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Mapping Forest Fires and Fuels in Canada with ALOS-2 SAR data

JAXA PI meeting (Nov 7-11 2022)

BC Wildfire Service, University of Alicante, Indian Institute of Technology, University of Stirling, Natural Resources Canada

Overview

- Project info
  - Purpose & Targets
- Data and Results
  - Monte Lake, BC
  - Fort Simpson, NWT
    - Explore some parameters
  - Fort McMurray, AB
    - T3 matrix elements
    - Dual-pol parameters and interpretation
    - Freeman parameters
    - Improved ground-ref
    - QP/DP comparison
- Next steps

Project Info

Research Agreement: The 3rd Earth Observation Research Announcement (EORA-3) Collaborative Research Agreement (Non-Funded) between the Japan Aerospace Exploration Agency (JAXA) and the Research Organization (RO)

Project Title: BC Wildfire Service -- Predictive Services Unit -- Fuel Type Layer Project

Principal Investigator: Ashlin Richardson, Senior Scientist, BC Wildfire Service

Co-Investigators:
Hao Chen, Canadian Forest Service
Dr. Subhadip Dey, Indian Institute of Technology
Dr. Armando Marino, University of Stirling
Dr. Lucio Mascolo, University of Alicante

Purpose of Research for Wildfire

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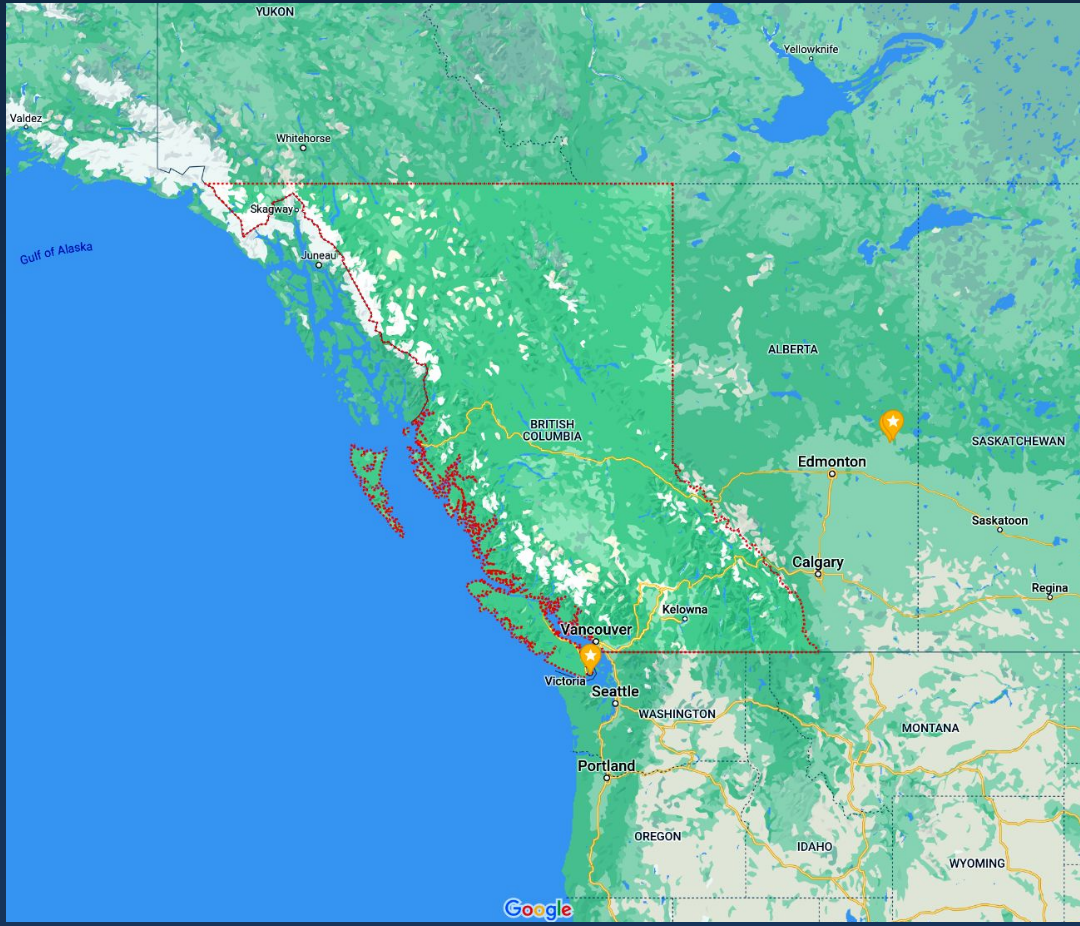
- Wildfire is a significant intra-jurisdictional climate issue: hard to map & predict
- Continuous vegetation info updates needed
  - On wide areas e.g. **> 900,000 km² in BC**
- JAXA’s weather-resilient, “24/7” PALSAR systems are **uniquely sensitive to vegetation**
- Collaborate to push the envelope on RS info to support wildfire prevention, preparedness, response, and recovery
- Assess operational potential of JAXA technology
  - engage front-line operations personnel in value-added product R&D
- Support disaster management by applying advanced JAXA technology
  - better situational awareness for firefighters & first responders



Research target

- Leverage advanced JAXA satellite tech in synergy
  - w novel combinations of physical info retrieval methods being developed & evolved by the research partners
- Develop terrestrial situational awareness in three iterations of:
  i. Reference data curation
  ii. Analysis Ready Data (ARD) production
  iii. Added-value products generation
  iv. Refereed publication
- Forest attributes determination, change detection, physical decomposition, pol-SAR interferometry
- Machine learning (ML) inference of
  i. Forest Structure and
  ii. Forest fire hazards Present, historical or anticipated
- Expand situational Awareness & decision support product options for emergency geomatics applications

Sample related work

- (2021) Parker et al “Survey of Transverse Range Fire Scars in 10 Years of UAVSAR Polarimetry”
- (2021) Wildfire today "NASA uses UAVs and satellites equipped with radar to monitor recovery from vegetation fires"
- (2018) C. Raines “Detection of Fire Burn Scars by UAVSAR: Immediate, Short-term, and Multi-year Observations and Applications”
- (2018) Plank et al “Burn Scar Detection Using Polarimetric ALOS-2 Data”
- (2018) Touzi et al “Scattered and Received Wave Polarization Optimization for Enhanced Peatland Classification and Fire Damage Assessment Using Polarimetric PALSAR”
- (2016) JAXA “ALOS-2/PALSAR-2 Observation Results on Wildfire in Canada”
- (2013) Polychronaki et al “Evaluation of ALOS PALSAR Imagery for Burned Area Mapping in Greece Using Object-Based Classification”
- (2015) Heo et al “Airborne synthetic aperture radar for near-real-time wildfire monitoring using NASA’s UAVSAR instrument”
- (2011) Goodenough et al “Mapping Fire Scars Using Radarsat-2 Polarimetric SAR Data”
- (2011) Cloude et al "Radar Polarimetry for Forestry Applications: ALOS and Radarsat-2 studies in Canada" ForestSat 2010

White Rock Lake (2021 fire, British Columbia)
Visual POC for differencing (Dual-pol)

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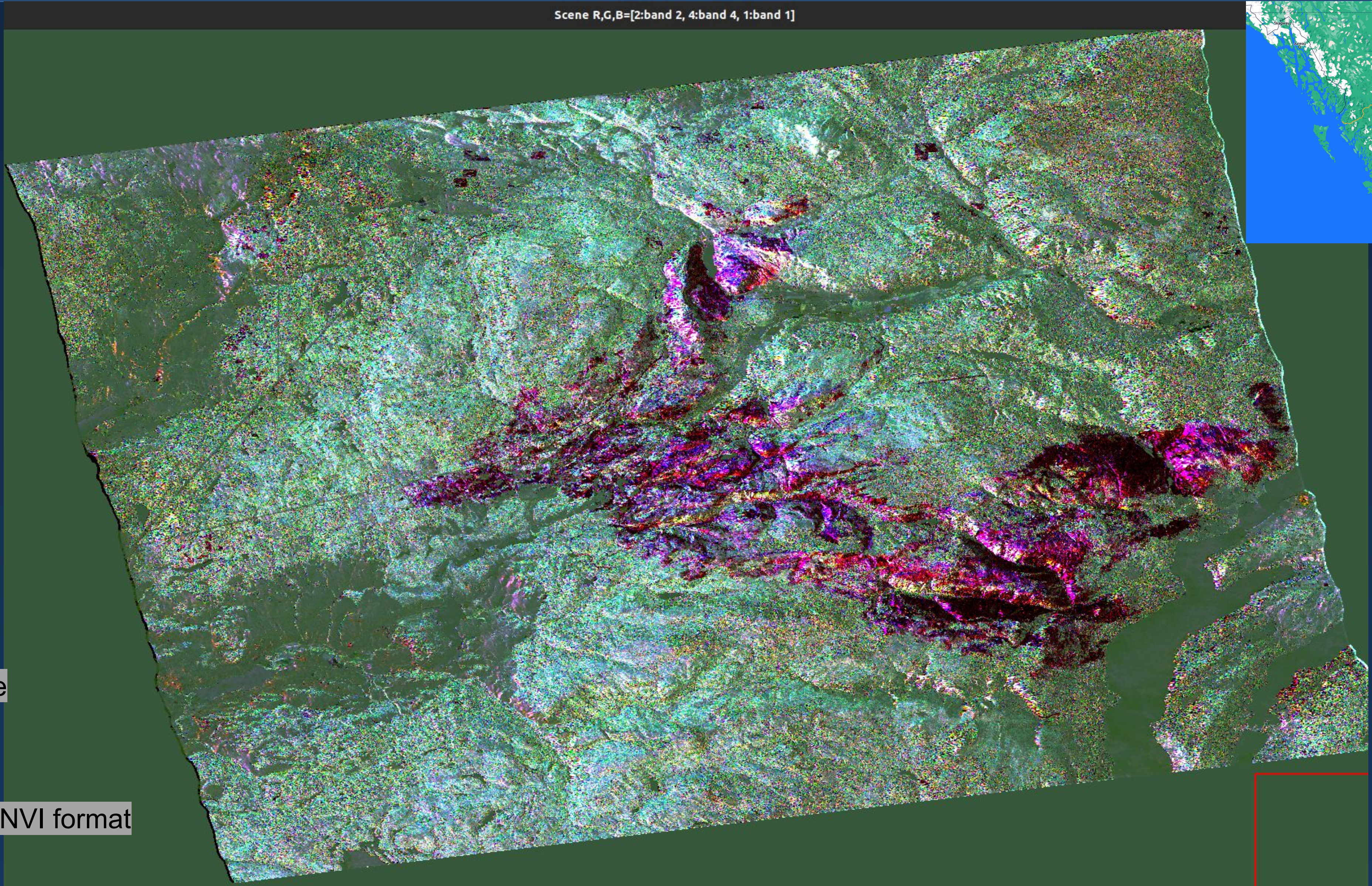
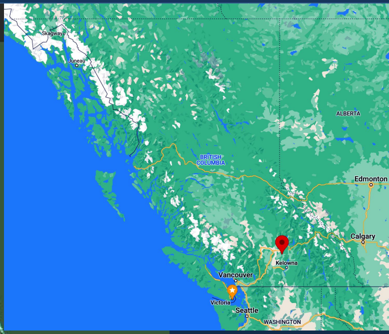
JAXA L-band dual-pol

Shown: Difference:
(2022 - 2021) of

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

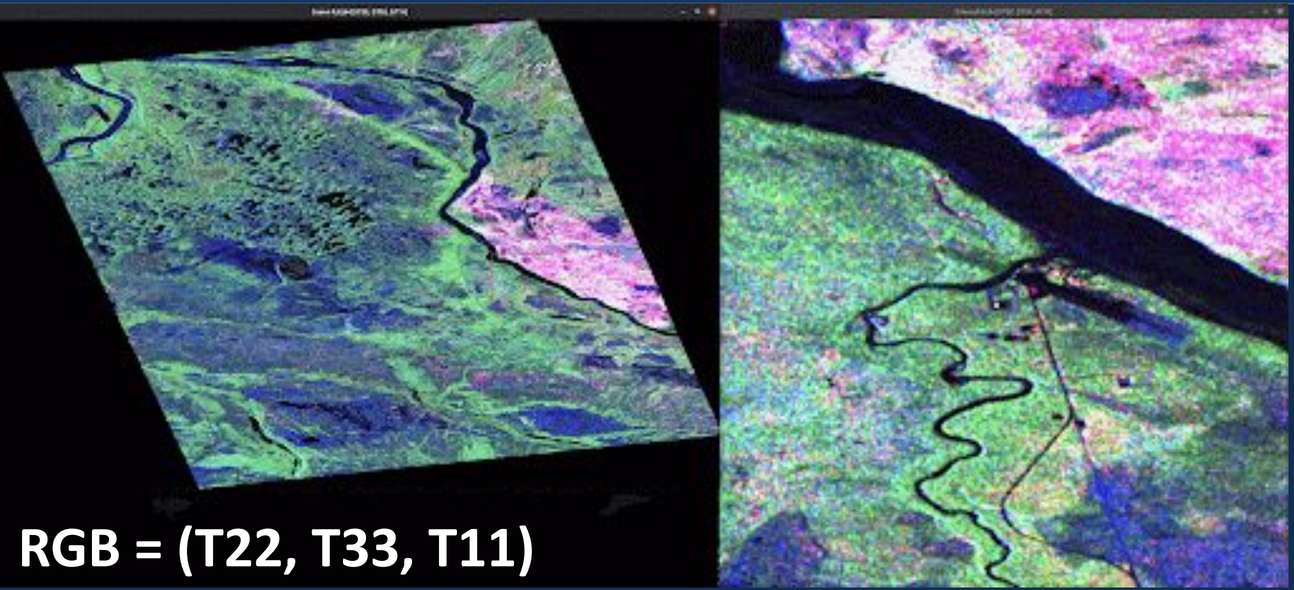
Burned area is the big pink/purple Pattern!



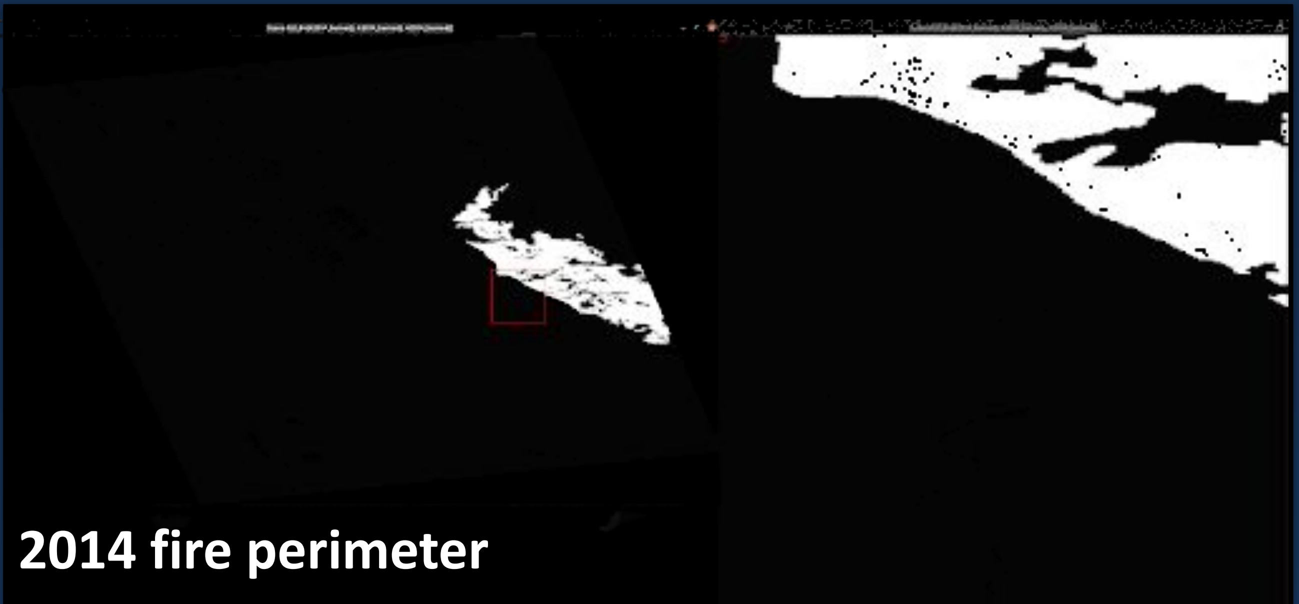


Processing steps (SNAP):
1) Radiometric calibration
2) Multilook to approx square
3) 5x5 box filter
4) Range-Doppler TC (Copernicus 30m dem)
5) Convert to PolSARPro / ENVI format
6) Co-locate with GDAL

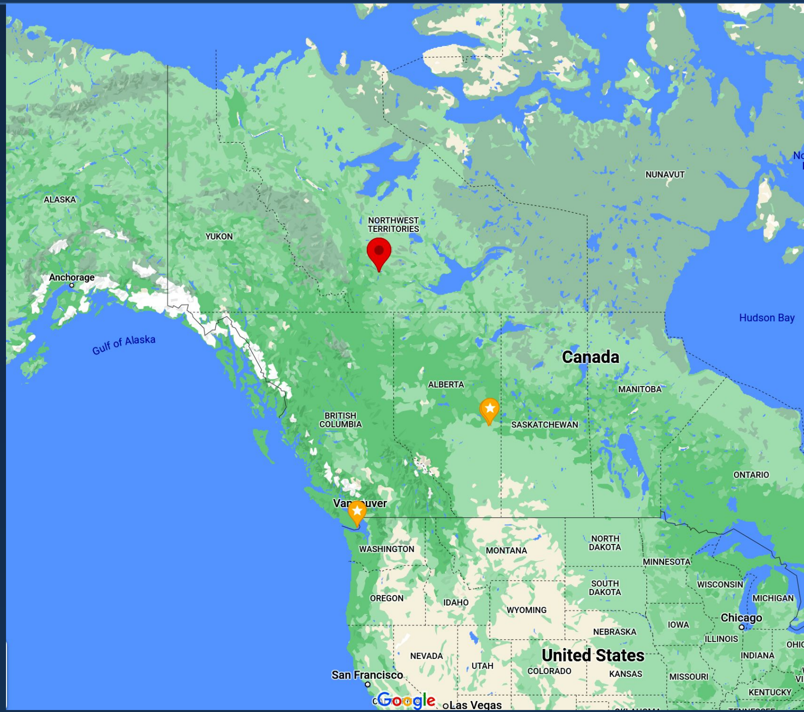
Fort Simpson, NWT, Canada (20150424)



RGB = (T22, T33, T11)



2014 fire perimeter

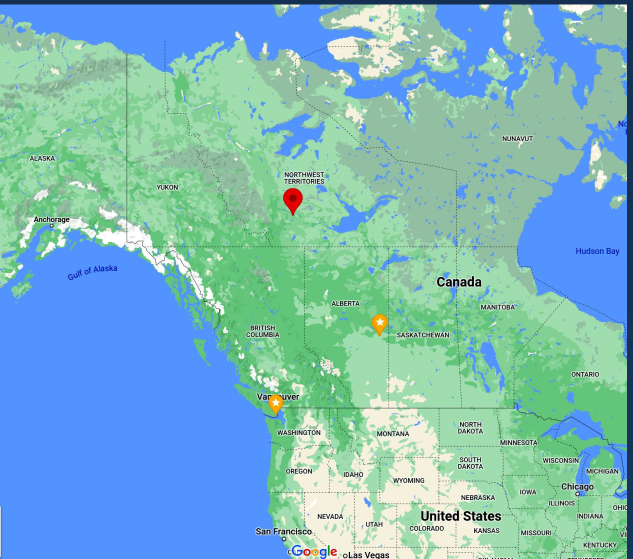


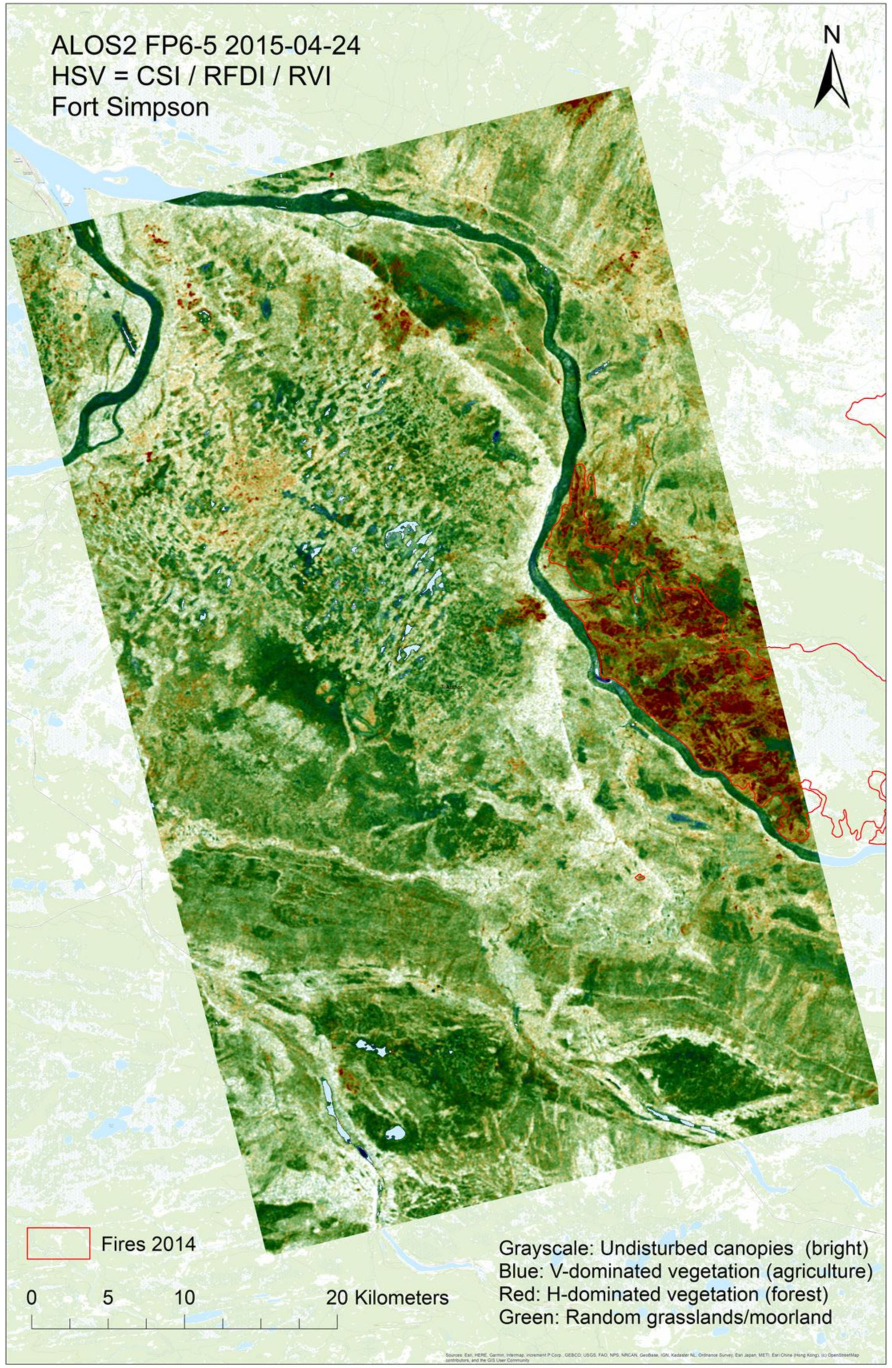
Burned area is visible. This burn scar can be distinguished by Span parameter

Fort Simpson, NWT, Canada (20150424)

- Standard Forest Parameters
  - Provided by Hao Chen (CFS, NRCAN)
  - Present CFS work: Compact-pol versions of these to be introduced!
- Affected area is clearly visible

- Next slide: emulated Dual Pol (DP)





Simulation of Dual-pol (DP) parameters

1) Obtain C3 from T3

$$[C_{3A}] = \frac{1}{2}\begin{bmatrix}1 & 1 & 0\\ 0 & 0 & \sqrt{2}\\ 1 & -1 & 0\end{bmatrix}[T_{3A}]\begin{bmatrix}1 & 0 & 1\\ 1 & 0 & -1\\ 0 & \sqrt{2} & 0\end{bmatrix}. \quad (21)$$

- Cloude: "A review of Target decomposition theorems in radar polarimetry"
- Pottier & Lee: "Polarimetric radar imaging: from basics to applications"

2) Obtain C2 from C3, by considering sub-matrices of C3.

A. (HH-HV)

$$\boldsymbol{C}_3 = \langle \underline{\Omega} \cdot \underline{\Omega}^{*T} \rangle = \left\langle \begin{bmatrix} |\Omega_1|^2 & \Omega_1\Omega_2^* & \Omega_1\Omega_3^* \\ \Omega_2\Omega_1^* & |\Omega_2|^2 & \Omega_2\Omega_3^* \\ \Omega_3\Omega_1^* & \Omega_3\Omega_2^* & |\Omega_3|^2 \end{bmatrix} \right\rangle$$
$$= \begin{bmatrix} \boxed{\begin{matrix} \langle |S_{XX}|^2 \rangle & \sqrt{2}\langle S_{XX}S_{XY}^* \rangle \\ \sqrt{2}\langle S_{XY}S_{XX}^* \rangle & 2\langle |S_{XY}|^2 \rangle \end{matrix}} & \begin{matrix} \langle S_{XX}S_{YY}^* \rangle \\ \sqrt{2}\langle S_{XY}S_{YY}^* \rangle \end{matrix} \\ \begin{matrix} \langle S_{YY}S_{XX}^* \rangle & \sqrt{2}\langle S_{YY}S_{XY}^* \rangle \end{matrix} & \langle |S_{YY}|^2 \rangle \end{bmatrix} \quad (3.39)$$

B. (VH-VV)

$$\boldsymbol{C}_3 = \langle \underline{\Omega} \cdot \underline{\Omega}^{*T} \rangle = \left\langle \begin{bmatrix} |\Omega_1|^2 & \Omega_1\Omega_2^* & \Omega_1\Omega_3^* \\ \Omega_2\Omega_1^* & |\Omega_2|^2 & \Omega_2\Omega_3^* \\ \Omega_3\Omega_1^* & \Omega_3\Omega_2^* & |\Omega_3|^2 \end{bmatrix} \right\rangle$$
$$= \begin{bmatrix} \langle |S_{XX}|^2 \rangle & \begin{matrix} \sqrt{2}\langle S_{XX}S_{XY}^* \rangle & \langle S_{XX}S_{YY}^* \rangle \end{matrix} \\ \begin{matrix} \sqrt{2}\langle S_{XY}S_{XX}^* \rangle \\ \langle S_{YY}S_{XX}^* \rangle \end{matrix} & \boxed{\begin{matrix} 2\langle |S_{XY}|^2 \rangle & \sqrt{2}\langle S_{XY}S_{YY}^* \rangle \\ \sqrt{2}\langle S_{YY}S_{XY}^* \rangle & \langle |S_{YY}|^2 \rangle \end{matrix}} \end{bmatrix} \quad (3.39)$$

- Divide XY element by 2, so that the SPAN of emulated DP element equals XX+XY (for HH-HV case) or XY+YY (VH-VV case)
- Divide the off-diagonal elements by sqrt(2), so that the correlation between cross-and copolar channels equals XX*conj(XY) or XY*conj(YY)
  - In the (HH-HV and VH-VV cases, respectively)

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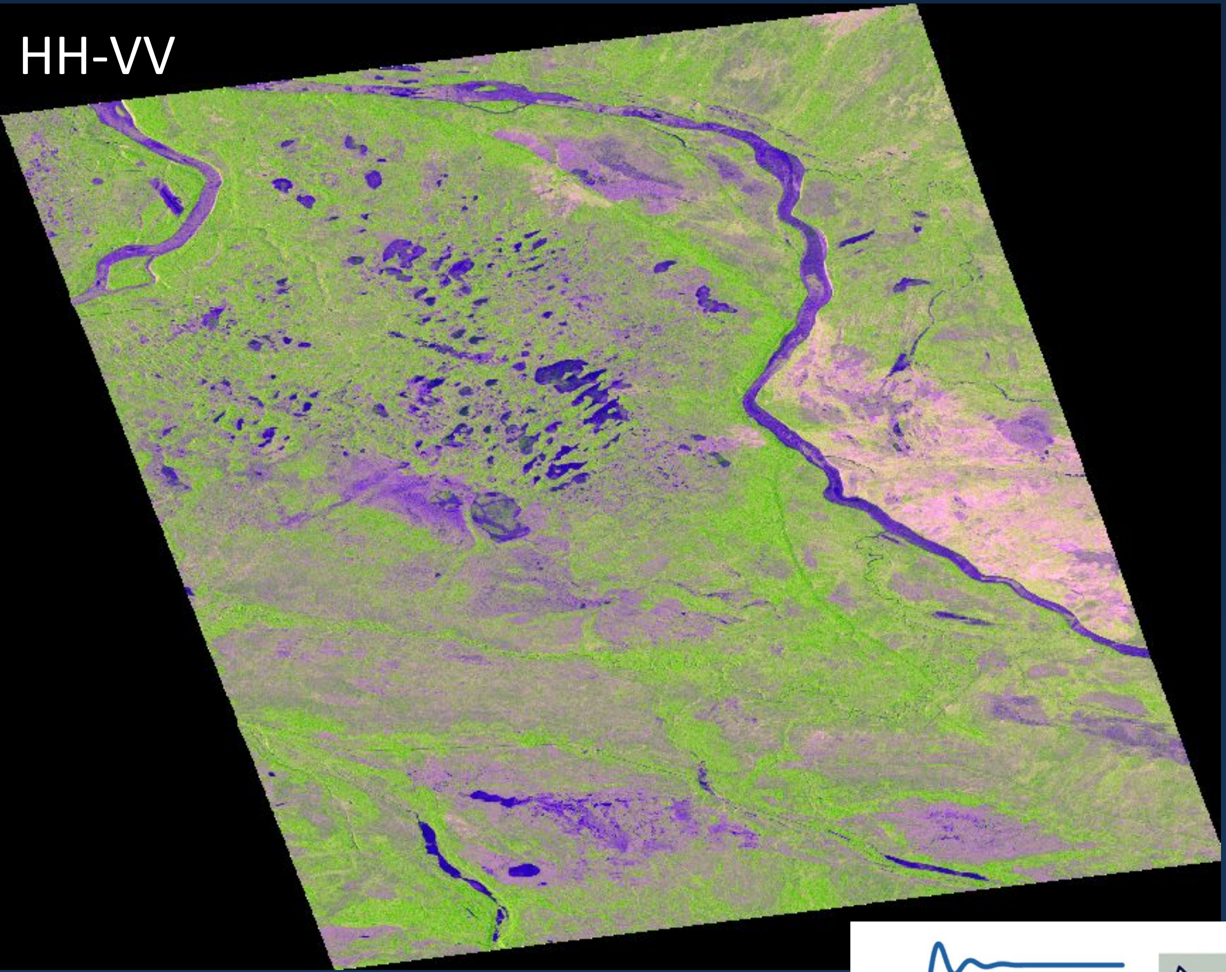
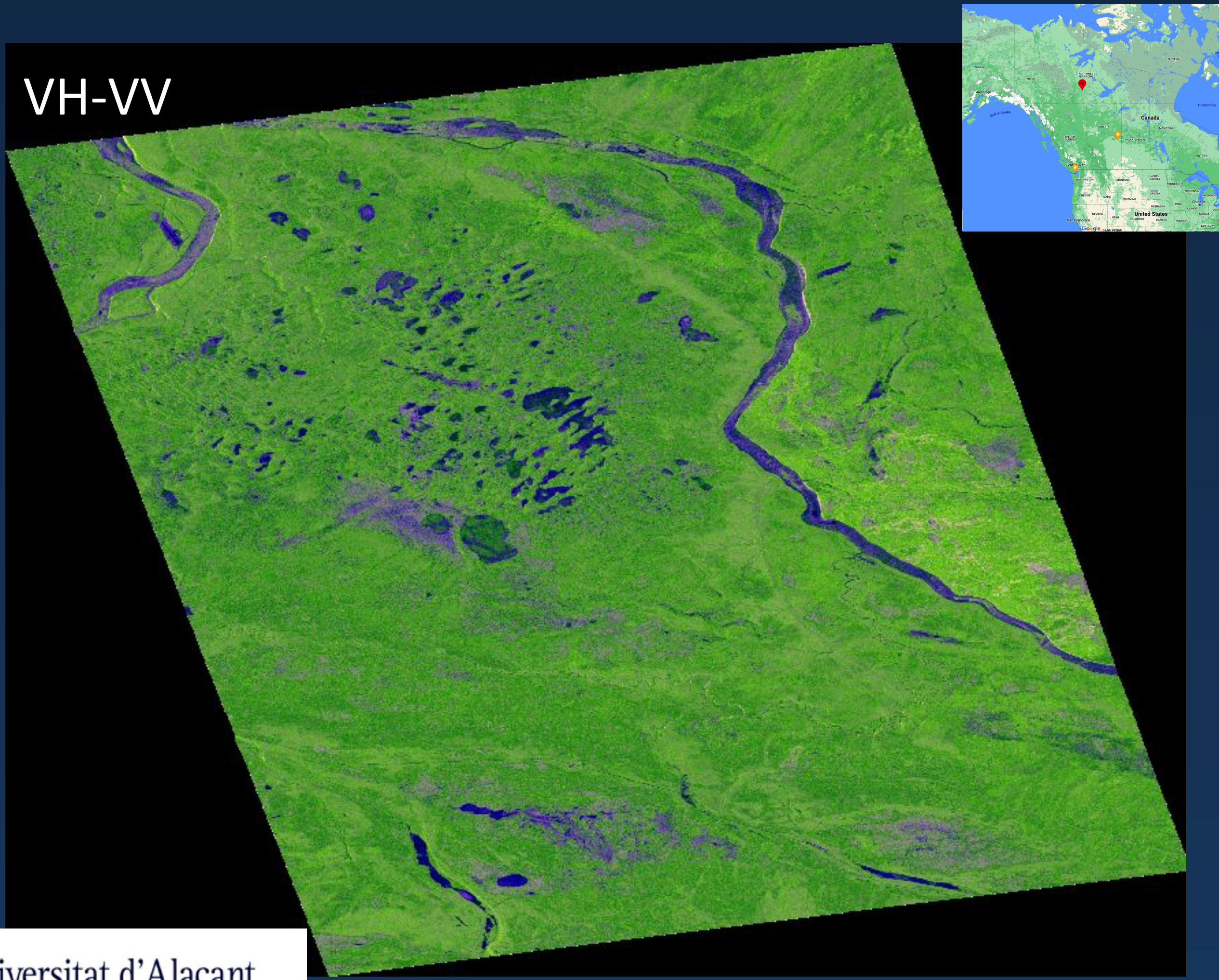
- RGB: from emulated dual-pol params (will explain later)

[1] Mascolo et al "Model-based decomposition of dual-pol SAR data: application to Sentinel-1" Transactions on Geoscience and Remote Sensing





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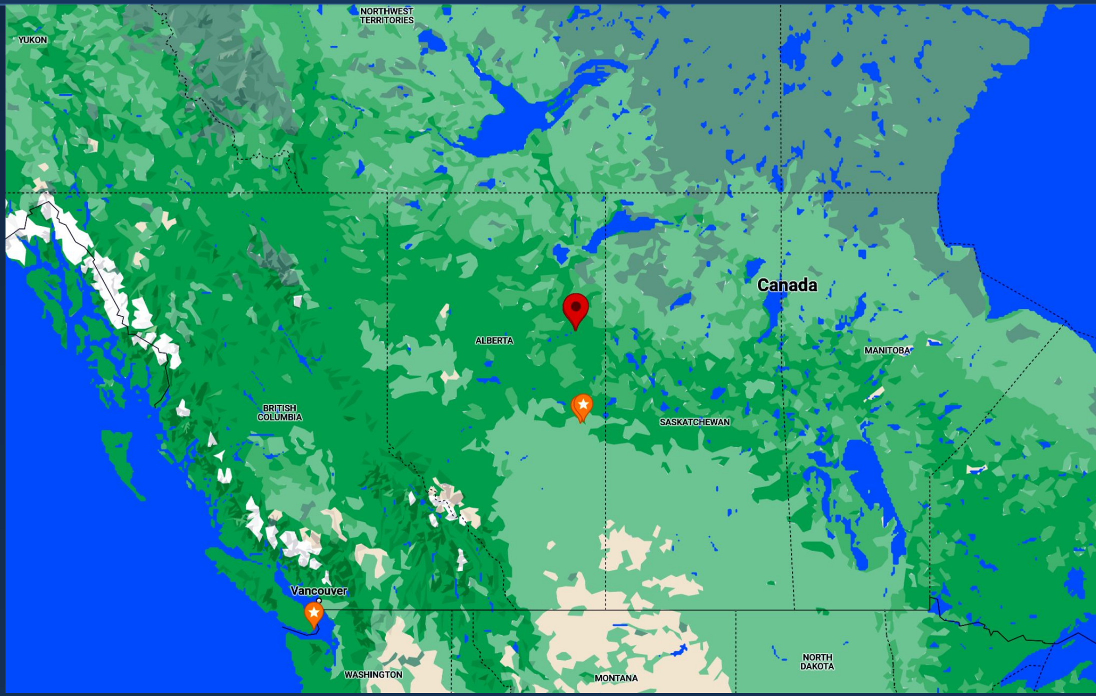
Results: Fort MacMurray (2016)

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, co-locate ground-reference, assign no-data areas (where the image pair not overlapping)
8. Multilook x2



References

- https://www.eorc.jaxa.jp/ALOS-2/en/img_up/dis_pal2_can-forest_fire_20160509.htm
- https://ieeexplore.ieee.org/document/8517822
- https://www.alberta.ca/assets/documents/Wildfire-MNP-Report.pdf

Physical polarimetric interpretation

A First step: PolSAR analysis: Fire event →

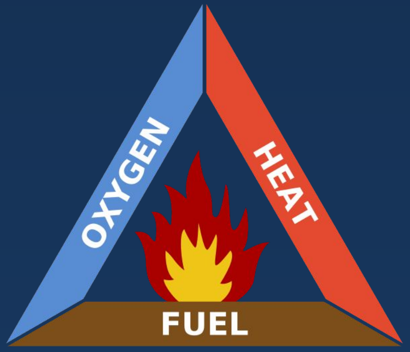
- Vegetation destruction (volume scattering changes)
- Decreased soil moisture / water content

Diagonal elements of T matrix: Ratio between the first two diagonals should be sensitive to soil moisture [1]

$$\frac{T_{22} + T_{33}}{T_{11}} = \frac{|R_S - R_P|^2}{|R_S + R_P|^2} \quad (22)$$

[1] "Inversion of Surface Parameters From Polarimetric SAR" Hajnsek et al, 2003

Further studies: study physical interpretation for detailed land-cover classes (e.g. fuel types)



Results: Fort MacMurray (2016) T-matrix

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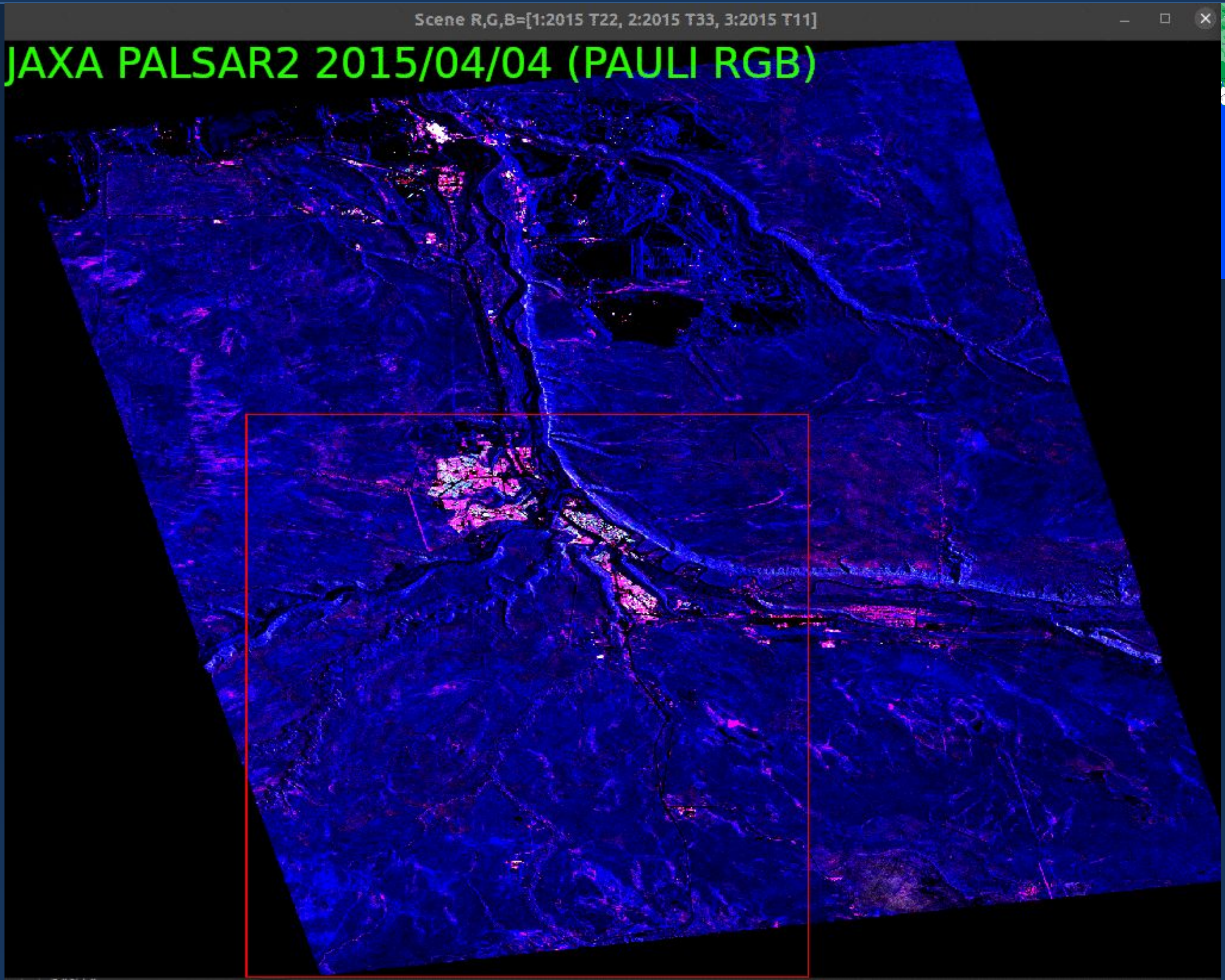
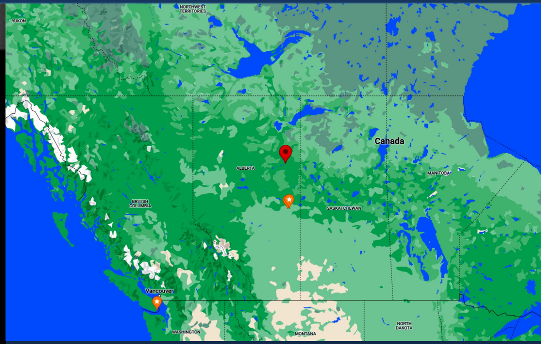
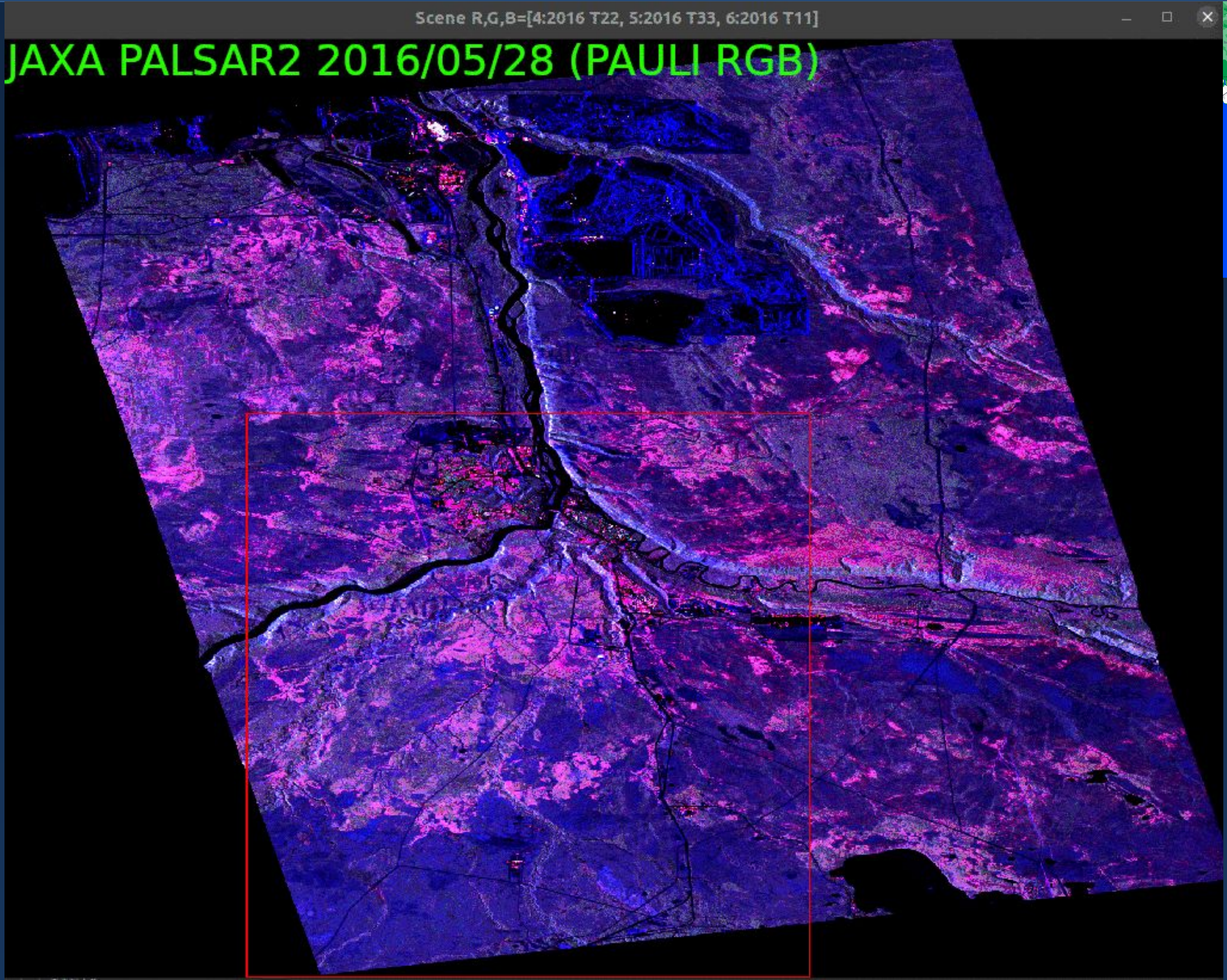
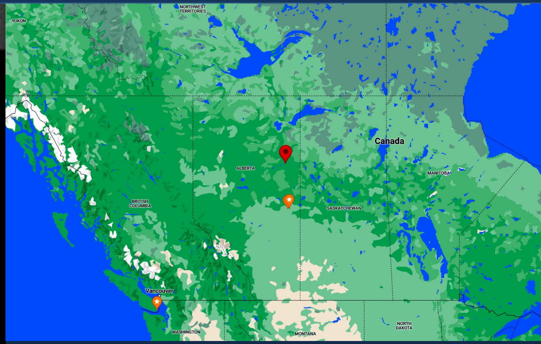


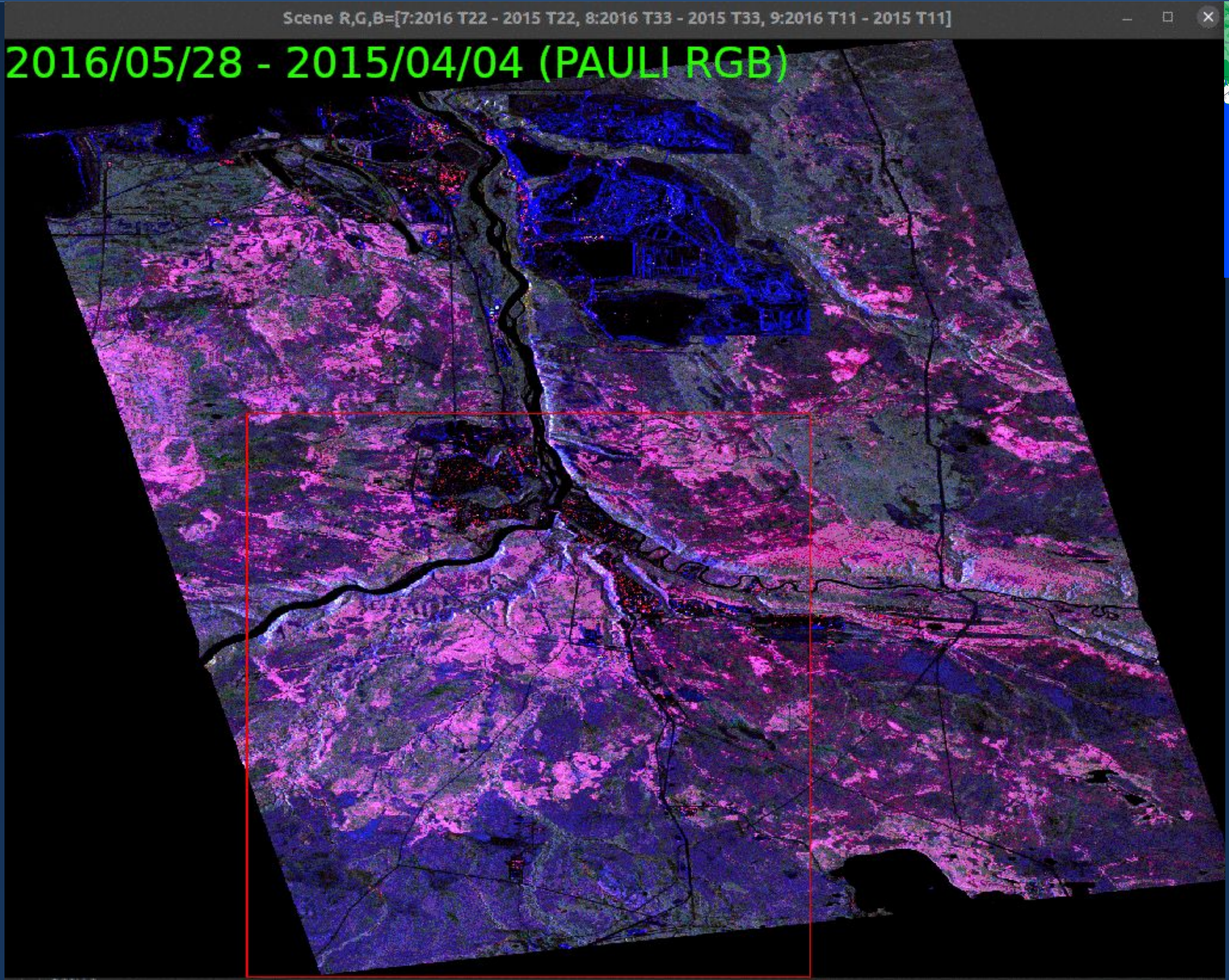


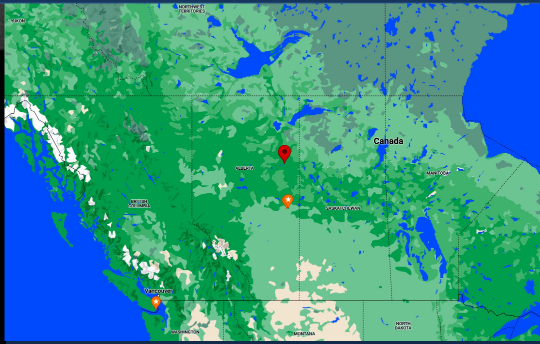
Results: Fort MacMurray (2016) T-matrix





Results: Fort MacMurray (2016) T-matrix





Results: Fort MacMurray (2016) Ground-ref

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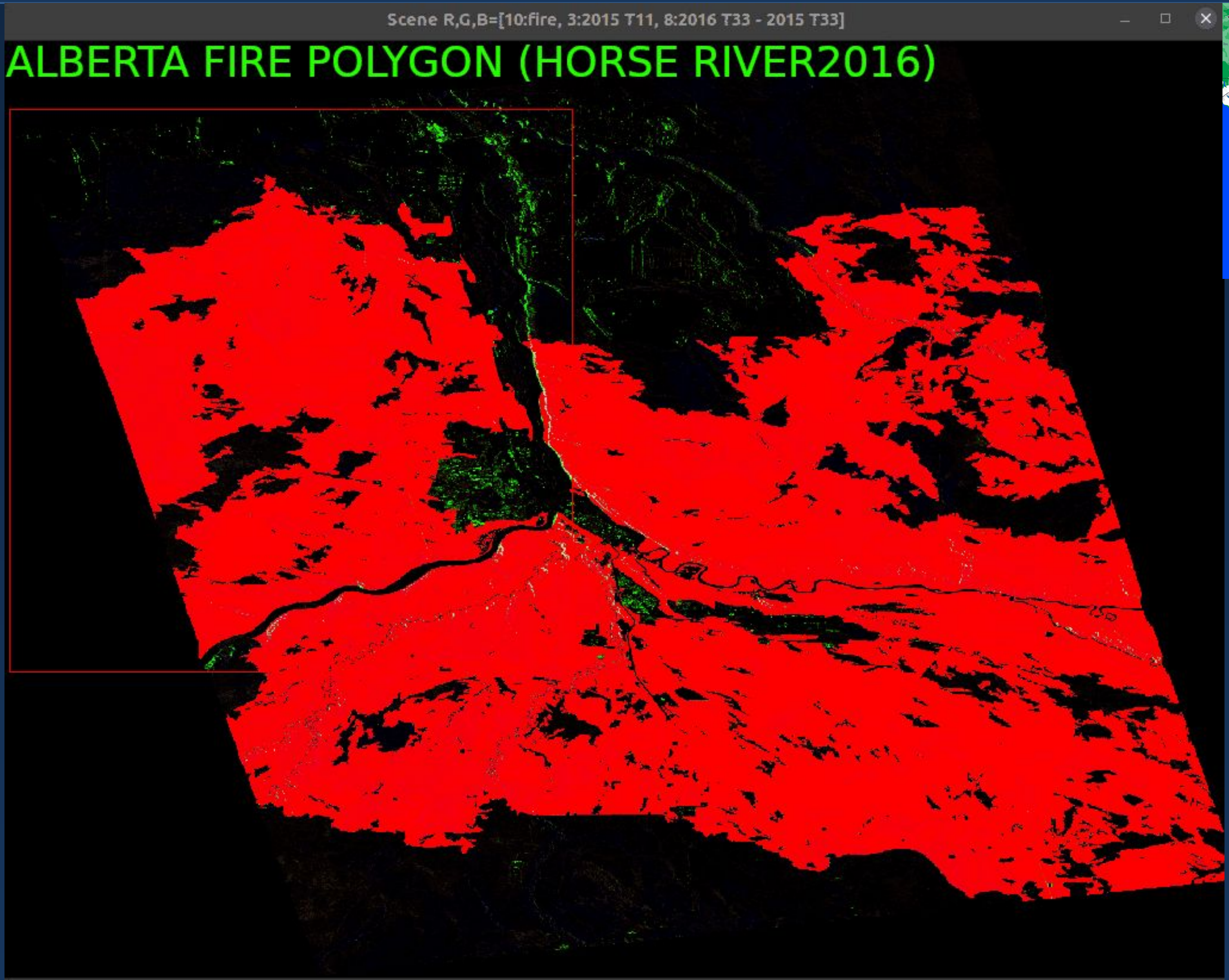

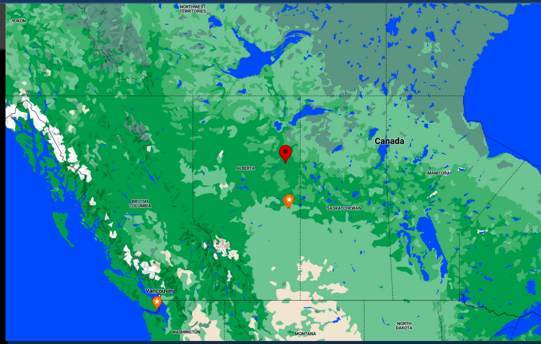

Dual pol parameters [1]

1. From the full-pol data we extract dual-pol (reduced polarimetric info) to “emulate” dual-pol products in: **HH-HV and VH-VV** modes

   (*) From Quad-pol T3 matrix, **extract C2 matrices** for both:

   HH-HV and VH-VV dual-pol products
2. Apply model-based decomposition for dual-pol data [1] for both HH-HV and VH-VV to get:

   m_p: completely polarized power AKA “polarized contribution to the backscattered wave”. Contribution from polarized targets in the scene!

   m_v: partially polarized power (“random-dipoles cloud” used as volume model, as in the Freeman Durden decom.) AKA “partially polarized contribution”. From “random volume” targets in the scene! e.g. Forests

3. Visualize as: (R, G, B) = (m_p, m_v, m_p)

[1]: L. Mascolo, S.R. Cloude, J.M. Lopez-Sanchez, "Model-based decomposition of dual-pol SAR data: application to Sentinel-1", Trans. and Geosci. Remote Sens.

Polarimetric interpretation of colors!

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(R, G, B) = (m_p, m_v, m_p) (*)

Note: unlike the conventional dual-pol-RGB often seen in the literature:
(i.e., (R,G,B) = (VV power, G: VH power, B:, VH/VV)

- this RGB representation (*) is more grounded in the physics of polarimetry
    - Colors are associated w polarized and partially polarized contributions of the reflected waves, not w simple received powers

Aside: could we mix the two representations?

Dual pol parameters 20150404

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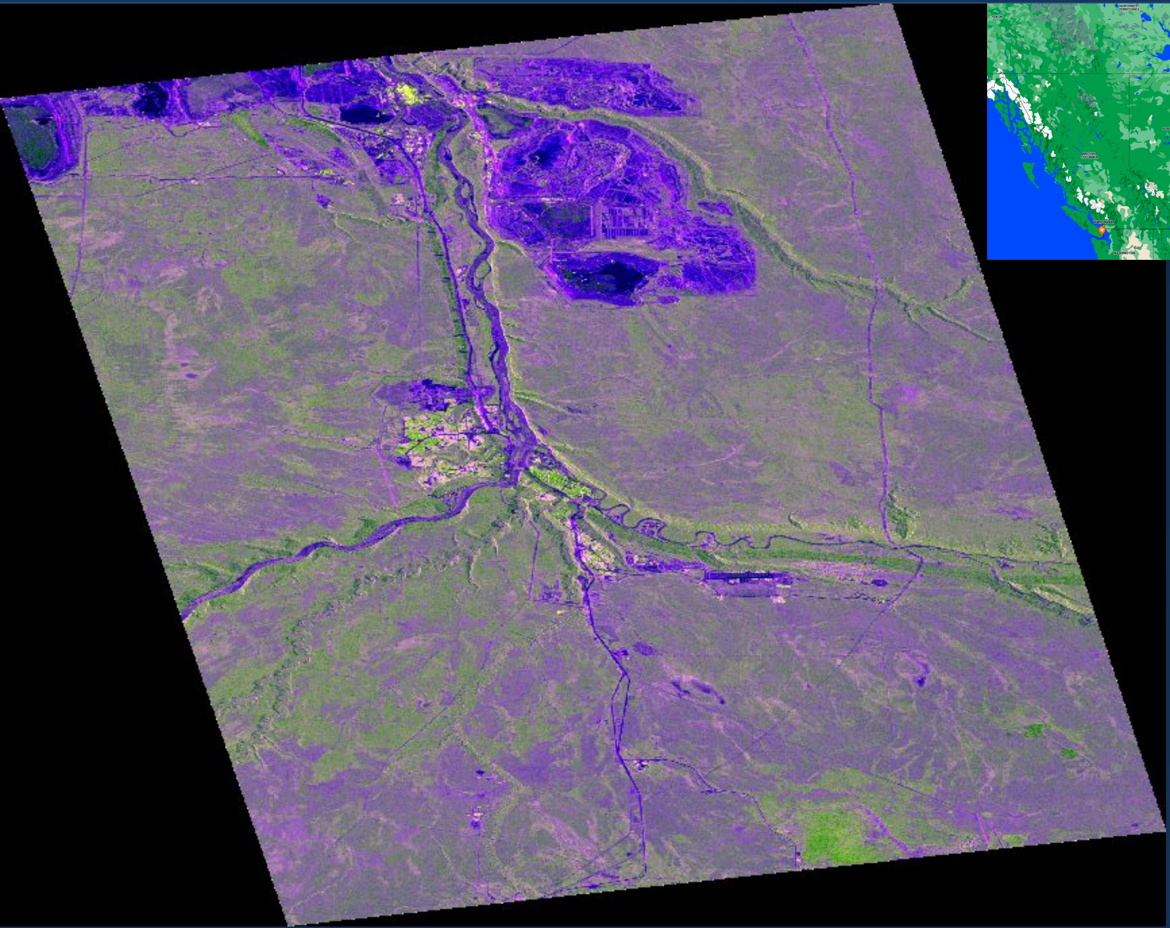

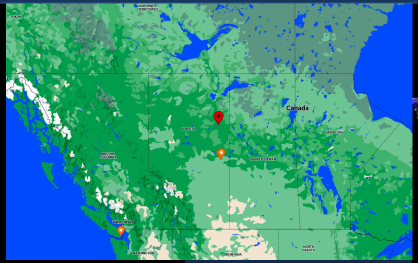

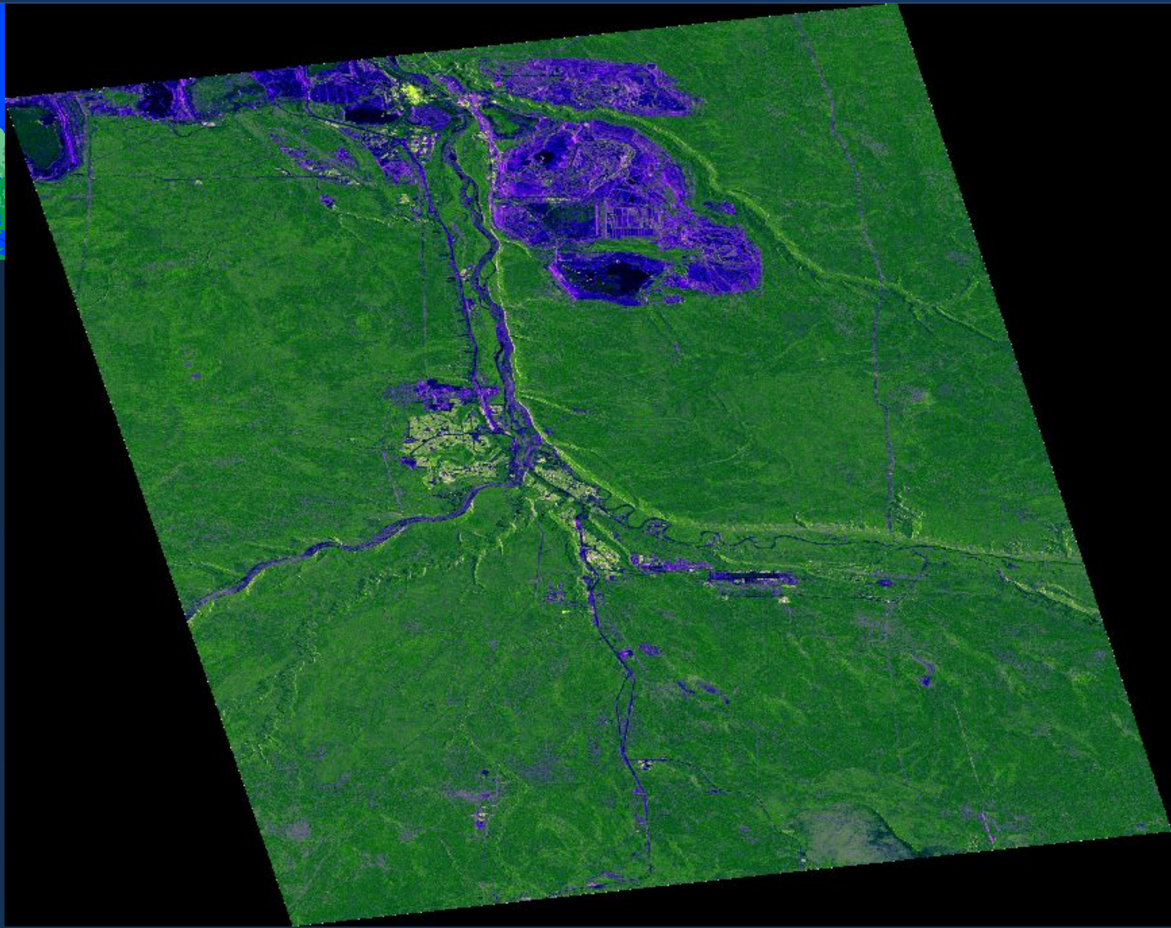

- Much more volume contribution in VH-VV than in HH-HV case.
- Possible explanation: sensitivity of L-band to long elements such as stems.
- Vertical stems attenuate V-polarized waves: m_p << m_v hence we see more green!
- HH-HV case: H-polarized waves are less attenuated: less volume scattering, hence we see less green

Dual pol parameters 20160528

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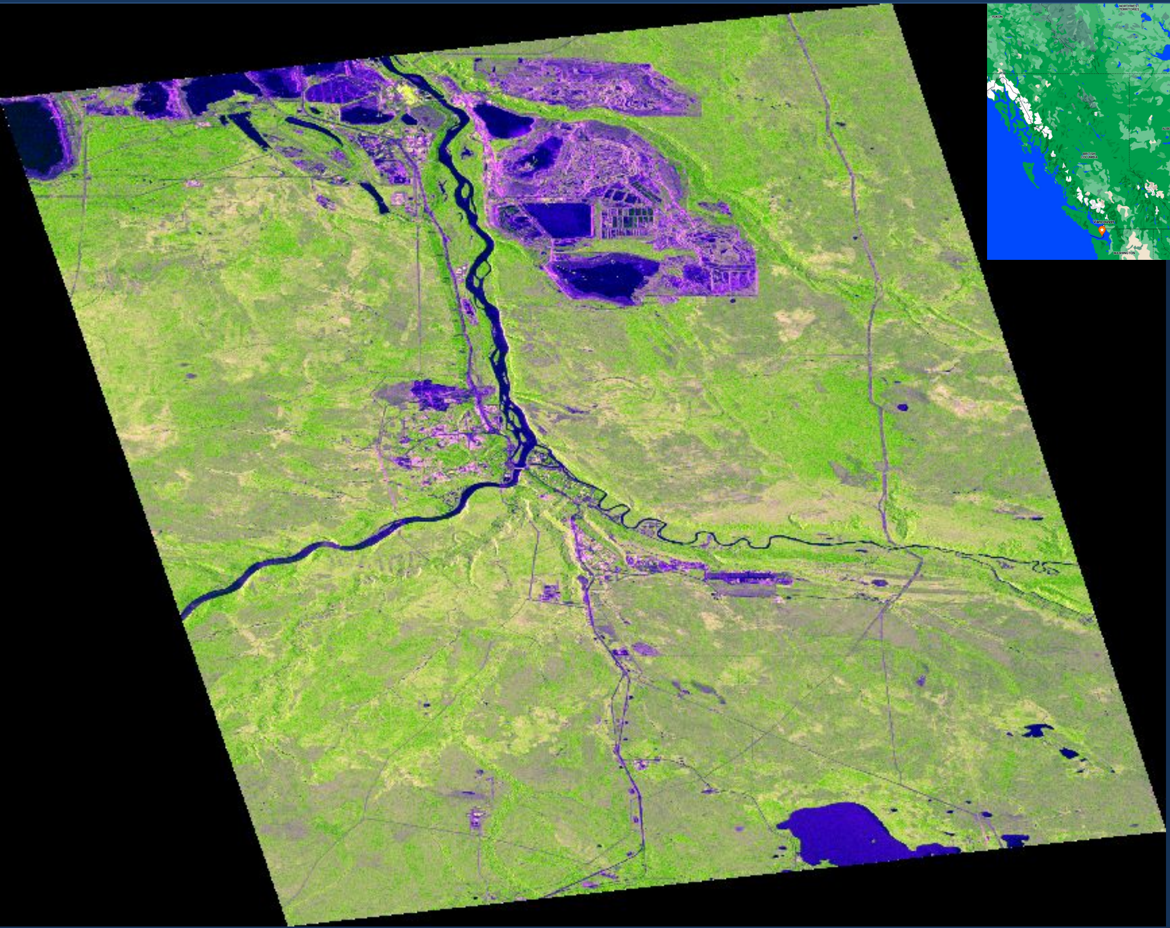
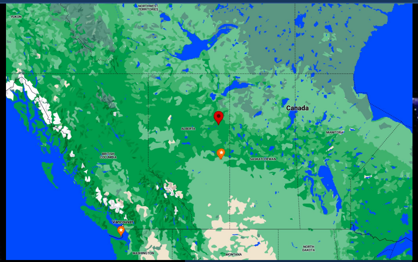
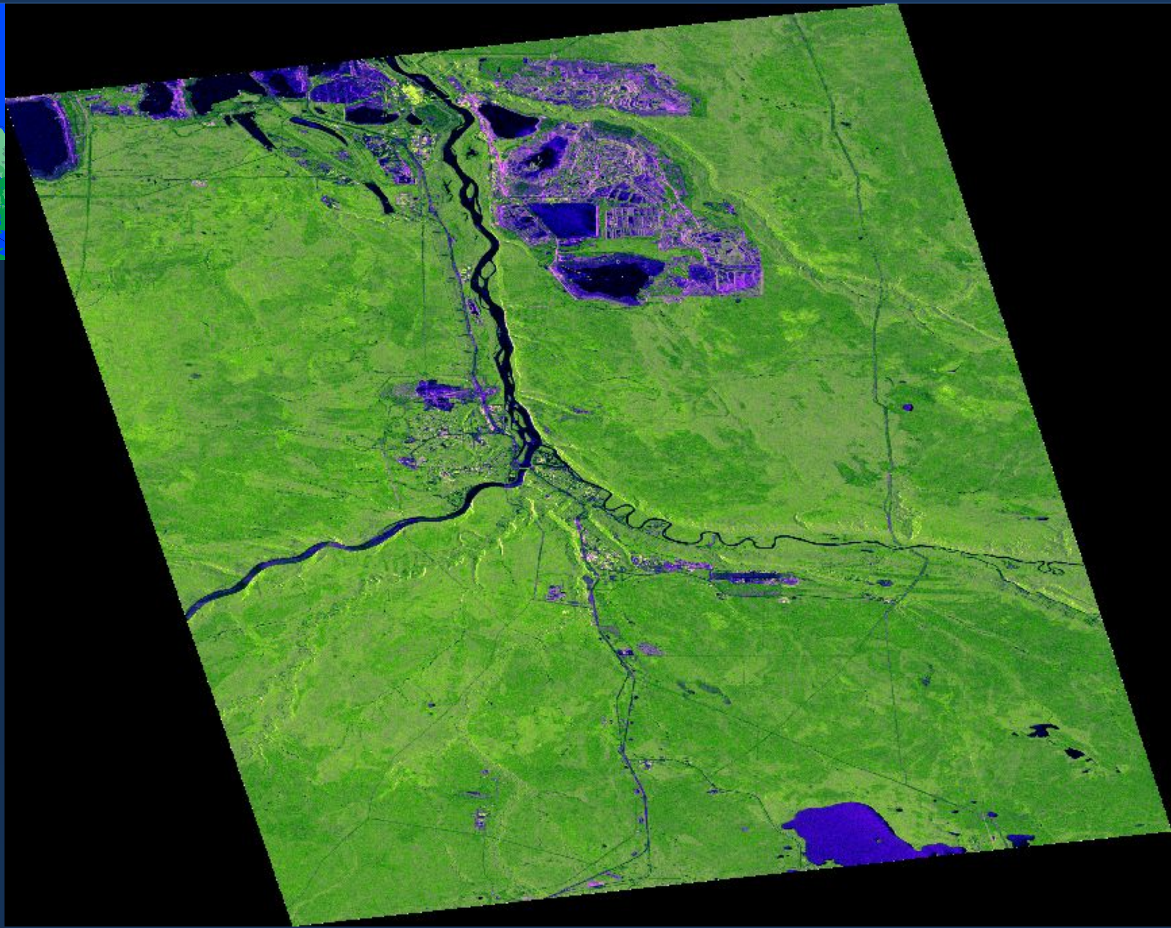
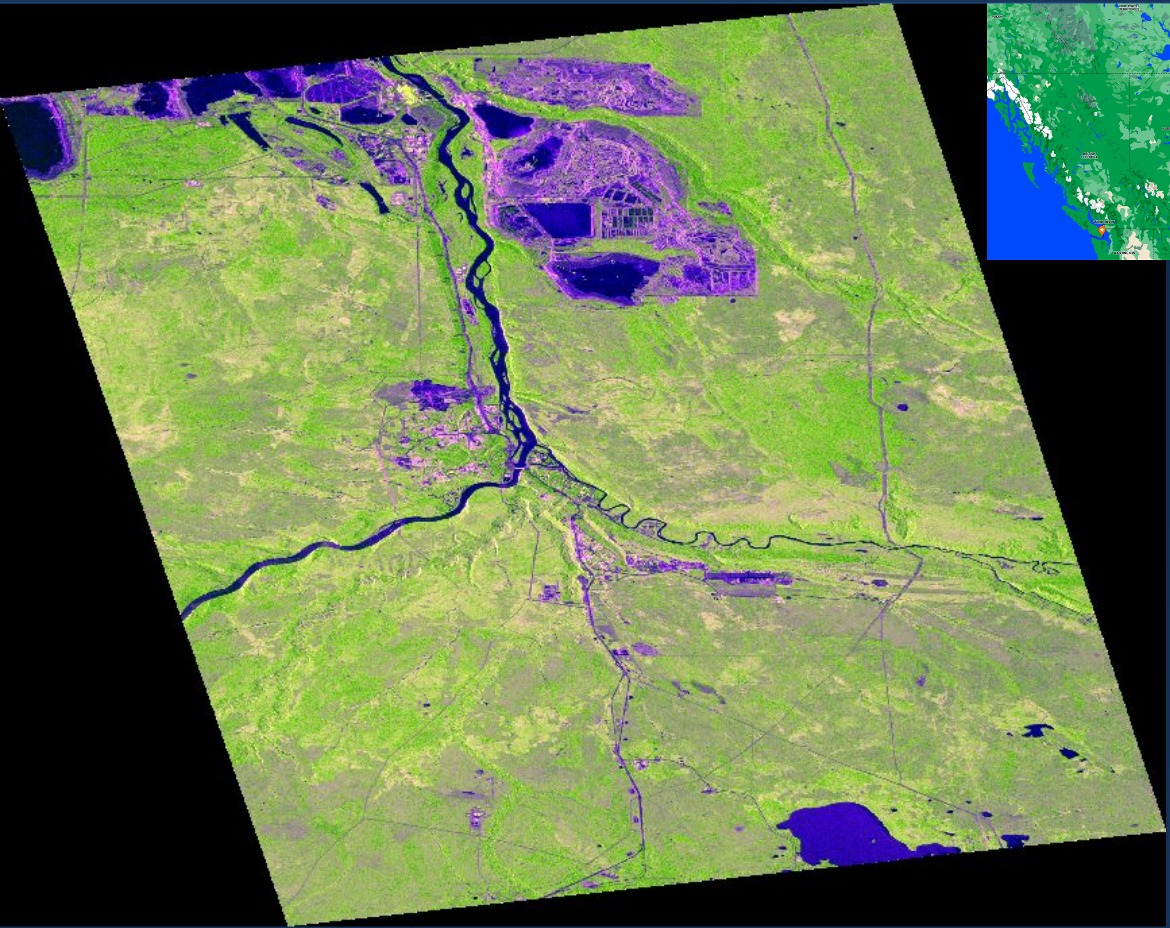


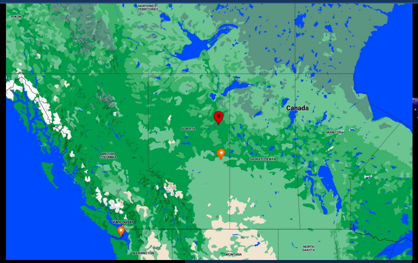


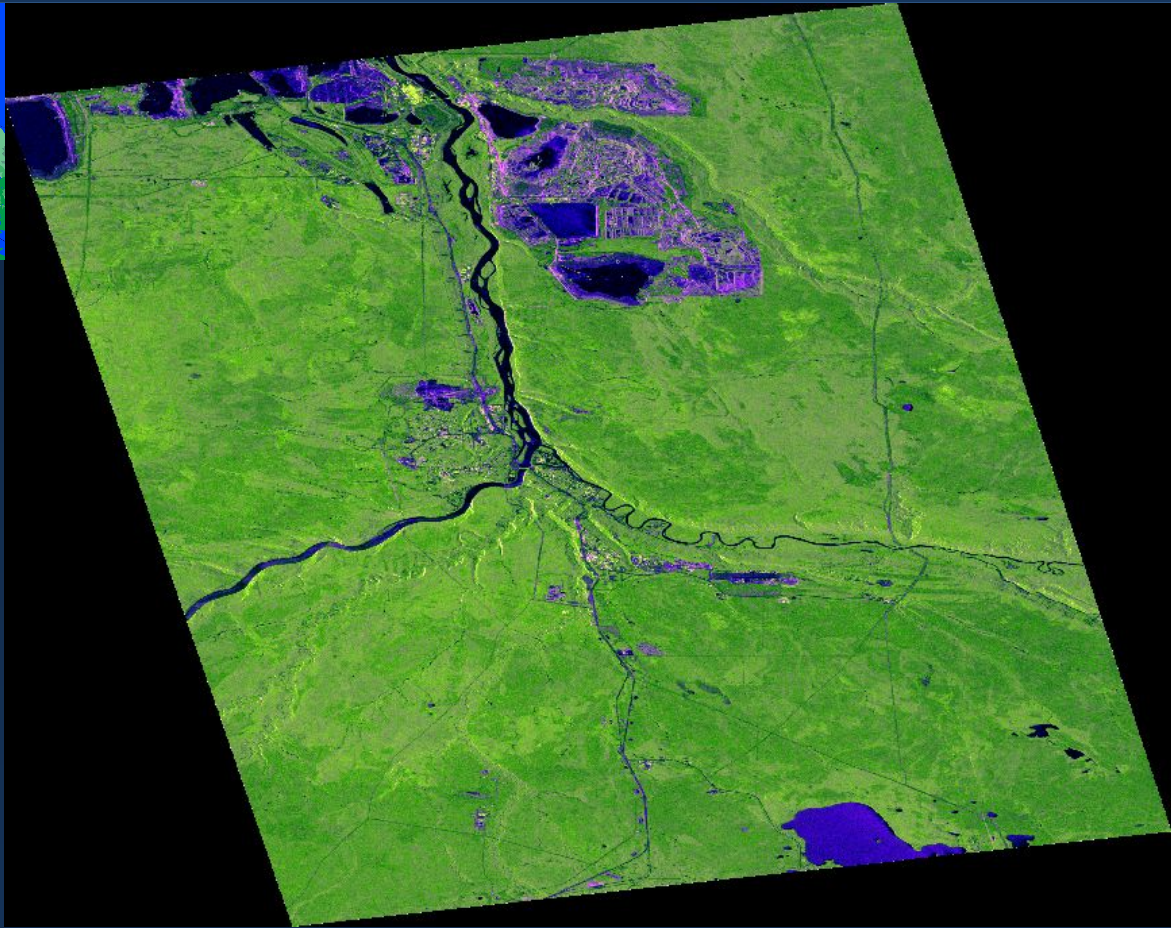


- Compared to the pre-fire images, the volume component of the backscattered wave increases for both modes
- However, the increase is more significant for the HH-HV mode.
- Possible explanation: Stems partially collapse after the fire. The remainder of the stem is vertically oriented, the collapsed portion is random

Dual pol parameters 20160528 cont’d (1/2)







- Possible explanation (1, cont’d): Hence, the collapsed portion of the stem increase the volume contribution. This increase is more prominent for HH-HV case: H-polarized waves see mainly the random collapsed matter.
- On the other hand, the m_v increase is less visible for VH-VV, since here we are more sensitive to the remaining vertical elements, and less sensitive to the random collapsed material

Dual pol parameters 20160528 cont'd (2/2)

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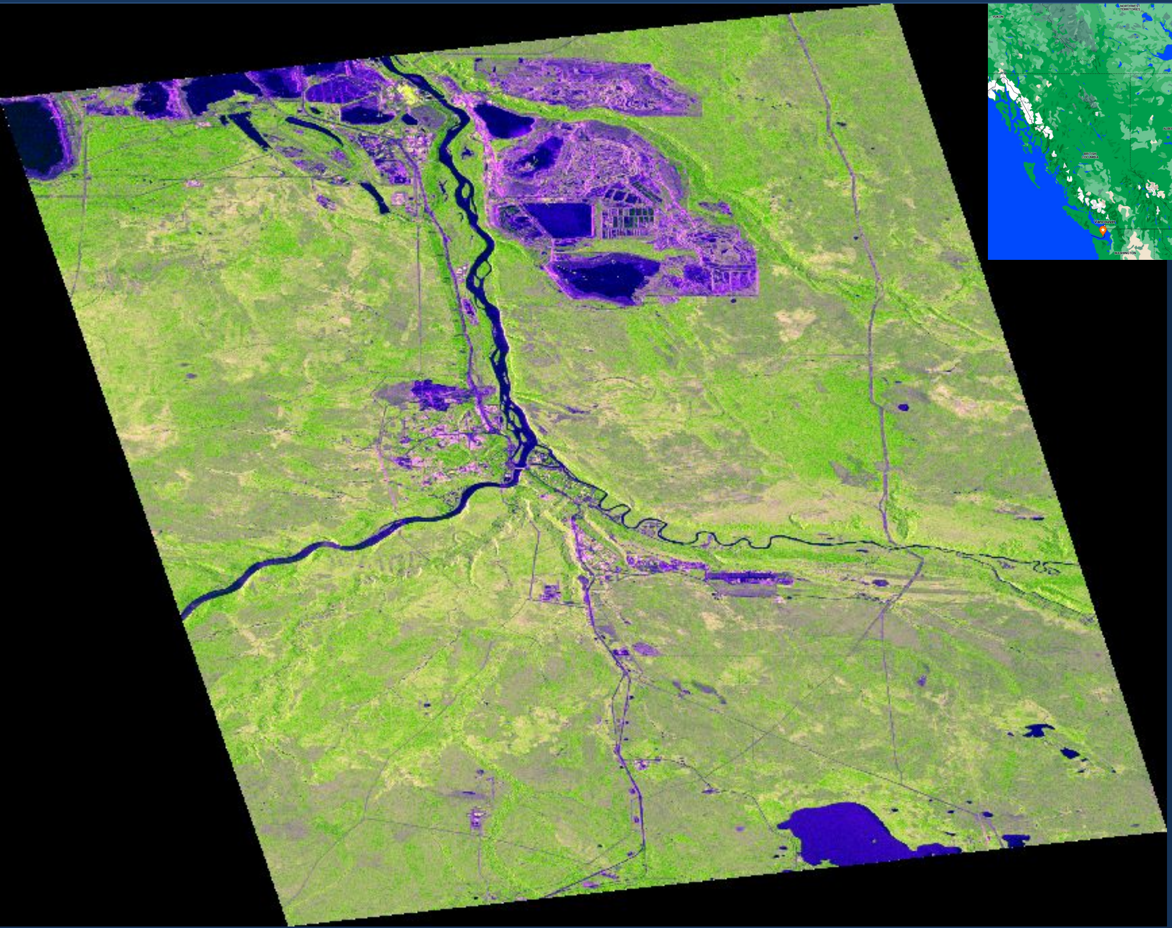

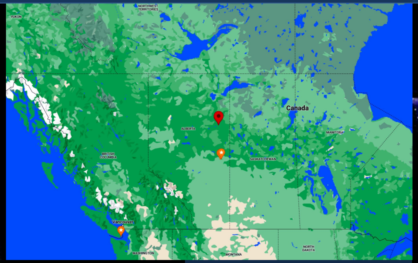

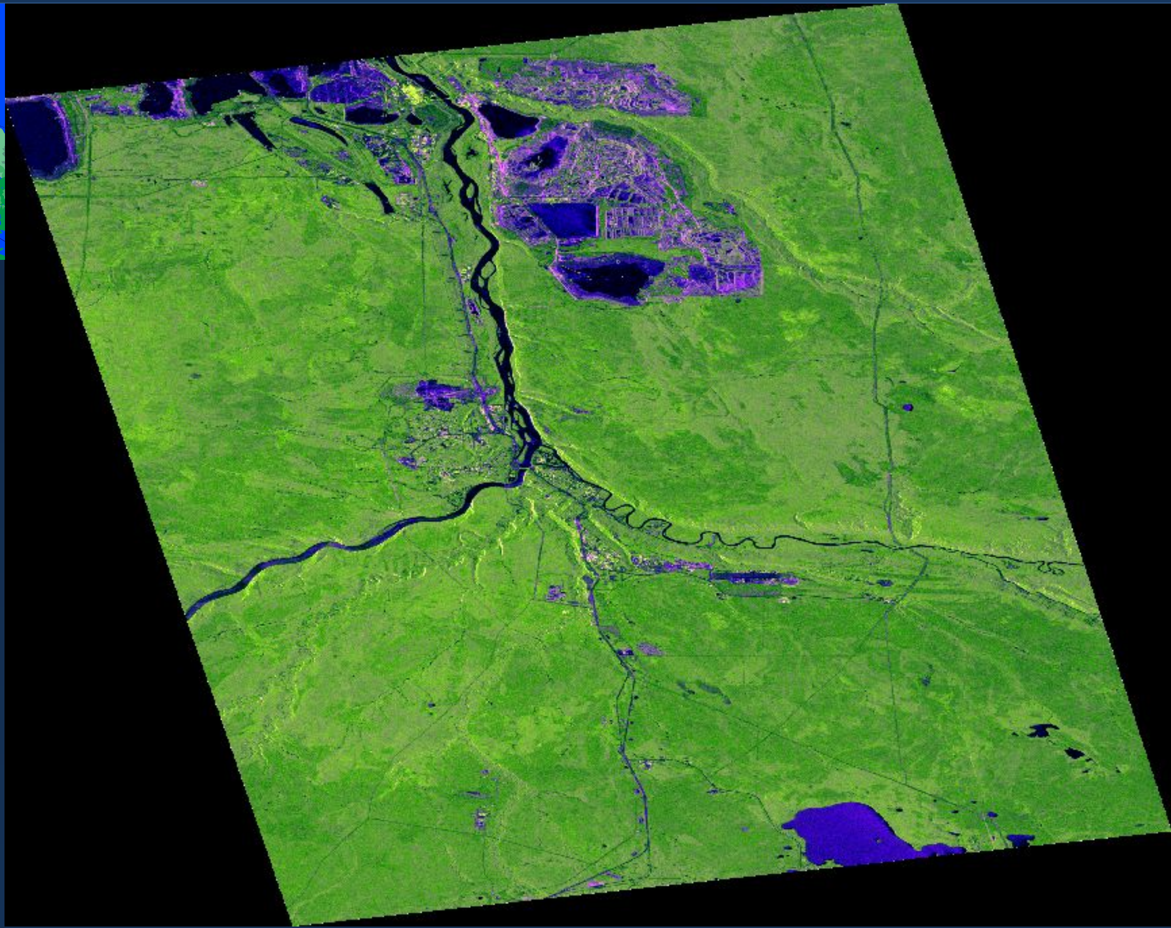

- Possible explanation 2) the observations could be related to water content of the stems, which could be high on May 26, as noted in (2018) Plank et al

Check DP interpretation by using Freeman parameters

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1. Calc. freeman 3-component decom for 2015 & 2016 dates
2. Calc. the difference: 2016 - 2015 (for the three Freeman params)
3. Partition the data into unburned and burned portions (according the national fire database polygon)
4. Plot histograms for each fraction, see if they move

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Freeman decom (difference 2016-2015): unburned area

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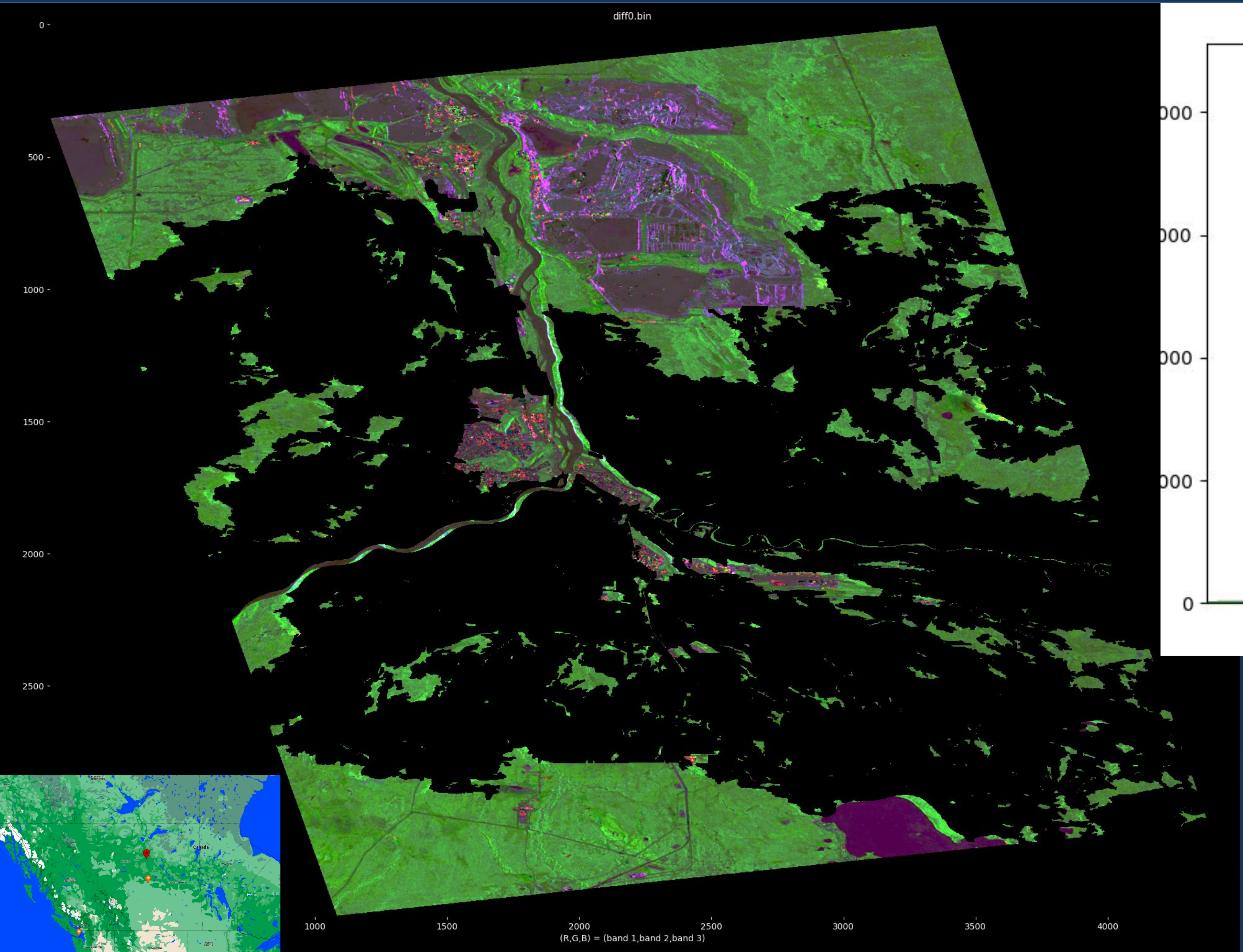
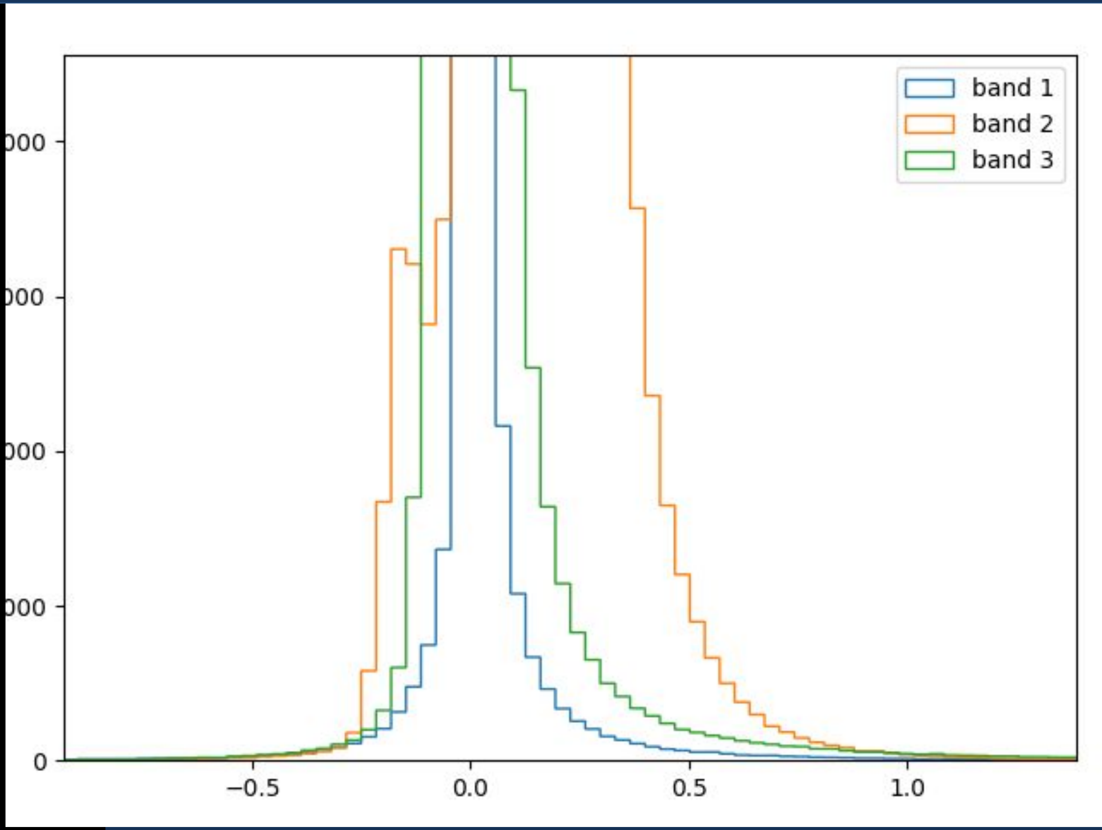
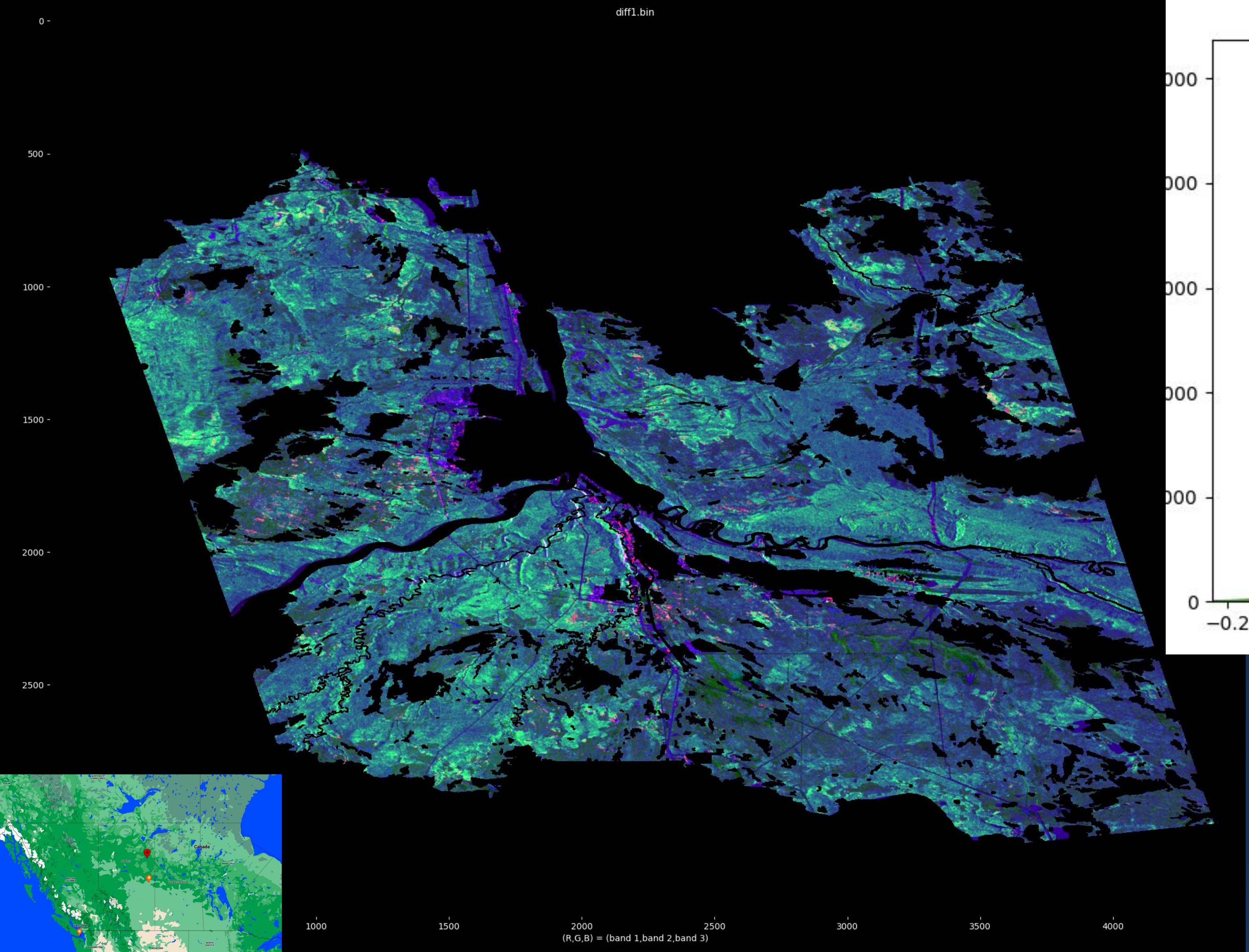
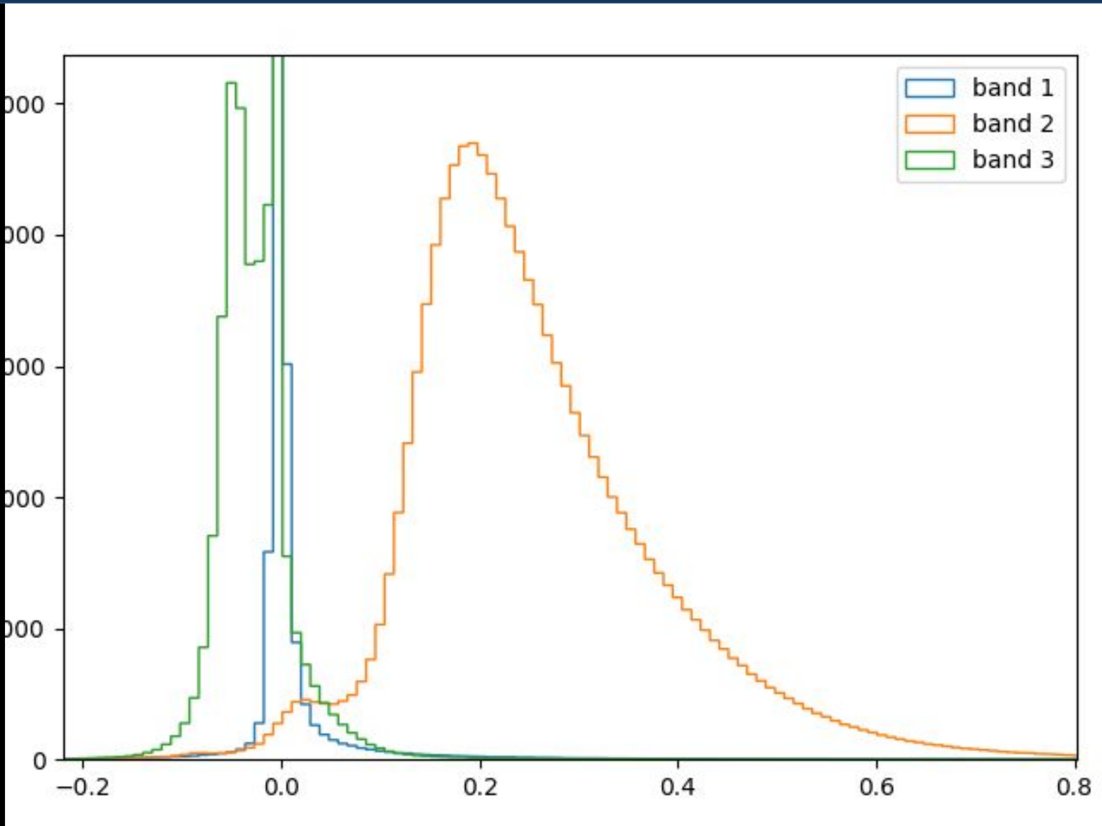




- No conclusive bias observed
- Should stratify by land-cover types to understand more

Freeman decom (difference 2016-2015): burned area





- Clear bias observed
- The histograms moved!
- Volume-scattering changes observed! As anticipated

For a fair DP/QP comparison: create a “new” ground-ref (less false positives)

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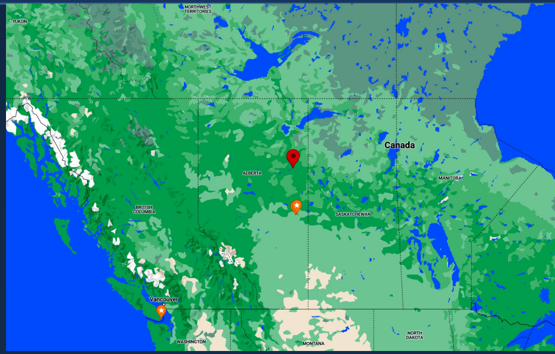
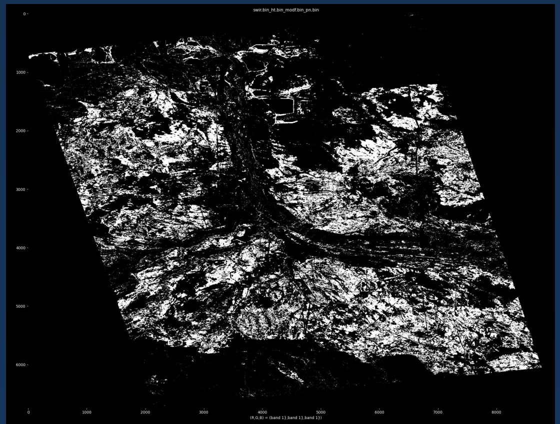
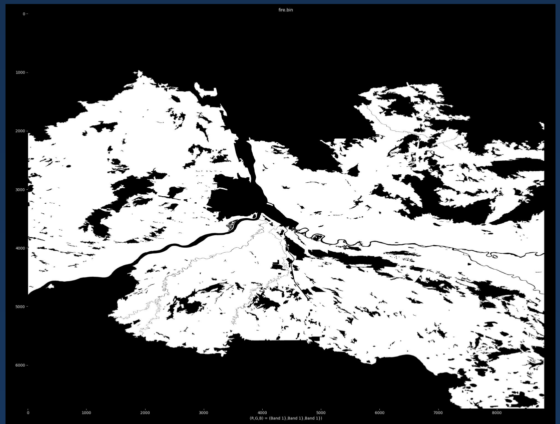


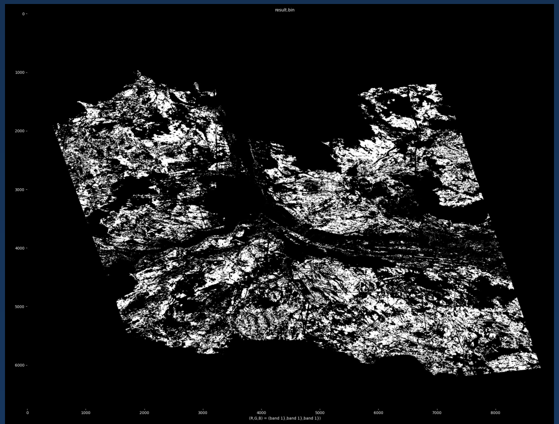
1. Download two landsat frames:
   a. LC08_L2SP_042021_20161003_20200906_02_T1.tar
   b. LC08_L2SP_042020_20161003_20200906_02_T1.tar
2. Merge using **gdal_merge.py**
3. Use **gdal_translate** to project onto ARD radar data
4. Use spectral interpolation to **emulate Sentinel2 bands: B12, B11, B9** (resilient to atmosphere)
5. **Histogram trim 1%** each channel and **scale each band to range [0, 1]**
6. Apply channel-wise **histogram mode filter** to reduce the number of values
   a. https://github.com/bcgov/wps-research/blob/master/cpp/modf.cpp
7. Use simple NN binary classifier (trained on manually selected pixels) to produce a **burned mask (LEFT)**
   a. https://github.com/bcgov/wps-research/blob/master/cpp/pn.cpp
8. Multiply by the **National Fire Database polygon data (MIDDLE)**
   a. https://cwfis.cfs.nrcan.gc.ca/downloads/nfdb/fire_poly/current_version/NFDB_poly_large_fires.zip
9. Result: a **more conservative estimate of burned area extent, with less false positives included (RIGHT)**



*



=



Detail of step 7 (last slide): select N=36 points
Quick and dirty selection, first attempt

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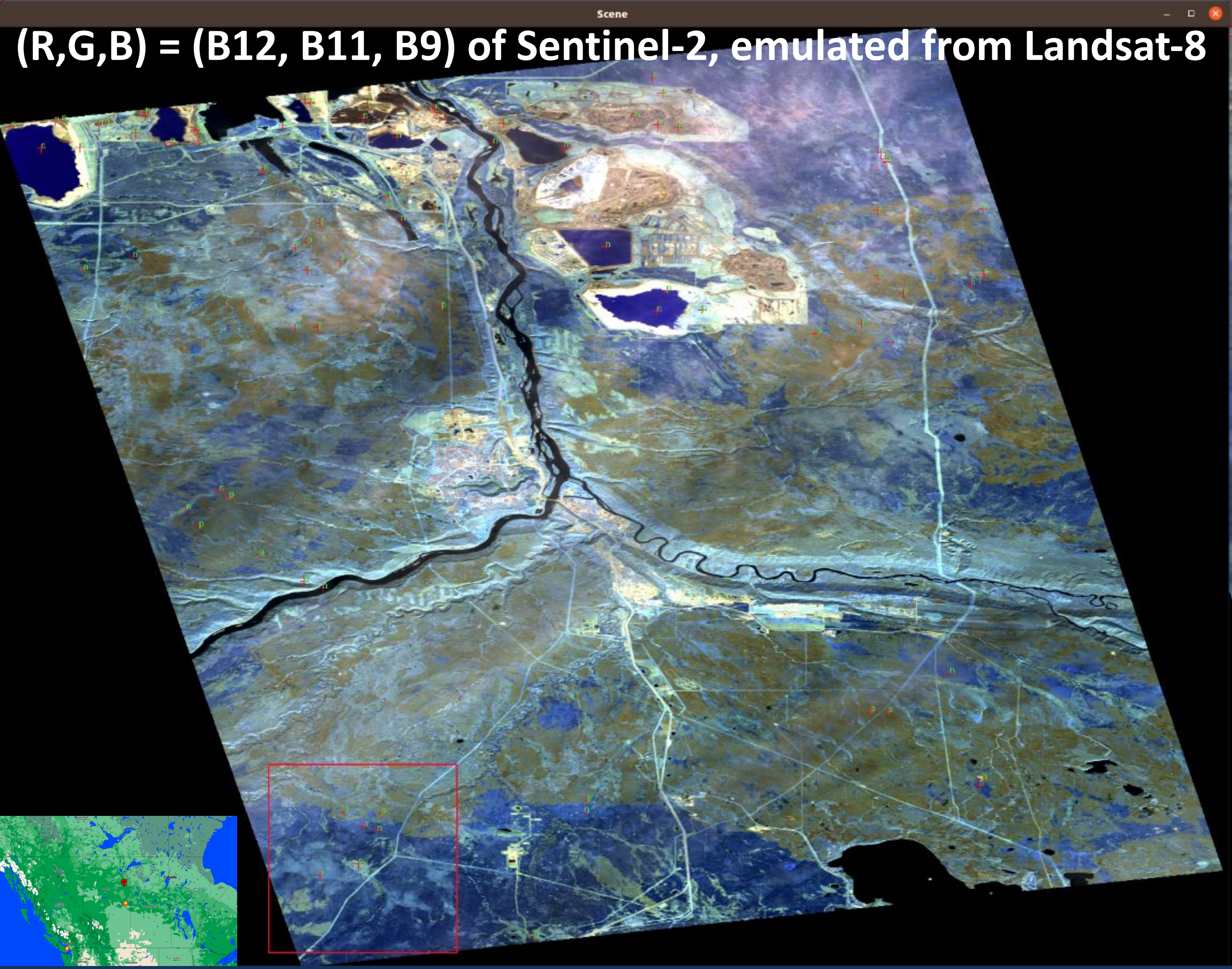

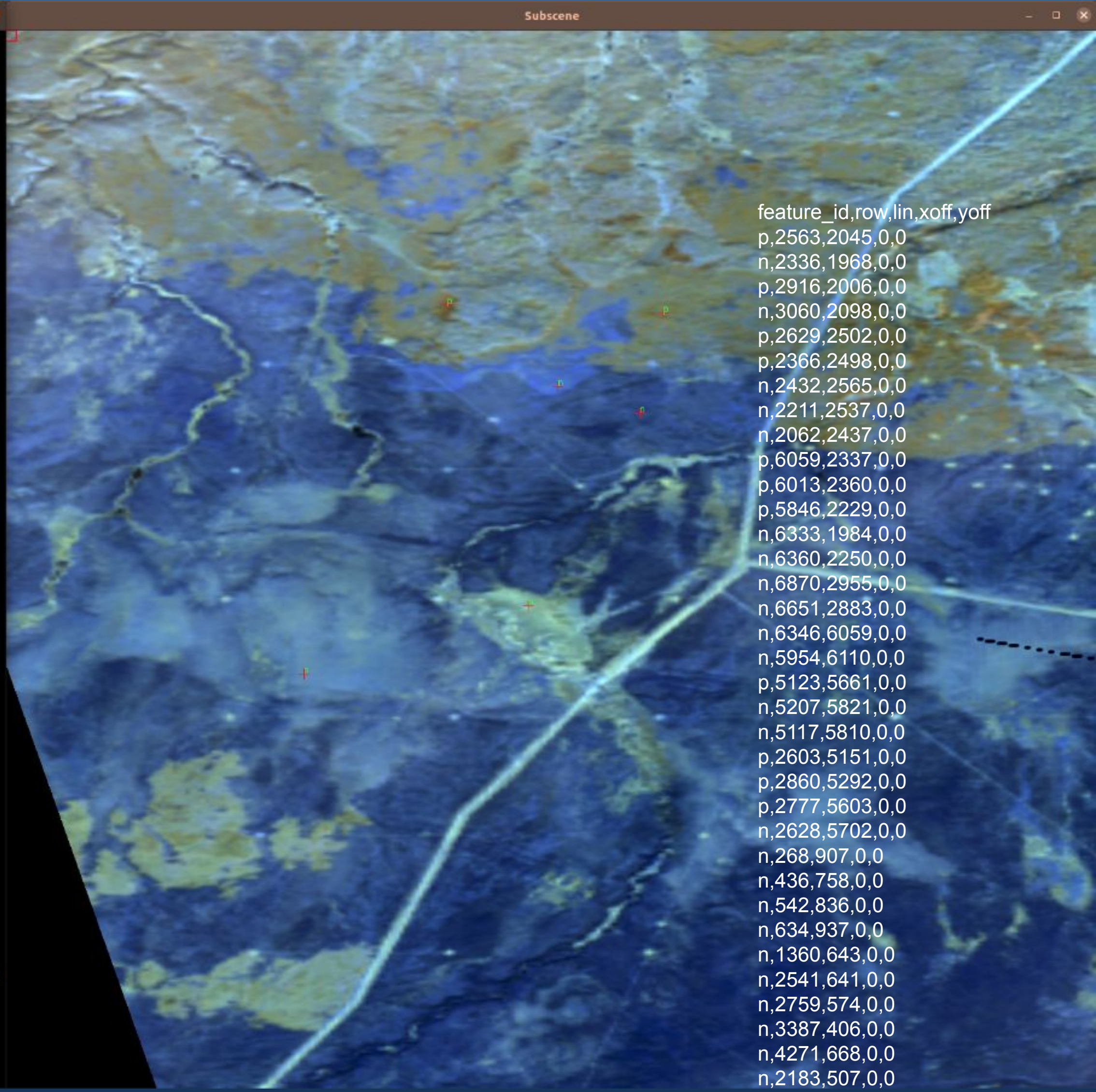


```
feature_id,row,lin,xoff,yoff
p,2563,2045,0,0
n,2336,1968,0,0
p,2916,2006,0,0
n,3060,2098,0,0
p,2629,2502,0,0
p,2366,2498,0,0
n,2432,2565,0,0
n,2211,2537,0,0
n,2062,2437,0,0
p,6059,2337,0,0
p,6013,2360,0,0
p,5846,2229,0,0
n,6333,1984,0,0
n,6360,2250,0,0
n,6870,2955,0,0
n,6651,2883,0,0
n,6346,6059,0,0
n,5954,6110,0,0
p,5123,5661,0,0
n,5207,5821,0,0
n,5117,5810,0,0
p,2603,5151,0,0
p,2860,5292,0,0
p,2777,5603,0,0
n,2628,5702,0,0
n,268,907,0,0
n,436,758,0,0
n,542,836,0,0
n,634,937,0,0
n,1360,643,0,0
n,2541,641,0,0
n,2759,574,0,0
n,3387,406,0,0
n,4271,668,0,0
n,2183,507,0,0
n,1013,603,0,0
```

Radar classification: annotate small # of training pixels (n=20)
Then apply NN classifier again (T22 channels only!)

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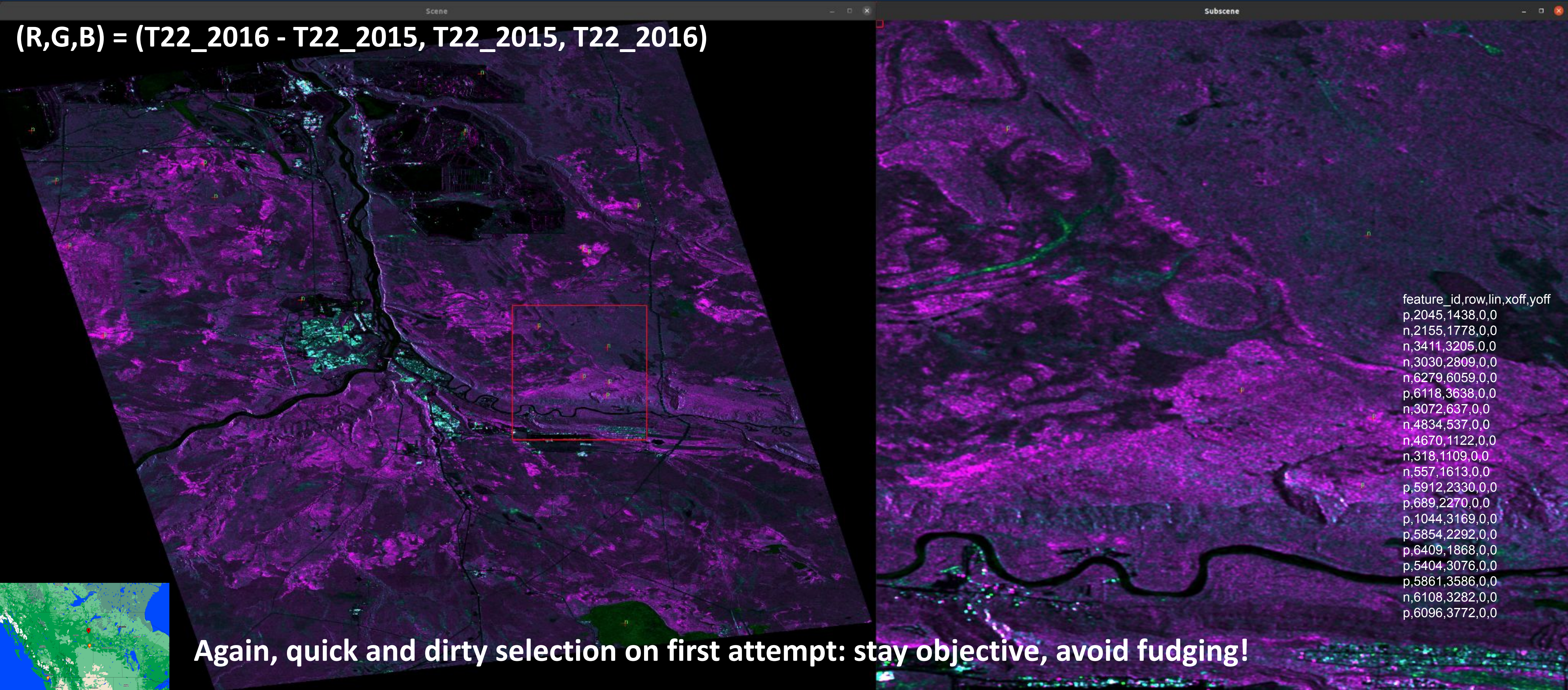

Again, quick and dirty selection on first attempt: stay objective, avoid fudging!

T22 only result (two dates): 77% Accuracy (N=20)

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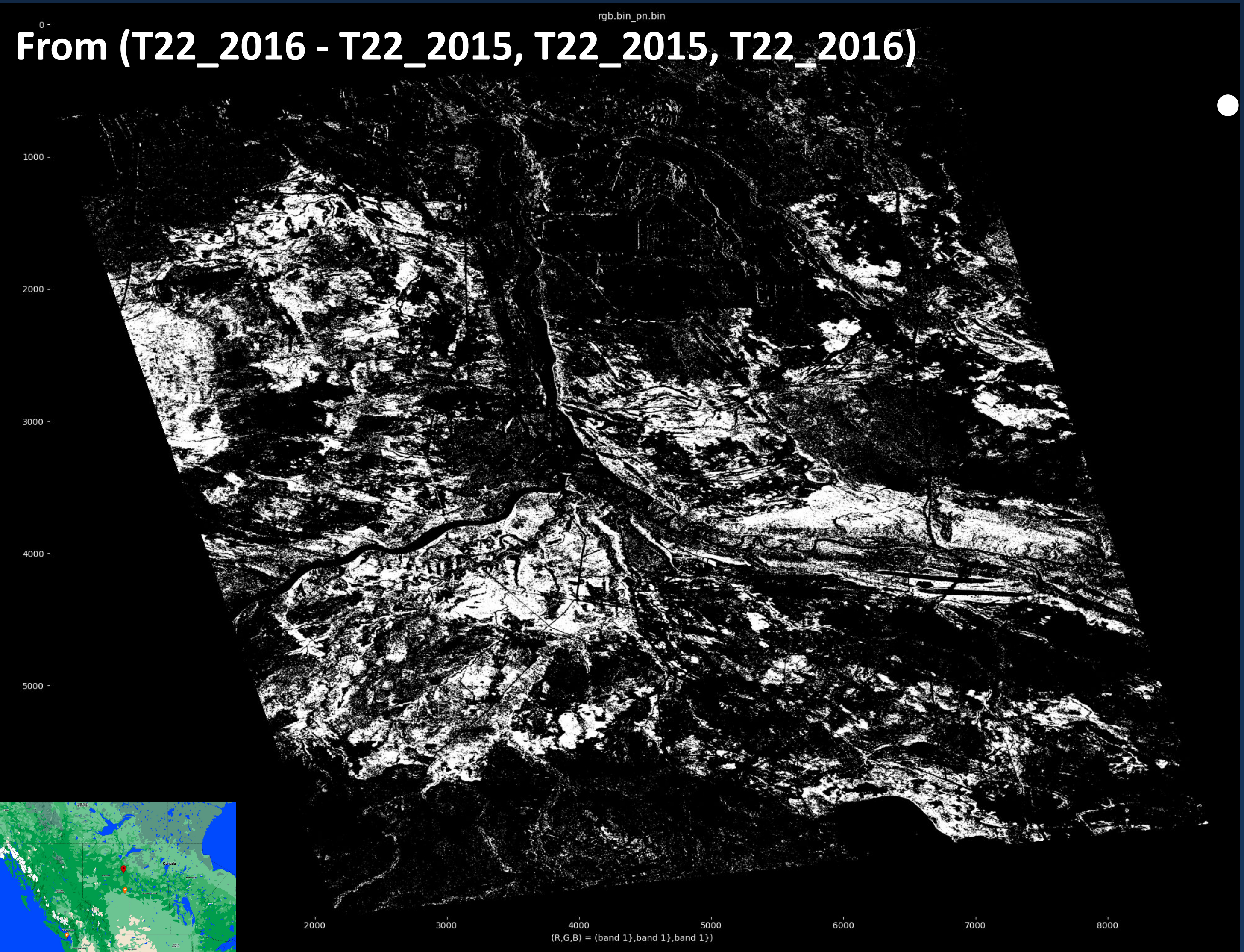


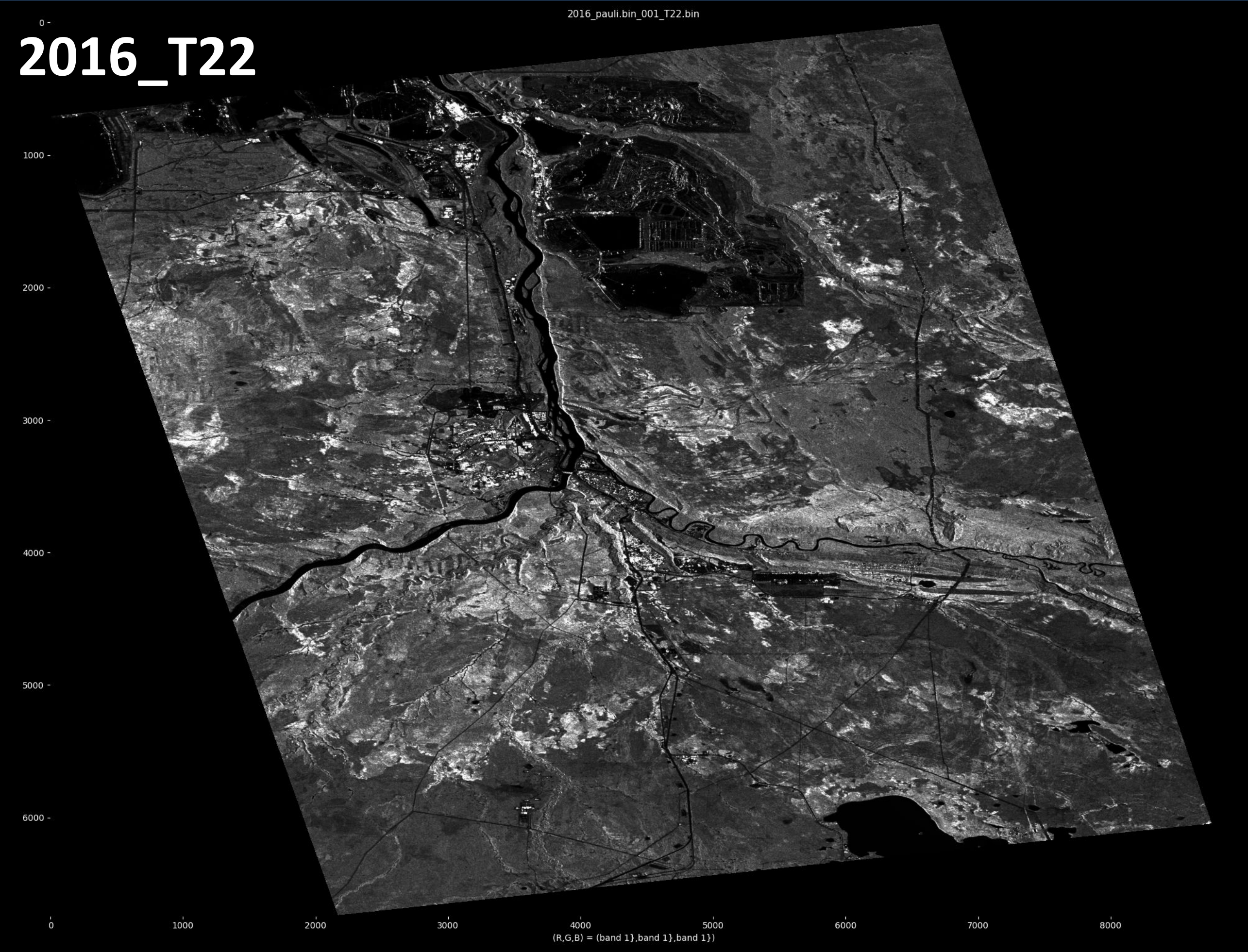
- Got 71% Accuracy from using the original (simple) fire polygon data
- Got 80% accuracy by using T22, T33, T11 for both years (6 bands) with histogram trim (1% each side)

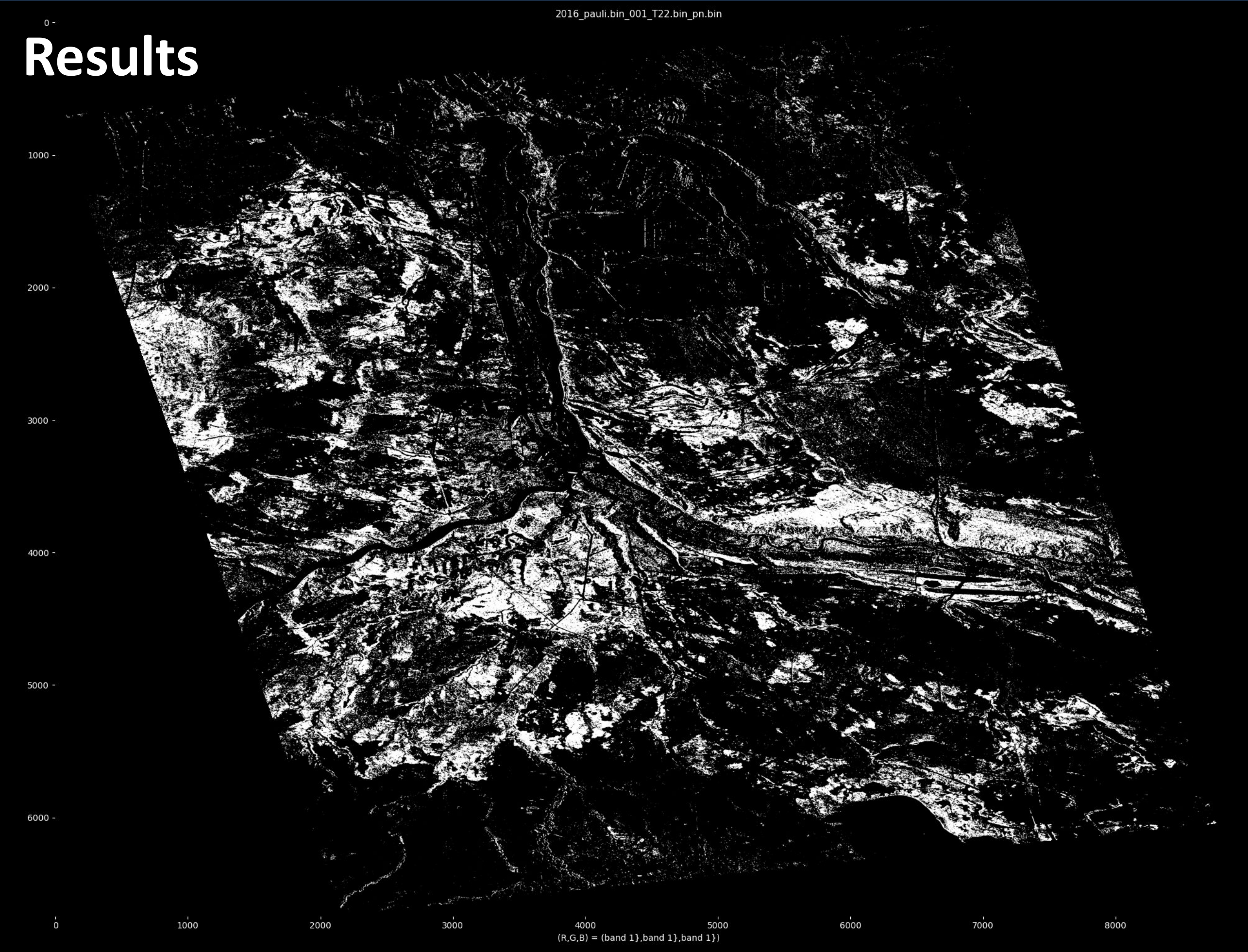
  - Used the most basic “chainsaw science” to show the potential
  - More sophisticated stats would improve the results

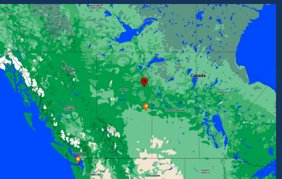
class_map,ground_ref,P%,N%,TP%,TN%,FP%,FN%,TPR,TNR,PPV,NPV,FNR,FPR,FDR,FOR,PLR,NLR,**ACC**,BA,F1,BM,MK
rgb.bin_pn.bin,mask.bin,14.041385,28.255510,4.254117,28.255510,9.670004,9.787269,0.302970,1.000000,0.305521,0.742730,0.697030,0.342234,0.694479,0.257270,0.885270,0.697030,**0.768606**,0.651485,0.304240,2.302970,0.048251

feature_id,row,lin,xoff,yoff
p,2045,1438,0,0
n,2155,1778,0,0
n,3411,3205,0,0
n,3030,2809,0,0
n,6279,6059,0,0
p,6118,3638,0,0
n,3072,637,0,0
n,4834,537,0,0
n,4670,1122,0,0
n,318,1109,0,0
n,557,1613,0,0
p,5912,2330,0,0
p,689,2270,0,0
p,1044,3169,0,0
p,5854,2292,0,0
p,6409,1868,0,0
p,5404,3076,0,0
p,5861,3586,0,0
n,6108,3282,0,0
p,6096,3772,0,0

Single date, one channel only (2016_T22)
75% Accuracy

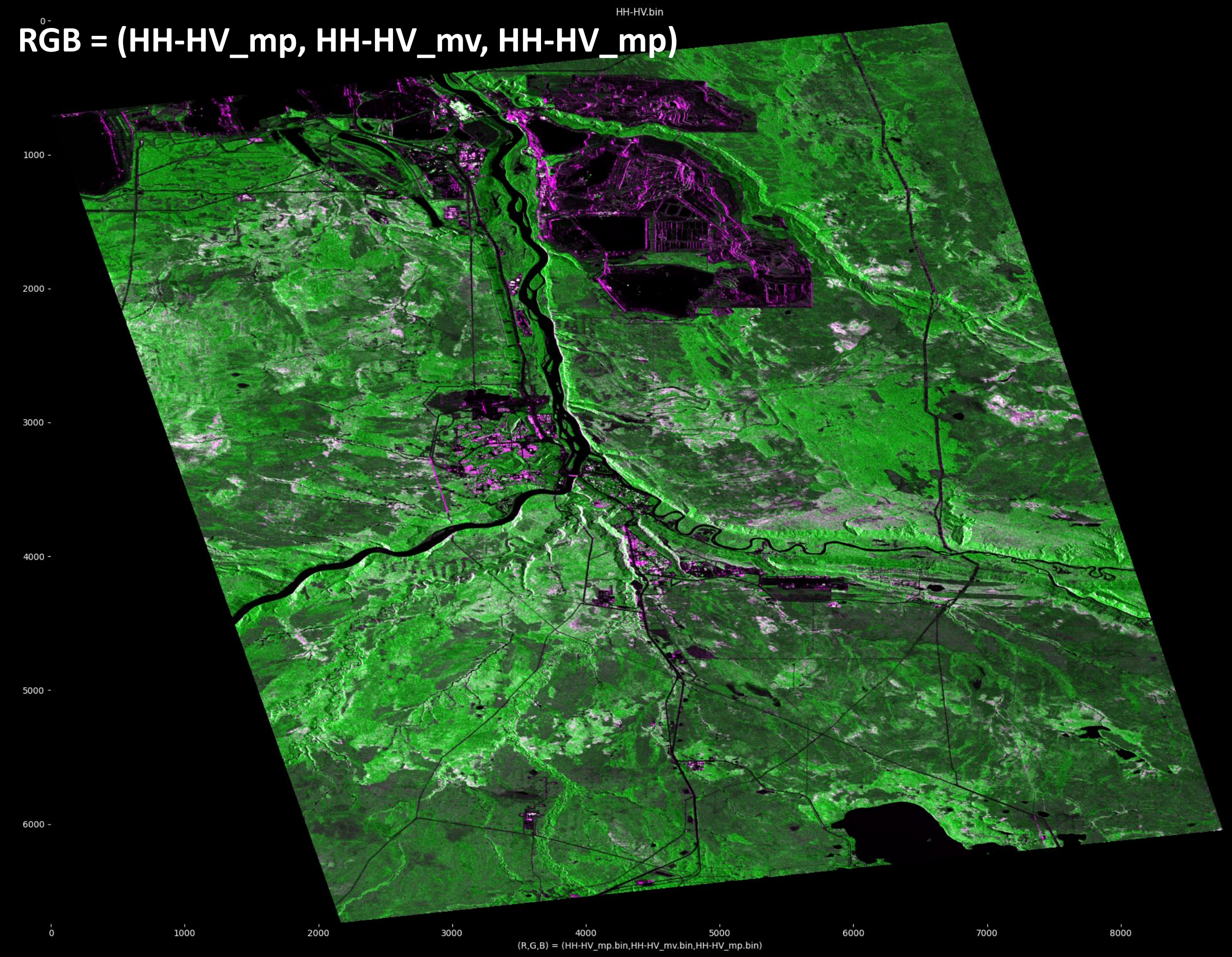


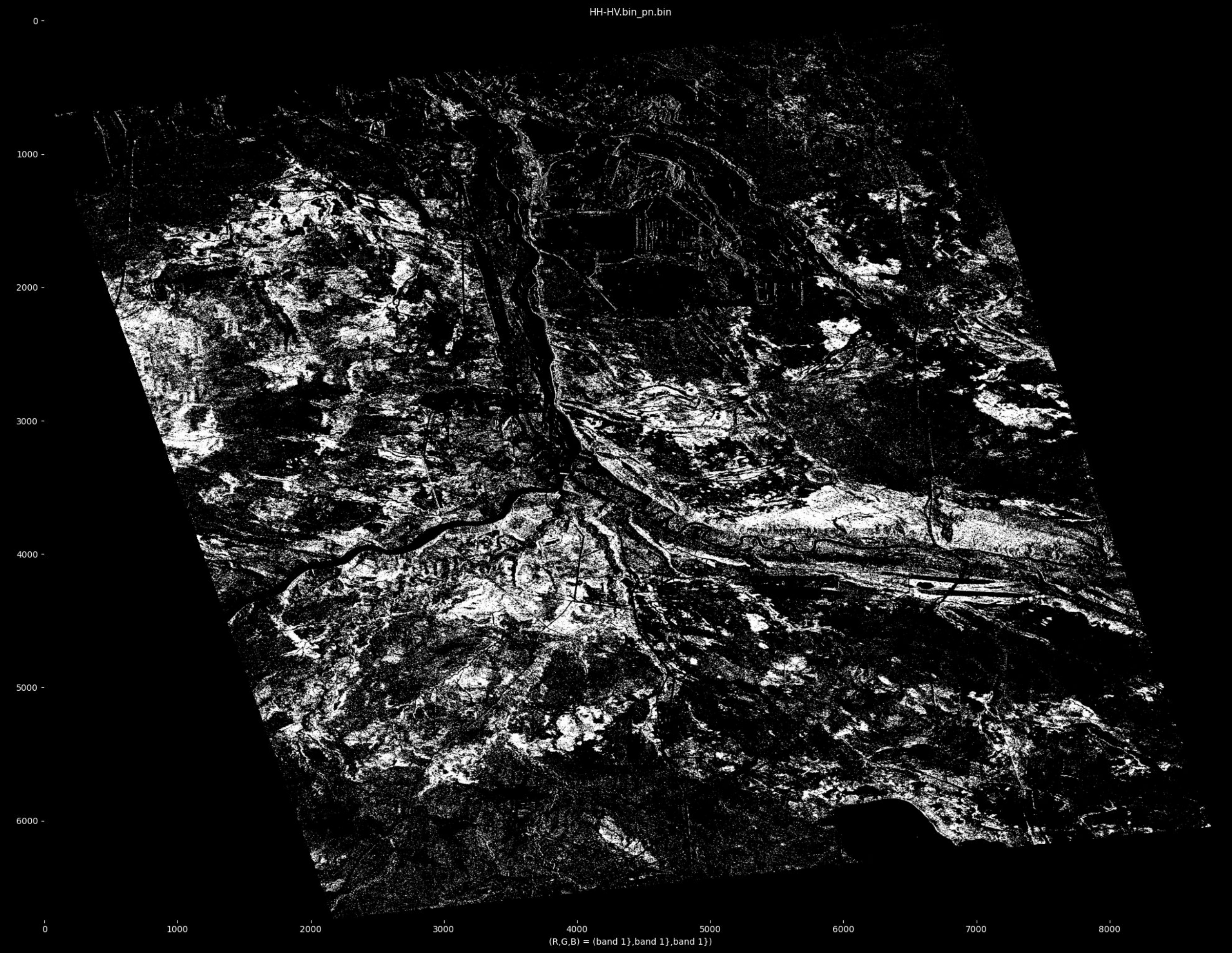


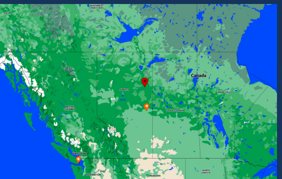


class_map,ground_ref,P%,N%,TP%,TN%,FP%,FN%,TPR,TNR,PPV,NPV,FNR,FPR,FDR,FOR,PLR,NLR,ACC,BA,F1,BM,MK
2016_pauli.bin_001_T22.bin_pn.bin,mask.bin,14.041385,28.255510,3.442727,28.255510,8.167476,10.598658,0.245184,1.000000,0.296526,0.727220,0.754816,0.289058,0.703474,0.272780,0.848219,0.754816,**0.749422**,0.622592,0.268422,2.245184,0.023746

2016 Dual-pol: (HH-HV_mp, HH-HV_mv) parameters: 75% Accuracy







(*) Results from emulated Dual-pol, are comparable to results from Quad-pol

Closing remarks + Thanks!

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- JAXA's unique L-band Synthetic Aperture Radar (SAR) system shows operational potential for for fire mapping
  - In both Quad-pol (QP) and Dual-pol (DP) modes
- Initial comparison of QP w emulated DP shows that DP gives similar results
  - Need to verify that using a corrected T3 matrix (QP) to emulate DP parameters, does not overstate DP results
- Results need to be confirmed over more fire incidents in BC!

Next steps JFY 2022

- Perform synergy study with C-band SAR data from CSA
- Upgrade ground-ref to burn severity, and fuel types
- Document findings in applications article

Thanks to:

- ***JAXA for the EORA3 collaboration opportunity. Domo arigato gozaimashita!***
- *All the collaborators for their contributions!*
- *JAXA, CSA, ESA, NASA, ASI for data provision and other support*
- *NRCAN, BC Forest Inventory and BC Gov RS CoP for their support*