Operational Near-real-time Pixel-based Image Compositing for Large-area Fire and Burned Severity Mapping in British Columbia

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ABSTRACT

Satellite RS (Remote Sensing) is critical for assessing and responding to large scale fires (>50,000 ha) which challenge the physical limitations of aircraft and other capture methods in a chain of command decision structure. In 2023 the BC Wildfire Service (BCWS) conducted operational trials of satellite active-fire perimeter mapping in British Columbia using Sentinel-2 and Landsat (Richardson, 2023). Moreover, BCWS's GS (Geospatial Services) and PSU (Predictive Services Unit) teams derived roughly 25% of all public-facing fire polygon updates in 2023 via Short-wave infrared (SWIR) Sentinel-2 data. "Low-latency" fire polygon updates generated semi-automatically by PSU numbered >300 in 2022 and >400 in 2023 and were vetted by the GS team and fire centres. Availability of high-level scanning (airborne thermal) services was limited in 2023, underscoring the value of satellite-based SWIR fire mapping, and the cost effectiveness of expanding the remote sensing program area.

Supported by Knowledge-exchange activities with the CFS WildfireSat team (McFayden, 2023), BCWS Sentinel-2 data exploitation is also bolstered by infrastructure support from NRCan – namely the mirror of Sentinel products maintained via the AWS (Amazon Web Services) S3 service. In 2023 NRCan's AWS S3 mirror (EODMS Team, 2024) dependably providing Sentinel-2 L1C and L2A data for incident mapping together with the accessible AWS CLI allowed producing same-day fire intelligence products at increasingly large spatial scale to keep pace with unprecedentedly large fire perimeters.

Braced by the flexibility of the S3 mirror BC Wildfire created a novel in-house NRT (Near-real-time) image compositing technique: MRAP (Most Recent Available Pixel). This unusually simple method varies the theme of the BAP (Best Available Pixel) method (White, 2014), developed by researchers at NRCan's Pacific Forestry Centre. Whereas BAP is designed for annual national application, MRAP aims to be re-applied immediately on any scale when new data are available. Therefore cloud-free observation, data currency and frugal computing resources are MRAP's design priorities. Although other embodiments are possible such as cloud-masking by thresholding L1C Sentinel-2 data, our initial MRAP code merely selects the most recent available "cloud free" pixels according to the Scene Classification Map product served within L2A Sentinel-2 data as produced by ESA's Sen2Cor processor.

Implemented late July 2023, MRAP permitted generating Sentinel-2-based fire map updates for the Donnie Creek wildfire, which on June 18th, 2023 became the largest wildfire in BC's history. Due to the extreme scale, and cloud-free conditions not occurring on the whole fire until October, compositing was needed to stitch together the most current available data. Seven Sentinel-2 scenes (each approx 100km x 100km) were needed to cover the entire incident. MRAP compositing allowed retrieving new 2023 fire activity information that would otherwise be unavailable, since intricate partial cloud cover made the large imagery too complex to manually exploit. Even the highly accessible semi-automated method:

B12 > B11 && B12 > B9

retained its operational effectiveness when applied to imperfect MRAP products including no-data areas (black).

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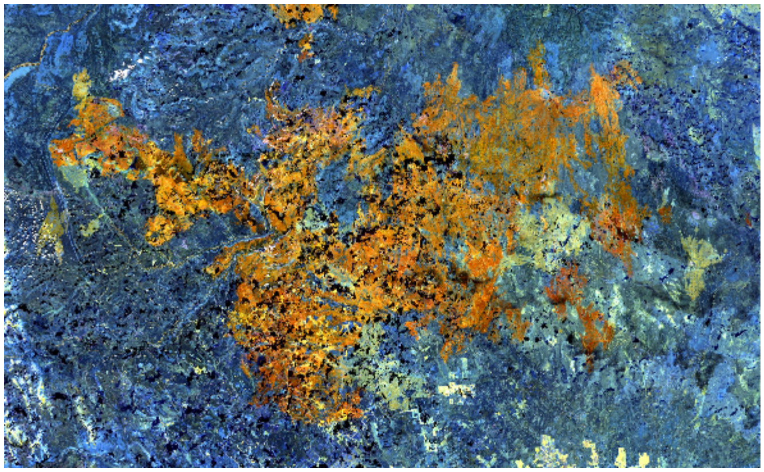

Figure 1: July 30th, 2023 MRAP composite: Donnie Creek fire, with false color encoding RGB=(B12, B11, B9)

For the 2024 fire season we will study using MRAP to perform NRT (interim) Burn Severity (BS) assessments. The full presentation will explain MRAP workflows, highlighting the evolution of the active fire mapping product for the Donnie Creek fire and other events, and demonstrate additional developments such as BS mapping based on spectral differencing:

$$\mathbf{NBR = (B08 - B12) / (B08 + B12); \quad dNBR = NBR_{prefire} - NBR_{postfire}}$$

for large fire events, especially in areas not actively flaming yet still combusting. Whereas RS based burn severity assessments are often generated after cloud-free imagery becomes available over the whole incident and/or the fire is deemed extinguished, we expect that coupling this compositing technique with BS estimation will offer significant potential for increasingly-proactive intelligence to enable earlier recognition of existing fire impacts, and to support advanced planning of recovery efforts. ESA's plans to launch Sentinel-2C in 2024 increase the benefit.

As incidents grow larger, spanning multiple regions, stakeholder interests, and risk factors on the landscape: building a common vision of current and emergent situations will be increasingly important. Having an increasingly complete picture of the incident available for an ops meeting or exterior brief, especially integrated with related sources including low-res satellites, cubesats and SAR (Synthetic Aperture Radar) will be crucial to fire management moving forward. Tools developing large scale, simplified mapping products to facilitate common operational and tactical language will be critical in unifying efforts of a wide range of actors attempting to strategically manage fires on regional, provincial and national scales. Better updating public and communities to support potential wildfire evacuation orders and alerts will also be of vital concern.

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Assessment of ALOS-2 L-Band Polarimetric SAR for Fire Danger Monitoring in Mountainous Forests of British Columbia

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KEY WORDS: Polarimetric radar, L-band, wildfire, fuel moisture, fire danger, fire weather index, British Columbia

ABSTRACT

Decisions in response to Canada's increasingly challenging wildfire situation often rely on incomplete or inaccurate information. Improving information availability for better decision making is critical to ensure effective preparedness, allocation of resources, and suppression. Combining weather data with topography, fuel, and risk information and continually improving these data sources will help support development of the next generation of existing decision-support systems in Canada including the Fire Weather Index (FWI), Fire Behaviour Prediction (FBP), and the Fire Occurrence Prediction (FOP) systems. To understand fire danger, a quantifiable assessment of fire potential requires detailed inputs on fuel moisture, a significant contributing factor to fire ignition probability, spread potential, and expected behaviour. Wildfire managers across Canada rely on weather station networks to record daily observations at explicit spatial points. Data interpolation between such points adds considerable error. The validity of observations is limited beyond the specific geographic locations of the stations, and confidence decreases as distance to the nearest station increases. These shortcomings are exacerbated by sparse and uneven distribution of weather stations. Weather stations provide the most critical foundation of ground-reference information supporting our understanding of fire weather. However their quantity cannot be effectively scaled up to accurately map requisite spatial variability of environmental conditions such as precipitation and fuel moisture at finer spatial scales, hence synergistic use of data from space-based remote sensing platforms offers a way forward.

Satellite-based synthetic aperture radar (SAR) offers an advantage by capturing the fine-scale spatial variability of moisture across large and remote areas, regardless of cloud cover or daylight, consistently and repeatedly. Monitoring changes in radar backscatter and polarimetric parameters can offer insight into fire danger and fuel moisture conditions (Bourgeau-Chavez et al. 2013a). For example, C-band backscatter and specific polarimetric discriminators are observed to correlate with long-term rainfall and soil moisture with strong linear correlations with FWI components, most significantly in slow-drying coarse fuels and deeper in organic soils. Multi-parameter moisture retrieval algorithms have demonstrated effectively combining multiple polarimetric variables to retrieve fuel moisture with accuracy under homogeneous conditions such as flat topography and homogenous mature black spruce forests (Bourgeau-Chavez et al. 2013b). The practical application of soil moisture retrieval has thus far been limited largely by the heterogeneity of fire landscapes and the necessity to overcome challenges in adjusting for intrinsic variations in surface roughness, topography, and biomass.

Additional wavelengths such as the longer L-band with greater penetration offer promise to improve fuel moisture retrieval due to lesser interactions with the physical structure of above-ground biomass. The ability for L-band fully polarimetric SAR to predict fuel moisture and wildfire danger in Canada's forests has not been reasonably tested, particularly in mountainous areas with steep slopes representative of British Columbia. The goal of this study is to assess the potential of L-band fully polarimetric SAR imagery to distinguish between wet versus dry fuel conditions, corresponding to fire danger variations in the mountainous forests of Southeast British Columbia. ALOS-2 imagery collected by JAXA near Windermere, British Columbia in summer 2023 were accessed via CFS by agreement with CSA and JAXA. Subsequently it was determined the images represent a variety of seasonal FWI conditions including low and high fire hazard states. Polarizations (L-HH, L-HV, L-VV, L-LL, L-LR, L-RR), polarimetric decomposition parameters (Van Zyl, Cloude-Pottier, Freeman-Durden, Touzi) and polarimetric

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discriminators (coefficient of variation, polarization fraction, minimum and maximum degrees of polarization, polarized versus non-polarized component, received power, scattered intensity) were compared with FWI system variables measured at BC's PALLISER weather station located at Lat 50 29 40, Lon 115 39 59 and 1100m elevation within the ALOS-2 images' extent.

Our initial results suggest L-band fully polarimetric radar is practical for differentiating various levels of fuel moisture and degrees of fire hazard. This paper will compare how each of the observed variables responds to change and further our understanding of which polarimetric variables are most appropriate for repetitive utilisation for fire danger monitoring, as previewed in Fig. 1. An understanding of each variable's response to change is necessary to facilitate developing soil moisture retrieval algorithms that can account for confounding variations such as: changes in topography fuel type, surface roughness, and biomass across the greater fire landscape. The ability to reliably collect spatially accurate information will become more critical as wildfires continue to increase in severity, frequency, and season duration. Moreover, increasingly spatially accurate information will be required to support the development of improved fire behaviour and fire weather prediction systems. Recent developments in empirical parameter-retrieval algorithms, in conjunction with reductions in revisit times by synthesizing data from virtual constellations of existing and planned polarimetric SAR satellites such as Radarsat-2, RCM, Sentinel-1, ALOS-2, SAOCOM, ALOS-4, NISAR, Sentinel-1-NG, BIOMASS and ROSE-L will increase availability of fire weather data across the landscape and benefit decision-makers, fire weather and fire behaviour specialists, firefighters on the ground, and the public.

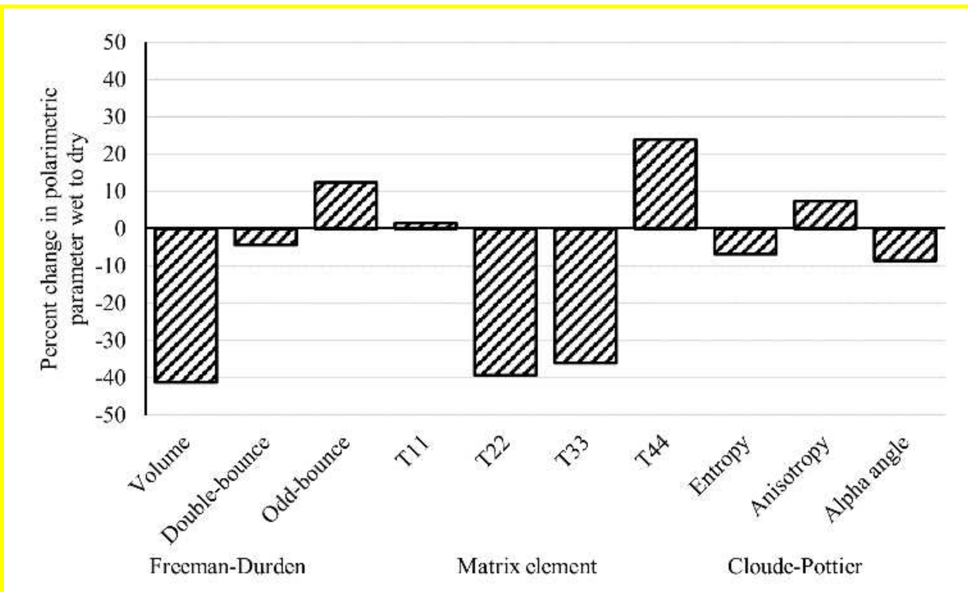

Figure 1. Comparison of percentage change of the Freeman-Durden decomposition, matrix elements corresponding to covariance between polarization channels, and the Cloude-Pottier decomposition between images acquired during wet and dry conditions. Please click here for more info on Fire Weather Index (FWI) acronyms. Wet image conditions are with FFMC = moderate, DMC = low, DC = moderate, ISI = moderate, BUI = low, FWI = moderate. Dry conditions are FFMC = moderate, DMC = extreme, DC = extreme, ISI = moderate, BUI = extreme, FWI = high.

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RADARSAT Constellation Mission SAR Data and Deep Learning for Wildfire Monitoring

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KEY WORDS: RADARSAT Constellation Mission, SAR, Deep Learning, Wildfire.

ABSTRACT

Due to human-induced climate change, wildfires are increasing in intensity, frequency and duration around the world in recent years. Wildfires kill and displace people, damage property and infrastructure, burn vegetation, threat biodiversity, increase CO2 emission and pollution, and cost billions to fight. Therefore, near real-time monitoring of wildfire progression are critical to support effective emergency response and management. Past studies have demonstrated that Synthetic Aperture Radar (SAR) is able to detect burned areas (e.g, Ban et al. 2021, Zhang et al, 2021, Hu et al., 2022, and Zhang et al, 2023), serving as an essential data source for wildfire monitoring when optical sensors are hindered by dense smoke or cloud cover or darkness. The overall objective of this research is to evaluate RADARSAT Constellation Mission (RCM) SAR data and deep learning for wildfire monitoring.

RADARSAT Constellation Mission consists of three identical satellites with C-Band SAR sensors at 5.405 GHz frequency. RCM SAR Multi Look Complex (MLC) data with compact polarization CV/CH at a spatial resolution of 30 meters were collected over the selected 2023 wildfire events in Alberta, British Columbia (BC), and Quebec, shown in Fig. 1. Among them, eight wildfire events (shown in blue rectangle in Fig. 1) were selected to generate a training set with a shape of 256 by 256 pixels. For testing, Donnie Creek fire, the largest wildfire in BC, the wildfires west of Edmonton in Alberta (RWF-034-2023 & RWF-031-2023) and the largest wildfire of Quebec in 2023 were selected (shown in red rectangle in Fig. 1). The RCM MLC images within the period from May 1st to June 30th are collected as the training set and test set. The land cover of the selected wildfires consists mainly of needle-leaf forests, broad-leaf forests, mixed forests, grasslands, or wetlands.

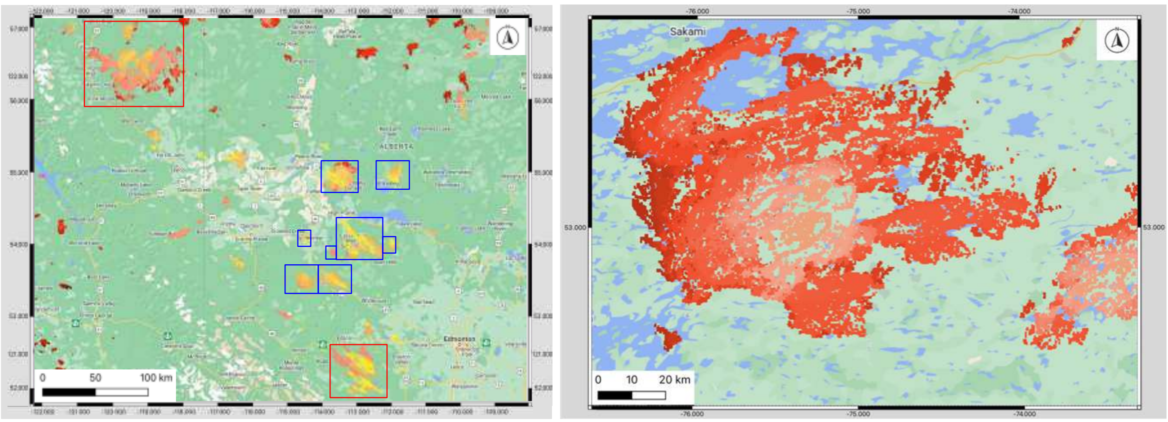

Fig. 1. Selected wildfire events of Alberta, British Columbia, and Quebec, Canada in 2023. Wildfires in the blue rectangle are used as the training set, and wildfires in the red rectangle are used as the test set.

The methodology includes four major processing steps. First, the MLC data were pre-processed using Sentinel Application Platform (SNAP) for terrain correction and speckle filtering. Then log-ratio of the pre-fire and post-fire SAR images is performed to detect changes caused by wildfire. To generate log ratio images, the pre-fire images and post-fire images were selected from the same orbit and beam modes to ensure that they have the same incidence angles and look direction. Then the median image of the pre-fire image collection is used as the pre-fire image. Then the log-ratio images were generated by using every image within the post-fire image collection to subtract the median of the pre-fire images. The pre-processing workflow is presented in Fig. 2 (Left).

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For burned area mapping, U-Net, an effective deep learning segmentation model was chosen (Fig. 2, Right). U-Net has an encoder-decoder architecture with skip connections between the encoder and decoder. The skip-connection ensures the segmentation models preserve the high-level texture information of the input image, i.e., the log-ratio image. The training labels were generated by thresholding the log-ratio images. Each log-ratio image was binarized with a threshold to ensure the best detection of the burned area. However, because of the speckle noise in the RCM data, the binarized image can be noisy. To reduce noise in the labels, Sentinel-2 images were used to generate wildfire perimeters. The noises outside the perimeters were then filtered out from the labels. For accuracy assessment, F1 score and IoU were used.

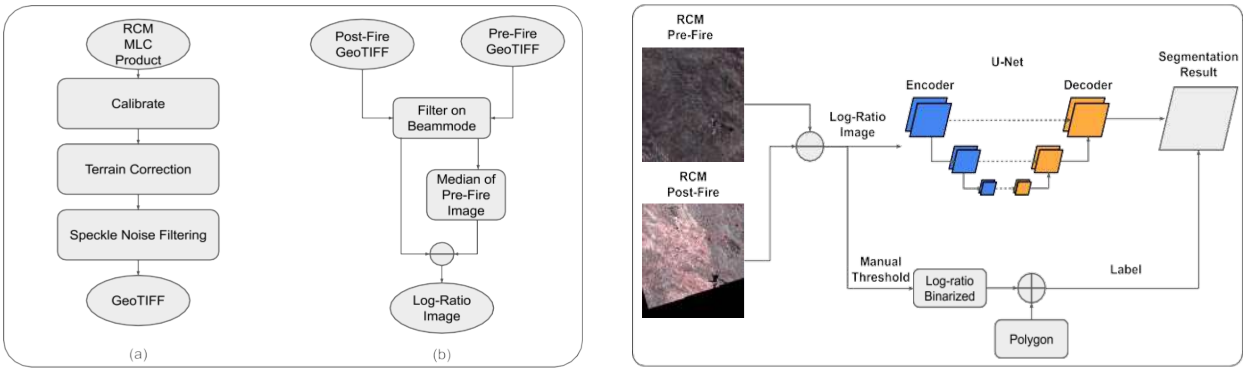

Fig. 2. Left: RCM SAR data pre-processing; Right: Deep learning framework for burned area mapping

The qualitative results of wildfire detections and their respective RCM log-ratio images are presented in Fig. 3. These results show that the U-Net-based deep learning framework can effectively detect burned areas in the test areas. Quantitatively, an F1 Score of 0.765 and an IoU Score of 0.620 was achieved for the test area in Alberta, and an F1 Score of 0.714 and an IoU Score of 0.555 for the Donnie Creek fire. This research demonstrates that RCM SAR data with deep learning is able to distinguish burnt areas, thus can play an important role in wildfire monitoring.

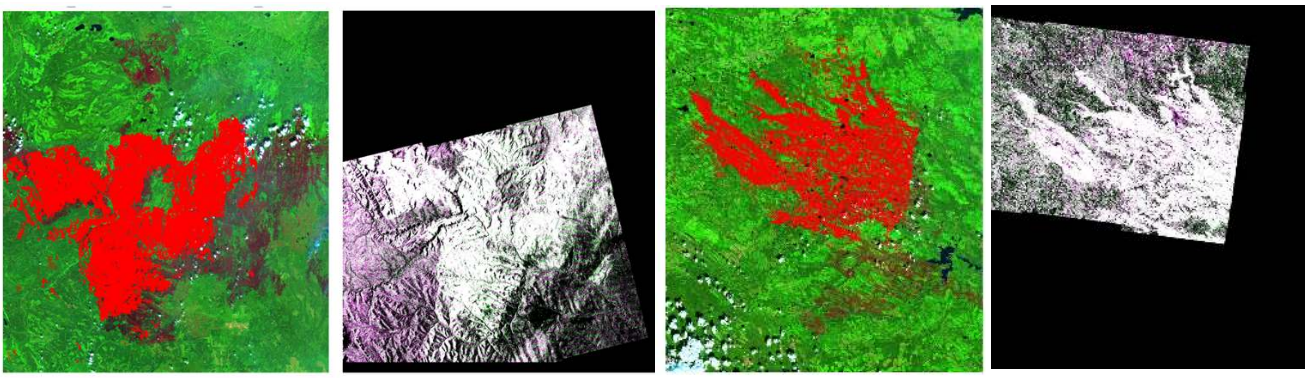

Fig. 3. Qualitative results of Donnie Creek fire on 2023-06-19 (Left) and Wildfire RWF-034-2023 & RWF-031-2023 with images on 2023-06-19 (Right)

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