Radar in Forestry

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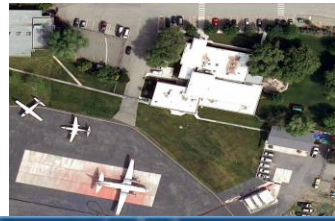


BRITISH COLUMBIA

Overview

- Motivation
- Opportunity
- Applications:
  - Change detection
  - Near real-time wildfire progression mapping
  - Forest heights, fire scar mapping
  - Forest structure parameters from L-band Quad-pol
  - Sophisticated 3d algorithms
- Outlook

Why Radar?

- Resilient to weather + illumination:
  - Cloud / smoke penetration
  - Active sensing: works at night

  - Radar measures **shape**

  (Optical measures **chemistry..** complementary info..)

- **3d capability** (advanced techniques)

Worth investing in. Typically:

- Specialized training (EE, CEng, Math/Stat. etc)
- High performance computers

Why Radar for Predictive Services?

New Radar missions: **NISAR, Tandem L, etc.**

..a Golden age for Radar for Forestry

To support:

1. **Wide-area, regular coverage and revisit times**

2. Advanced **3d techniques**:
   Interferometry, Polarimetry and Tomography. Why?

..Predictive Services Unit (Emerg. Response mandate) needs
3d / structure attributes!

..Esp. For: **Fuel Type Layer (FTL) Modernization project**

3D representation of the Stadtwald forest in Traunstein, Germany. The forest height was derived from radar data using polarimetric SAR interferometry.

From Tandem-L Handbook, Copyright © DLR

The FBP System -- Fuel specific

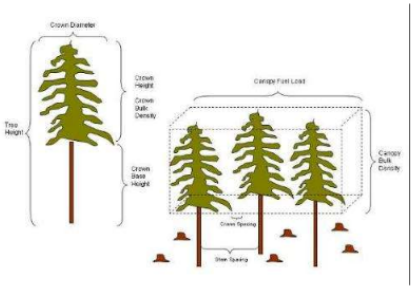
- 16 fuel types that use inputs (wx, FWI, …) and tailor fire behaviour to specific forests or grasslands
- Divided into three groups
  1. Conifer forest
  2. Deciduous and mixedwood forest
  3. Open (grasslands, forest slash)

..limitation: BC's V.R.I. (and hence BCWS's FTL) rely on manual updates by forestry co's..

FBP System: Fuels characterization

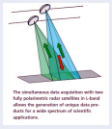
- CFS is currently working on the integration of various data sources with the goal of having basic national coverages that include estimates of these fuel attributes
  - Remote sensing, forest inventory plots, forest resources inventory, etc
  - Agencies may still want to develop their own more spatially detailed fuels layers

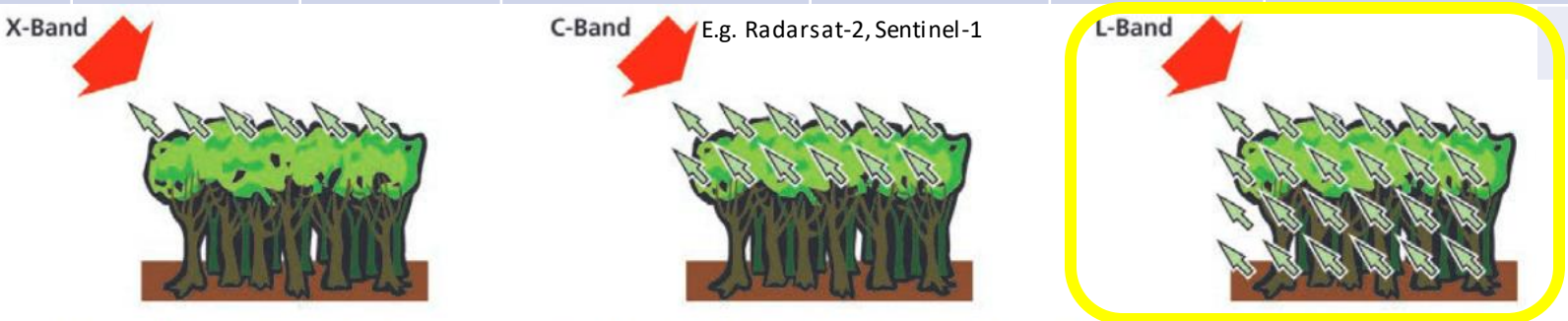
- For the most part fuels characterization focuses on:
  1. Canopy density and fuel available to burn….and also to reduce instand wind (e.g., CFL, CBD)
  2. Vertical structure (e.g., CBH)
  3. Surface fuel loading and impacts on surface fire intensity



Opportunity to measure vertical structure w the new radar missions..

Opportunity

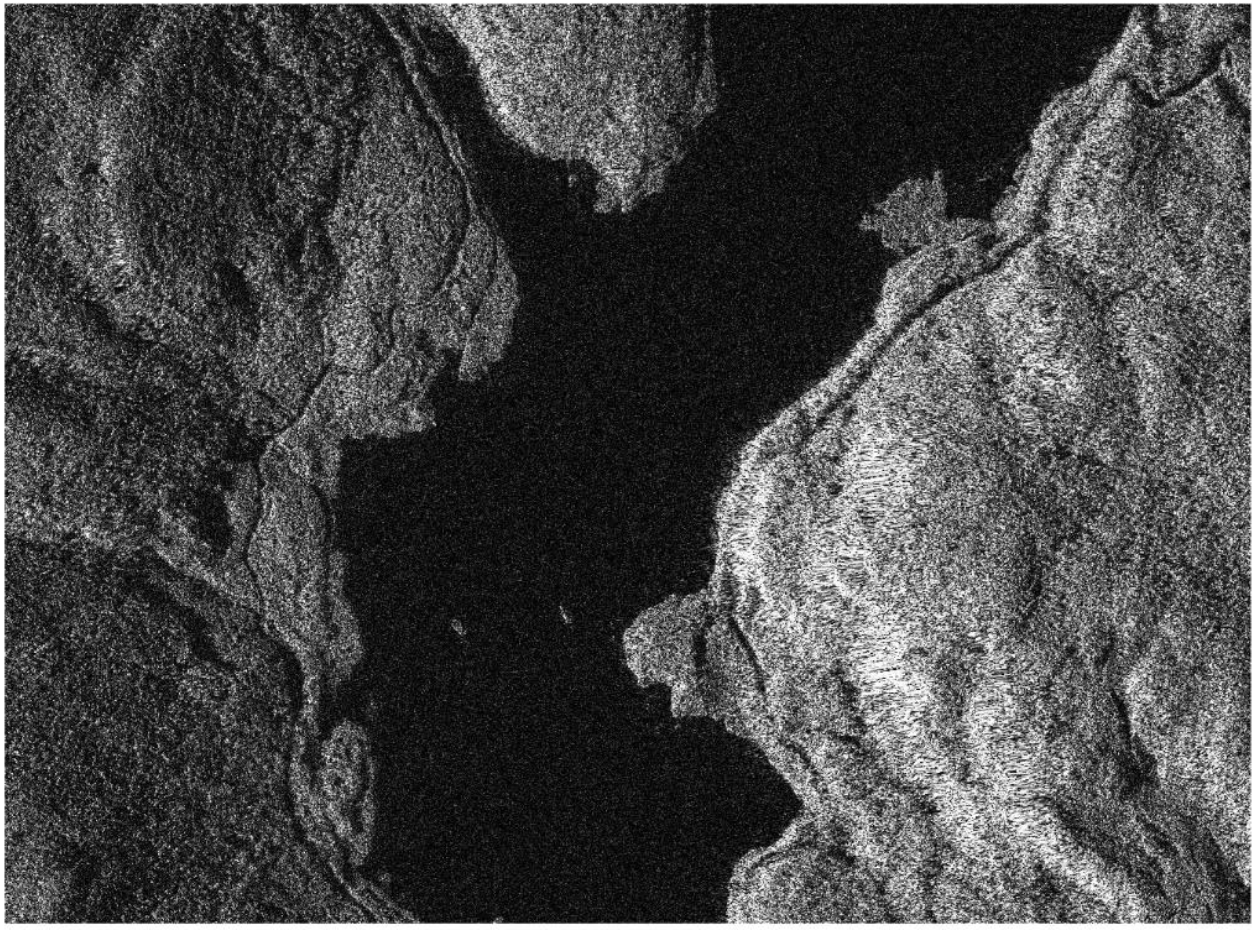
Name	Country	Life	Freq (GHz)	Min. Pixel size	Revisit (days)	# Sensors: Polarisation
Tandem-X	Germany	2007-	9.65 (X Band)	1x3 m	11	**2x:** Single, Dual, Quad
ALOS-2	Japan	2014 -	1.2 (L Band)	3x1 m	14	1x: Single, Dual, **Quad**
RCM	**Canada**	**2019 -**	**5.4 (C Band)**	**1x3 m**	**4**	**1x: Single, Dual / Compact**
Tandem-L	***Germany***	***2022 -***	***1.26 (L Band)***	***1x3 m***	***16*** 	***2x: Single, Dual Quad*** 2x sensors: like stereo vision…
NISAR (Open access! North America coverage)	***US/India***	***2022 -***	***1.25 (L Band), 3.2 (S Band)***	***3x8***	***12***	***2x: Single, Dual, Quad***



Comparison of the penetration depth in vegetation for X, C and L-band with 3 cm, 5 cm and 24 cm wavelength. While radar waves in X-band are only reflected from the upper canopy, L-band penetrates down to the ground. Only L-band radar systems can receive signals from all parts of the vegetation.

Opportunity

Radarsat-2 Ascending/Descending



Radarsat-2 **ascending** image: U20 HV SGF 20080606

45 degrees

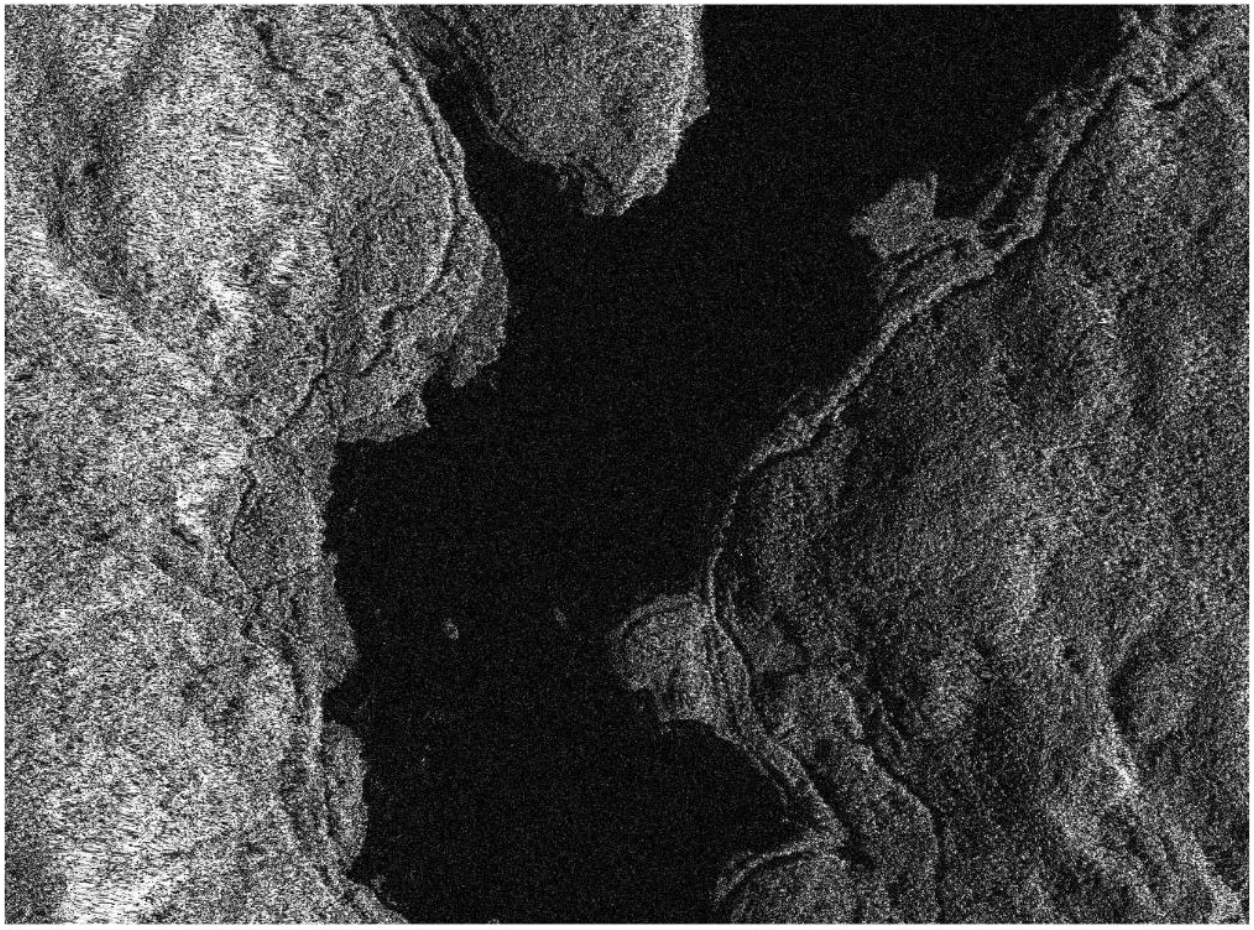
Natural Resources Canada
Canadian Forest Service

Ressources naturelles Canada
Service canadien des forêts

How to collect Radar?

May need to Consider Multiple angles..

Radarsat-2 Ascending/Descending



Radarsat-2 **descending** image: U20 HV SGF 20080707

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Canadian Forest Service

Ressources naturelles Canada
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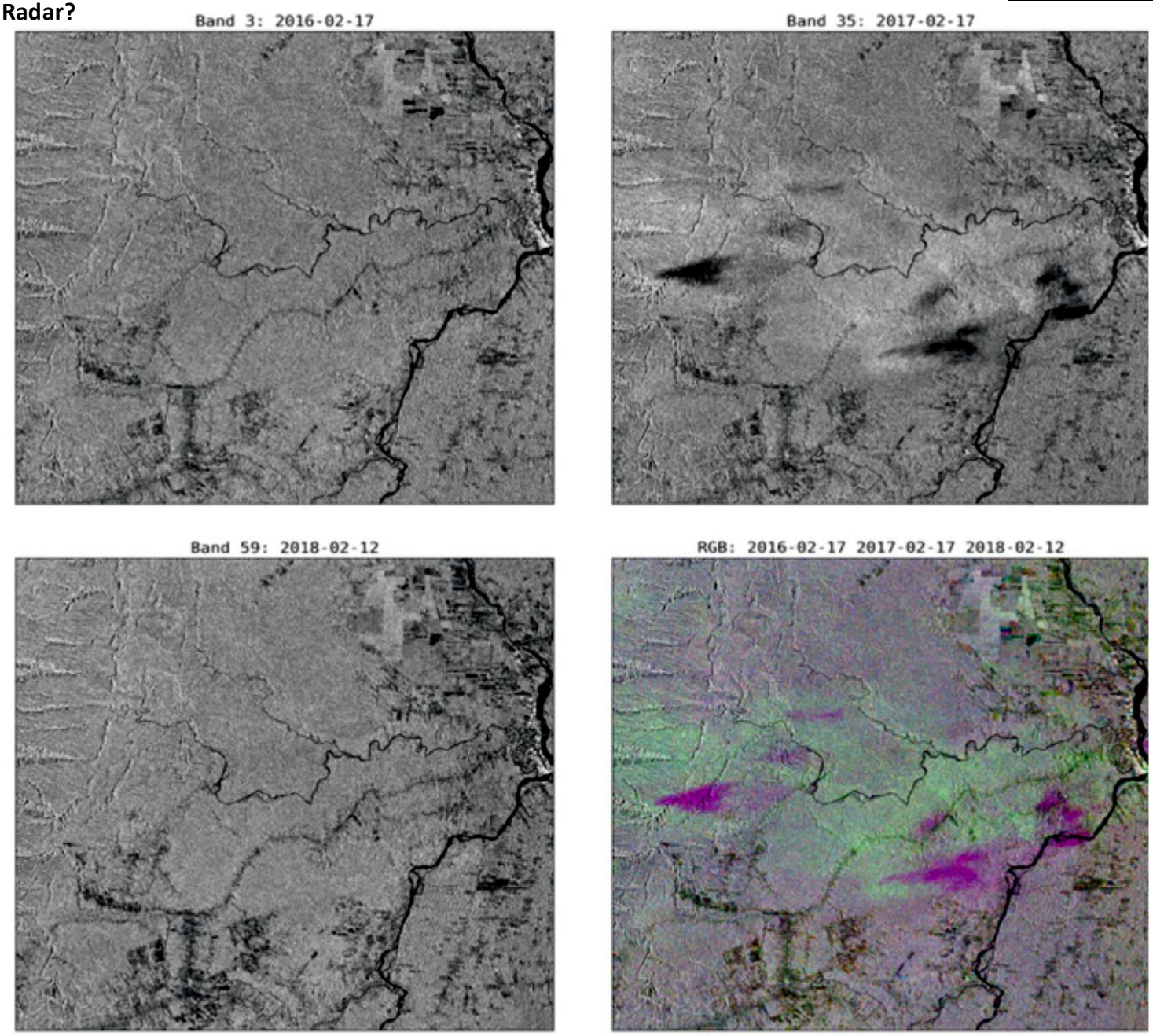
Opportunity

How to collect Radar?

Cloud free but watch out for precipitation effects..



Opportunity

Analysis ready products might select frames by analyzing weather data

Figure 3.13 *Sentinel-1 CVV example of moisture influence on enhancing and darkening backscatter*

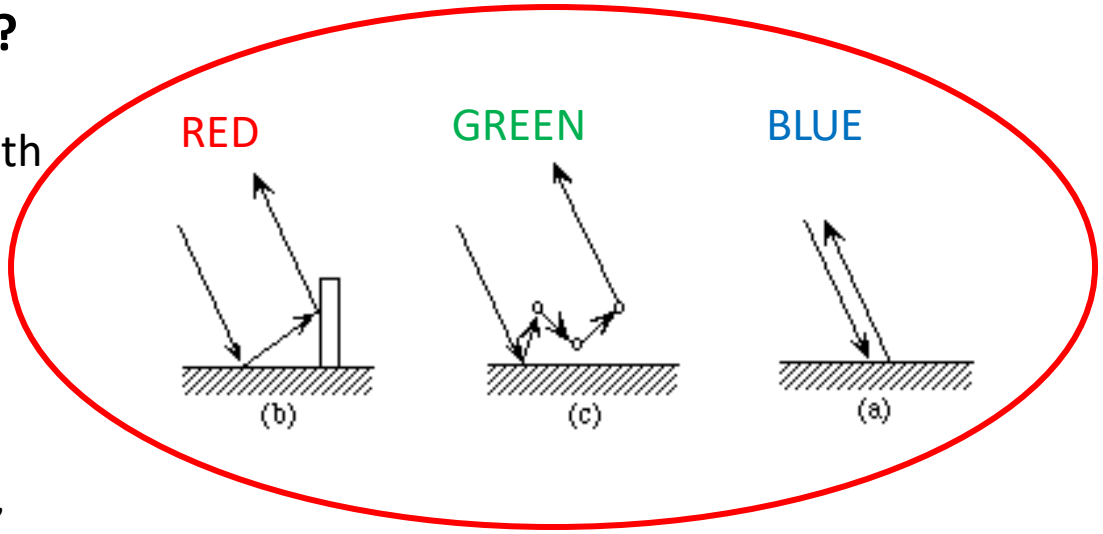
What does Radar data look like?

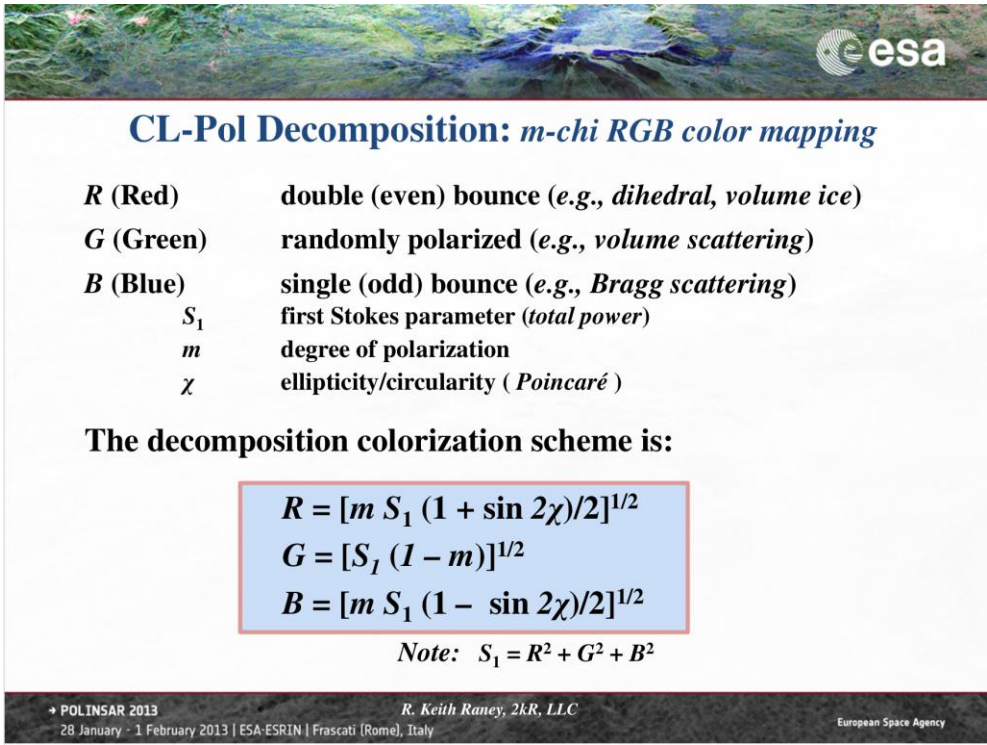
"False colour" encoding (same as with Optical)..

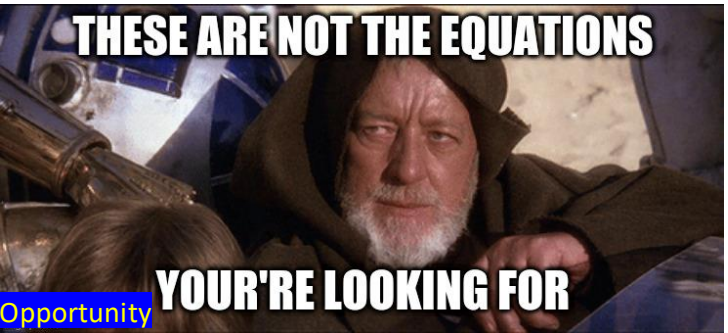
*Radar encodings show **Shapes** (vs. **Chemistry for optical**)

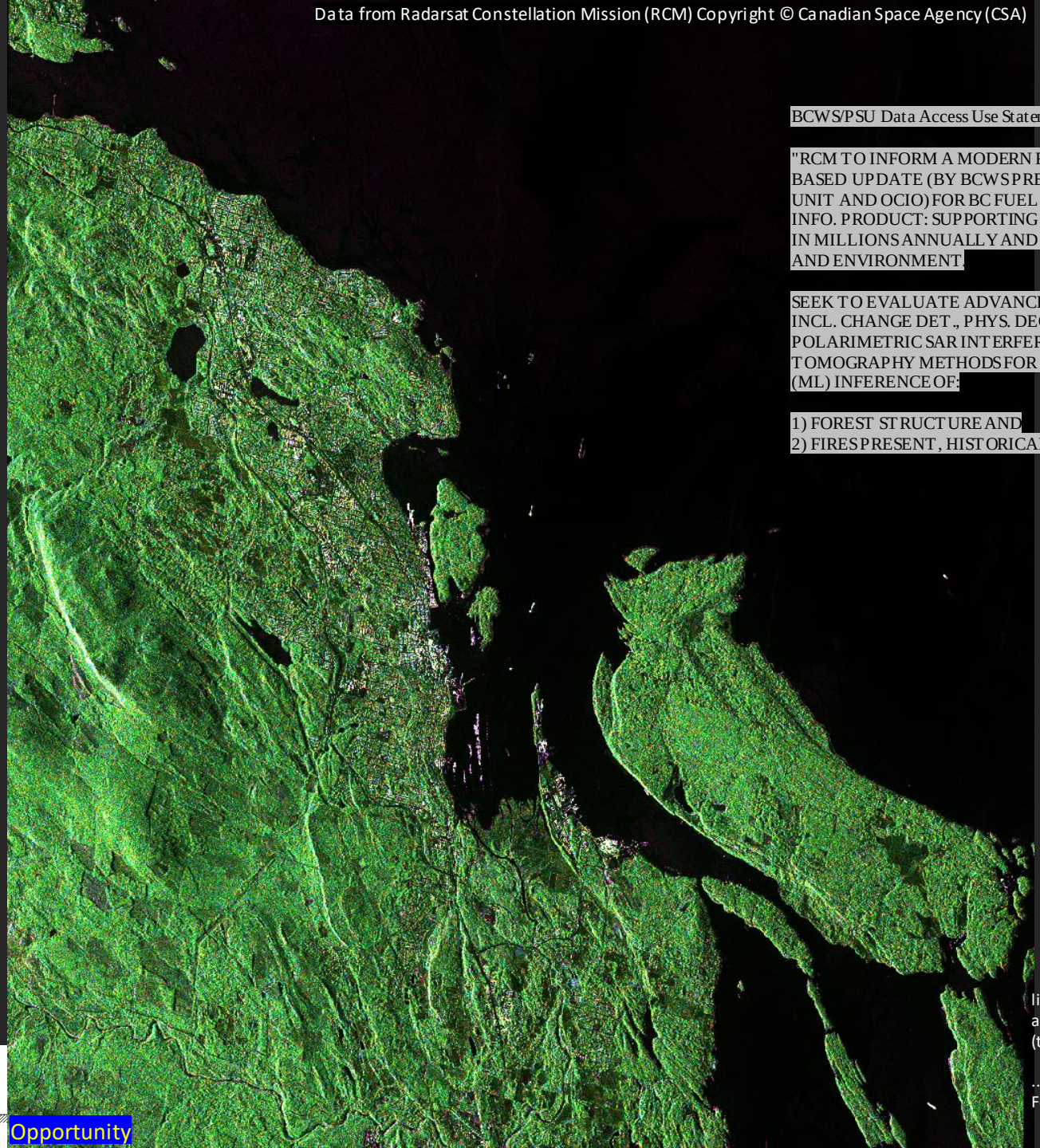
* **Each mode** (single, dual, compact, quad, etc.) **needs a special encoding**

* ..Right: **RGB encoding for compact mode (used for RCM)**









BCWS/PSU Data Access Use Statement for RCM:

"RCM TO INFORM A MODERN REMOTE SENSING (RS) BASED UPDATE (BY BCWS PREDICTIVE SERVICES UNIT AND OCIO) FOR BC FUEL TYPE LAYER (FTL) INFO. PRODUCT: SUPPORTING DECISIONS VALUED IN MILLIONS ANNUALLY AND AFFECTING CITIZENS AND ENVIRONMENT.

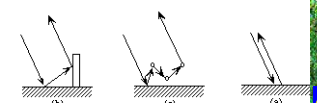
SEEK TO EVALUATE ADVANCED APPLICATIONS INCL. CHANGE DET., PHYS. DECOMP., COMPACT-POLARIMETRIC SAR INTERFEROMETRY AND TOMOGRAPHY METHODS FOR MACHINE LEARNING (ML) INFERENCE OF:

1) FOREST STRUCTURE AND
2) FIRES PRESENT, HISTORICAL OR ANTICIPATED"

likely need our Execs. to support an acquisition pattern change request (to CSA) to deliver..

..Need regular / periodic coverage on Forested areas!!

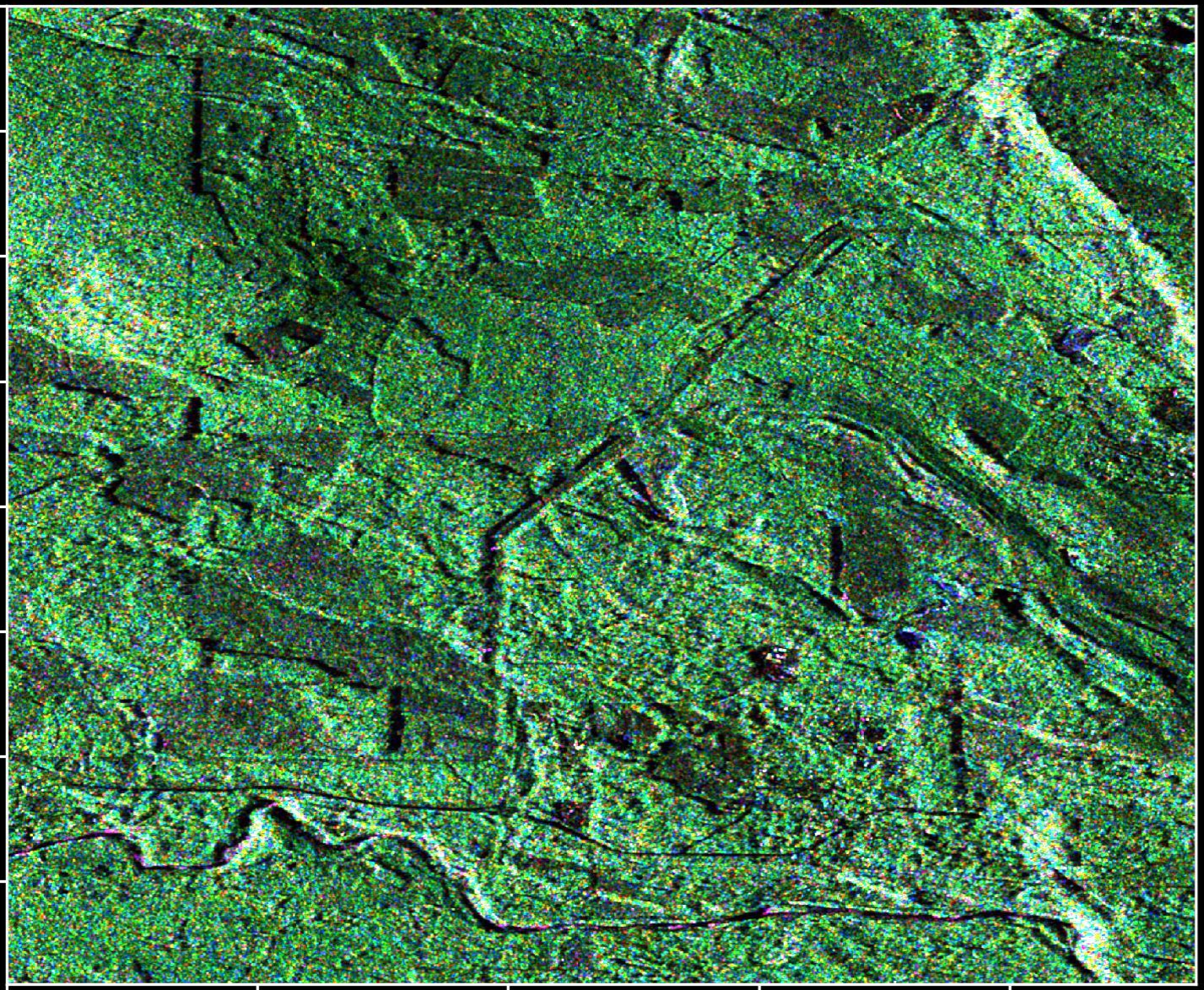
RED GREEN BLUE



Opportunity

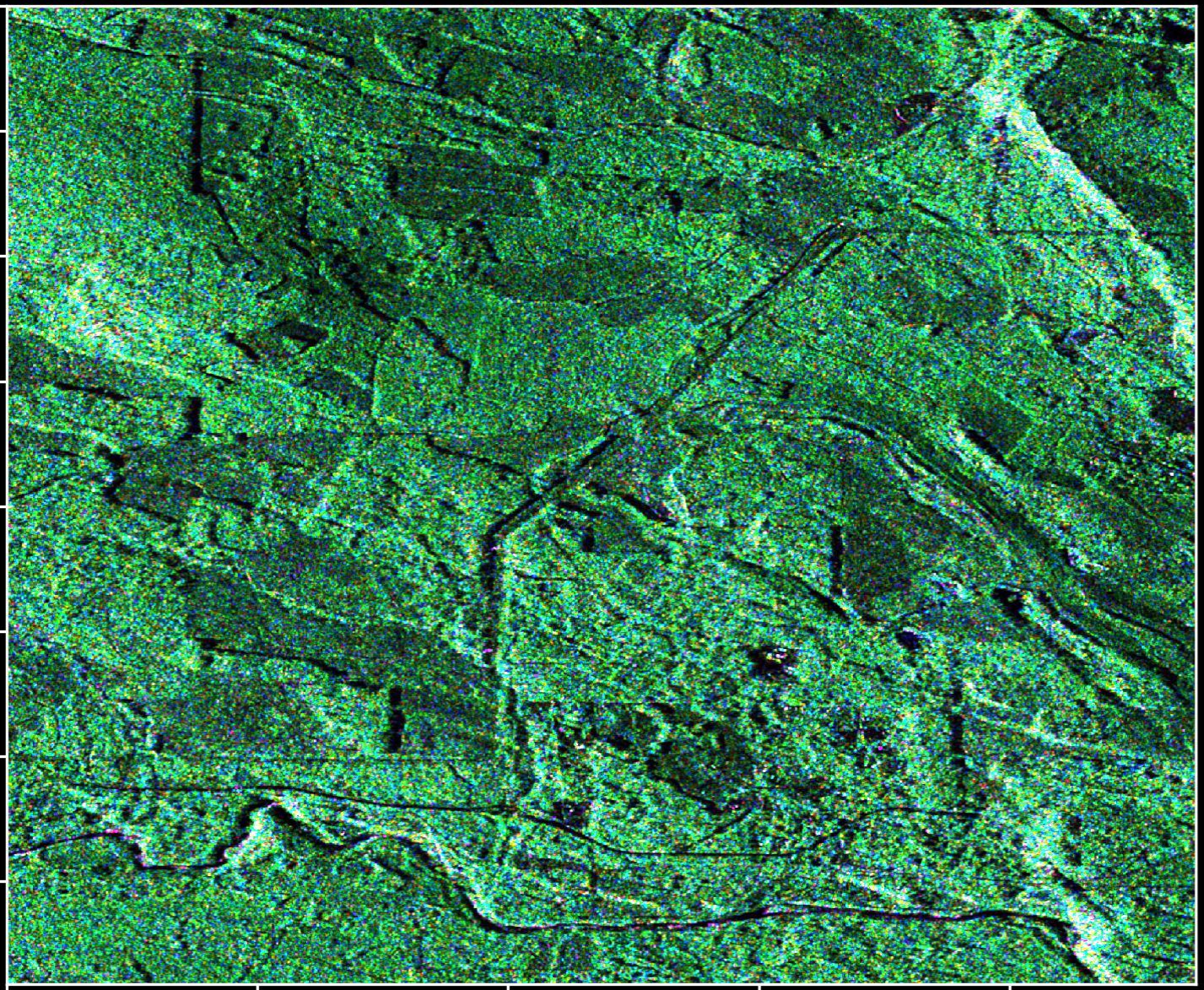

Data from Radarsat Constellation Mission (RCM) Copyright © Canadian Space Agency (CSA)
Opportunity

RCM 20200815



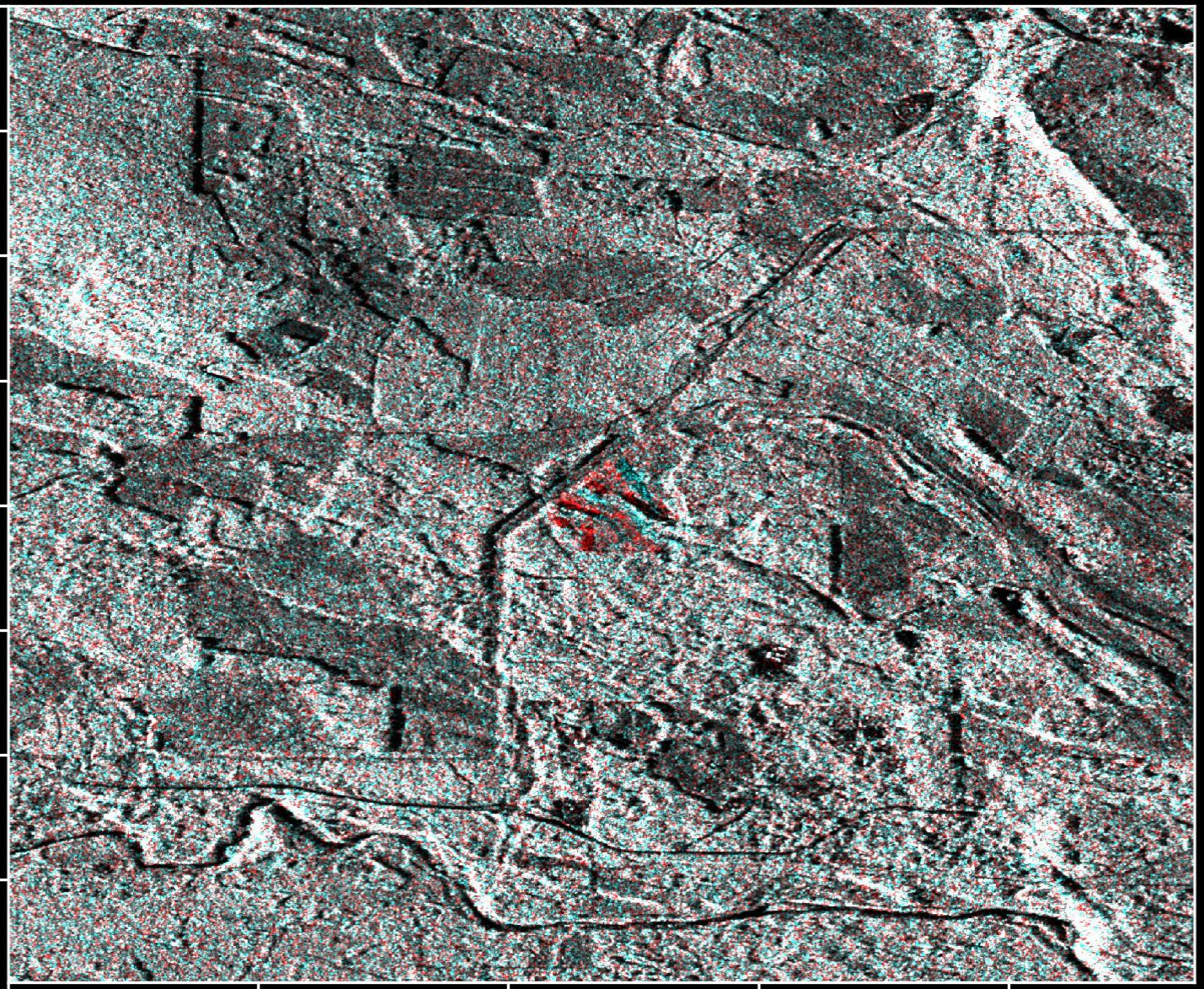
R, G, B = (dihedral, volume, surface)

RCM 20200831



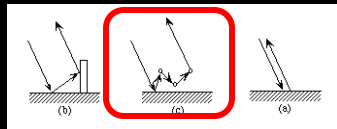
R, G, B = (dihedral, volume, surface)

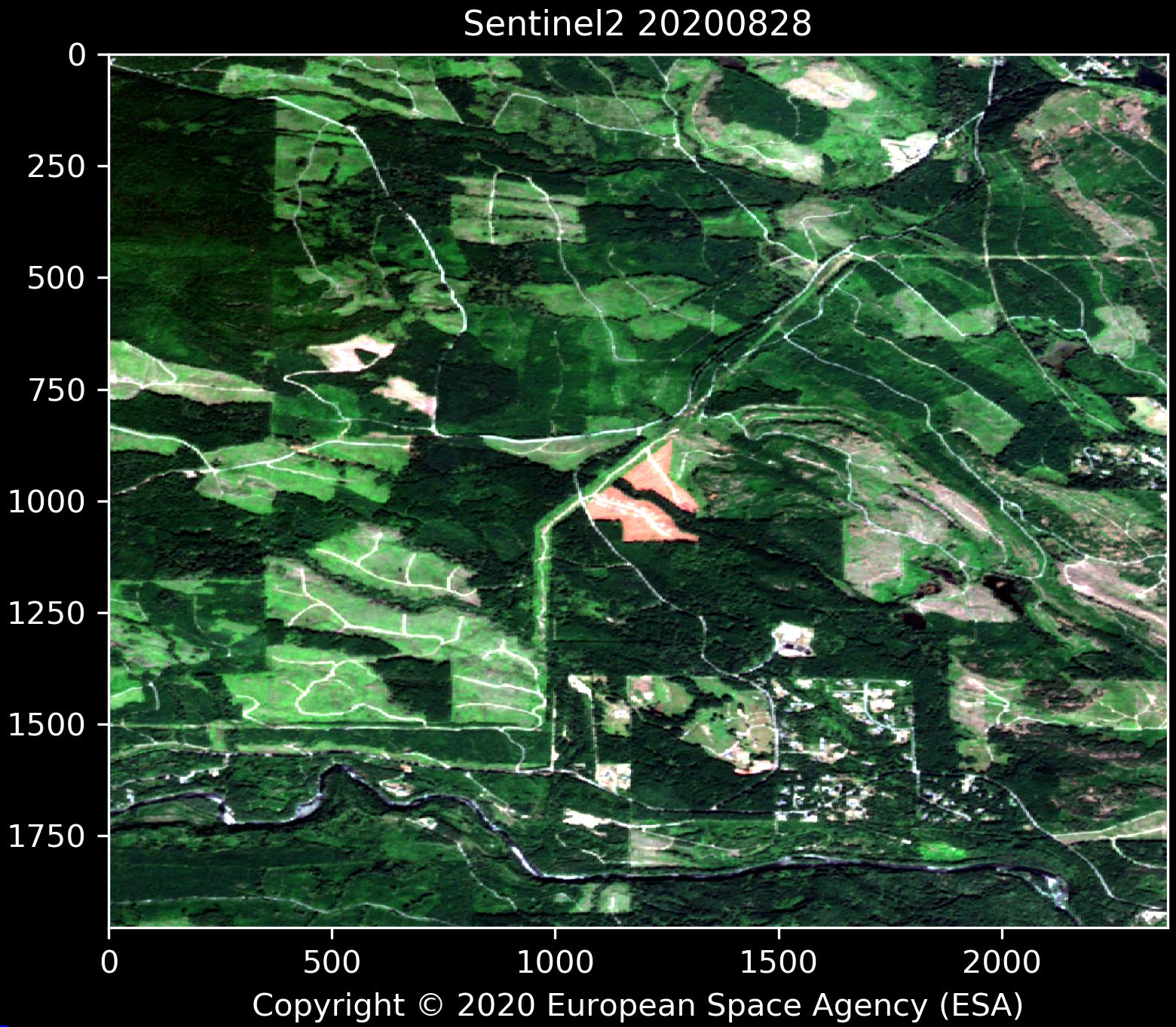
R, G, B = vol(0815), vol(0831), vol(0831)



Applications

Crude calibration: Match means (0831 := 0831 - (mu(831) - mu(815)). Assign volume element from 1st date as red





Applications

RCM can do change detection. For 3d interferometry applications, may need to data-mine the archive to find the best repeat-passes...

Now.. Near real-time Wildfire progression monitoring..

Sentinels have the regular coverage / open data access that other programs don't!

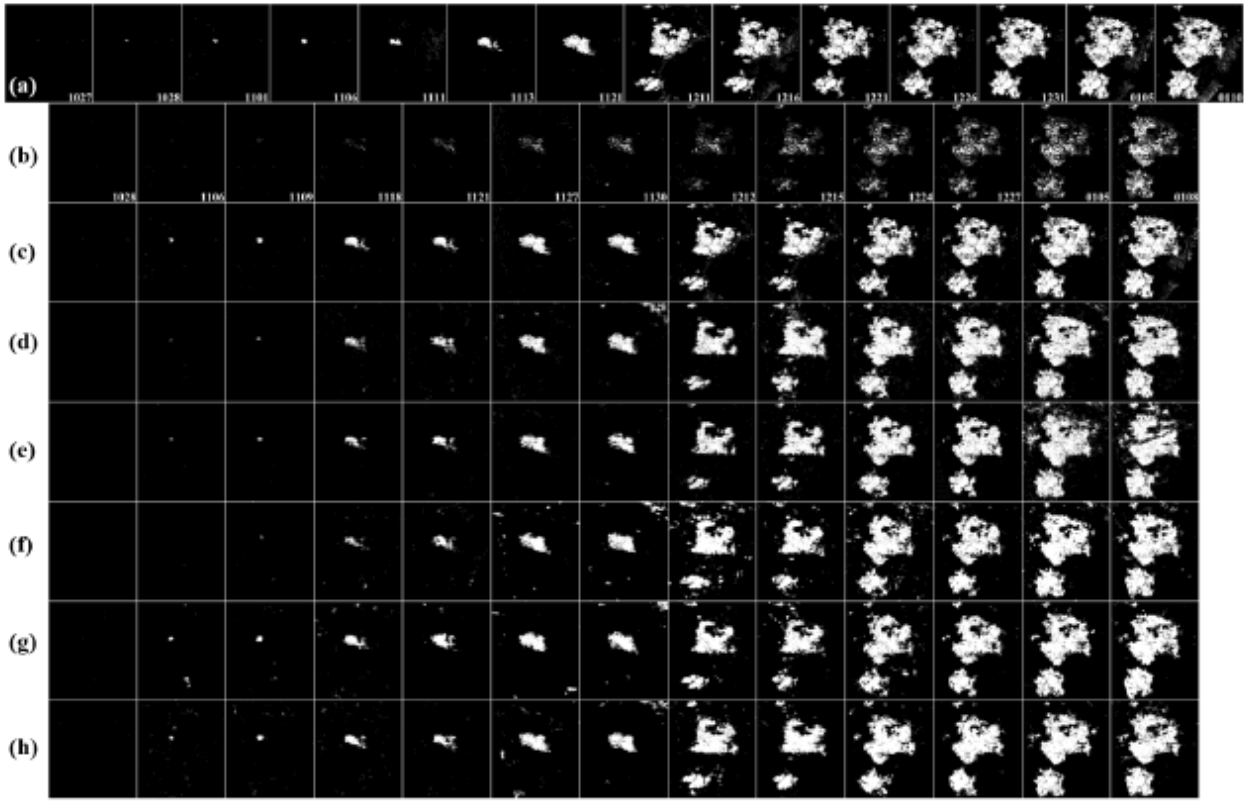


Figure 8: Results on the Sydney fire: (a) Optical Pseudo reference masks. (b) SAR-based Pseudo reference masks. (c) Fused reference masks. (d) U-Net Segmentation results on SAR data (Initialize encoder network once with pre-trained ResNet-50, train decoder only). (e) U-Net Segmentation results (Re-initialize encoder network every new coming date with pre-trained ResNet-50 on ImageNet dataset, train decoder only). (f) U-Net with LwF ($\lambda = 0.5$, Backbone: ResNet-18). (g) U-Net with LwF ($\lambda = 0.5$, Backbone: ResNet-34). (g) U-Net with LwF ($\lambda = 0.5$, Backbone: ResNet-50).

Applications

Ban, Y., Zhang, P., Nascetti, A., **Bevington, A. R.,** & Wulder, M. A. (2020). Near real-time wildfire progression monitoring with Sentinel-1 SAR time series and deep learning. Scientific Reports, 10(1), 1322. https://doi.org/10.1038/s41598-019-56967-x

Now.. Near real-time Wildfire progression monitoring..

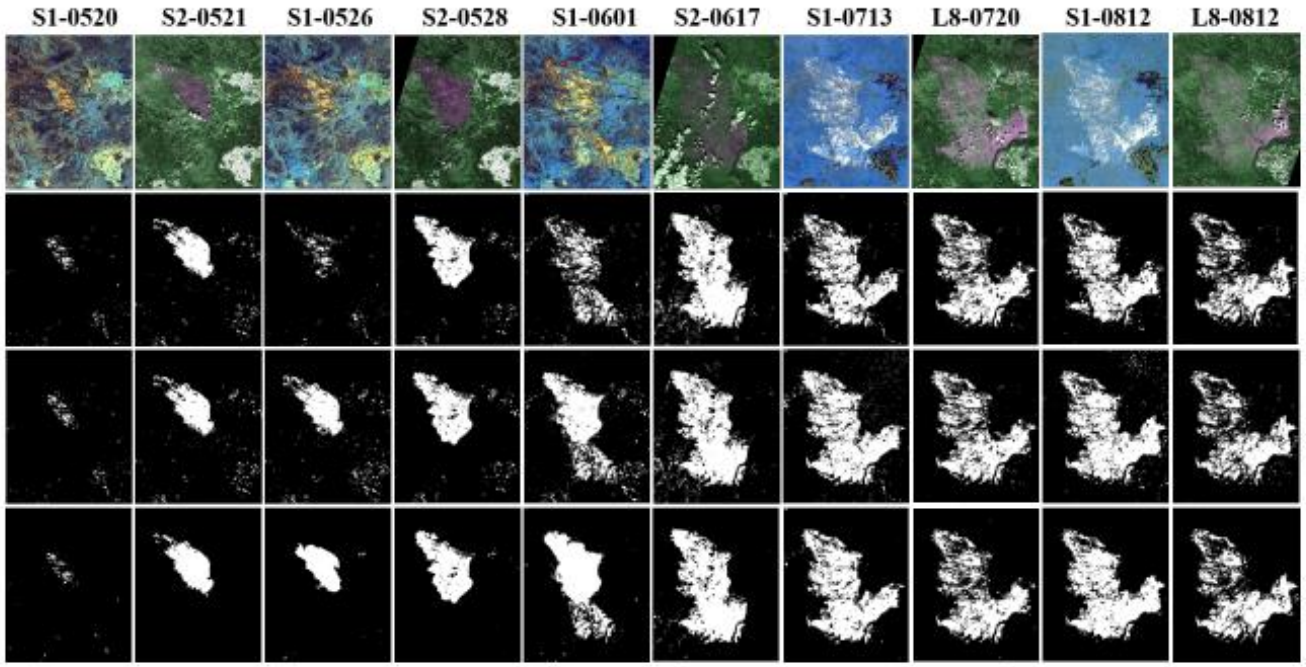


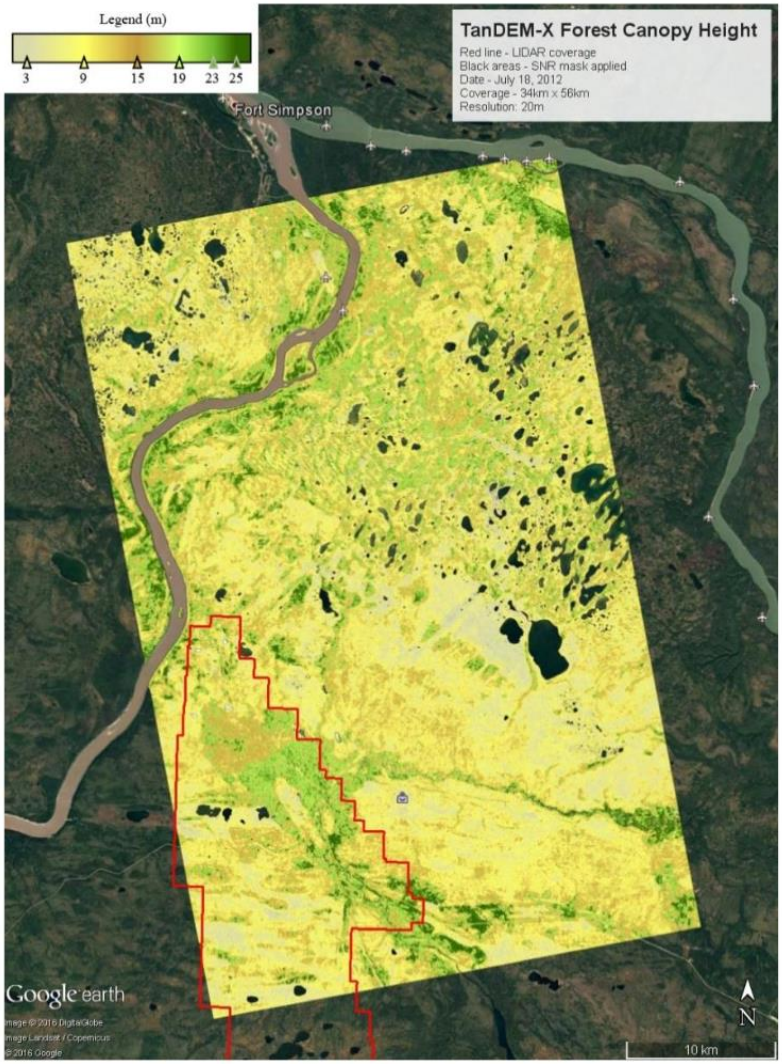
Figure 9: Results on the Chuckegg Creek Fire. (a) Optical and SAR false color composite maps (optical: [SWIR2, SWIR1, SWIR2], SAR: [kVV, kVH, kRBR]). (b) Single-sensor based Pseudo reference masks (optical: binarized dNBR1, SAR: binarized kVV). (c) Fused Pseudo reference masks. (d) Predicted burnt area maps by U-Net with LwF ($\lambda = 0.5$, Backbone: ResNet-50).

Applications

Ban, Y., Zhang, P., Nascetti, A., **Bevington, A. R.,** & Wulder, M. A. (2020). Near real-time wildfire progression monitoring with Sentinel-1 SAR time series and deep learning. Scientific Reports, 10(1), 1322. https://doi.org/10.1038/s41598-019-56967-x

Forest Height from TanDEM-X Interferometric Data

- Used TanDEM-X interferometric data for spatially-extensive forest height mapping over a study region near Fort Simpson in the NWT;
- Applied a simplified RVOG model to combine TanDEM-X interferometric data and the Canadian Digital Surface Model accounting for local slope variations;
- Validated against the field survey data and a LiDAR stand height map; good linear agreement was found, but with bias and forest cover type effects;
- Corrected the bias of TanDEM-X heights using LiDAR-based and cover-specific linear adjustments, providing a final TanDEM-X height map with R^2 of 0.83 along with RMSE of 2.94 m at 25 m pixels across all forest cover types;
- Support the perspective of wall-to-wall mapping of forest height across large stretches of northern boreal forests in the NWT with good accuracy.

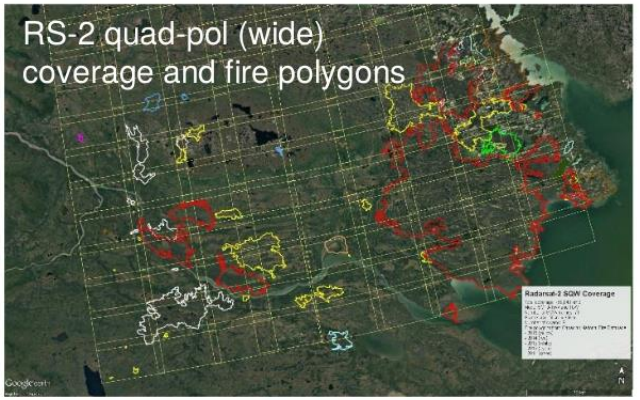


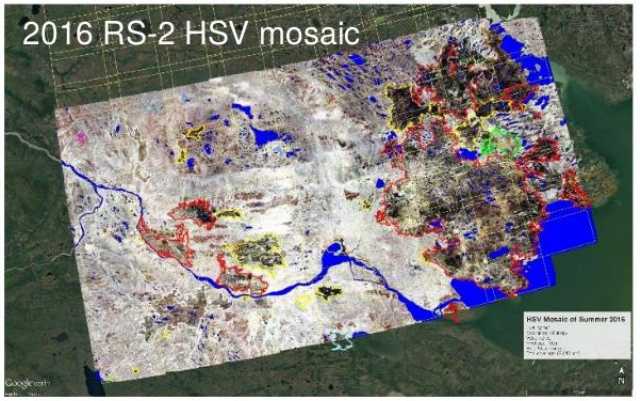
H. Chen, A. Beaudoin, D. A. Hill, S. R. Cloude, R. S. Skakun & M. Marchand (2019): Mapping Forest Height from TanDEM-X Interferometric Coherence Data in Northwest Territories, Canada, Canadian Journal of Remote Sensing, DOI: 10.1080/07038992.2019.1604119, May 2019

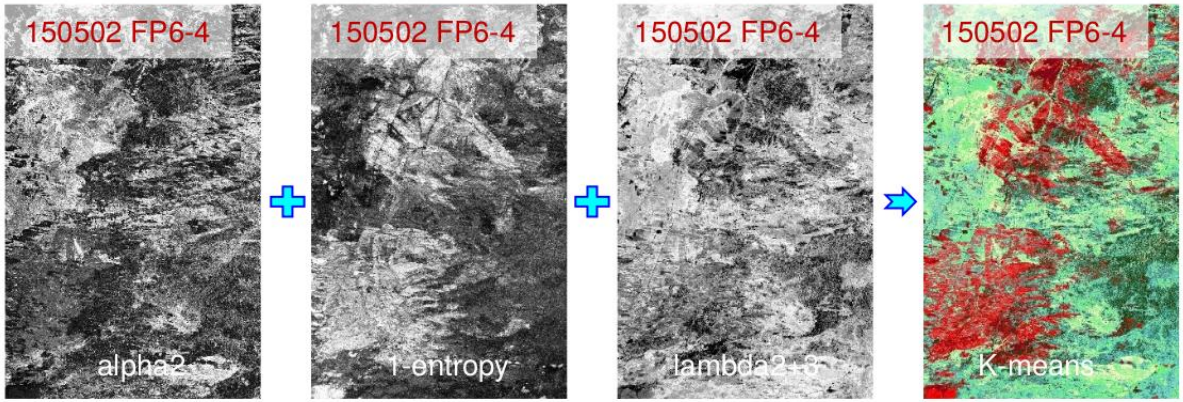
Now.. Historical fire scars have distinct signatures in Quad-pol..

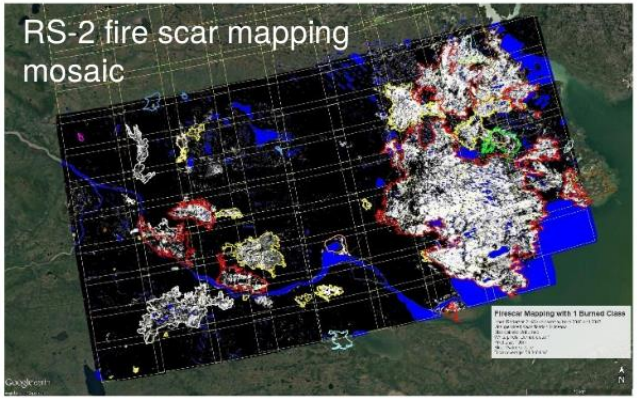
SAR-based Fire Scar Mapping

- Polarimetric-based fire scar mapping methods
  - Eigenvector-based decomposition parameters to create HSV mosaics for polarimetric information of fire scars
  - K-means for a second-stage classification
- Fire scar mapping from Radarsat-2 C-band polarimetric data
  - A regional mosaic of 71 individual SQW10-18 scenes to cover an area of 328 × 180 km^2 in NWT at a pixel size of 100 m
- Fire scar mapping from ALOS-2 L-band polarimetric data
  - An area of 42 × 68 km^2 with 30m pixels









Multi-Parameter Radar Forestry:
a Glimpse of the Future

NASA-ISRO NISAR Radar:

- Planned Launch 2022

- Long Wavelength (L-band) High Resolution

- Wide Area/Frequent Imaging

- Full North America Coverage

- NASA open data policy

- QuadPOL mode = new forest products..
…an example

The present…

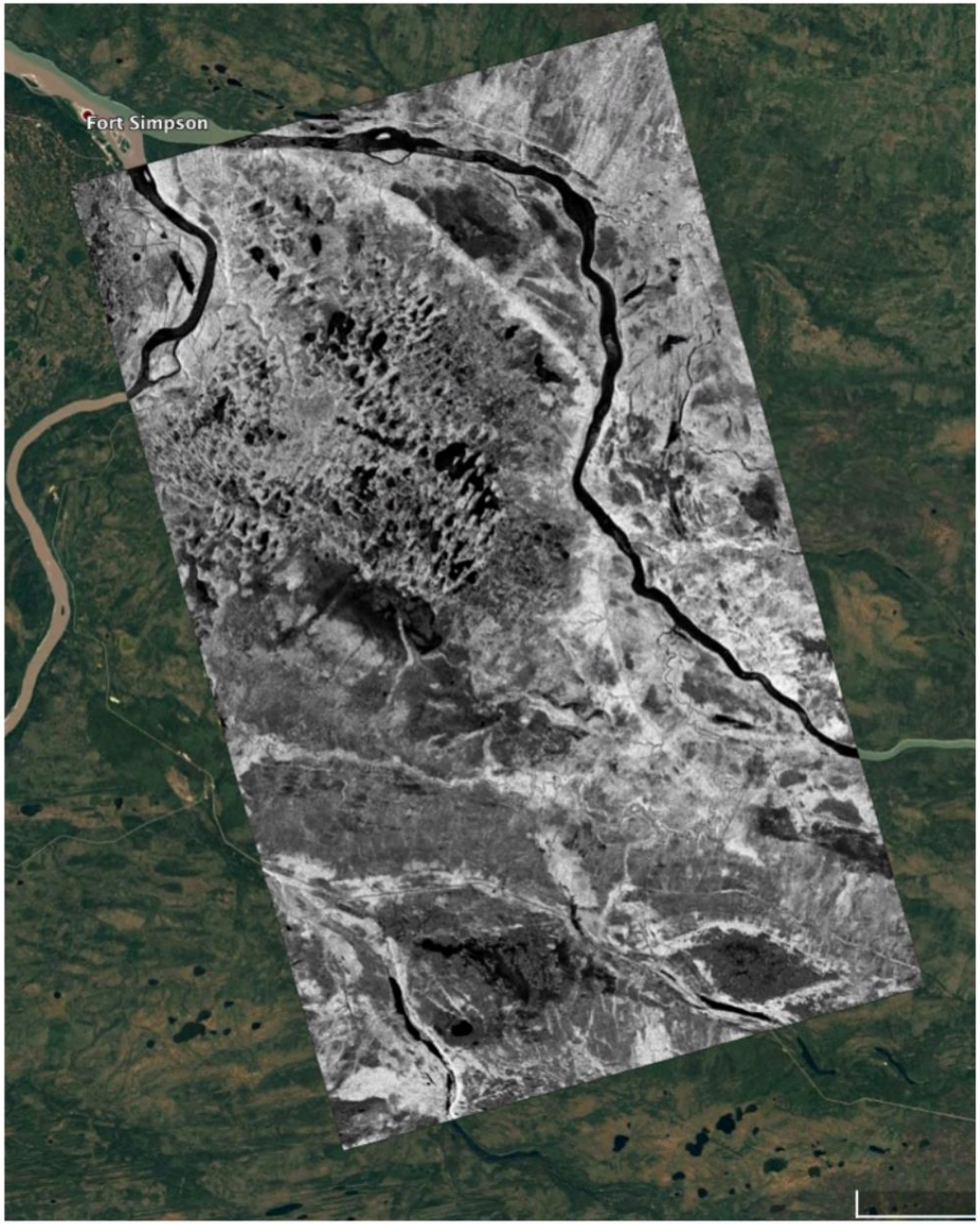
L-band HV image..typical product

..around Fort Simpson NWT….
24th April 2015

Bright areas = forest

Cross-polarization channel
detects vegetation biomass..
but no information about
structure…

Data from L-band ALOS-2
courtesy of JAXA



The future…

L-band QuadPOL image around Fort Simpson NWT….

3 new forest parameters:

-Radar Vegetation Index (RVI)
-Canopy Structure Index (CSI)
-Forest Degradation Index (FDI)

Combined into single RGB to obtain:

White = healthy canopy forest
Green = non-forest
Red = disturbed forest

Data from L-band ALOS-2 courtesy of JAXA

Why are QuadPol techniques special?

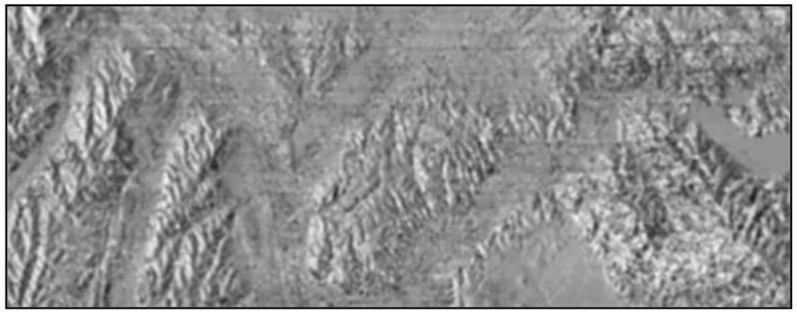
- Extra parameters for classification
- Quadpol data inherently **three-dimensional**

θ Compensation (1)

- Given θ, compensate scattering matrix (S2)

$$S^{(new)} = \begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix} \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix}$$

- A θ image bellow derived from an 1996 AirSAR P-band data over Camp Roberts, California, using our implementation matched the results published in the Dr. Lee's paper.



θ image derived from AirSAR P-band data over Camp Roberts

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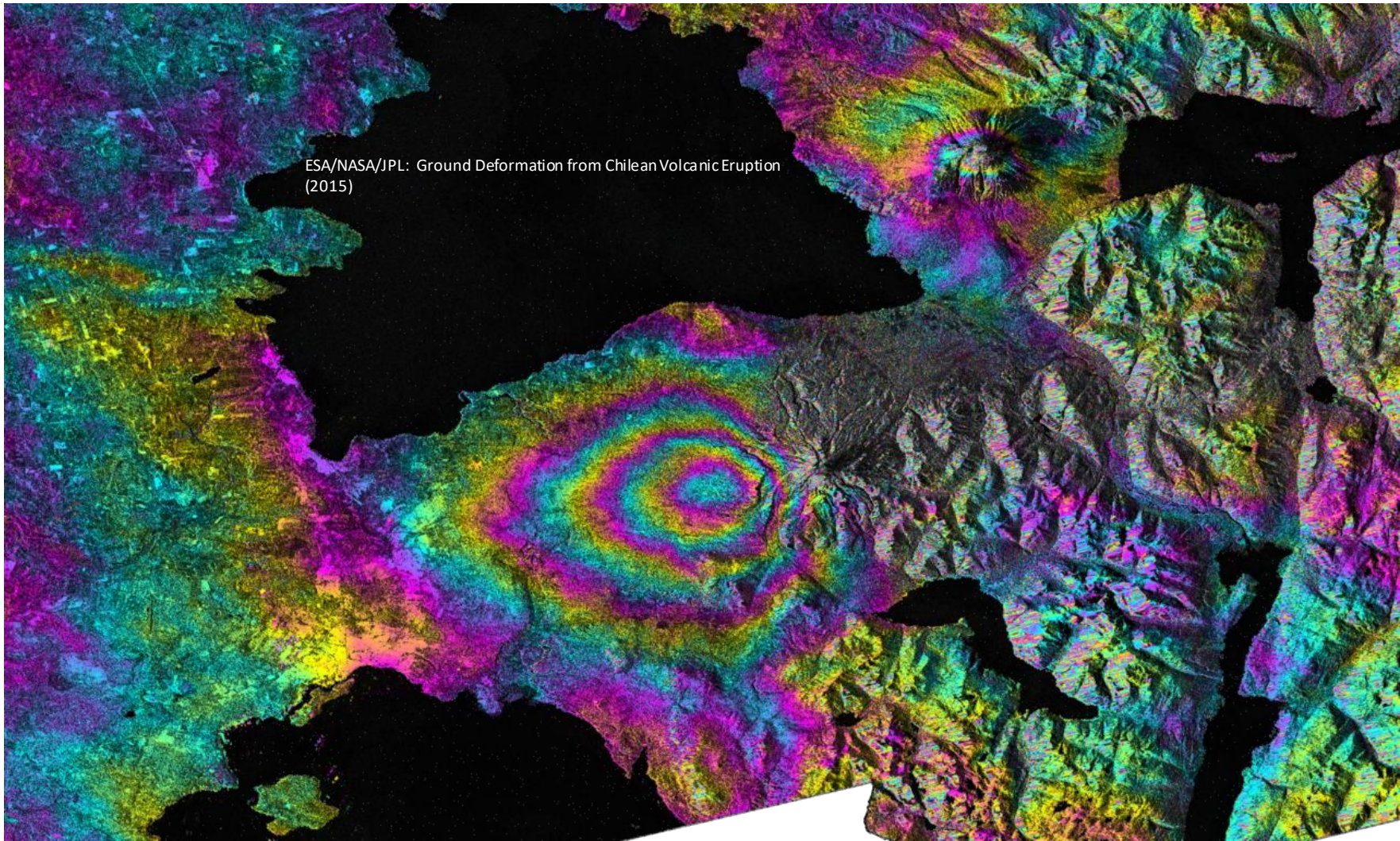
Why are Interferometry (InSAR) techniques special?

- **3-D imaging. How?**
- Radar data is made of **complex numbers:**
  - Complex numbers **have phase (below).. interferogram**



How to learn QuadPol / Interferometry techniques?

- Hope to benefit from knowledge transfer with ESA..

..access to the best people!

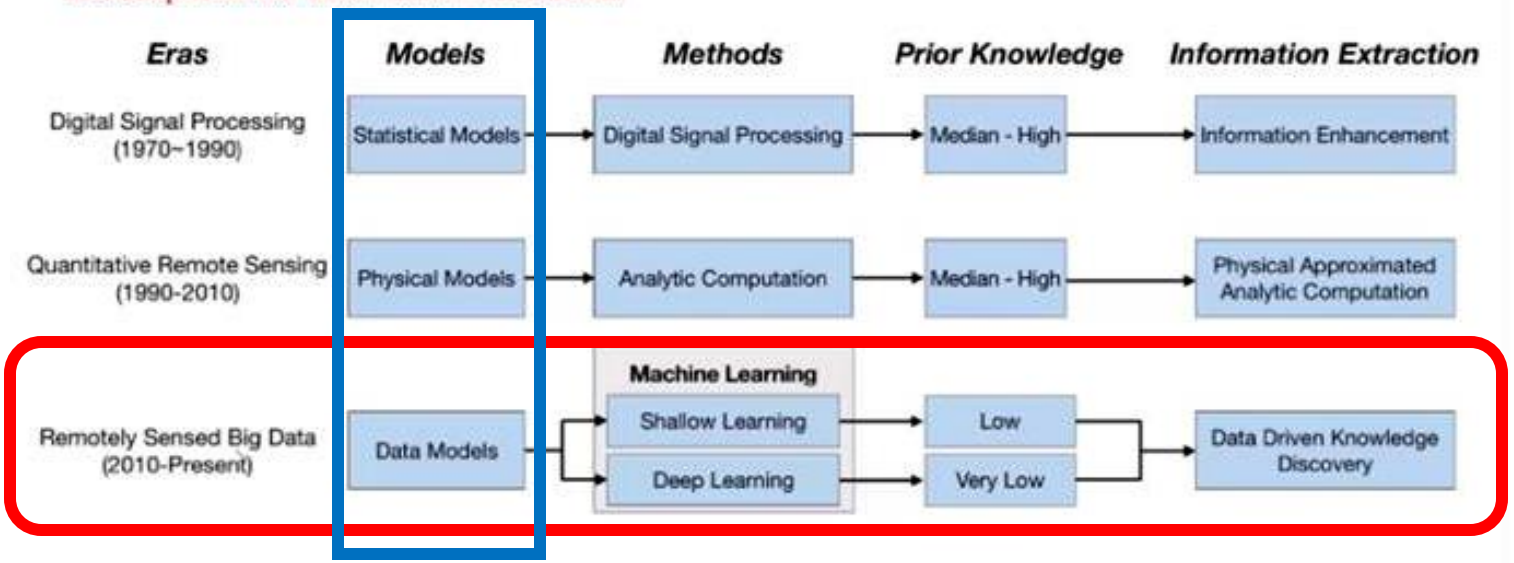
Outlook

Three eras of Remote Sensing…

.. in Big Data era, might we also need the best computers?

Background

Proceedings of the IEEE has published an article "Remotely Sensed Big Data: Evolution in Model Development for Information Extraction."



- Remote sensing data information extraction technologies are gradually entering a "remotely sensed big data era."
- It is important to combine the advantages of statistical models, physical models and data models to leverage their unique capabilities in complex scenarios.

..HPC req'd to inhabit Big Data era?

Outlook

Hypothetical suggestions…

1. More National / Int'l collab?

- Team up on better sensors w more-regular updates in space and time, particularly good coverage to support NR applications?

2. Can BC prepare for NISAR / TandemL missions, now? E.g. develop internal radar remote sensing capacity as a shared service..

a) Hire EE, CEng, CSc, Math/Physics Grads (or masters level co-op students)..

..dedicated to **test / flesh out complex Quad-pol / Interferometry data flows?**

b) Industry standard HP-Z8 linux HPC node for:
streaming filtering, integration and stacking of Sentinel-1, Sentinel-2, Sentinel-3, etc.? E.g. 100 thread, 1TB ram, 8x16TB HDD

* **AI / ML applications**
* **analysis ready products (full province)** at e.g. monthly interval for internal use
* Internal capacity to adapt to new missions, **without risk of IT cost overruns**

* Future option: could benefit from NRCAN lessons learned and scale up to: in-house research compute facility for NR Sector (e.g. PFC Boreal cluster)

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AEL consultants

Thanks to partners!

OCIO

Office of the Chief Information Officer