Supplementary Information

2023-02-15

Canadian Fire Management Agency Readiness for WildFireSat: Assessment and Strategies for Enhanced Preparedness

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S1. The Survey Engagement Summary

The following is a summary of the survey questions provided to each fire management agency. This survey was about identifying the characteristics of an agency, how it is structured, its familiarity with remote sensing, its adaptiveness to innovation, and technical requirements. We requested a single written response from each agency.

Questions:

Section 1) Characterize the organization: This information will assist in informing us of the agency organizational complexity which corresponds to different strategies that support successful knowledge and technical transfer.

1. Jurisdictional question – what other groups/agencies have fire services that your agency works with (e.g., municipalities)?
2. What mechanisms are in place for your agency to share fire information/data with them?
3. Is your fire agency a member of any associations or organizations that are geared towards collaboration and communications for fire management operations and activities (e.g., Great Lakes Forest Fire Compact)? – please list all.
4. What groups or organizations does your agency collaborate with specifically regarding the development of new relevant science and translation of this into your agency?
5. What groups or organizations does your agency collaborate with specifically regarding training or implementation of new policies and procedures?

Section 2) Familiarization: This information will assist in informing of us of the familiarization the agency has with similar products and identify situations of use and the corresponding procedures for implementation. These are important to identify what needs the agency has for strategies that support successful knowledge and technical transfer.

Please fill in the statistics (approximations are fine). These will help us identify what scale and scope of supports for similar products and knowledge are already in place within an agency.

1. Number of staff with innovation/knowledge transfer as a defined responsibility as part of regular duties (i.e., developing, sustaining, and implementing knowledge/science/technology).

2. What % of their time is dedicated to innovation/knowledge transfer

3. How is knowledge of fixed wing or drone remote sensing knowledge organized in your agency? (e.g., coordination of high-level IR, Aga, contract services). Is this work centralized to one work unit, distributed amongst several work units?

4. Do you currently use any space-based earth observation data in your organization? If so what kind, by whom and for what? (E.g., MODIS, VIIRS)

5. How are standard operations for fire mapping carried out for large fires?
   o What kinds of maps?
   o Who uses them?
   o What do they use them for?
   o When are they made?
   o How often in a day are they updated?

6. How are standard operations for monitoring fires carried out?
   o How is monitoring done?
   o What kinds of criteria are used to determine monitoring needs or frequency?
   o How often is monitoring done?

7. In larger scale situational awareness (say a province/territory or specific region) what are the processes used to maintain this routine situational awareness?
   o What information is being used (e.g., weather observations, active fires)?
   o What tools are used?
   o What does routine situational awareness inform and how is it used?

8. Consider a situation where the fire arrivals are escalated and there are limited resources to assess and respond to fires. In this context, what tools are used to collect information on current fires, new fires and what criteria are used to prioritize for response?

9. Does your agency have policies or procedures that govern the approval and use of fire intelligence (maps, information etc.,) on an Incident Management Team (IMT) or within operations in general?

10. How does your agency decide what fire intelligence can be, must be or may be used? Please elaborate on the processes.

11. Which best describes how your agency currently utilizes external products (e.g., websites, government such as Canadian Wildland Fire Information System, or public)?
    a. Standard operations
    b. Frequent, infrequent or context dependent

12. Please identify critical times in your operational planning cycle for daily preparedness and large fire operations:

13. What documents or plans are created, what is their purpose and what are the associated timeframes (e.g., when planning starts, when plan is issued)?

Section 3) Information management and information technology: The following section is to help us consider technical requirements needed to best suit your agency needs.

1. How would your agency develop or implement new software or tools into operations (e.g., is there a corporate process, requirements for vendors of record)?
2. Does your agency have specific geospatial systems teams/personnel?
3. What considerations would there be for your agency to use an accessible website to access fire intelligence information)?
    c. What benefits would you see?
    d. What drawbacks?
    e. What would you want to know more about to use this kind of platform in daily operations and planning?
4. If it were to be provided, would your agency be likely to use a centralized web-based presentation of WildFireSat products (e.g., access through an external website, interactive GIS map)?
    a. Almost always
    b. Often
    c. Sometimes
    d. Seldom
    e. Never
    • Please explain selection:
5. If it were to be provided, would your agency be likely to use data within your own products or for development of new uses (e.g., use of rest services, webservices, ftp/http download) of WildFireSat products?
    a. Almost always
    b. Often
    c. Sometimes
    d. Seldom
    e. Never
    • Please explain selection:
6. Please list Raster GIS formats that are compatible with your system (e.g., .geoTiff, ENVI, HDF5, NetCDF, etc.)
7. Please list known Vector GIS formats that are compatible with your system (e.g., Shapefile, geodatabase, geopackage, KML, etc.)
8. Does your agency currently use Open-source (e.g., WMS, WFS, WCS, etc.) and/or Proprietary web services (ex: ArcGIS Server web services, etc.)?
    • If yes, please list all web services currently being used:
9. What are your agency's barriers (if any) on using Open-source web services (e.g., are there any that cannot be used, or license/approvals restrictions)?
    • If any, what would help overcome these barriers?
10. What are your agency's barriers on using Proprietary web services (if any)? (e.g., are there any that cannot be used, or license/approvals restrictions)

- If any, what would help overcome these barriers?
11. Are there existing metadata or data standards requirements for your organization to accept and ingest data?
    - If Yes, and known, what are the requirements (e.g., ISO standards, CIFFC IM/IT recommendations)?
12. How important to your agency is having access to archived Level 1B (geocorrected/orthorectified) WildFireSat imagery (NOT the derived operational data products discussed in the introduction) by special request?
    a. Very Important
    b. Important
    c. Moderately Important
    d. Slightly Important
    e. Not Important
    - Please explain selection.

Section 4) Closing: The following question is to determine what your agency would value in collaboration with the WildFireSat team and advice you have for the team.
1. What kind of products or services would you want to see from WildFireSat?
2. Initially, who (what roles) do you think is the primary user in your agency?
3. What attributes does your agency value in a collaborative relationship, or what can the WildFireSat team bring to the table (e.g., active participation, expertise)?
4. What kind of activities would you expect, or want to see from the WildFireSat team for preparedness and knowledge exchange prior to launch, and after launch?
5. Are there specific groups or cadres in your agency we should be engaging?
6. Please feel free to provide any other advice to help us work together and prepare for WildFireSat.

S2. Readiness Indicator Narratives

The following table lists the indicators and an example of accompanying narrative descriptions from coding authors to illustrate how the indicator relates to the readiness components (i.e., increases readiness). These descriptions are for illustration and do not include of all the influences or examples considered in the coding process. There are obvious interactions between indicators. In determining relationship and weighting for each indicator there were iterative sessions with varying perspectives. This table does not capture these detailed conversations that occurred between coding authors or differences in perspectives.

Readiness indicators	Narrative descriptive example of relationship to readiness for implementation of WildFireSat
Official duration of the fire season	The official fire season duration influences the duration of work for staff and the potential for more opportunity to gain training and expertise especially in the case of seasonal workforces. The more time in a fire season, the more exposure there is to situations where remote sensing tools are products are needed and used. With this indicator we expect a relatively low weighting for readiness.
20 yr. median annual number of fires (2002-2021)	The median number of annual fires provides context to the steady state of the number of fires an agency must deal with. The larger the number of fires, the more resources are needed, and the more potential there is to gain familiarity in fire management activities, especially those pertaining to the use or understanding need for remote sensing. With this indicator we expect a relatively moderate weighting for readiness.
Ratio of 95th percentile and median annual number of fires	This is intended to characterize the severity of extreme fire loads relative to the fire loads that the agency is accustomed to. The closer the steady state is to the 95th percentile the more prepared an agency is likely to be. When there are higher ratios, agencies are likely to be in triage situations more often, and likely to be fire intelligence hungry. These situations are rare however, which may mean fewer opportunities to experience and learn from these situations of peaks. With this indicator we expect a relatively low/moderate weighting for readiness.
20 yr. median annual area burned (2002-2021)	The more fire there is on the landscape in a steady state can indicate more impacts in high-risk situations, or just as likely more monitored fire in low-risk situations. Either case can indicate a use for and familiarity with collecting fire intelligence and monitoring. More fire on the landscape fosters understanding and growth because it is more frequent, and agencies need to develop capacity. With this indicator we expect a relatively moderate weighting for readiness.
Ratio of 95th percentile and median annual area burned	This was intended to characterize the severity of extreme fire loads relative to the fire loads that the agency is accustomed to. This is assumed to capture more about dealing with impacts. This likely leads to more demand for program review and system wide change. With this indicator we expect a relatively moderate weighting for readiness.
10 yr. number of wildfire disasters (2012-2021)	These are wildfire disaster events that conform to the Emergency Management Framework for Canada. Agencies experiencing more disasters will have increased exposure to emergency management, jurisdictional partners, sharing information and decision-making in extreme events which likely include higher demand forecasting and assessment of risk. Increased major impacts may lead to greater demand for spatial analyses and monitoring. With this indicator we expect a relatively moderate weighting for readiness.

10 yr. number of evacuation events (2012-2021)	Evacuations are a critical impact of wildfires. Presence of evacuations indicates a necessary level of organizational resilience. Typically, experience with more of these events requires a level of planning, analysis and coordination which has some similarity with WildFireSat proposed products. With this indicator we expect a relatively low/moderate weighting for readiness.
10 yr. median fixed costs, adjusted to 2019 dollars (2008-2017)	The median fixed costs of an agency suggest the level of resources available. The higher the median fixed costs, the more potential for more people, information technology, and overall human resources capacity. With this indicator we expect a relatively high weighting for readiness.
Relative average change of fixed costs (trend) adjusted to 2019 dollars (2008 - 2017)*	This is used to indicate whether the agency is shrinking, stable, or growing. Shrinking agencies are assumed to be less able to devote time and effort to innovation and implementation. With this indicator we expect a relatively high weighting for readiness.
Fire suppression service partnerships	More fire service or suppression partnerships indicate a greater potential for organization capacity including developing partnerships, sharing responsibilities, communicating protocols, and sharing fire intelligence. With this indicator we expect a relatively low weighting for readiness.
Fire management partnerships	More fire management partnerships indicate a greater potential for organization capacity including developing partnerships, shared resources, access to other knowledge and perspectives. With this indicator we expect a relatively low weighting to overall readiness.
Science and translation collaborative partners	More partners in the development and translation of science into fire management policies, practices and procedures indicates increased capacity in human resources, domain expertise and perspectives, which may lead to enhanced readiness for understanding the implementation needs for WildFireSat. With this indicator we expect a relatively moderate/high weighting for readiness.
Training and implementation collaborative partners	More partners in training and collaboration for the implementation of science into training indicates maturity and understanding for mitigating the barriers to applying innovations to fire management practices through formalized training. With this indicator we expect a relatively moderate/high weighting for readiness.
Innovation and knowledge transfer full time equivalent positions (weighted by staff count)	Possessing dedicated capacity for innovation indicates the ease of implementation in both resources and process. The more capacity the easier the implementation through for example focus of people, existing processes. With this indicator we expect a relatively high weighting for readiness.
Number of plans for preparedness and operations	More planning processes indicates familiarity with the use of modelling and inclusion of processes to interpret and communicate intelligence for decision-making. With this indicator we expect a relatively low/moderate weighting for readiness.
Expected type of users for WildFireSat (e.g., all levels in the	The listing of diverse or different levels of use (e.g., provincial to fire) and users (e.g., specific roles and functions) can indicate the current level of understanding for the potential application of WildFireSat in strategic planning. With this indicator we expect a relatively low weighting for readiness.

organization, function specific)	
Number of geospatial staff	Geospatial staff have specific domain expertise in the IMIT, processes and approaches to understand and implement spatial products in fire management and more staff indicates increased capacity. With this indicator we expect a relatively low /moderate weighting for readiness.
How knowledge of fixed wing and drone remote sensing is organized (e.g., centralized, distributed)	A centralized approach may indicate a more mature organization and processes of implementation of similar remote sensing systems. However, any use of similar system indicates some knowledge of use for implementation of WildFireSat. With this indicator we expect a relatively low weighting for readiness.
Types of remote sensing platforms currently used	The greater number of platforms (e.g., public, rotary, drone) currently used indicates a willingness and direct knowledge in the use, interpretation, and processes for operational fire management. With this indicator we expect a relatively high weighting for readiness.
Use of current space-based earth observation data	More use of current accessible space-based fire products indicates a willingness and direct knowledge in the use, interpretation, and processes. With this indicator we expect a relatively high/very high weighting for readiness.
Degree of implementation of space-based earth observation data (e.g., derived products)	Using publicly available space-based data and products to derive custom products or for creative uses for fire management indicates a culture of innovation and knowledge of remote sensing. With this indicator we expect a relatively high/very high weighting for readiness.
Large fire mapping process	Processes for large fire mapping indicate a maturity in the policies, processes, and implementation of mapping for large fires and supported decision-making. With this indicator we expect a relatively moderate weighting for readiness.
Sophistication of operating procedures for fire monitoring	Fire monitoring with varied conventional methods (e.g., high-level infrared, reconnaissance patrols) requires similar knowledge and procedural supports for space-based earth observation monitoring. More complex existing systems means more readiness. With this indicator we expect a relatively moderate weighting for readiness.
Landscape scale situational awareness methods sophistication	The scale, scope and tools used to maintain whole-of jurisdiction situational awareness requires different information technology, monitoring systems and the necessary knowledge. More complex systems would indicate a level of readiness for additional or new fire intelligence via WildFireSat. With this indicator we expect a relatively low/moderate weighting for readiness.
Escalation triage, the sophistication of methods and tools to prioritize fires	The sophistication of the tools used in escalation may indicate the requisite processes, and abilities for assessing risk spatially, one of the prospective outcomes of WildFireSat. With this indicator we expect a relatively moderate weighting for readiness.
Existence of polices and procedures to	Absence of policies or processes to select and use fire intelligence formally may indicate, in some cases, slow broad scale implementation. Some policies may also slow implementation, however we take an optimistic stance. With this indicator we expect a relatively moderate weighting for readiness.

govern approval of fire intelligence	
Degree of process to determine what intelligence can be used operationally (e.g., directed, ad-hoc)	Directed process to determine intelligence may be more effective than ad-hoc or passive means. This may increase organizational readiness. With this indicator we expect a relatively moderate weighting for readiness.
Frequency of use of current external intelligence sources	The degree to which agencies already make use of external intelligence speaks to the likelihood that they will be able to seamlessly adopt WildFireSat into future operations. With this indicator we expect a relatively high weighting for readiness.
Complexity of process to implement new software or tool	It is the interpretation here that having more complex processes to implement software could hinder WildFireSat readiness and reduce the adaptability or agility of similar tools or products from WildFireSat. With this indicator we expect a relatively moderate weighting for readiness.
Potential use of WildFireSat considering agency preference for external web-based access and in-house development	Agencies may have a preference to use publicly available sources of fire intelligence and develop in-house tools. In-house development can indicate a sophistication in understanding and processes. Public accessibility indicates familiarization and interest. With this indicator we expect a relatively high weighting for readiness.
Number of agency groups or cadres to be engaged in WildFireSat preparedness	This represents those groups or cadres (e.g., fire behaviour analysts, plans chiefs) within an agency that were identified as needing to be engaged prior to WildFireSat availability. Few identified could indicate the absence of groups within an agency or not recognizing the benefit of engagement. suggesting that an agency may not see the potential applications for WildFireSat. With this indicator we expect a relatively low weighting for readiness.
Current use of open-source and proprietary web services	Indicates familiarity with remote sensing products from open source which necessitates an increased level of knowledge and processes. With this indicator we expect a relatively moderate weighting to overall readiness.
Current barriers to open-source web service use	The presence of barriers indicates a slower potential update, thus less readiness. This may indicate a culture of change resistance. With this indicator we expect a relatively moderate weighting for readiness.
Current barriers to proprietary web service use	The presence of barriers indicates a slower potential update, thus less readiness. Proprietary barriers may indicate low agility with regards to updating procurement processes or a lack of funding capacity. With this indicator we expect a relatively moderate weighting for readiness.
Current agency metadata standards or requirements	Data standards can hasten the information management and information technology implementation of data such as WildFireSat. With this indicator we expect a relatively low/moderate weighting for readiness.

S3. Clustering Method and Results

The following explains the Hierarchical Agglomerative Clustering (HAC) method used to group agencies by their survey responses, as introduced in Section 3.2. Given there are 12 data records (agencies), there are 11 merging steps in each case. Moreover, the grouping and colouring of components of the dendrogram are computed automatically using a simple method as follows.

Our data sheet has N rows, and M columns labelled $j \in [0, \dots M)$ and we assume the values in a column are linearly transformed to be restricted to [0,1] so that a given indicator does not overpower others. To compare two data rows $x = \{x_j\} \left(j \in [0, \dots M)\right)$ and $y = \{y_j\} \left(j \in [0, \dots M)\right)$ we output a number (tolerant of missing values) known as the "dissimilarity"

Equation (S1)

$$d(x, y) = \left(\frac{M}{|G|} \sum_{j \in G} \left(x_j - y_j\right)^2 \right)^{0.5},$$

where G is the set of column labels for which the corresponding elements x_j and y_j of both rows are defined, and $|G|$ is the number of pairs of columns compared. When all entries are defined, the formula equals the usual "Euclidean distance" function. Moreover, the geometric interpretation of $d(x, y)$ is that of distance in a multi-dimensional space. I.e., if $d(x, y)$ is small (x and y are conceptually near), the objects compared are similar. However, if $d(x, y)$ is large (x and y are conceptually distant), the objects compared are said to be dissimilar. Hence the term dissimilarity.

We use the set distance function, $D(A, B)$, to compare two groups A and B of data rows, i.e., from the average of the distances $d(x, y)$ of pairs x ,y of rows with x in A and y in B.

Equation (S2)

$$D(A, B) = \frac{1}{|A| \cdot |B|} \sum_{x \in A} \sum_{y \in B} d(x, y).$$

S3.1 Colouring dendrogram branches

We colour portions of the dendrogram according to a method utilising inflection points of rates of change of the group dissimilarity function $D(A, B)$ (Equation [S2]) when plotted with the merging iteration number as the independent variable.

We model the derivative of $D(A, B)$ using a balanced first-order finite difference formula, plotting the second and third derivatives of $D(A, B)$. Before plotting, we linearly transform the second and third derivatives of $D(A, B)$ to the interval [0,1] in order to show them clearly on the same figure (Figures S1 to S3). The vertical dashed line corresponds to the merging iteration number where the third derivative is (on average) most extreme, with the additional requirement that only merging iteration numbers 3-10 were

considered of the possibilities from 0- 11. Limiting the possible inflection points of $D(A, B)$ reflected the intention to colour portions of the tree that were neither too small, nor too large.

The inflection points thusly derived were input to the dendrogram plotting routine as the parameter controlling colouring.
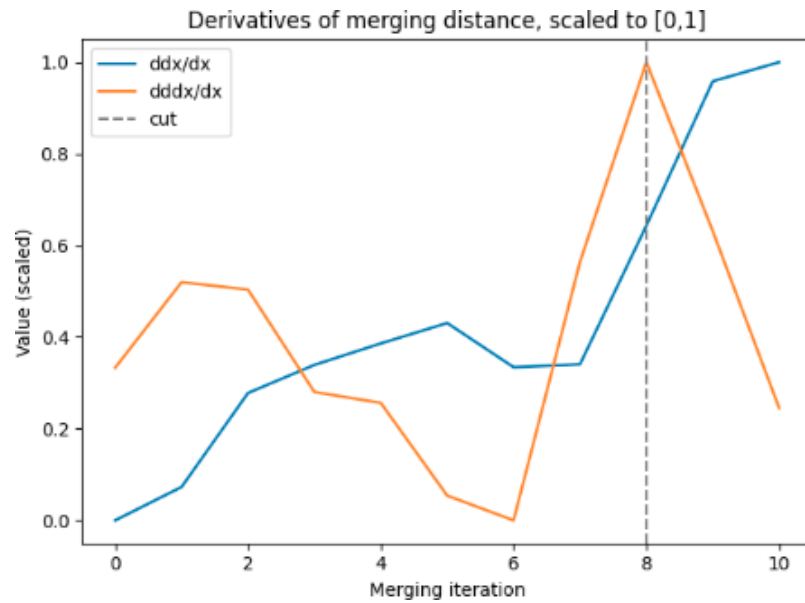

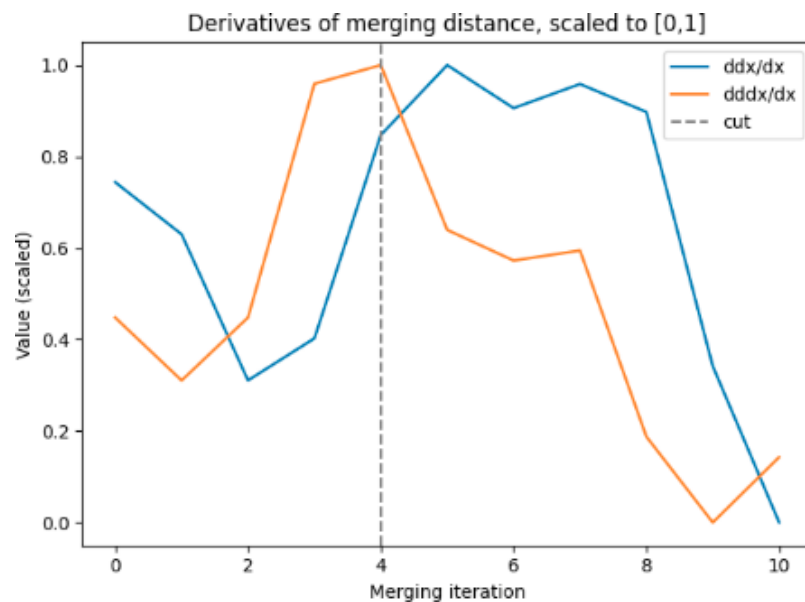**Figure. S1** Location of inflection points of group dissimilarity $D(A, B)$

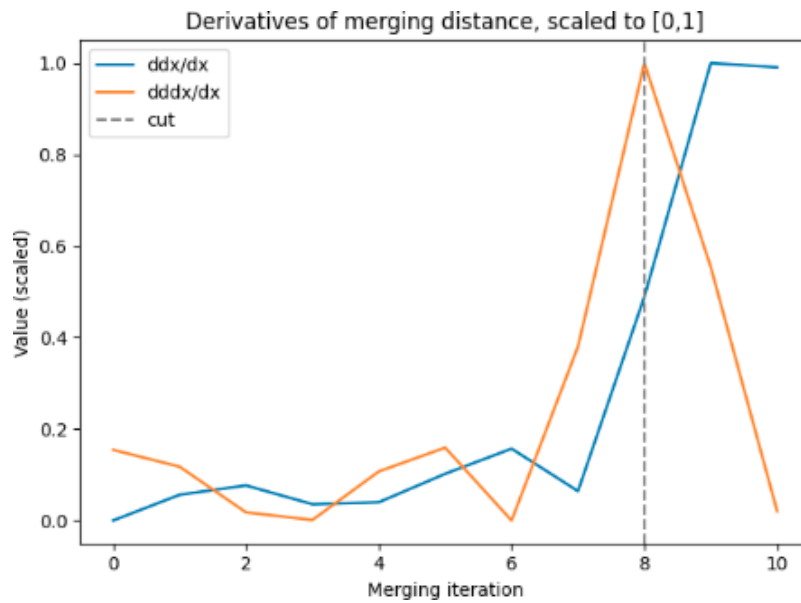**Figure. S2** Location of inflection points of group dissimilarity $D(A, B)$

Figure. S3 Location of inflection points of group dissimilarity $D(A, B)$

S3.2 Dendrograms

Figures S4 to S9 are the plots of the similarities of agencies not shown in the manuscript for those subsets of themes representing aspects of agency environment, workload and funding (Figure S4); organizational capacity for innovation and planning (Figure S5); operational use of fire intelligence (Figure S6); policies and procedures for approving and implementation new intelligence (Figure S7); openness and engagement (Figure S8); information management and information technology (Figure S9).

Figure. S4 Dendrogram illustrating fire management agencies in similar clusters considering only indicators from agency environment, workload, and funding.
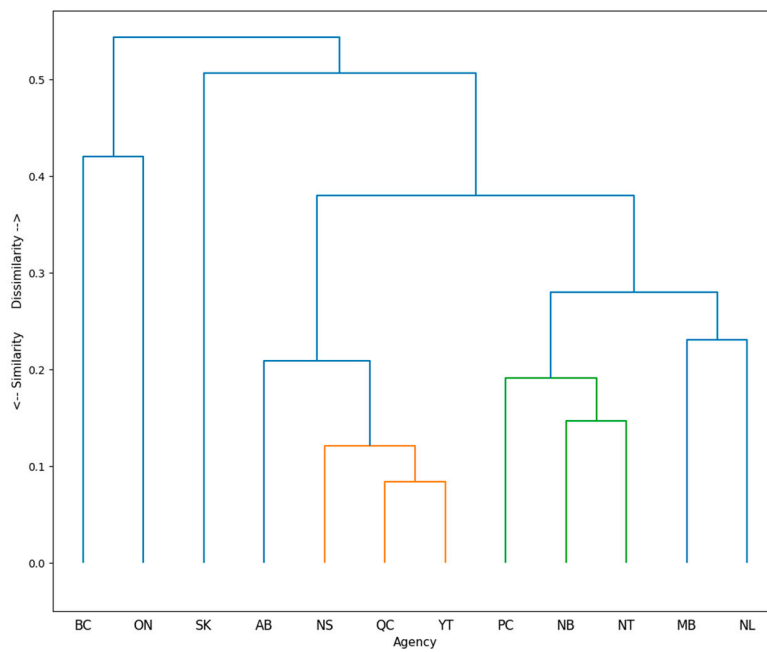

Figure. S5 Dendrogram illustrating fire management agencies in similar clusters considering only indicators from organizational capacity for innovation and planning.
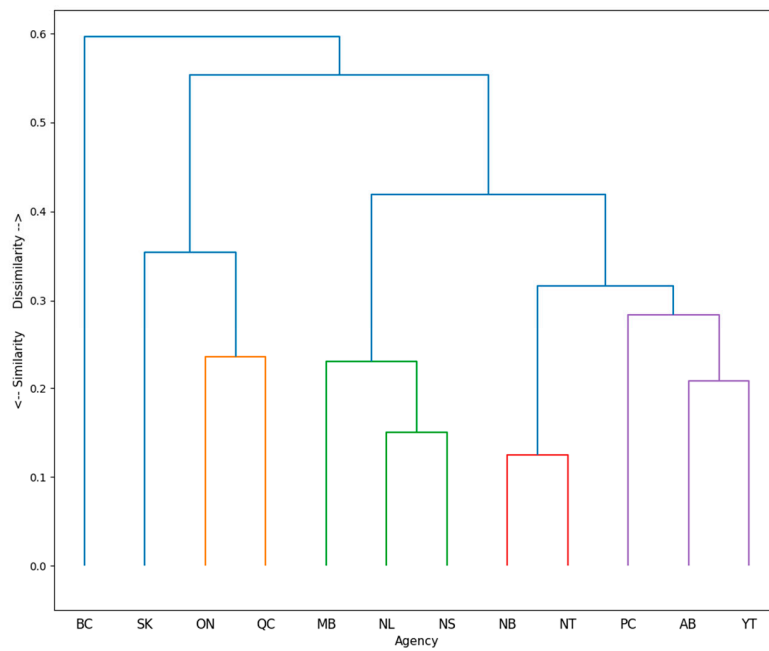
Figure. S6 Dendrogram illustrating fire management agencies in similar clusters considering only indicators from operational use of fire intelligence.
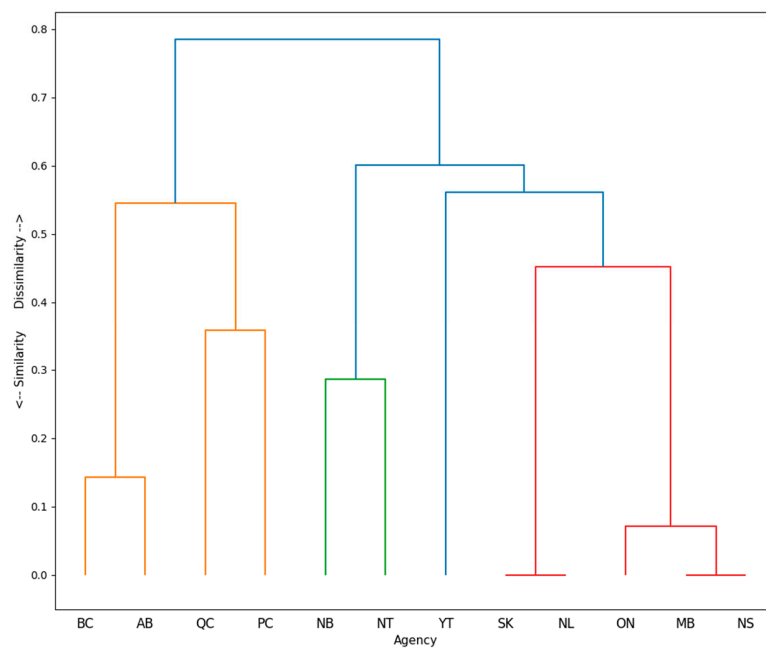

Figure. S7 Dendrogram illustrating fire management agencies in similar clusters considering only indicators from policies and procedures for approving and implementation new intelligence.
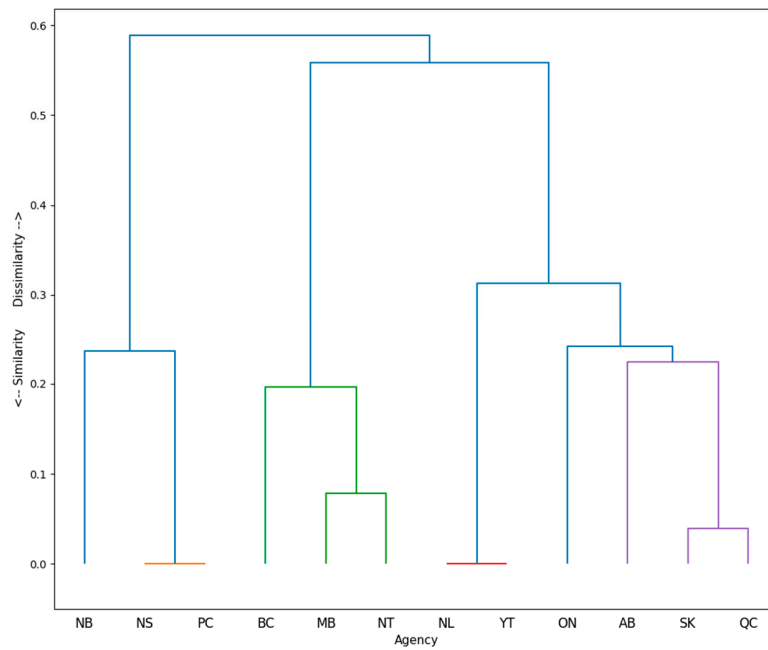
Figure. S8 Dendrogram illustrating fire management agencies in similar clusters considering only indicators from openness and engagement.
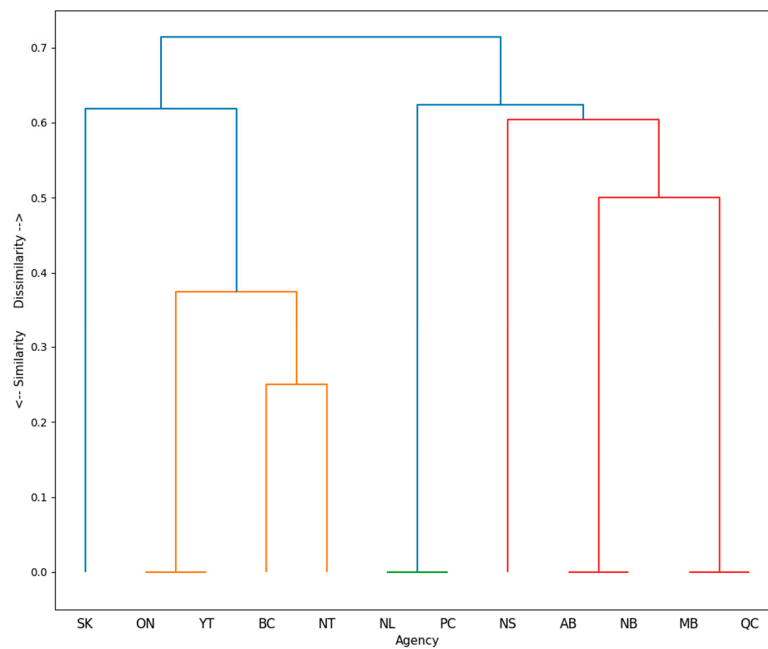

Figure. S9 Dendrogram illustrating fire management agencies in similar clusters considering only indicators from information management and information technology.

S4. WildFireSat Strategies and Activities to Increase Readiness

Below are lists of practical strategies and corresponding activities elicited from the survey and engagements with the fire management agencies. We propose that these may increase fire management agency readiness to implement WildFireSat products. We recognize that these strategies and activities are not in simple one-to-one relationships between themselves and between them and individual components of readiness. Rather, different activities can support multiple strategies and multiple components of readiness.

Strategy	Activities
Increasing education and training in remote sensing and for interpretation of fire intelligence for decision-making	- Develop a range of educational materials on the types, kinds, and uses of remote sensing for operational fire management. - Develop accessible training courses in the fundamentals of decision-making and model interpretation to better understand and use the fire intelligence possible with WildFireSat. - Ensure training/education is considered as a requirement for products and delivery mechanisms developed by WildFireSat.

"Would want learning opportunities (tutorials, web meeting) [to] be available to staff."

"Training opportunities to better exploit the full range of capability."

"…training opportunities so that users can gain confidence in knowing and understanding how to use WildFireSat to its best potential."

"Clear indication of the limitations of the data and products when used for decision making."

Strategy	Activities
Increasing expertise within agencies and within the broader fire management community	- Develop a community of practice for remote sensing and fire intelligence between fire management agencies and with subject-matter-experts within accessible national agency groups. - Create an environment (e.g., mock-up) for agencies to collaboratively try and experiment with remote sensing and fire intelligence prior to WildFireSat availability. - Create a forum for compiling lessons learned best practices and communications. - Support exchange of fire management staff between agencies of different levels of remote sensing readiness to learn from their experiences and approaches in use of current systems.

"From a wildland Fire perspective, the development of collaborative relationships/capabilities is absolutely key"

"We'd also be interested in seeing a community of practice prior to launch, where agencies could work together or share their development or ideas using synthetic [WildFireSat] outputs."

Strategy	Activities
Fostering active communications between development team and fire management community in the design and development of WildFireSat products	• Maintain a WildFireSat fire management knowledge exchange team, with Provincial and Territorial representation and the product development teams for WildFireSat. • Involve fire management staff in the development of WildFireSat products early and iteratively. • Regular meetings between WildFireSat team and with various fire management cadres, groups, and subject matter experts. • Participate in collaborative communications, conferences, and other venues. • Prioritize in-person engagement, learning and knowledge exchange opportunities.

"Open lines of communication, keeping our agency up to date on services provided and other deliverables."

"…workshops, written material, Presentations or videos of what products or services will/could result form the project."

Strategy	Activities
Alignment and compatibility of information management and technology with the fire management agencies requirements	• Provide open access to/from WildFireSat products and data. • Allocate time, and staff to promote use of free and open-source software. • Support and facilitate coordination of joint/common fire management data standards across agencies where possible and appropriate (e.g., the Canadian Wildland Fire Information Framework initiative). • Develop WildFireSat products for compatibility with agency data standards when not aligned with open standards. • Distribute test data products so that agencies can explore incorporating into their systems in advance of the real data being made available.

"Ensuring the products will be in a format that the [fire management agency] can incorporate into our existing systems and be ready for use by operational staff on incidents."

"[provision of] test datasets…initiate and prioritize the developments that must be carried out in order to integrate the data into the information systems."

Strategy	Activities
Increasing capacity for implementation.	• Automate WildFireSat data products and their dissemination mechanisms. • Increase or allocate the time, resources, and staff to develop implementation plans and procedures within agencies (e.g., formal assignments, internships). • Explore opportunities for agency partnerships in implementation readiness projects such as through the Canadian Interagency Forest Fire Centre, agency compacts. • Partner with fire management agencies of similar needs on joint implementation strategies. • Investigate use of new or existing national frameworks for dissemination of fire management data and products (e.g., Canadian Wildland Fire Information Framework).

"Staff are very limited, as is expertise, so any reliable products the WildFireSat team could bring to the table, without requiring significant time/feedback at our end, would likely be valued the most."

These are presented as conceptual strategies and activities and not directed to any one group to implement. The rate and extent that employing these strategies will increase readiness is not known in any quantitative sense, but they are expected to be beneficial.

Determining the impact of these suggested strategies is planned future work which can be revisited using a similar methodology some time prior to launch and again after operational use of WildFireSat in fire management. Depending on the type of activities that are pursued we may be able to explore more quantitatively the effects of different strategies to improve readiness.