed (see McFayden et al. in-press and references therein for more detail). KE is crucial for the successful development and integration of fire science with fire management. McFayden et al. (in-press) draw attention to readiness for innovation as a potential barrier or facilitator to success. Leaving the adoption of WildFireSat products to passive efforts is a high risk to fire management agencies, jeopardizing their ability to achieve the full benefit possible. Assessing end-user readiness pre-launch creates a baseline from which we can identify what different agencies require for support with further KE efforts.

In McFayden et al. (2023), we assessed this baseline of readiness for WildFireSat generally following the steps of Knol et al. (2010). We approached readiness as a two-level hierarchy, with the first level defining three primary components of readiness: understanding, organization and information management and information technology (IMIT). Secondly, we used environmental, survey and agency data to derive indicators for these three components of readiness, which we iteratively scored and weighted. Our scoring and weighting process is subject to some uncertainty, which we addressed via a Monte Carlo simulation that allowed us to assign distributions of probability to variables within the readiness calculations. Appropriate shapes for these distributions were elicited from discussions with the fire management agencies, generating distributions of "readiness" for the three core components for each agency. We then calculated a readiness index as the minimum value of the three readiness components (understanding, organization, and IMIT). We propose that all three readiness components are needed to support overall agency readiness, with the smallest

component constraining the overall level of current readiness (analogous to having three pillars to make a raised platform; the shortest pillar determines the height). We preformed a cluster analysis on the fire management agency data to explore similarities between agency readiness attributes. We concluded by suggesting general strategies to improve readiness, such as by increasing education and training and ensuring compatibility of information management and technology within the agencies.

The results of this analysis suggest that national gaps in understanding, organizational adaptability, and IMIT agility can be addressed to enhance the potential benefits from WildFireSat. The strategies identified through the engagement can inform actions to close the readiness gaps. Data on the similarities and differences between agencies can guide collaborations, where agencies with common gaps can work together and learn from those with complementary strengths. However, we also provided agency specific assessments, working directly with the agency to identify specific needs relative to their individual readiness assessment. The Northwest Territories is one example, where current capacity in IMIT and familiarization with remote sensing products should facilitate seamless integration. The greatest effort will focus on increasing understanding leading up to the launch of WildFireSat.

Keywords— satellite, wildfire, forest fire, fire management, smoke forecasting, air quality, situational awareness, suppression, fire intelligence.

REFERENCES

Canadian Forest Service, 2023 “WildFireSat: The world's first purpose-built operational satellite system for monitoring wildfires.” *Great Lakes Forestry Centre*, last modified 2023-02-08, https://cfs.nrcan.gc.ca/publications?id=40873.

Johnston, J.M., Jackson, N., McFayden, C., Ngo Phong, L., Lawrence, B., Davignon, D., Wooster, M.J., van Mierlo, H., Thompson, D.K., Cantin, A.S. and Johnston, D. 2020. "Development of the User Requirements for the Canadian WildFireSat Satellite Mission." *Sensors* 20 (8). https://doi.org/10.3390/s20185081

Knol, A.B., Slottje, P., Van Der Sluijs, J.P., Lebret, E. 2010. “The use of expert elicitation in environmental health impact assessment: A seven step procedure.” Environmental Health, 9, (1) pp. 1-16. https://doi.org/10.1186/1476-069X-9-19

McFayden, C. B., George, C., Johnston, L. M., Wotton, M., Johnston, D., Sloane, M., and Johnston, J. M. 2022. “A case-study of wildland fire management knowledge exchange: the barriers and facilitators in the development and integration of the Canadian Forest Fire Danger Rating System in Ontario, Canada.” *International journal of wildland fire*, 31 (9) pp. 835-846. https://doi.org/10.1071/WF22015

McFayden, C.B., Johnston, L.M., Woolford, D.G., George, C., Johnston, D., Boychuk, D., Wotton, B.M., & Johnston, J.M. in-press. “A Conceptual Framework for Knowledge Exchange in a Wildland Fire Research and Practice Context”, In *Applied Data Science: Data Translators Across the Disciplines*, edited by D. Woolford, D. Kotsopoulos, & B. Samuels, Springer

McFayden, C.B., Hope, E.S., Boychuk, D., Johnston, L.M., Richardson, A., Coyle, M., Sloane, M., Cantin, A.S., Johnston, J.M. and Lynham, T.J., 2023. Canadian Fire Management Agency Readiness for WildFireSat: Assessment and Strategies for Enhanced Preparedness. *Fire*, 6(2), p.73. https://doi.org/10.3390/fire6020073