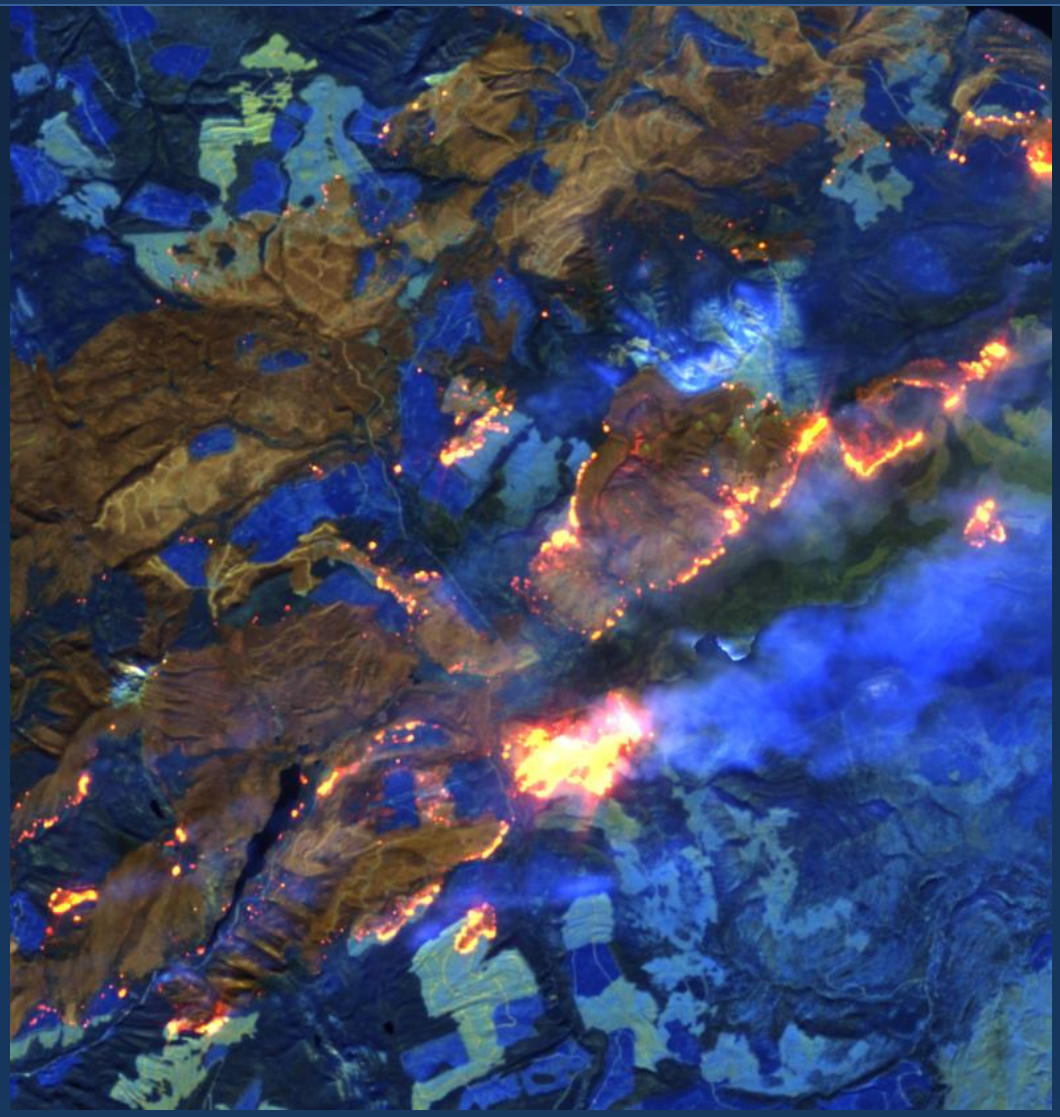
Fuel Type Mapping with Remote Sensing and Machine Learning

BC Wildfire Service



Wildland Fire Conference Canada, 1 Nov 2022 11:10

Ash Richardson & Predictive Services Unit

Predictive Services Unit

BRITISH COLUMBIA | BC Wildfire Service

What we do:

- Gather information and analysis using best available science, technology & human expertise
- Assist risk-based decision making for wildfire prevention, preparedness, response & recovery

Who we are: 3 prongs

1. Fire Weather Forecasters,
2. Fire Behavior Specialists, and
3. IT and Data Scientists

Overview

1) ***BCWS FTL project*: move towards NRT / continuous forest monitoring for improved situational awareness**
   A. Partners/ Engagement.. Your feedback requested for coordinated approach
   B. Projects + components
2) **Satellite fire mapping 2022 Operational Trial**
   A. Method
   B. Learnings + next steps
3) **Satellite fuels mapping (goal: 2022 op. trial)**
   A. Demo of proposed iteration towards method
      A. Check data consistency on 10,000 sq km area! (1% of prov)
   B. Learnings + next steps

BCWS Predictive Services
BCWS Geospatial Services

Partners and collaborators

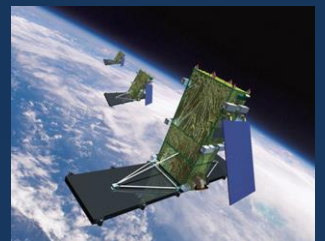
- Hopefully you?
- Your input appreciated!

RPAS

Sentinel1

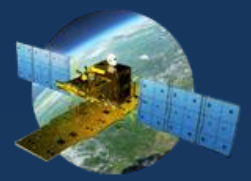
Sentinel2

RCM

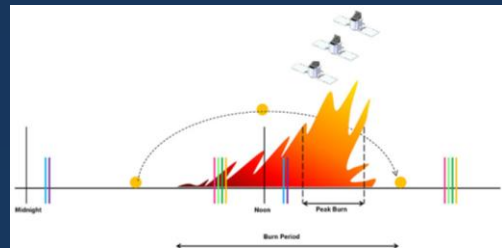


NiSAR (2023)

JAXA PALSAR-2



WILDFIRESAT

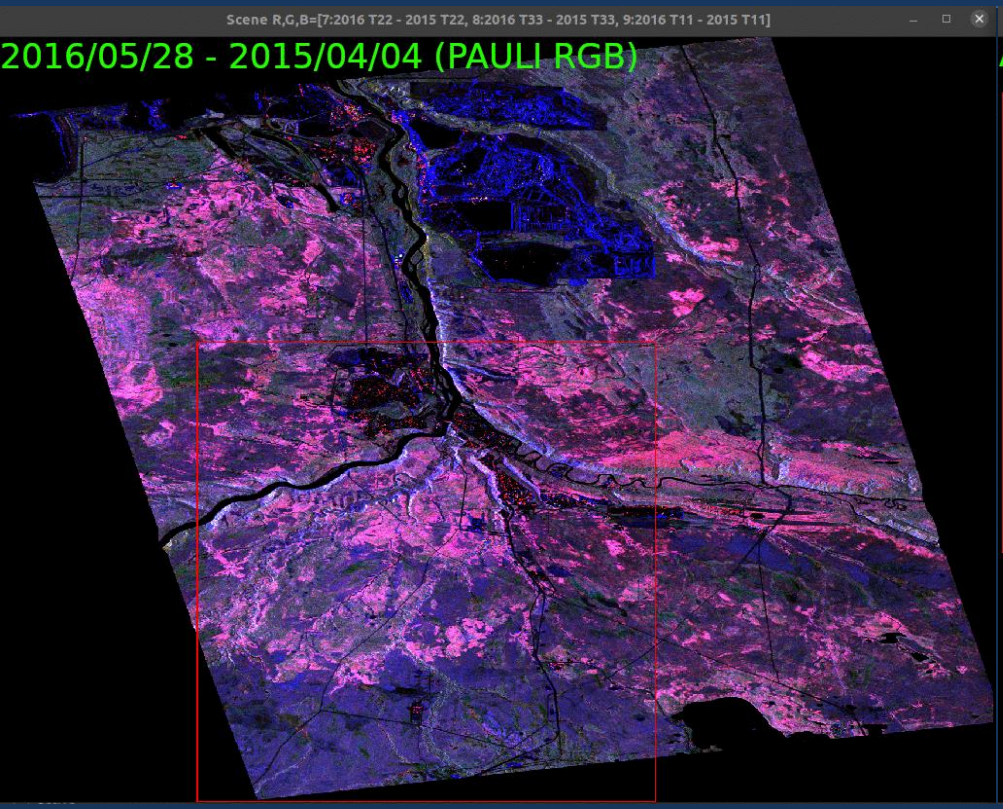


BCWS FTL project components

- Emerging tech collab w:
  - Canadian Space Agency (CSA): radar imaging
  - Italian Space Agency (ASI): hyperspectral imaging
  - Japanese Space Agency (JAXA): radar imaging. Int'l collaborators
- Mobile fuel typing app (ground data collection)
- Telegraph creek ground fuels study (2020, 2021, 2022 UAV study)
- **Active fire detection w Sentinel2**
  - **operational trial 2022 season**
- **Fuel type monitoring w Sentinel2**
  - **Aiming for operational trial 2023 season**
- Active fire detection (thermal UAV)
  - Aiming for operational trial 2023 season

Fort McMurray 2016 (Horse River fire) radar

BC Wildfire Service



JAXA Quad-pol L-band SAR data

National Fire Polygon Database Extent

Quad-pol processing steps

1. Radiometric calibration
2. Faraday rotation correction (Default option)
3. Multilook (2x2)
4. T4 matrix generation
5. Box filter 7x7
6. Range doppler terrain correction (Copernicus 30m dem)
7. Convert to PolSARPro format, use NAN in no-data areas, project ground-reference on top, assign no-data areas (where no image overlap)

References

- https://www.eorc.jaxa.jp/ALOS-2/en/img_up/dis_pal2_can-forest_fire_20160509.htm
- https://ieeexplore.ieee.org/document/8517822

White Rock Lake (2021, BC) radar image

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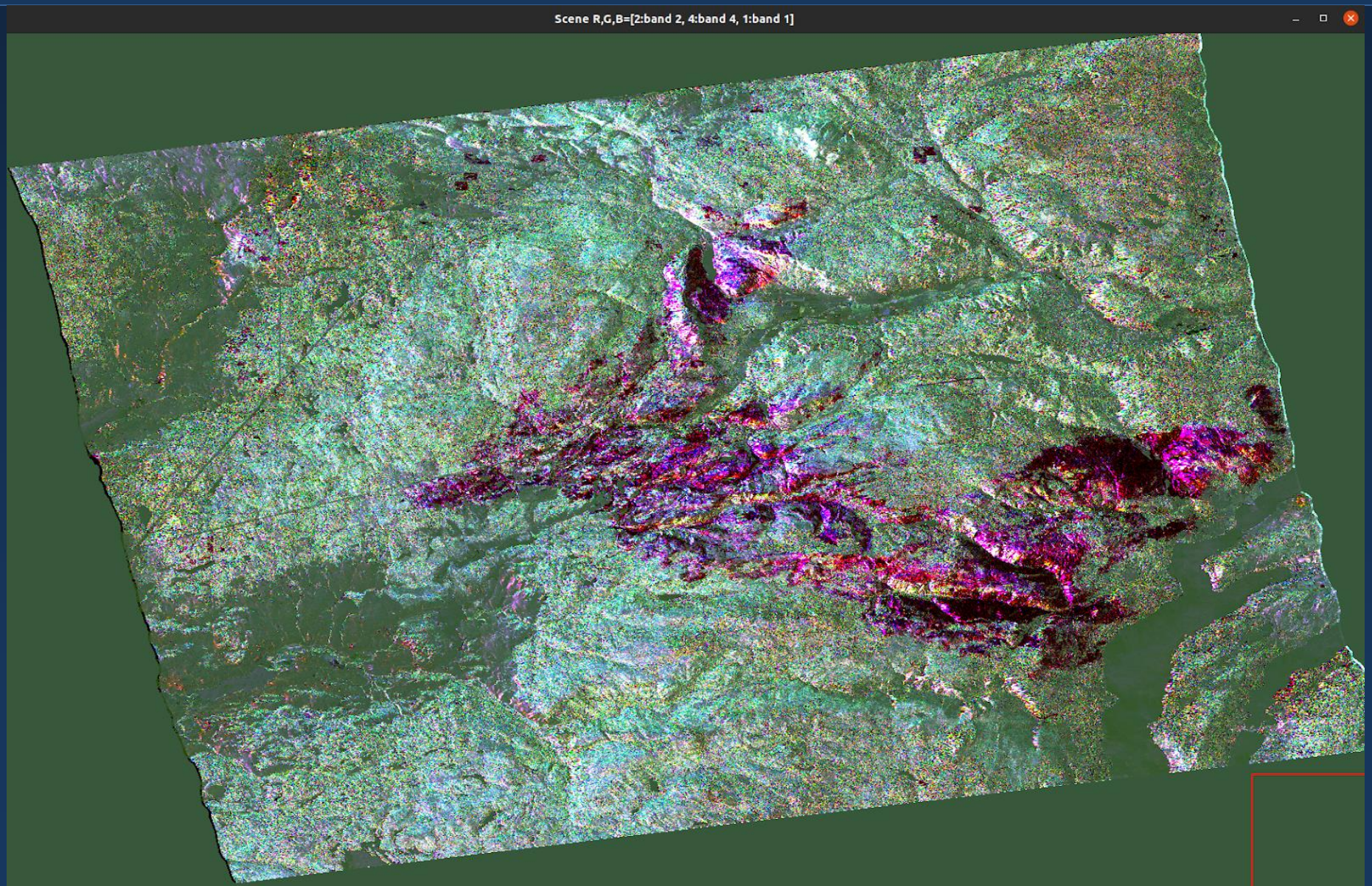
JAXA L-band Dual-pol

ShownDifference:
(2022 - 2021) of

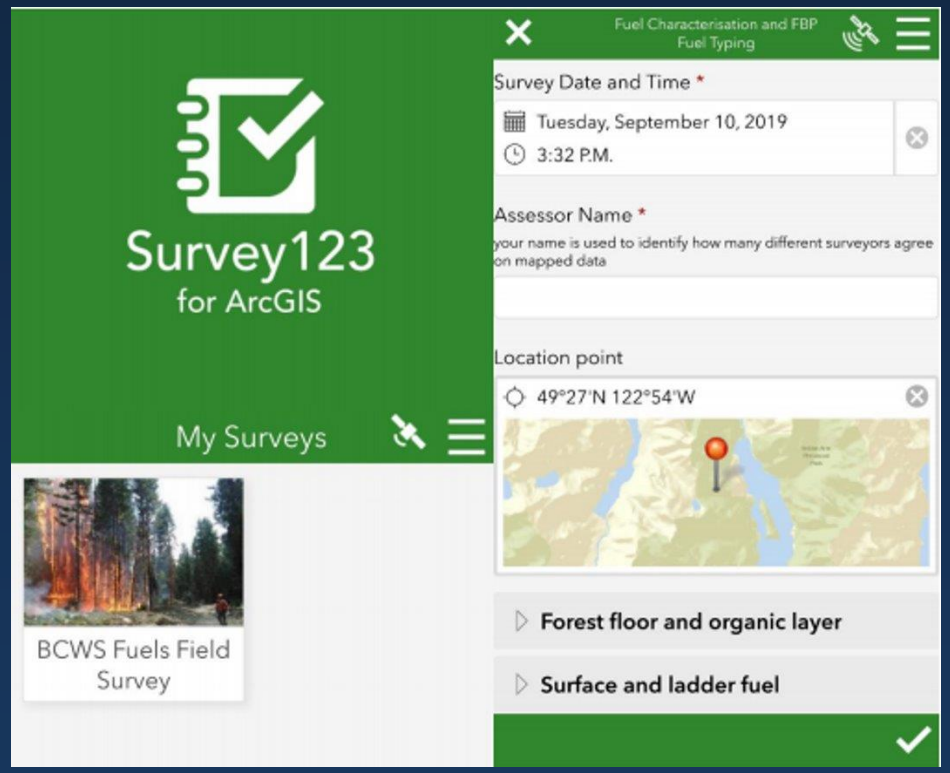
Re(C12) (red)
C22 (green)
C11 (blue)

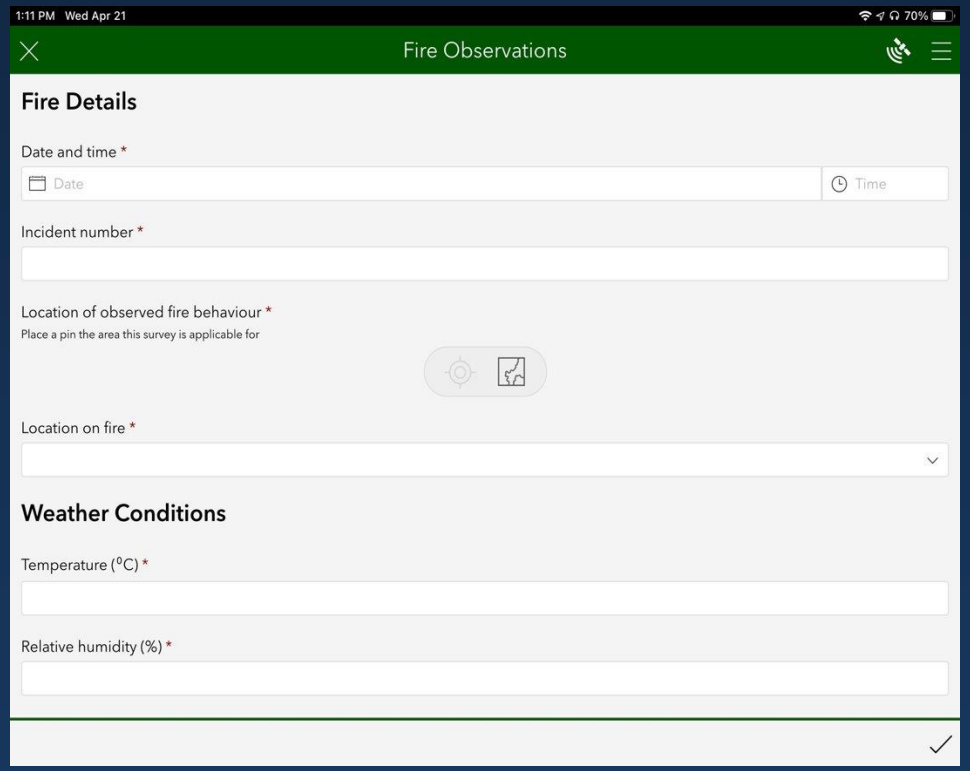
**** Fire scar is: the big pink/purple thing ****



Processing steps (SNAP):
1) Radiometric calibration
2) Multilook to approx square
3) 5x5 box filter
4) Range-Doppler TC (Copernicus 30m dem)
5) Convert to PolSARPro / ENVI format
6) Co-locate with GDAL

Survey 123 Phone app

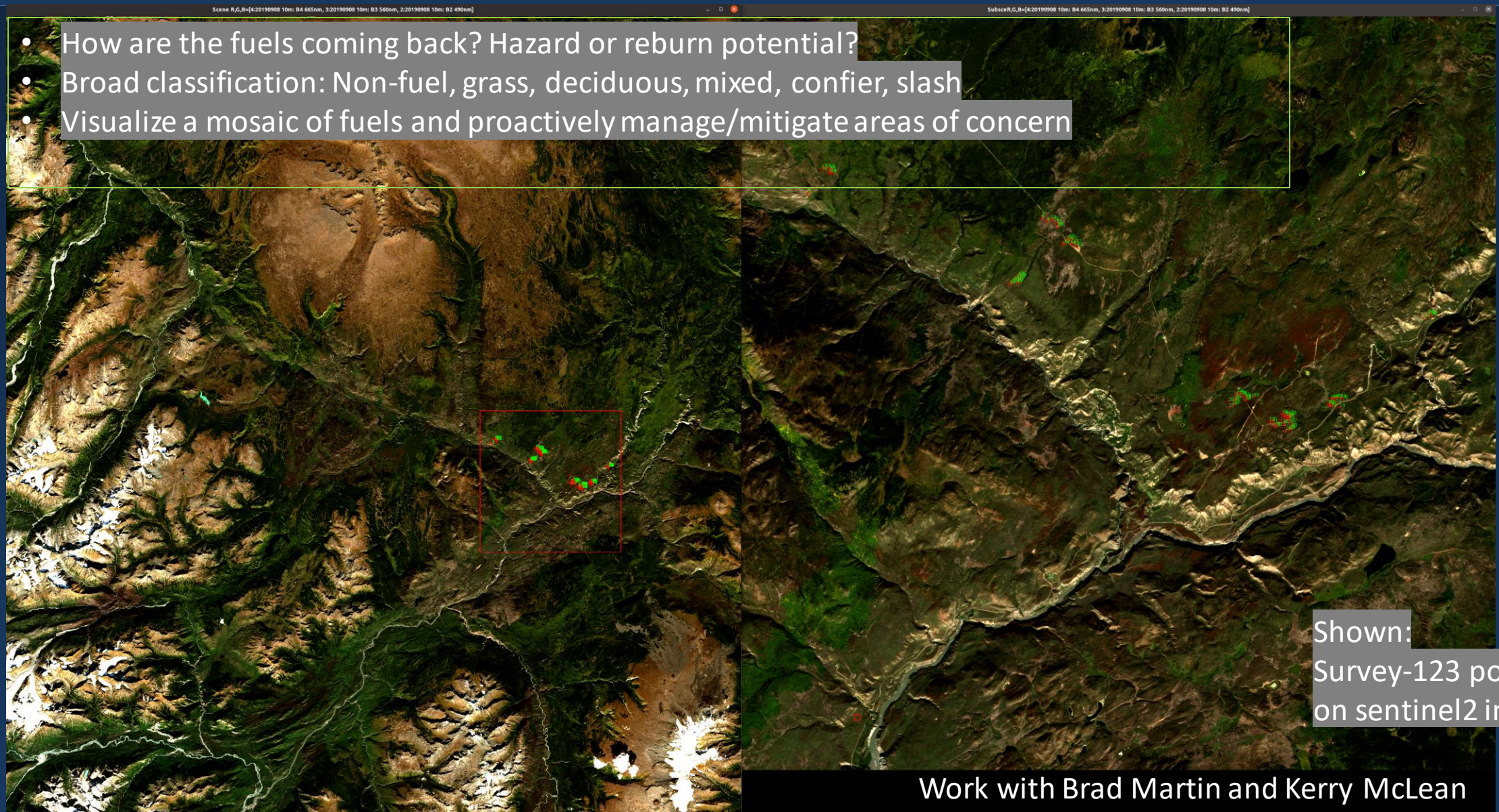




BCWS.PredictiveServices@gov.bc.ca

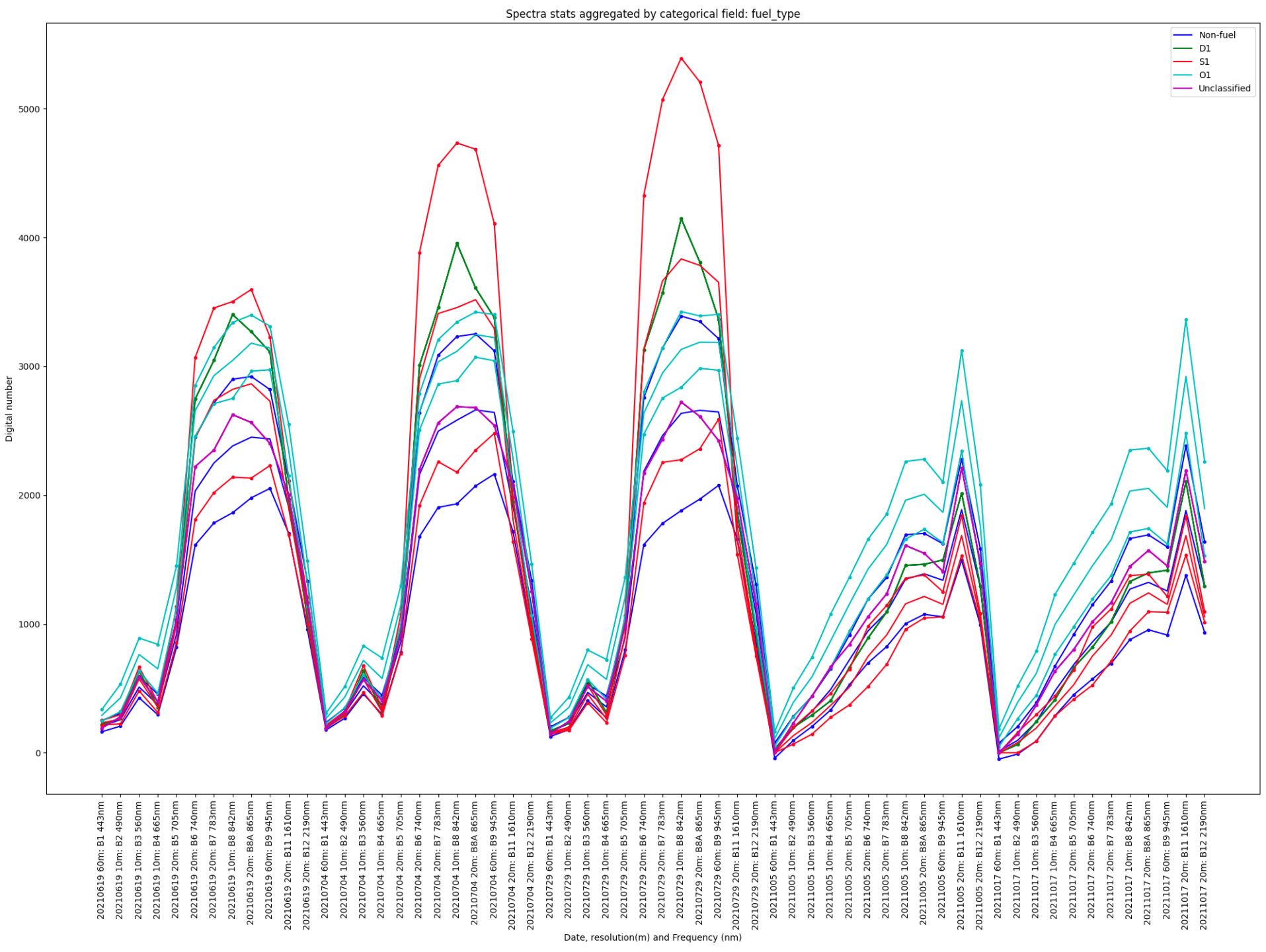
Telegraph creek study

- How are the fuels coming back? Hazard or reburn potential?
- Broad classification: Non-fuel, grass, deciduous, mixed, confier, slash
- Visualize a mosaic of fuels and proactively manage/mitigate areas of concern



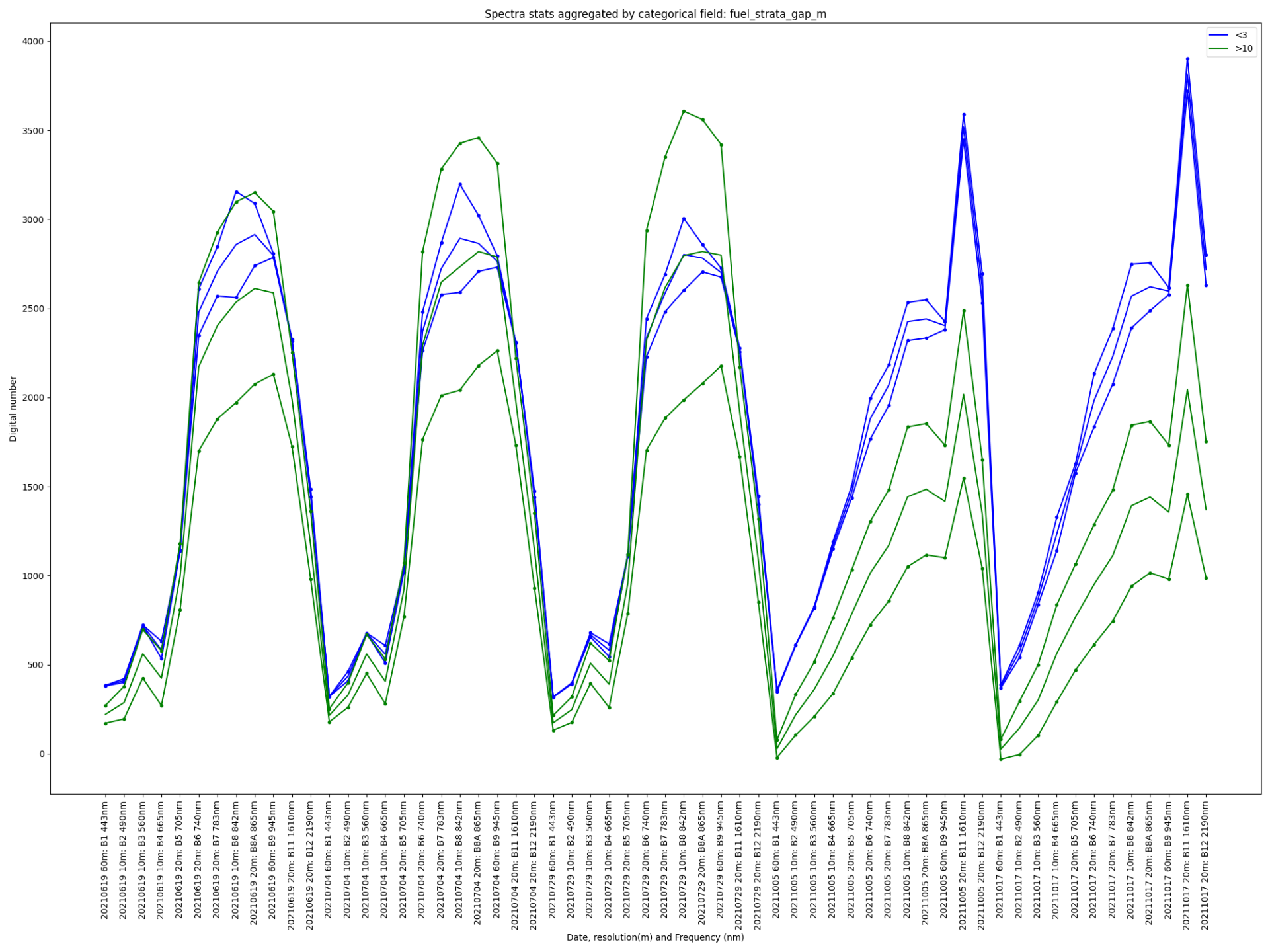
Shown:
Survey-123 points
on sentinel2 imagery

Work with Brad Martin and Kerry McLean



[Field Observations and Remote Sensing of Wildland Fuels: A Case Study, Bulkley Valley Research Centre, Oct 8 2021 2021]

Key finding:
Winter dates Help Discern Fuel types!

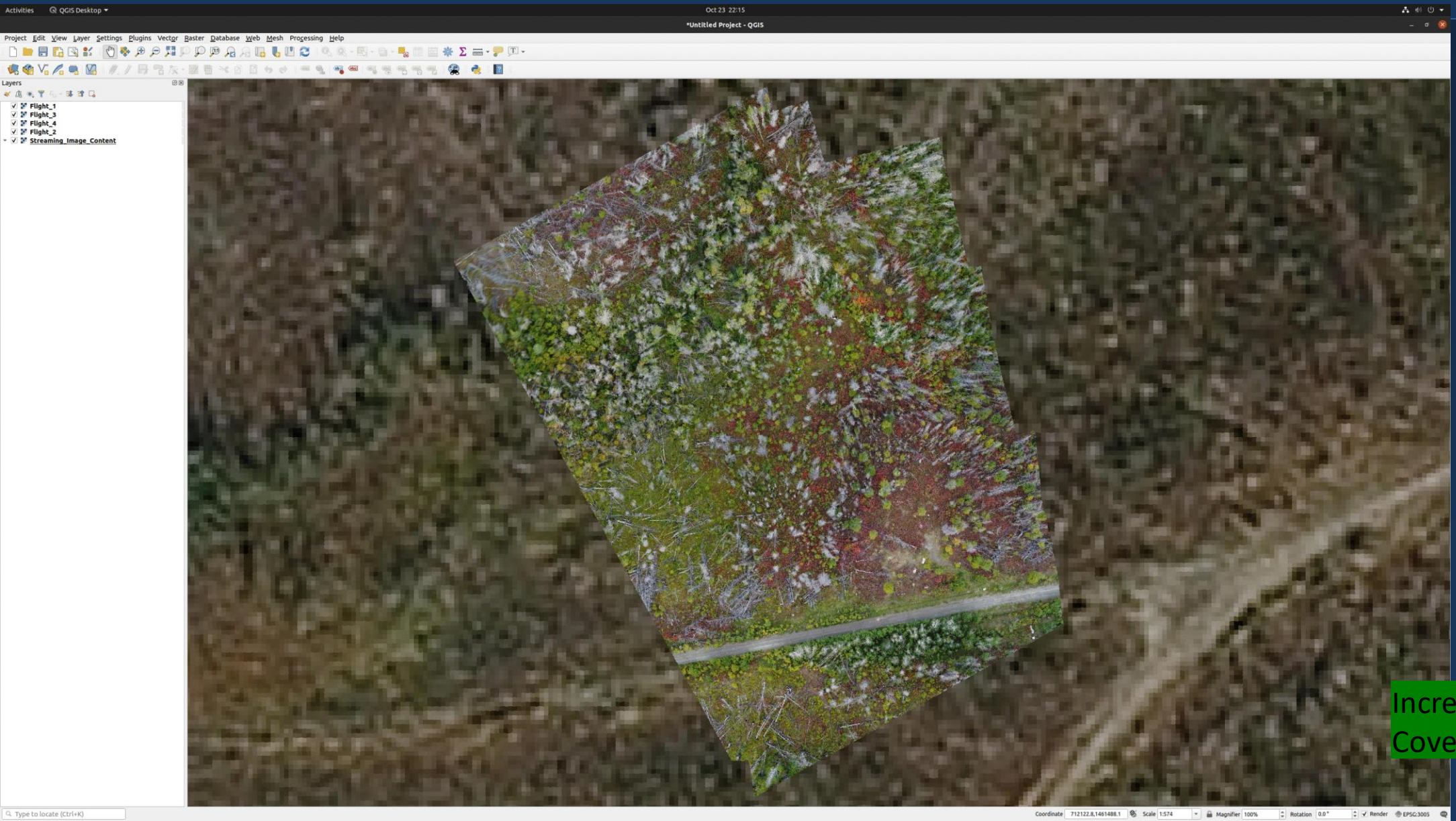


[Field Observations and Remote Sensing of Wildland Fuels: A Case Study, Bulkley Valley Research Centre, Oct 8 2021 2021]

Key finding:
Multitemporal could
Help get 3d parameters

Telegraph creek: add Drone imagery

BC Wildfire Service



Incredibly detailed,
Covers more ground

Operational trial 2022 (BCWS)

1. Goal: satellite fire perimeter mapping
2. Approach
   - Web app w PSU Agile team https://github.com/bcgov/wps-fire-perimeter
   - ESA Copernicus download (better latency)
   - Simple "A.I." Method(s)
3. What we learned
   - Wins
4. Next steps

BCWS Predictive Services
BCWS Geospatial Services

Satellite fire mapping

- Opportunity to monitor progression of fires not actively suppressed
  - Add situational awareness
  - Reduce high-risk flight reqt's
- Complement existing methods
- Additional frequency & fidelity for perimeter updates
  - Better intel for growth projections & other predictive services products
- ***Stepping-stone, towards continuous fuels mapping***
- Start w Sentinel-2 & add more (tried Landsat & Sentinel-3)

Why the method is unique

- Somewhat unusual
  - Not a retrospective pre/post veg comparison
    - Single-date imagery used (*)
    - NBR / dNBR not used
  - Thermal IR band not used
  - Fixed threshold method (v fast)
  - Not a hotspot detection, can catch transient fires
- Accessible:
  - no math/stats req'd
  - Free/open-source software & open data used!
  - Can try a simple "band math" expression in your preferred Geomatics tool (Arc, ENVI, SNAP, PCI, QGIS, ..etc)

(*) Can bring multi-date back to help with tricky cases

Approach: direct "low latency" data access

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1. Prepare Sentinel2/Landsat data
   - Download, extract, band selection, crop
   - Copernicus faster than SentinelHub
   - Save ~2h by downloading L1 & process to L2
2. Binary fire classification
   - Two classes: Fire vs NA
3. Scrub false positives (using GIMP)
   - E.g. Water
4. Convert to Polygon (kml)
   - ***Record GeoTiff raster for QC/QA and analysis***
   - Use QGIS to compare w public perimeter data
5. Submit to BCWS Geospatial Services team
   - SME review (+ Post processing)

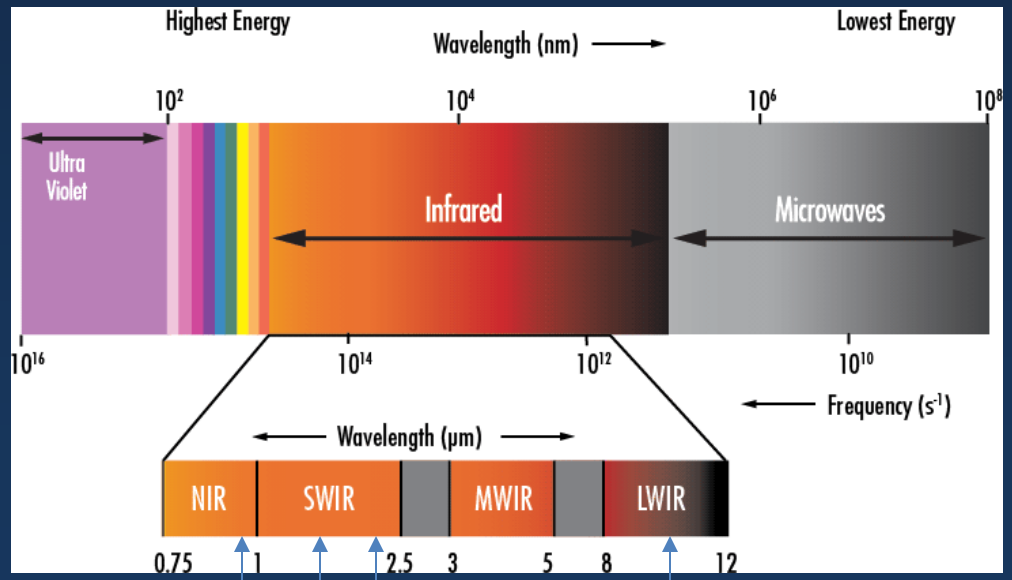
https://github.com/bcgov/wps-research/blob/master/py/binary_polygonize.py

1. Band selection: False color coding (right)

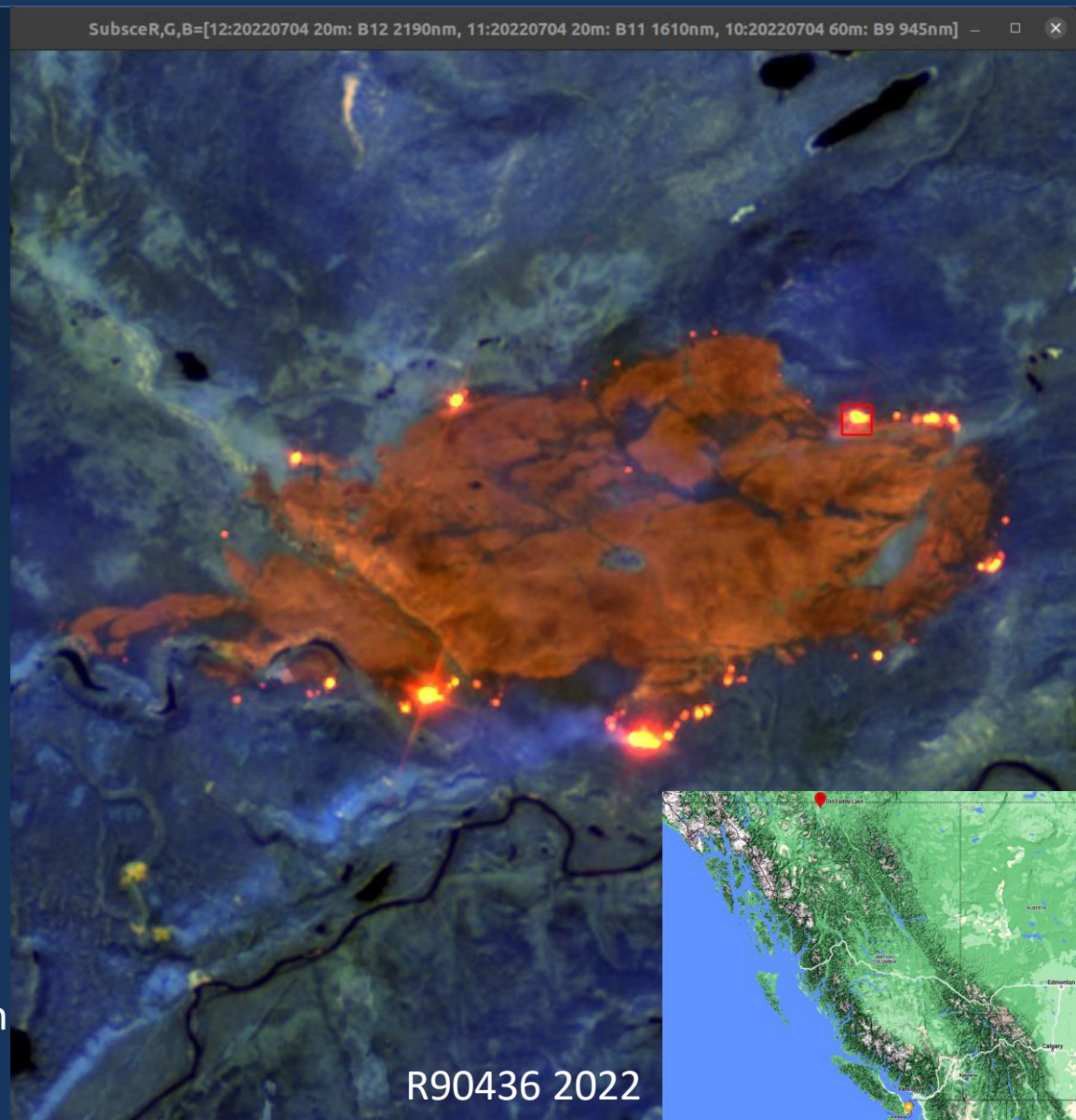
- Color encoding to generate map at right:
  - Red: "B12" 2190 nm = 2.2 µm
  - Green: "B11" 1610 nm = 1.6 µm
  - Blue: "B9" 945 nm = 0.95 µm

I.e. The B12, B11 and B9 are respectively plotted as Red, Green and Blue on the screen

- Vegetation is blue
- Hotspots are red
- Burned areas are orange



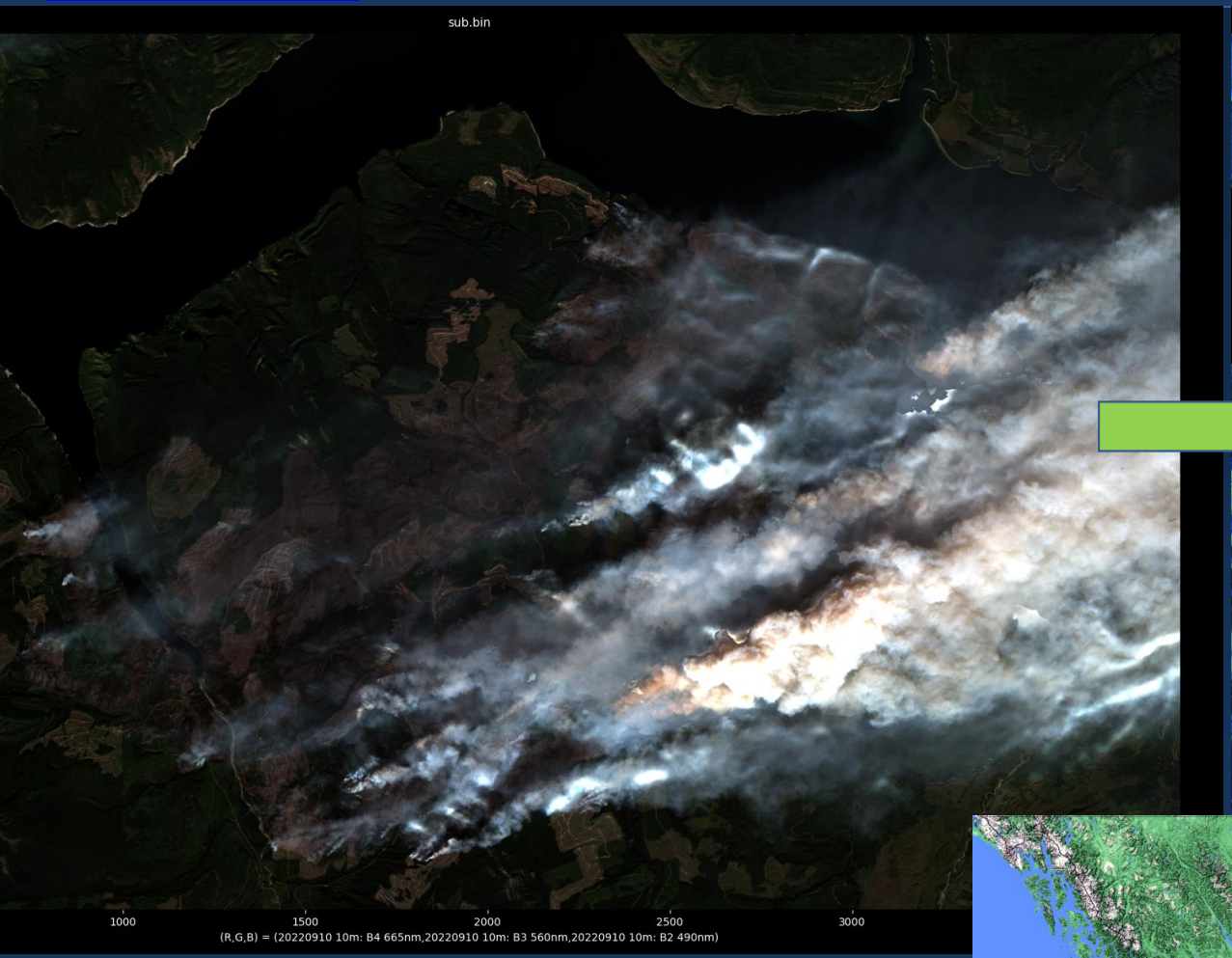
"Somewhere between visible and thermal"

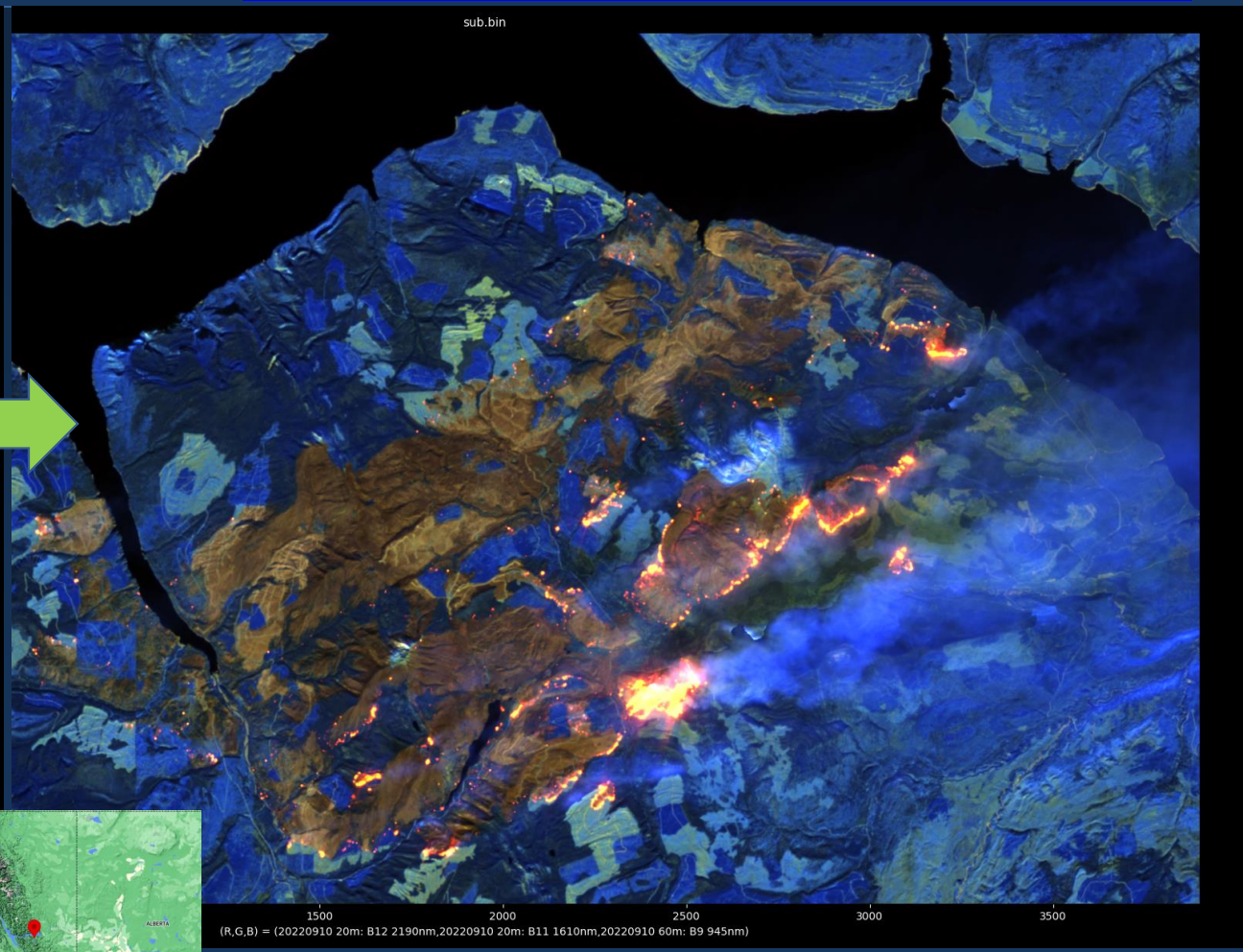


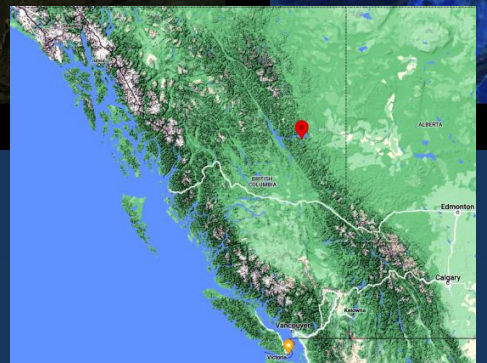
1) Sentinel2 data: Why use longest-waves?

RGB = RGB (visible) Battleship mountain (G72150) 20220910

RGB= (B12, B11, B9) shortwave IR. 3 longest-wave bands!







Battleship mountain (G72150) 20220910

2) Threshold

https://github.com/bcgov/bcws-psu-research/blob/master/cpp/sentinel2_active.cpp
https://github.com/bcgov/wps-research/blob/master/cpp/raster_dominant.cpp

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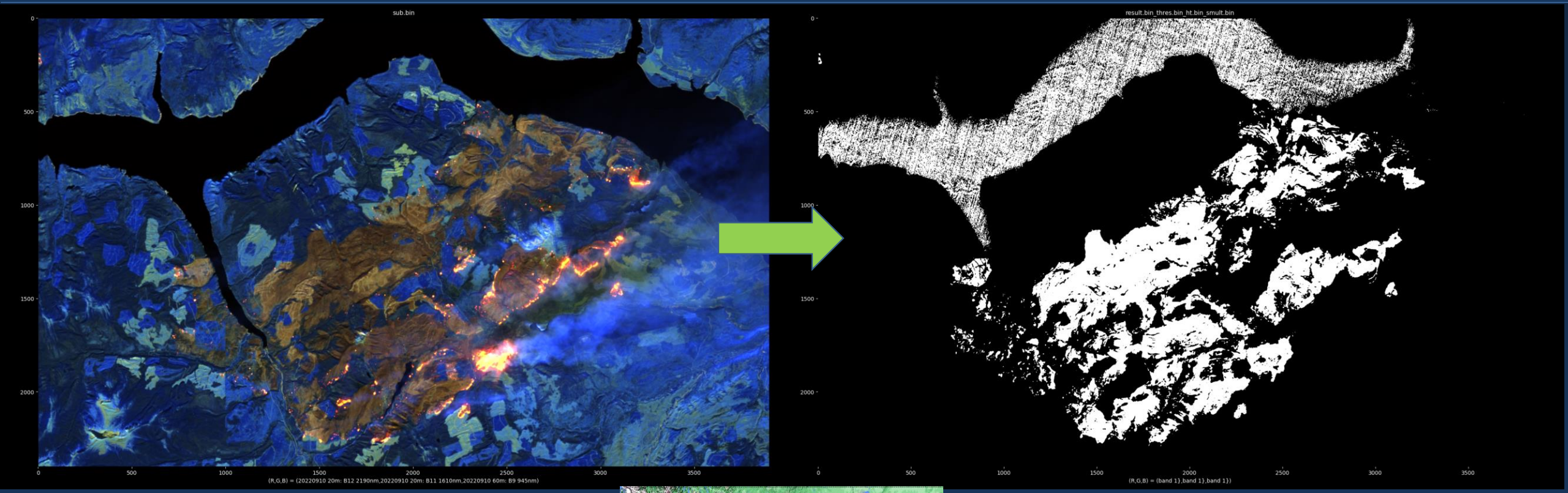
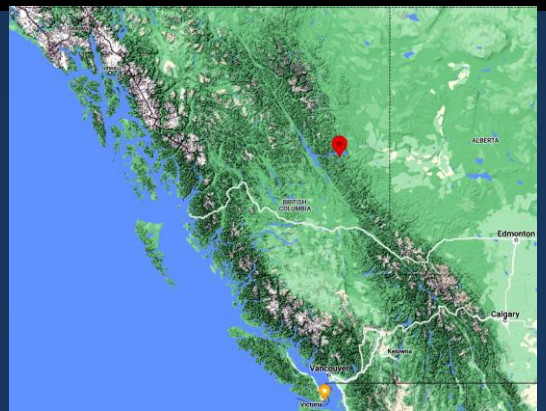


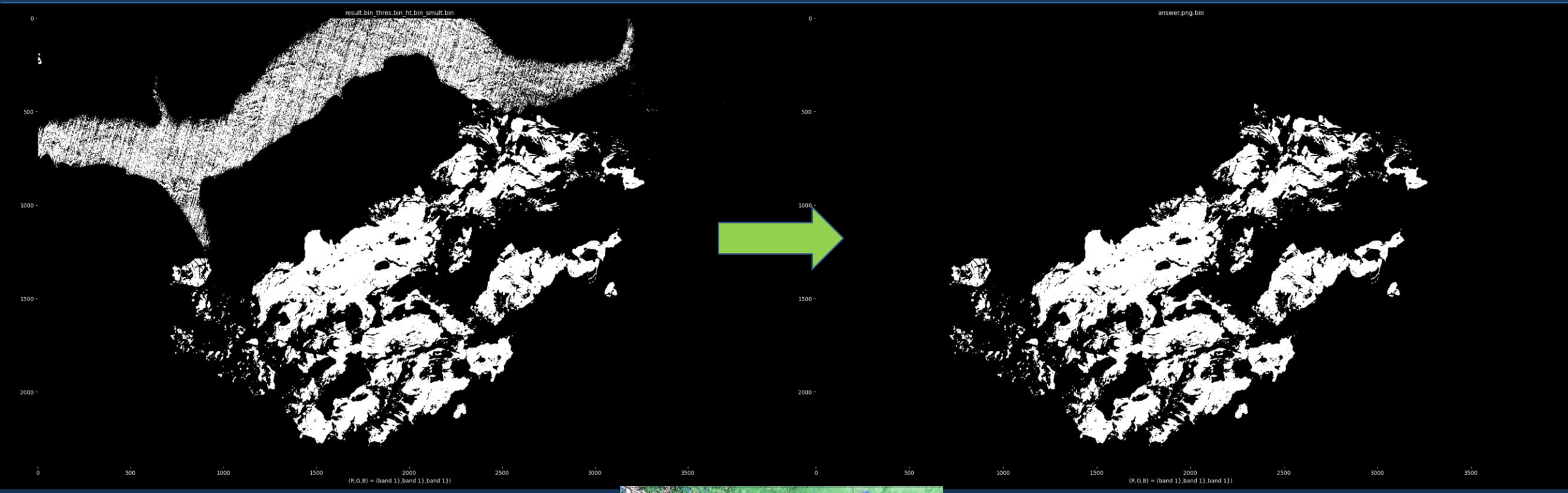


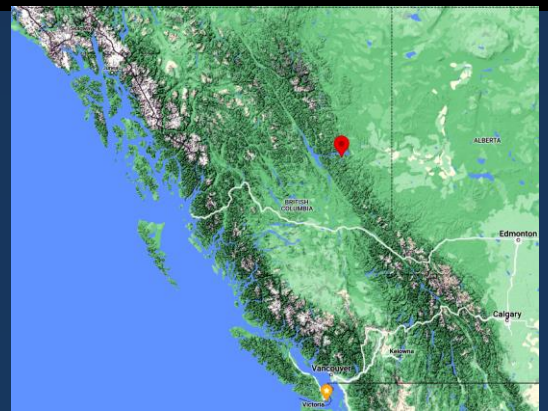
Battleship mountain (G72150) 20220910

(B12 > B11 && B12 > B9)

- Find image areas that are "more red"
- False positives incl. Reflection off water
- In-house private cloud app uses GEE land-cover to exclude water

3) Scrub

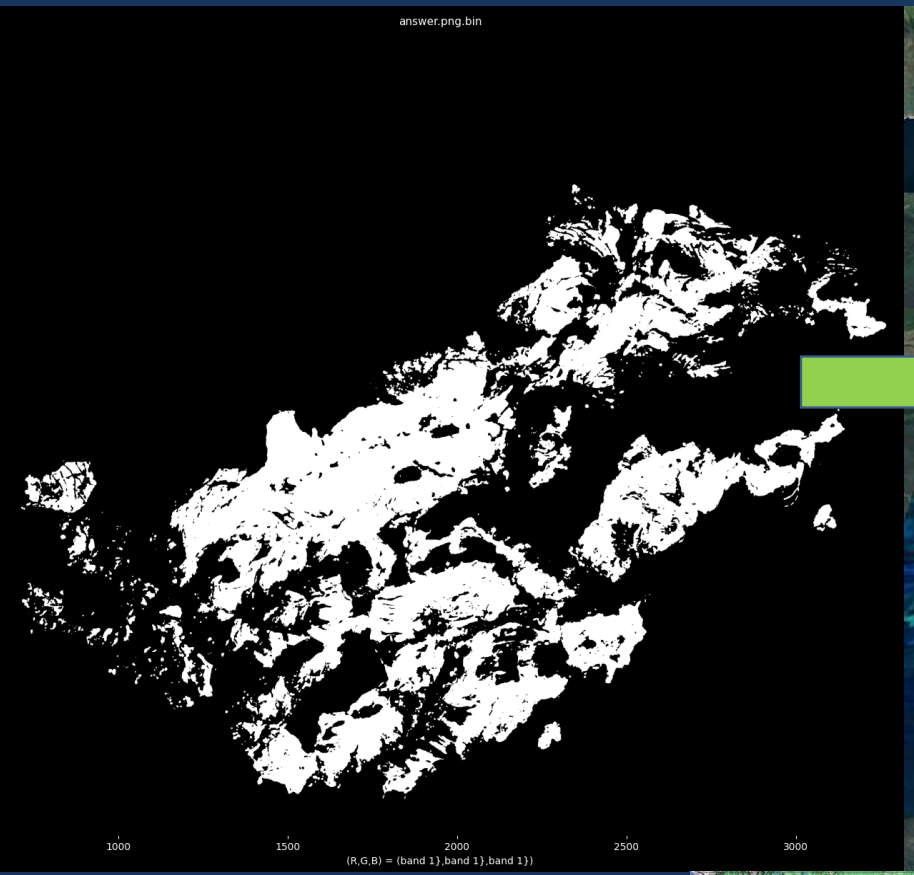


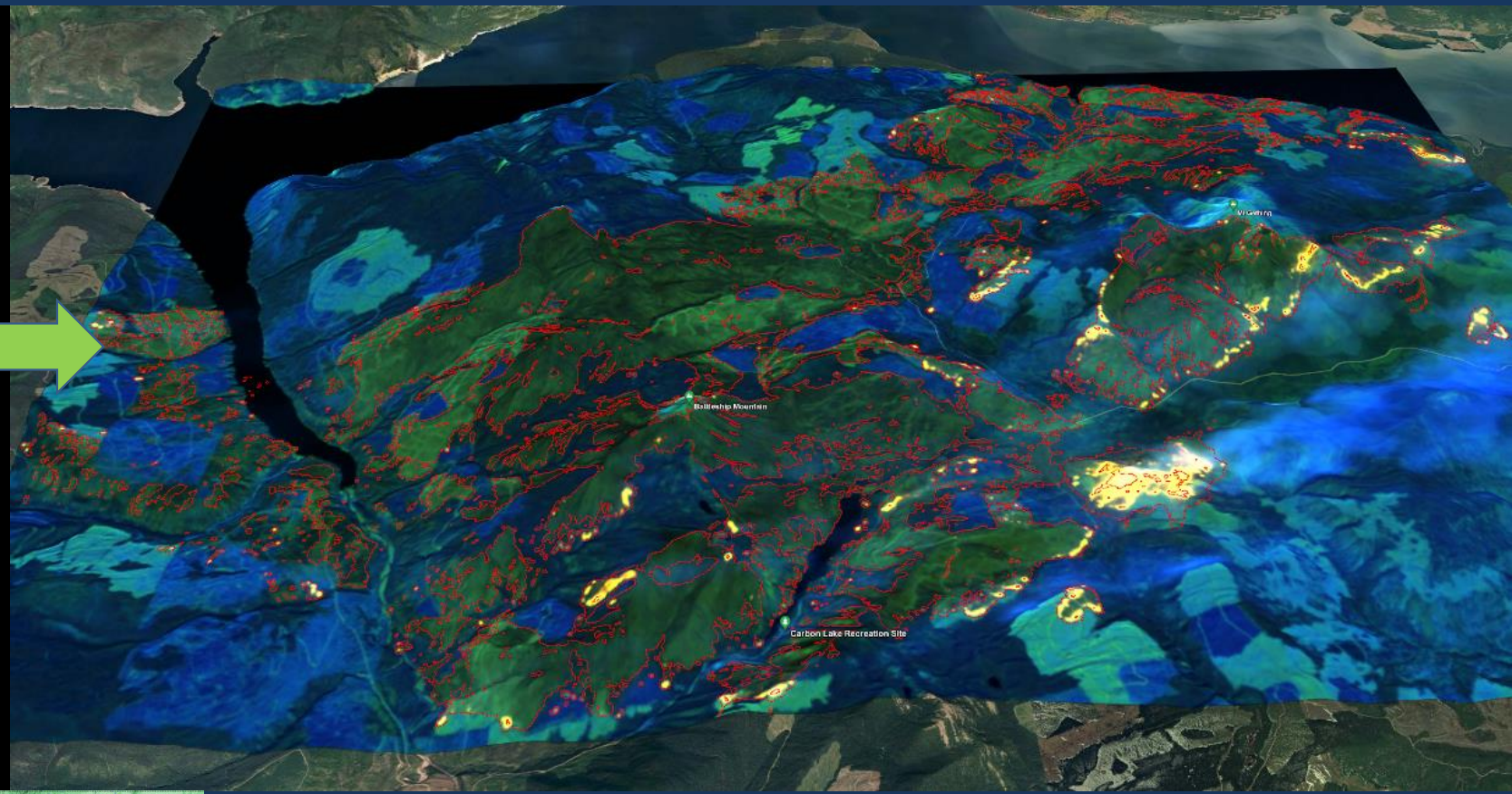


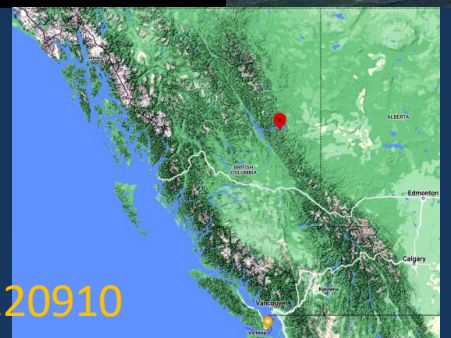
- Remove water areas etc.
- GIMP used for manual scrubbing
- Weather, illumination or other image quality issues could necessitate more scrubbing
  - Or more AI

Battleship mountain (G72150) 20220910

4) Convert to polygon and compare





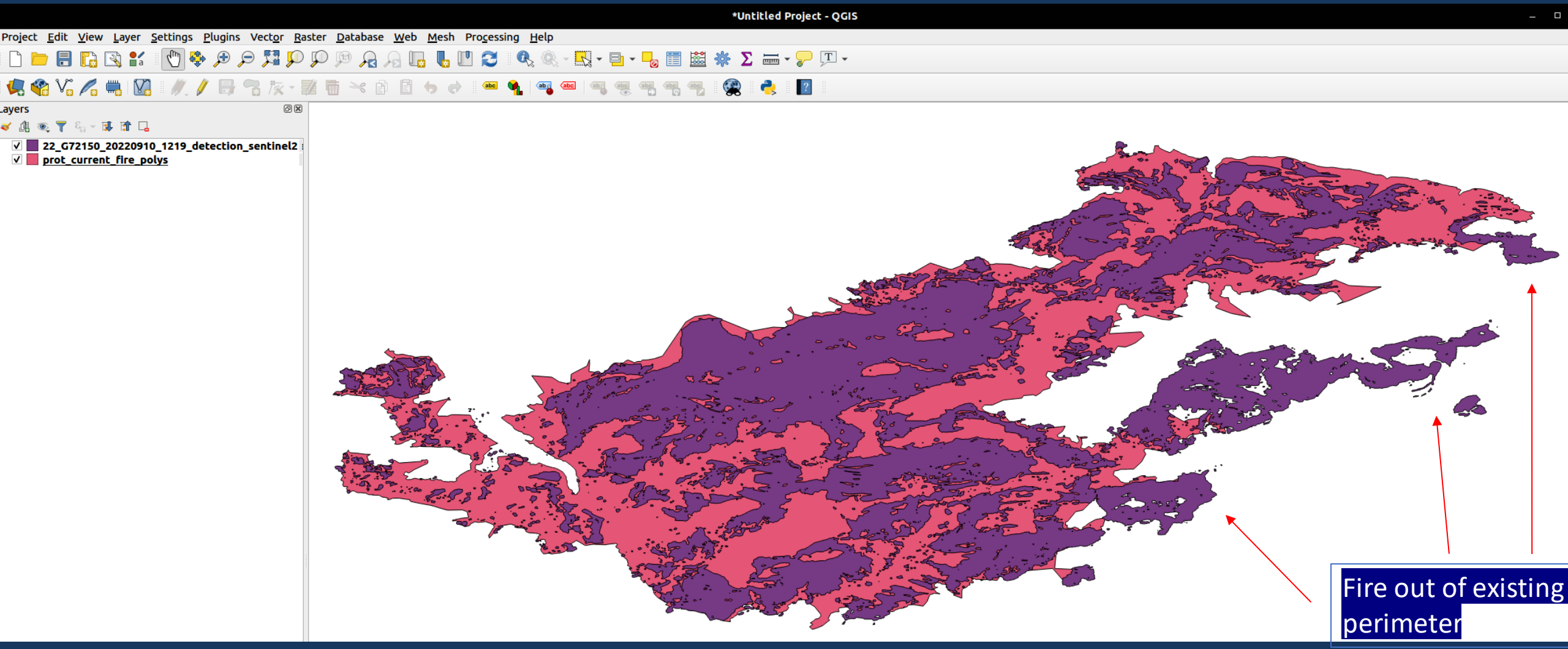


Battleship mountain (G72150) 20220910

- KML outline (RED) viewed in Google Earth
- SWIR band preview saved to TIFF
  - Scaled to 8-bit (each band)
- 5. SME post processing not shown

4. Polygon: compare w existing data!

BC Wildfire Service

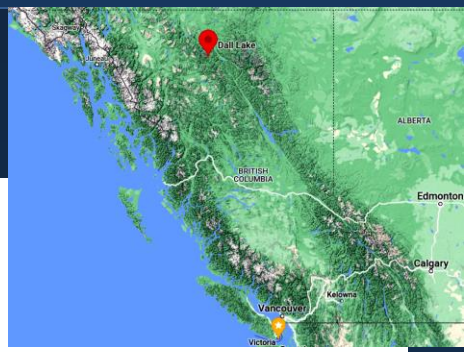


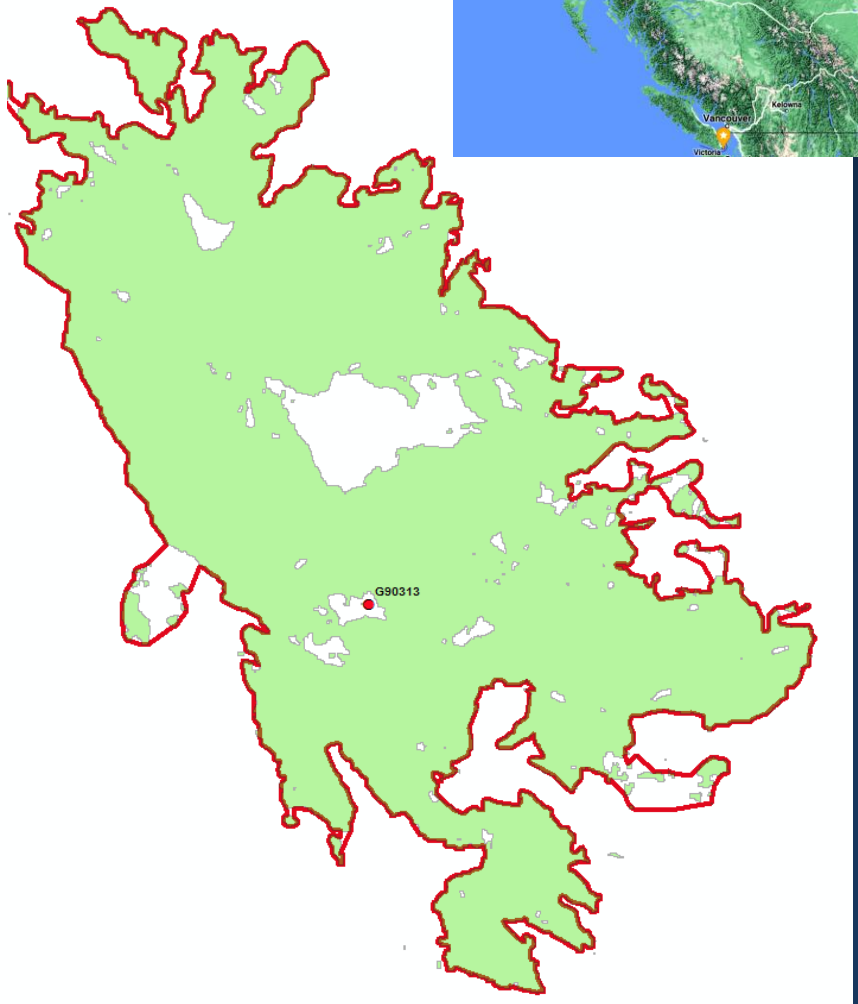
Battleship mountain (G72150) 20220910 Poly data 2022091021 (9-10pm)

Note: 12 Sep 2022 poly to boots on ground in 4h24m from image capture (approx noon)

5. Post processing

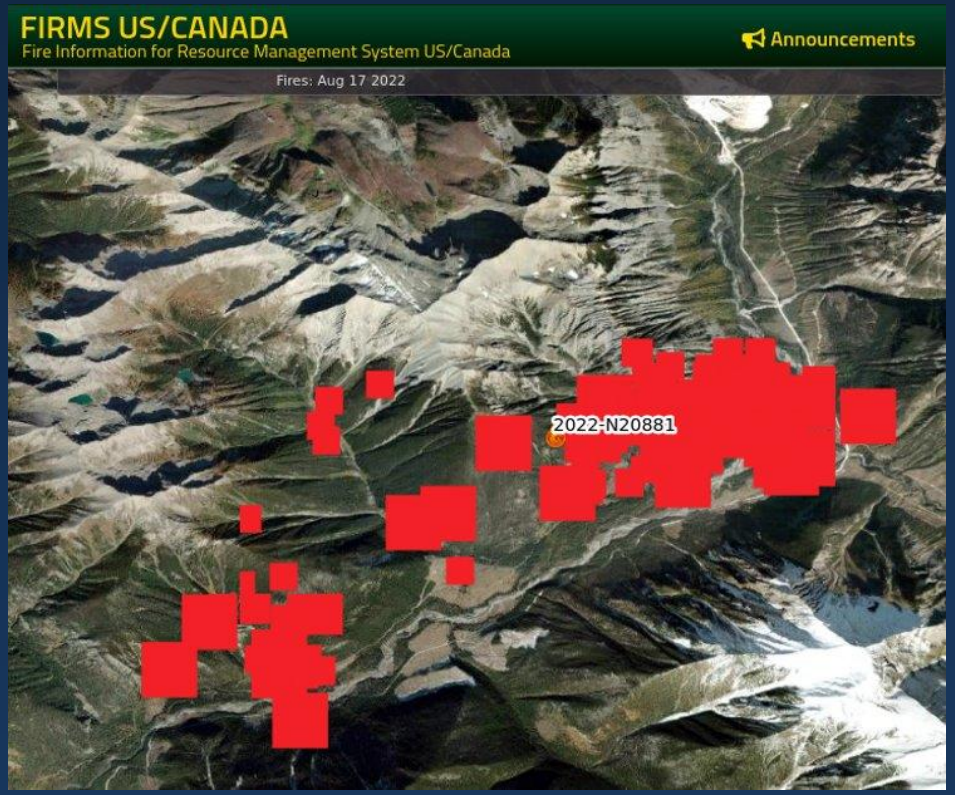
- Post processing completed in conjuction with current perimeter, Plans Chief and GIS Specialist
- Left: Sentinel2 derived detection. Middle: Generalized shape Right: comparison



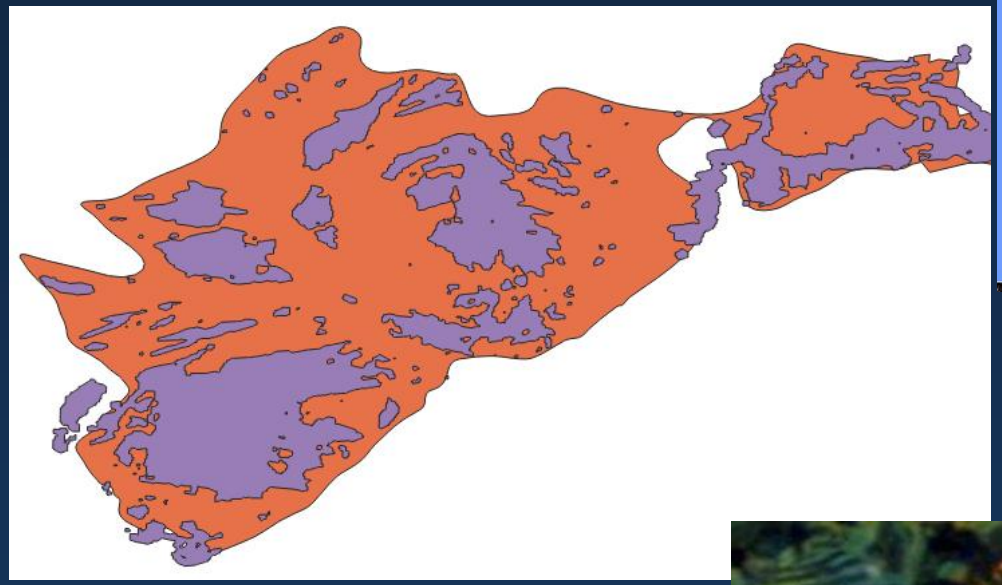


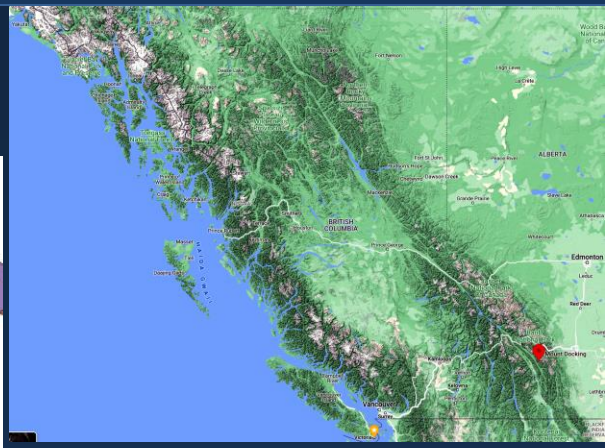
Comparing Sentinel2 result (right) with Firms

NASA Firms (MODIS and VIIRS) detection Aug 17

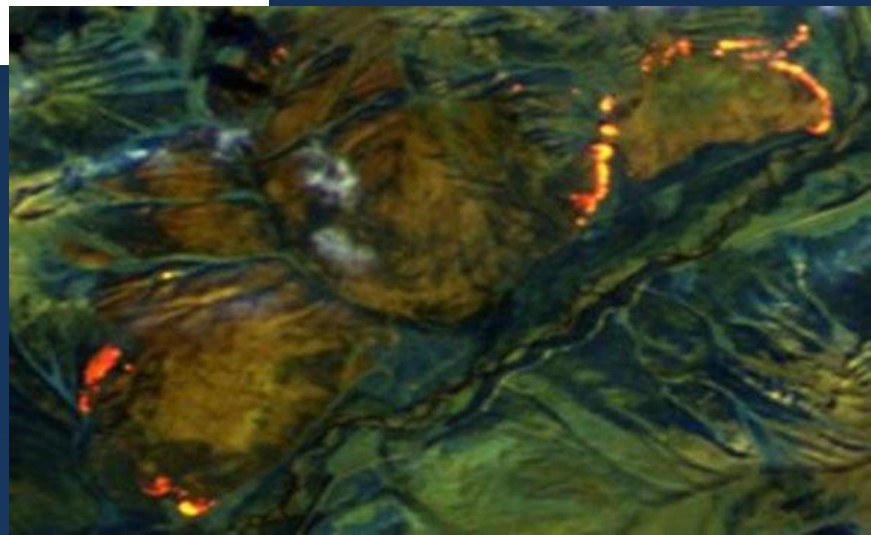


Purple – Sentinel-2 detection Aug. 17th
Orange – public perimeter as of 20220819





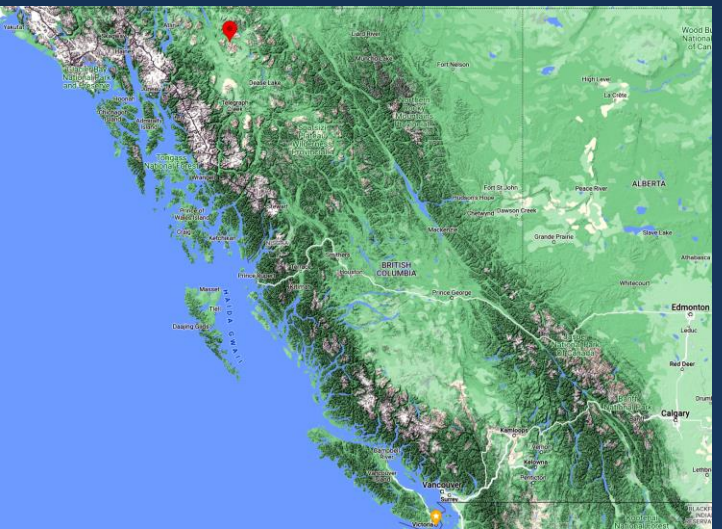
SWIR false color

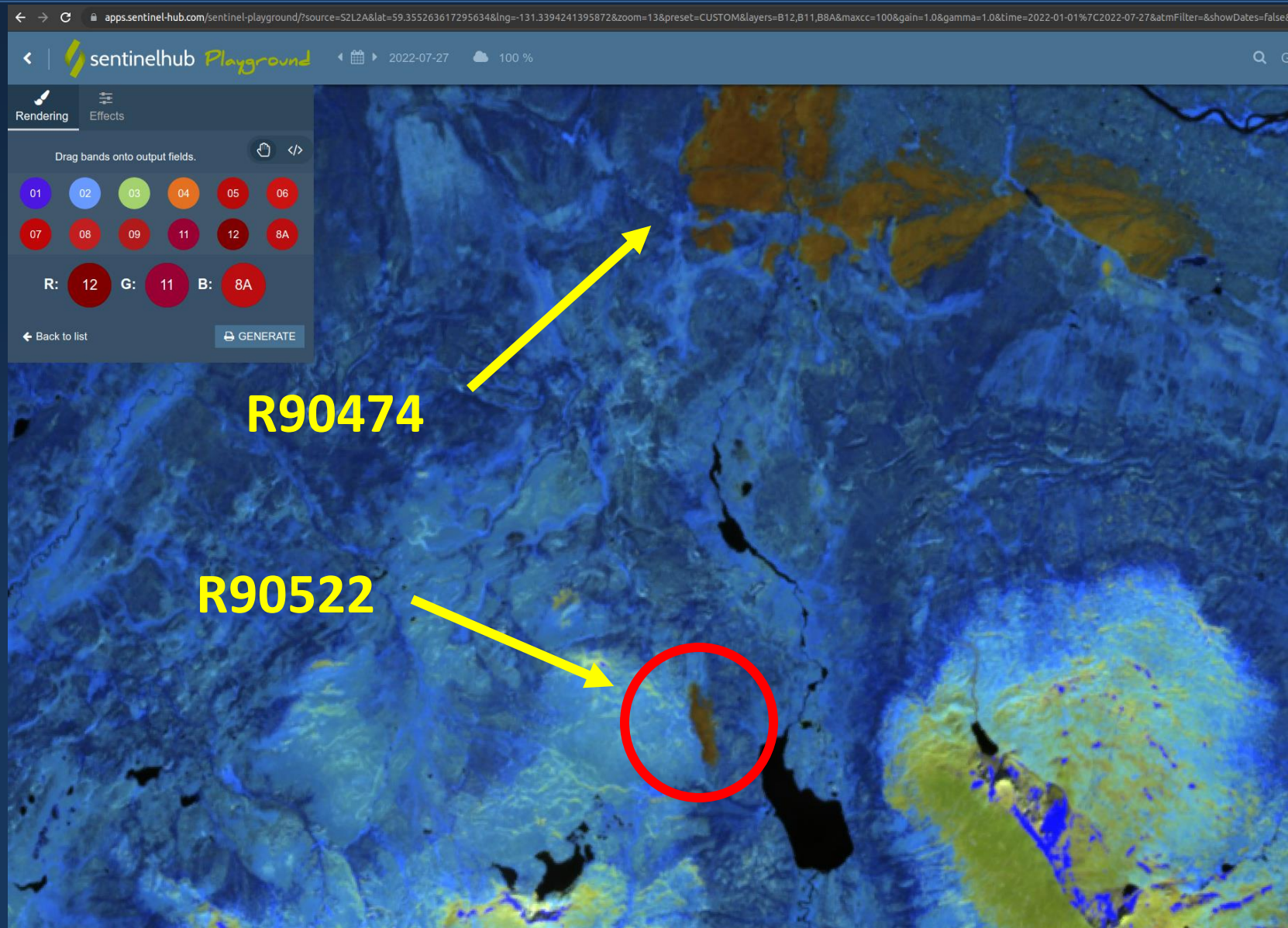


Fire: N20881 Date: 20220817

Finding unknown fires

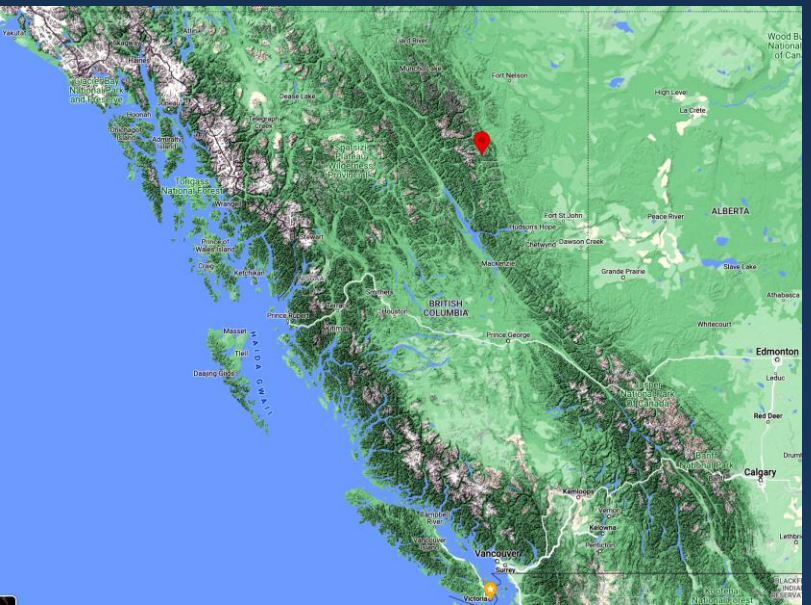
- Found on July 28 from Jul 27 imagery
- Aug 20 we confirmed it was assigned a fire number (status out)
  - R90522 / Tahoots Lake

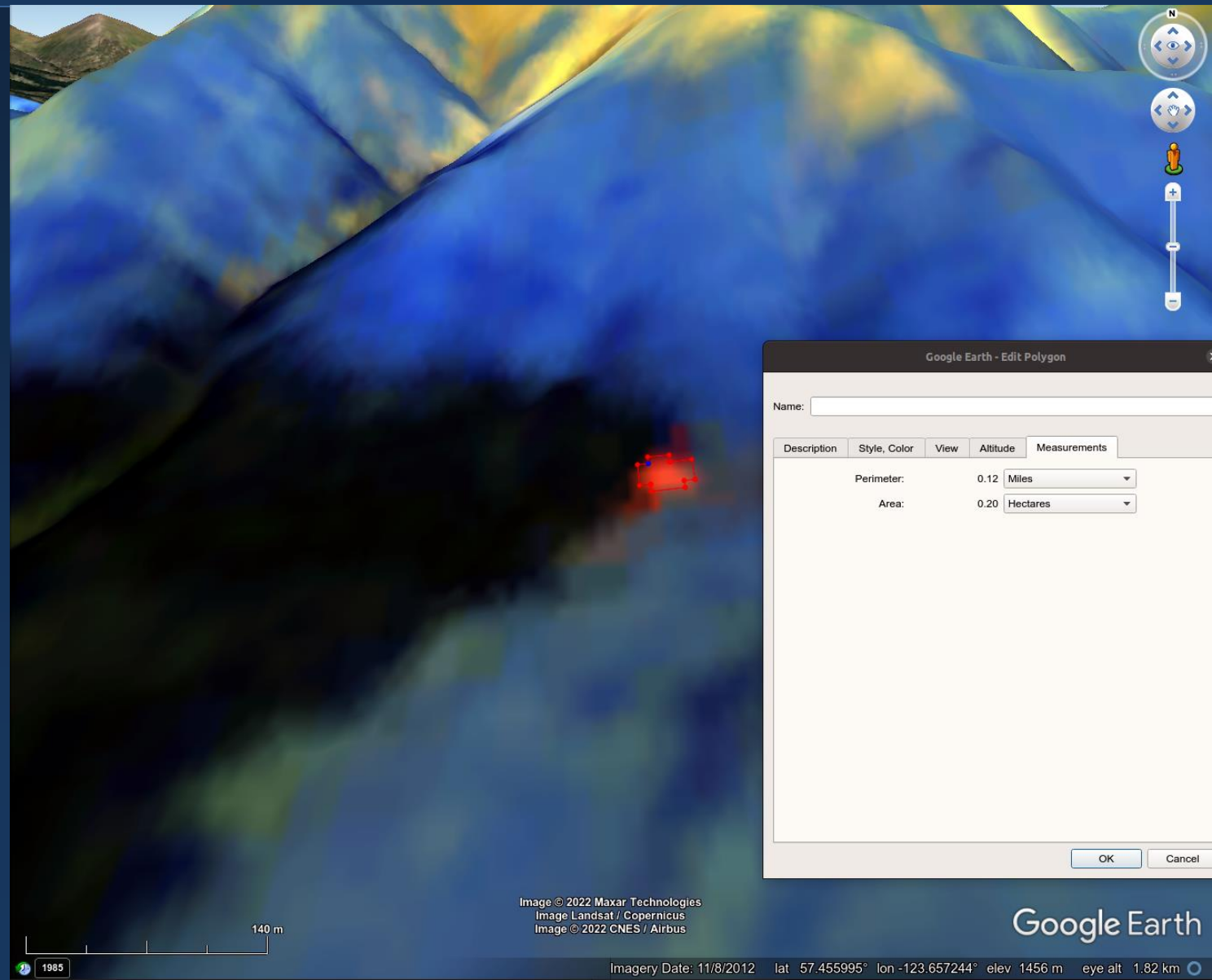




Small fires detected

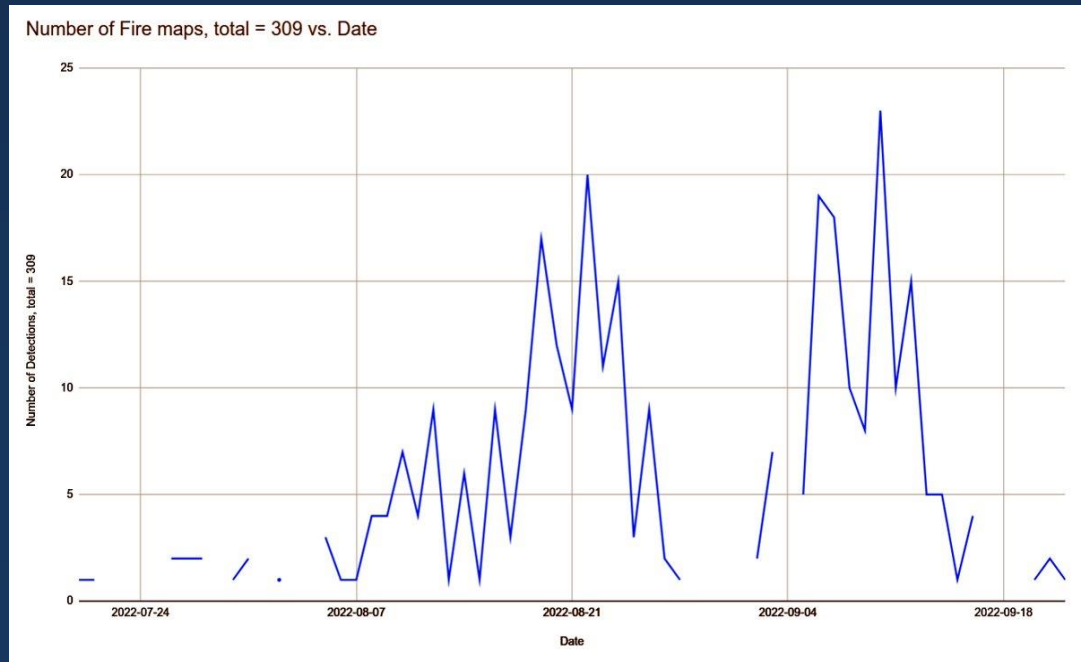
- Sub-hectare fires observed
- Fire: G82427
- Date: 20220913
- Size: 0.20 ha (Google Earth)





Wins

- More than 300 "low latency" fire mapping updates generated & vetted
  - Sentinel-2 (ESA) and Landsat (NASA)
  - Low latency: less than 12h possible
- Mapped small or unknown fires
- Mapped fires under smoke cover
- Value recognized by front-line staff in 2022
  - Increasing number of requests from incidents for operational use



Learnings

- Largest limitations: Frequency & Latency
  - 1-5 day repeat (Sentinel2), <= 9 day repeat (Landsat)
  - NRT access for Sentinel2 is possible (< 3 hours)
- Challenging cases:
  - Atmosphere, illumination, altitude, low-intensity fire, sub-canopy fire, data variation!
  - Multiple dates, more sophisticated algorithms needed to improve results
- Artificial Intelligence:
  - ***"Computer-based Decision Support Systems"*** (NRCAN PFC AFT group Definition)

IT resource usage →

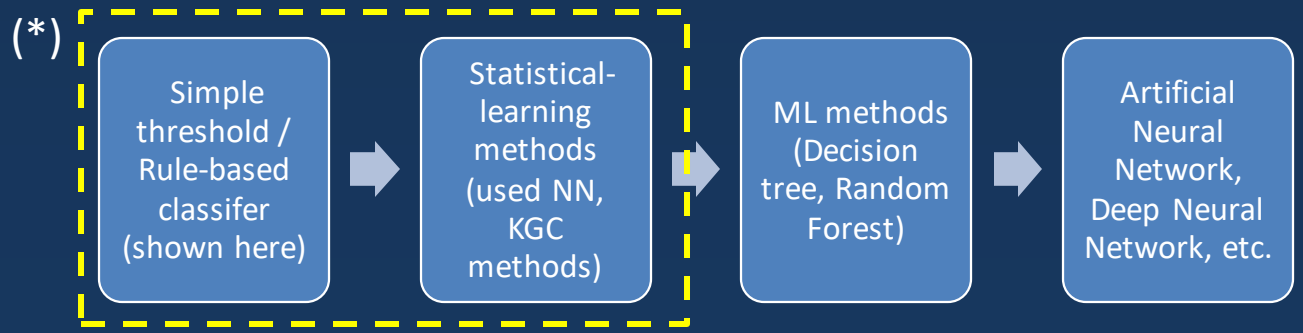
More automatic, generalize-able, flexible →

More modern / trendy →

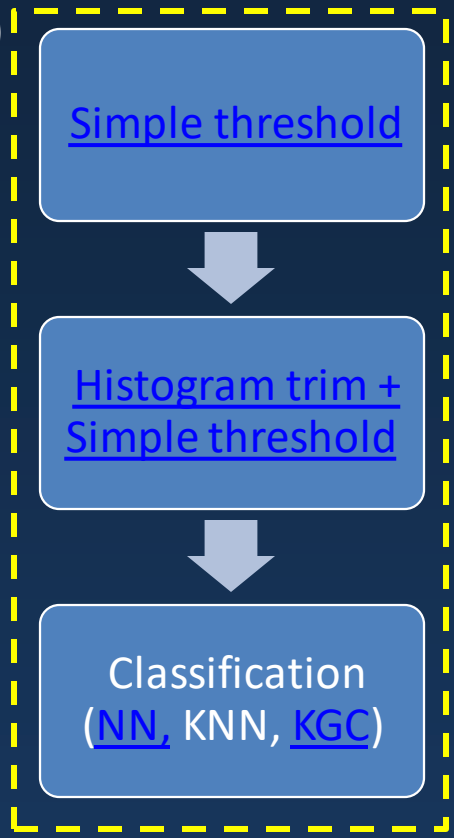
← More accessible / explainable

← More human intervention

(*)



(*)



Next: ***find the sweet spot between automatic vs explainable/accessible!***
Want to be a little more "AI"-like than (*)

Next Steps

- Also want physical models: Keen to explore **energy modelling w WildfireSat team!**
  - **And sensor fusion, too!**
- ***NRT/URT data access?***
- Automate & extend
  - Train "more-automatic" methods --> ***Reduce human intervention!***
  - Add terrain, geometry, climate variables?
  - Machine / API access for Landsat data
  - IT resources needed to scale up
- Continue work w CSA, BC Forest Inventory, NRCAN, JAXA, ESA, NASA, ASI & more partners
  - Cloud penetrating imaging to support Fire & Fuels mapping
  - Moisture, wind speed or other applications

Satellite fuels mapping overview

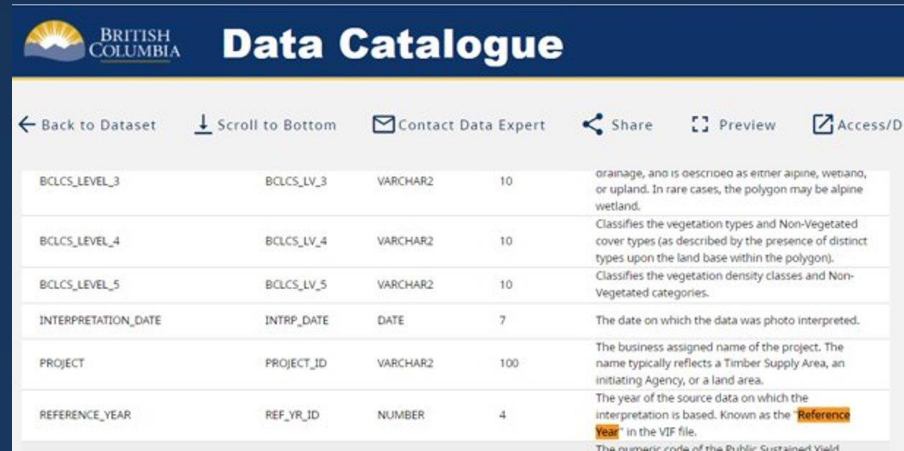
- Concept + Data preparation
- Algorithm
  - Abcd
  - Kabcd
- Kamloops example
- Next steps

Province-wide fuel type mapping concept

- Extend data eng. as Used in fire mapping
- Use as industry standard statistical inference
  - E.g. KNN (NFI & others)
  - More-automatic methods if necessary (ANN)
- Use existing fuels maps as ground ref
  - Use algorithms to find areas where ground-ref and satellite images are consistent! (*)
  - Incorporate local fuels studies & Annotation by local SME
  - Note: existing BCWS FTL is derived from Vegetation Resource Inventory (VRI) polygons
    - Multiple time stamps, rumored as old as 1950
- Use a "trajectory" approach (**)

(*) agreement between fixed-point of classifier w ground-ref
(*) Cross-reference RS observations with VRI changes

(**) Start with dense time series (year on year)
(**) Improvement: segment signatures w.r.t. time (change detection w.r.t a seasonal baseline)



Data preparation (proposed) Sentinel-2 & ref

- L1C data download from Google Cloud Platform (fast)
  - Select data with <= 7% total cloud cover only
- Convert L1C to L2A (surface reflectance)
- Warp all bands to 20m, order by wavelength (increasing)
- Set no-data areas and >=7% cloud probability, to NAN (etc.)
  - Set cloud shadow to NAN
- Option: convert to ieee-standard float16 (save 50% space)
- BC Fuel type layer 2020 dataset (based on 2019 VRI)
  - rasterize (1-hot encoding)

Abcd algo

- NN inference (multithread C++ version)
  - Special case of KNN (K=1)
  - Fast results. But grainy(*)
  - ***Unique: Conceptually unifies regression & classification***
- Answers the question: A is to B as C is to ____? For square images
  - Answer: D

- No K. Data skip factor:
  - increase it, get faster results
  - ***Inspired by Emergency geomatics! Optional "shift" factor that does something cool (see *)***

- ***Three functions (also test cases for implementing classifiers)***
  - A != B != C: regression or classification (supervised)
  - Set A = B = C: image compression!
  - Set A = C: image translation
    - Simulate one kind of data from another
    - Abcd method is a crude "babel fish" for image data

(*) A. Beaudoin et al (2022) Improved k-NN Mapping of Forest Attributes in Northern Canada Using Spaceborne L-band SAR, Multispectral and LiDAR Data

Note: uses texture!

(**) "tiny-AI challenge" to me (write pattern recognition algo in <=100 lines of code)

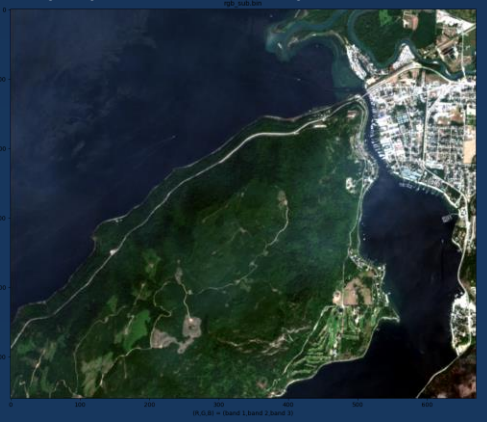
- ***Use classification maps as "reference data"***
  - ***A = Satellite data***
  - ***B = class map***
  - ***C = new Satellite data***
  - ***D = new class map!***

Abcd method: Sicamous (BC 2021)

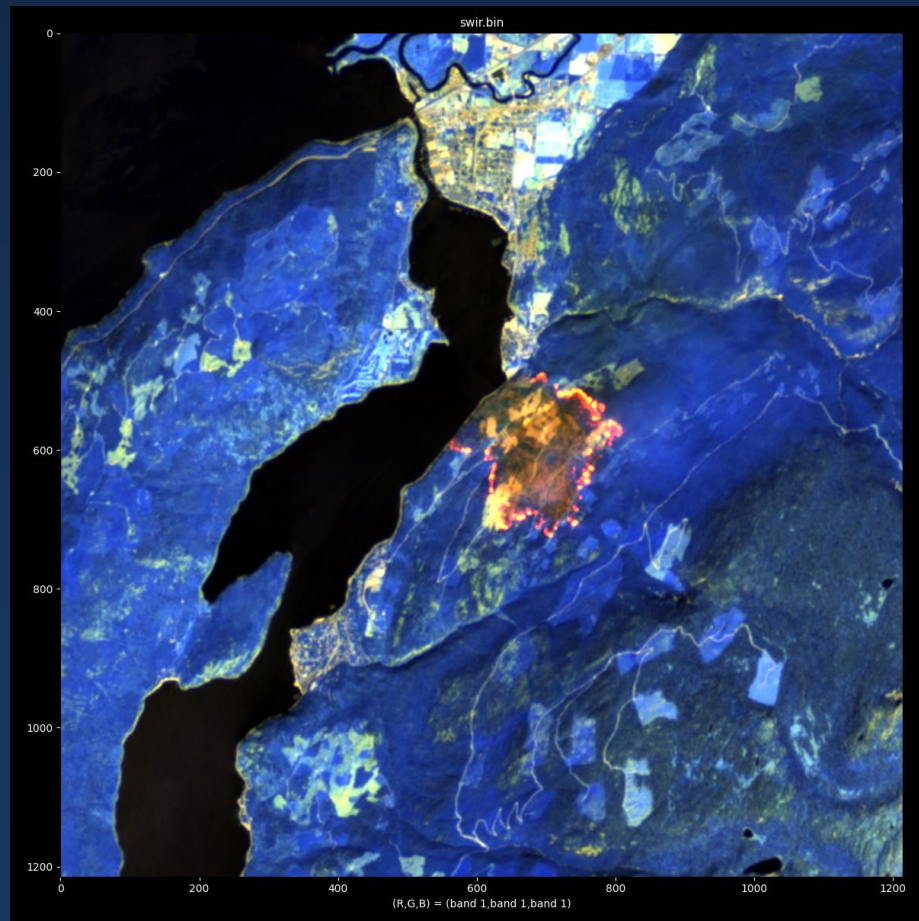
Image translation: translate "SWIR" imagery from "Visible" imagery. n=1476225, skip = 1111, 1329 = 0.09% retained
Abcd.exe swir.bin visible.bin swir_large.bin 1111 &

A) (B12,B11, B9) "SWIR"

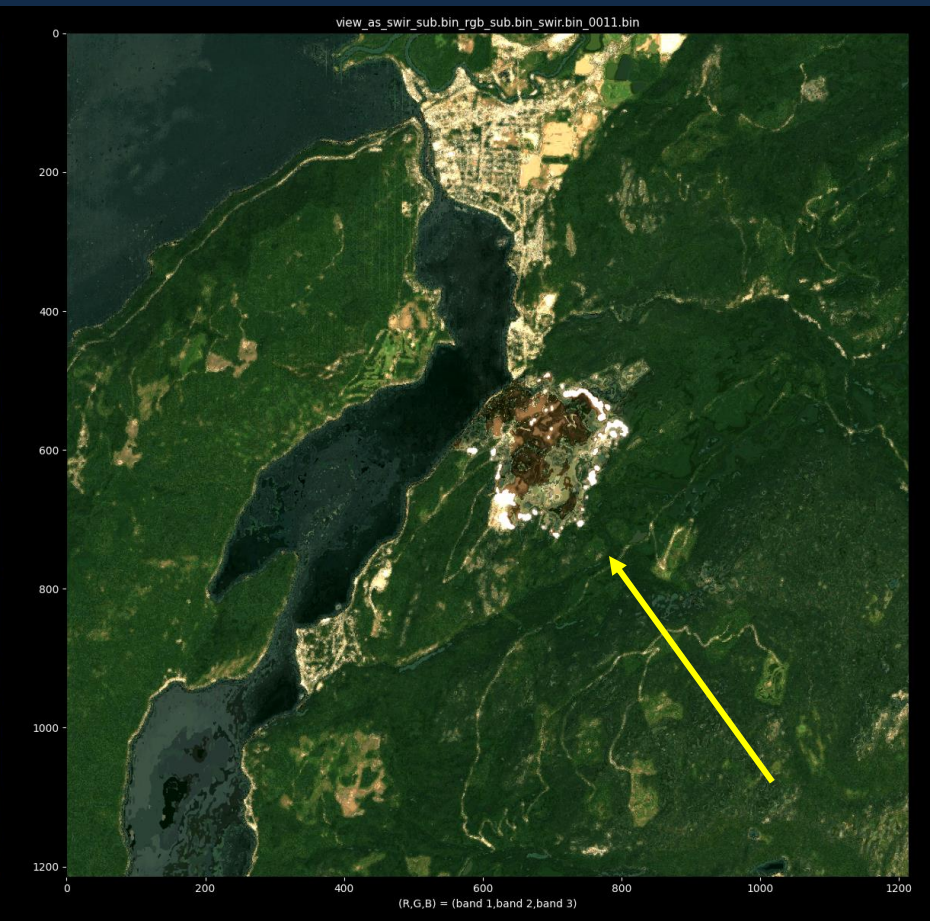
B) (B4, B3, B2) "Visible"



C) input: "SWIR" (larger chip)



D) prediction: "Visible" (larger chip)



K-abcd algo

- KNN classification (multithread C++ code)
  - To include classification and regression option
- Data skip factor: increase it, get a result quicker
  - supports "Back of the envelope" tests for relationships in data
- Fuel type application: use class maps as "reference data"
  - A = Satellite data
  - B = existing class map (class labels stored as band names)
  - C = ***new Satellite data***
  - D = ***new class map!*** (class labels in band names)

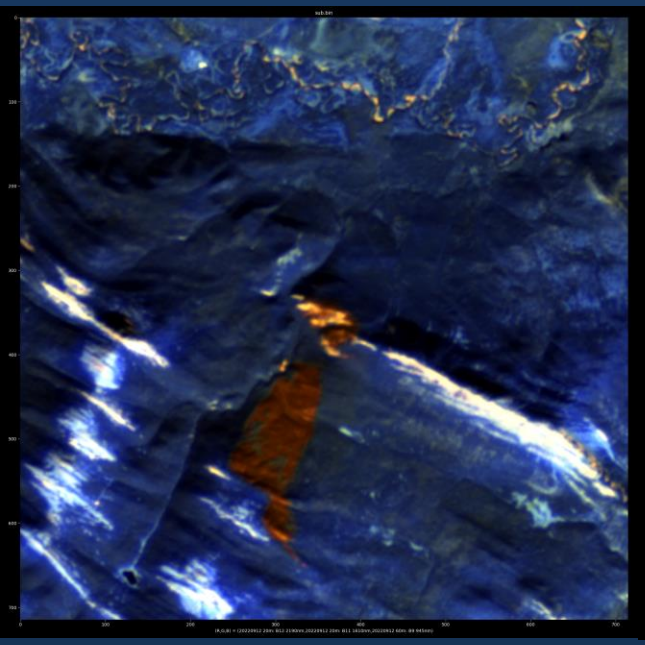
Approach proposed w. Joanna Wand in 2020 used patches :

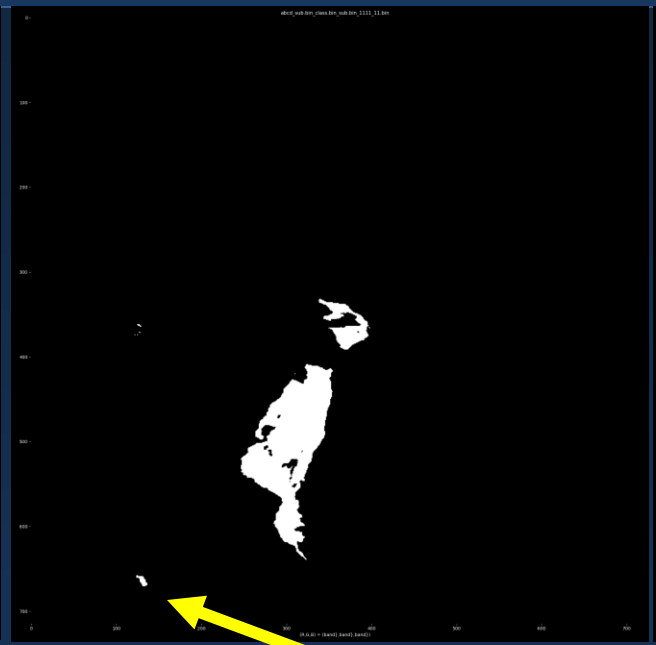
- Such texture info likely needed
- More computationally intensive

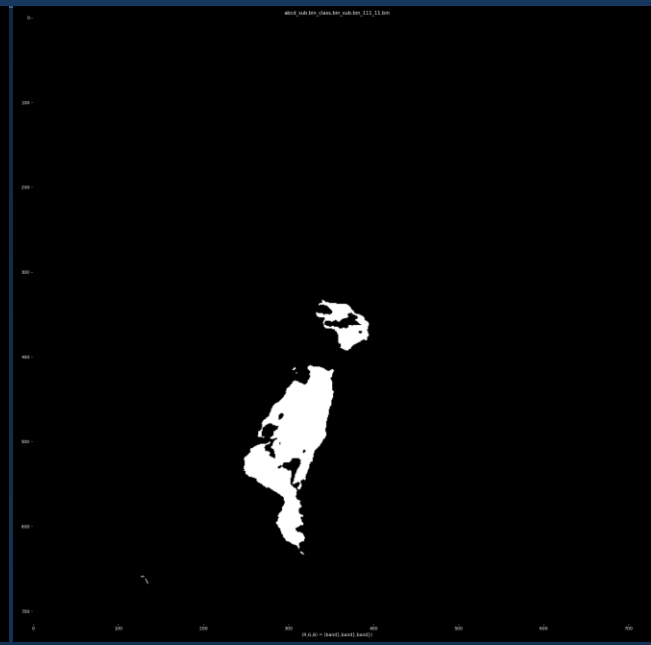
- Both presentations could use non-image ref. Data (just pack into image shape)

https://github.com/bcgov/wps-research/blob/master/cpp/kabcd.cpp

K-abcd algo test! 2022 trial output for "training" (K=7)







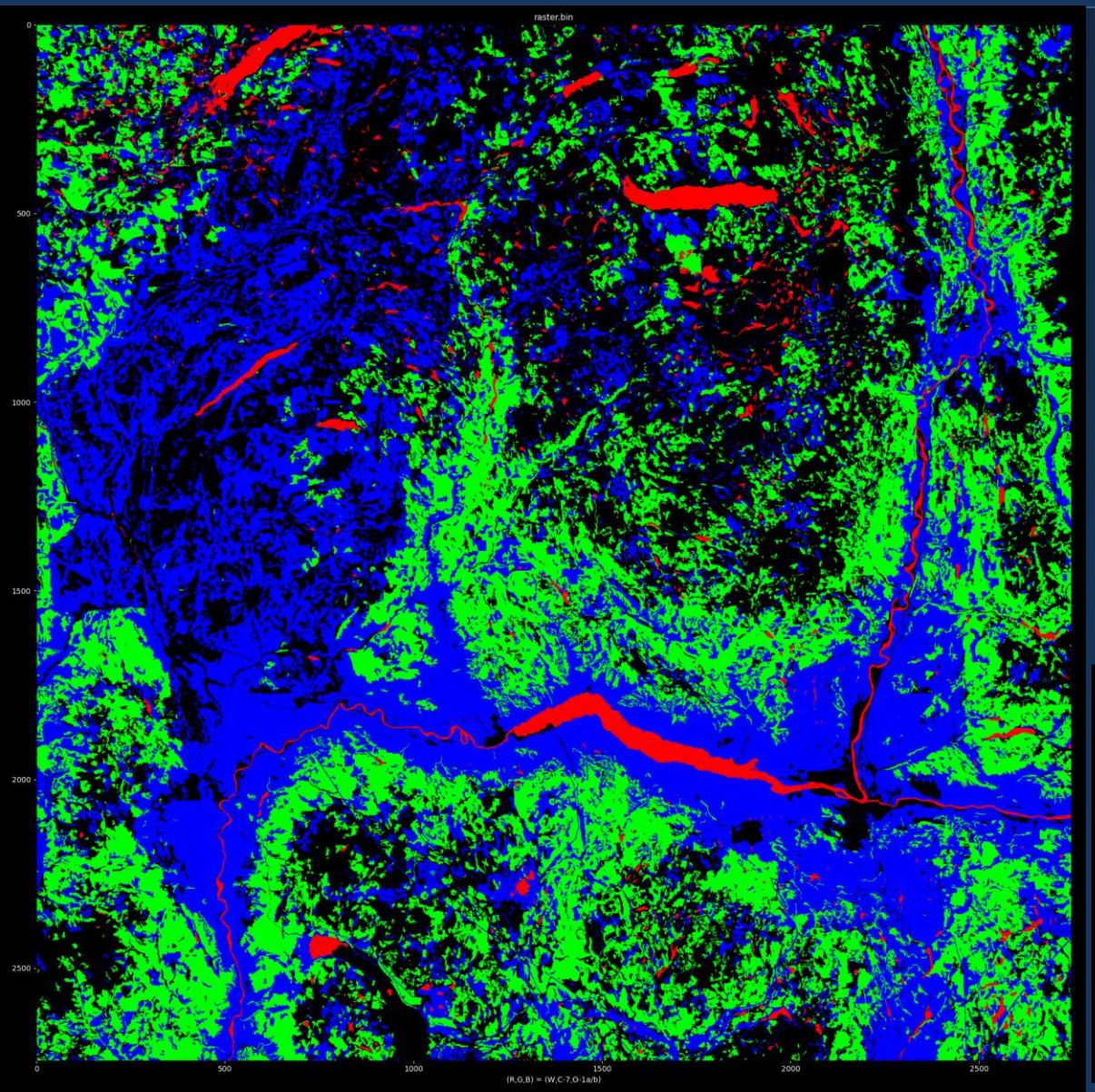
A) 12-band S2 image (RGB=B12, B11, B9) = B) (predict on same image)

B) Binary classification result from operational trial Rule-based classifier & human cleaning

D) result (slightly different) Skip = 1111 N = 511225 / 1111 = 460 0.09% N retained

D) result (slightly different) Skip = 111 N = 511225 / 111 = 4605 0.9% N retained (sampling grid touches the water)

FTL 2020 map (3 of 14 classes shown)



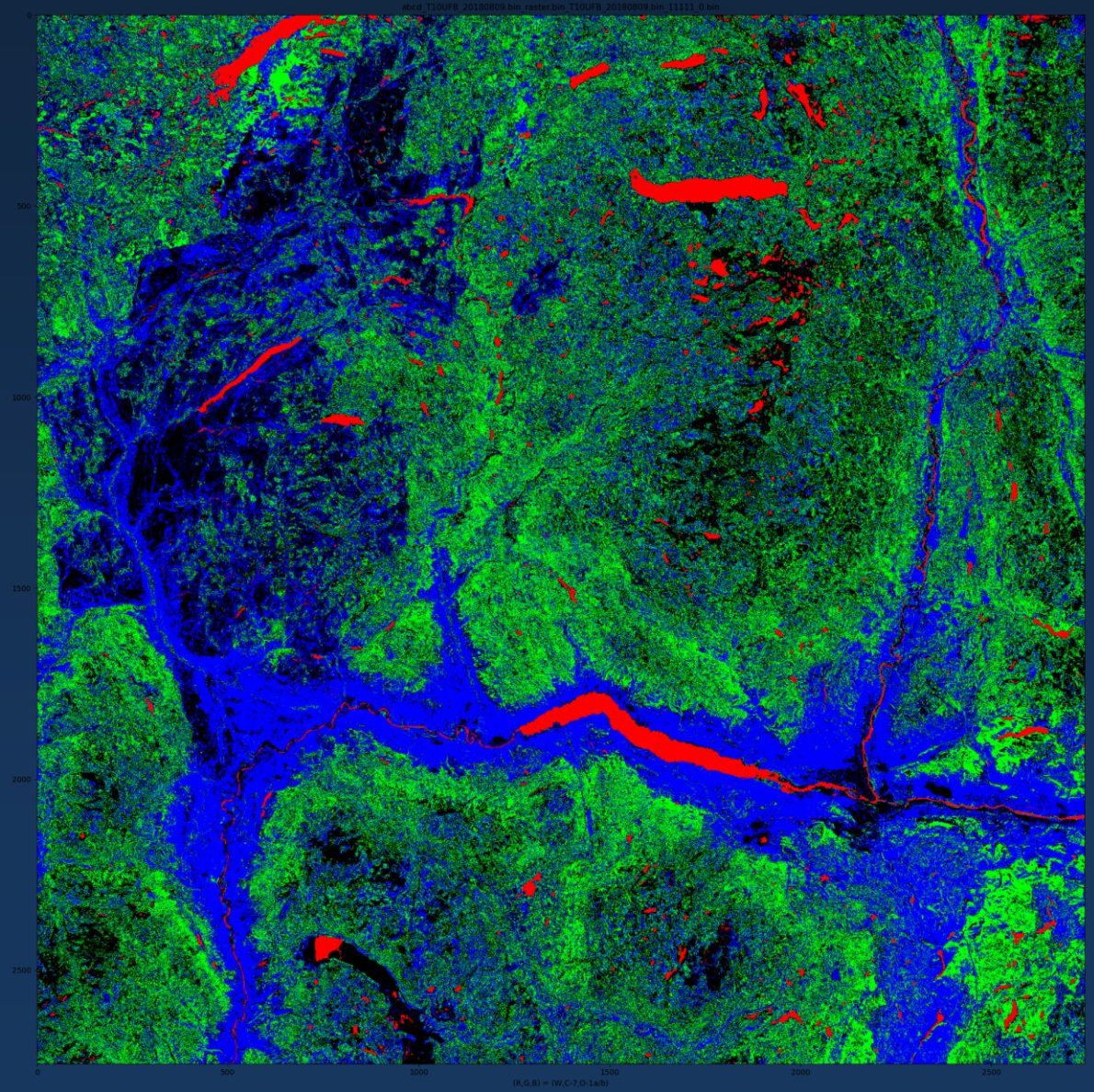

```
Ashlins-MacBook-Pro:subsample ashlinrichardson$ ~/GitHub/bcws-psu-research/cpp/raster_summarize raster.bin
hread: raster.hdr nrow: 5490 ncol: 5490 nband: 14 data_type: 4
hread: raster.hdr nrow: 5490 ncol: 5490 nband: 14 data_type: 4
[ 'W' 'C-3' 'M-1/2' 'D-1/2' 'C-7' 'C-5' 'C-2' 'C-6' 'S-1' 'O-1a/b' 'S-3' 'C-4' 'S-2' 'N']
[ '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0'] 6 1.9907e-07 %1.9907e-05 W
[ '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '1'] 359579 0.0119303 %1.19303 C-3
[ '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '1' '0'] 25401 0.000842764 %0.0842764 M-1/2
[ '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '1' '0' '0'] 26594 0.000882346 %0.0882346 D-1/2
[ '0' '0' '0' '0' '0' '0' '0' '0' '0' '1' '0' '0' '0' '0'] 10119649 0.335754 %33.5754 C-7
[ '0' '0' '0' '0' '0' '0' '0' '0' '1' '0' '0' '0' '0' '0'] 455722 0.0151201 %1.51201 C-5
[ '0' '0' '0' '0' '0' '0' '0' '1' '0' '0' '0' '0' '0' '0'] 241807 0.00802277 %0.802277 C-2
[ '0' '0' '0' '0' '0' '0' '1' '0' '0' '0' '0' '0' '0' '0'] 1082421 0.035913 %3.5913 C-6
[ '0' '0' '0' '0' '0' '1' '0' '0' '0' '0' '0' '0' '0' '0'] 70709 0.00234601 %0.234601 S-1
[ '0' '0' '0' '0' '1' '0' '0' '0' '0' '0' '0' '0' '0' '0'] 8081729 0.268139 %26.8139 O-1a/b
[ '0' '0' '0' '1' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0'] 2516686 0.0834996 %8.34996 S-3
[ '0' '0' '1' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0'] 2057029 0.0682489 %6.82489 C-4
[ '0' '1' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0'] 4227665 0.140267 %14.0267 S-2
[ '1' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0'] 875103 0.0290345 %2.90345 N
```

Kamloops demo first run (check consistency)

- Use classification maps as "reference data"
  - A = Satellite data
  - B = Class map
  - C = Same satellite data
  - D = output: Compressed class map (Q: ***can an image "code" the fuel types***)

- Iterative mindset:
  - Start w "back of envelope" assessment:
    - ***do the images and fuel type map match?***

Data consistency check:
abcd.exe T10UFB_20180908 ftl_2020.bin T10UFB_20180908 11111



Date	Difference (skip = 11111)
20180809 (shown)	8.67e+06 (71 %)
20190806	8.95e+06
20200806	9.20e+06
20210803	9.09e+06

- According to this method the 2018 date matches the Fuel Type map better
- Can "replicate" a fuels map from single date imagery (using .09% of the original fuels map) "approximately"
- There are continous areas of specific fuels that can be found and used as reference data

Next Steps for Fuels mapping

- Want non-categorical & frequently updated (e.g. monthly) forest parameters
  - Multiresolution updates (lower-res first)?
  - Standardized or data-driven mapping units? Cross-ref VRI changes w Satellite

How?

- Good models: Computationally expensive
  - Iterate and improve data until consistent & predictive (keep checking)
- **Trajectory methods:** extend fuel types to succession types? Q: "What next"?
  - ***Start with linear (temporal) interpolation on "dense" time series (~ 20-40 frames / year)***
  - ***Adapt kabcd (KNN) impl. for missing values (cloud, cloud shadow) (*)***

- ***Main Goal: Operational trial 2023 for Fuels mapping***
  - Start at incident level and scale up with humans in loop?
  - Start at high level and drill down where people want more?

(*) decrease denominator in metric, or interpolate to fill in

Thanks!

Questions?

Suggestions?

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