Radar Polarimetry for Forestry Applications: ALOS and Radarsat-2 studies in Canada

by

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Overview

- Introduction : Current Radar Satellites and Forestry
- Quadpol radar : a new dimension for remote sensing
- Application 1 : Fire Scar Detection
  - Automatic detection of fire scars
  - A coherence classifier and interpreting signatures
- Application 2 : Biomass Estimation
  - Higher Sensitivity and Saturation levels
  - Case Study : Temperate Rainforest on Victoria Island
- Conclusions and Future Work

Why Radar Forestry in Canada?

- Canada contains 10% of the world's forest cover and Canada's northern latitudes are dark six months of the year.

- Observed climate change is increasing frequency and size of wild fire events in Canada's forests. The size, distribution, and remoteness of these boreal forest fire events makes them a challenge to accurately monitor. Need to monitor historical fire scar rates to assess change…

2 main test areas used here

GVWD, Victoria : temperate rainforest
Key River, Alberta : Fire scar region

Support data includes:

3-D landcover maps from
- UVic airborne system:
- Hyperspectral data
- Lidar

Satellite radar remote sensing

- Examples of current systems

Name	Country	Life	Frequency (GHz)	Pixel size*	Revisit time (days)	Polarisation
Envisat	ESA	2002-11	5.31	20 x 4 m	35	Single or dual but not coherent
ALOS-PALSAR	Japan	2006-11	1.27	10 x 10 m	46	Single, dual, Quad
Radarsat-2	Canada	2008-12	5.405	5 x 7 m	24	Single, dual, Quad
TerraSAR-X Tandem-X*	Germany	2007-12	9.65	1 x 3 m	11	Single, dual coherent Quad (experimental)

*Tandem-X launched successfully on June 21st 2010
….to provide single pass interferometry

Quadpol radar :The extra information

Quadpol radars image all possible combinations of horizontal (H) and vertical (V) polarisations..leads to matrix generalisation of backscatter cross-section…

$$\sigma_{ijkl} = \lim_{\substack{r \to \infty \\ A \to \infty}} \frac{4\pi r^2}{A} \frac{\left\langle E_i(\underline{r}) E_k^*(\underline{r}) \right\rangle}{E_j E_l^*} \longrightarrow [C] = \begin{bmatrix} \sigma_{HHHH} & \sigma_{HHHV} & \sigma_{HHVH} & \sigma_{HHVV} \\ \sigma^*_{HHHV} & \sigma_{HVHV} & \sigma_{HVVH} & \sigma_{HVVV} \\ \sigma^*_{HHVH} & \sigma^*_{HVHV} & \sigma_{VHVH} & \sigma_{VHVV} \\ \sigma^*_{HHVV} & \sigma^*_{HVVV} & \sigma^*_{VHVV} & \sigma_{VVVV} \end{bmatrix}$$

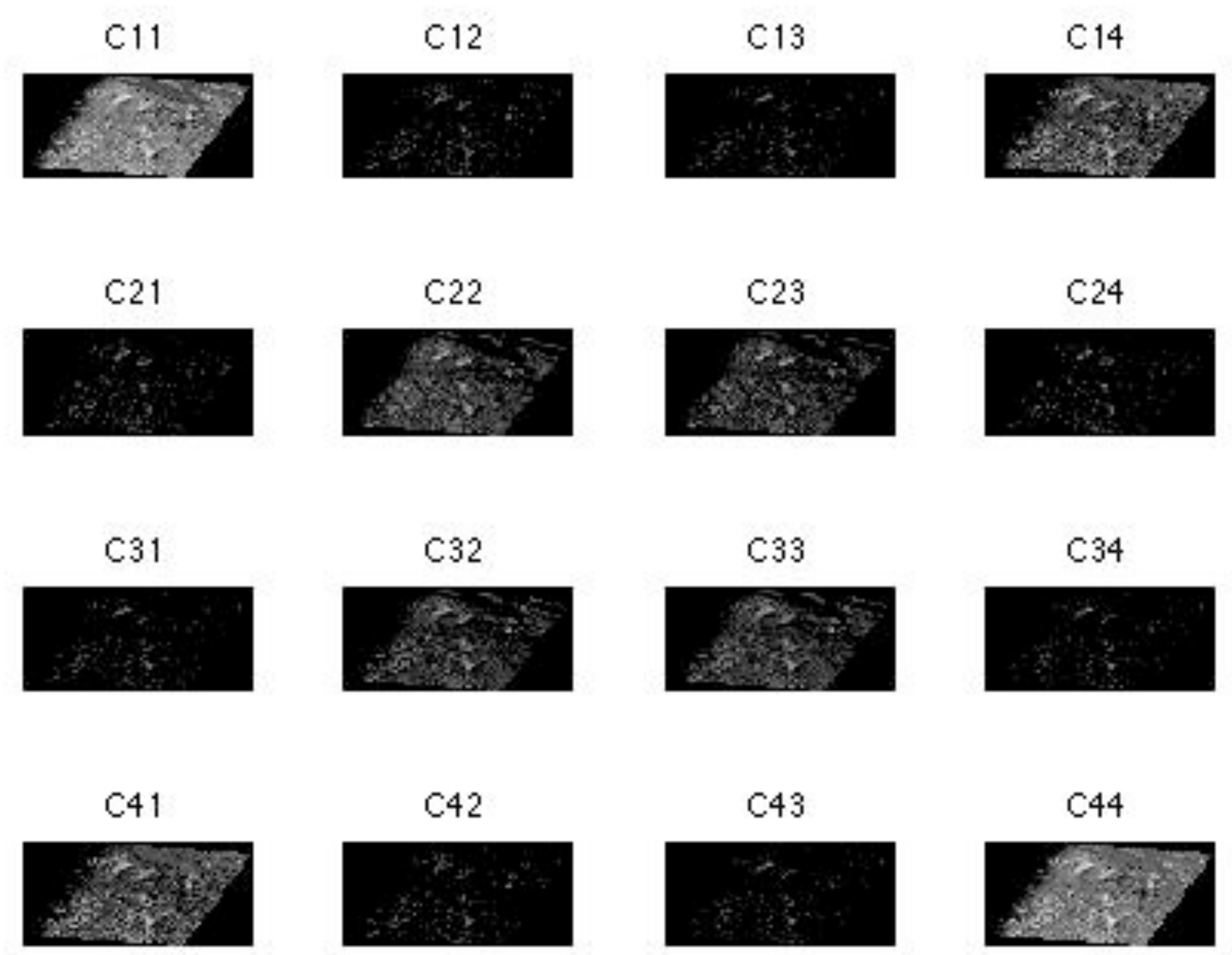
3 important points:

1. 'Standard' cross sections lie along diagonal

2. New off-diagonal terms are complex…i.e. amplitude and phase

3. From the eigenvalues and eigenvectors of [C] we can derive two important parameters : entropy H and alpha angle α*

*S R Cloude "Polarisation:Applications in Remote Sensing", Oxford University Press, 2009



Geocoded Covariance Matrix Elements:
ALOS PALSAR L-Band Data GVWD, Victoria

Application 1 : Historical Fire Scar Detection

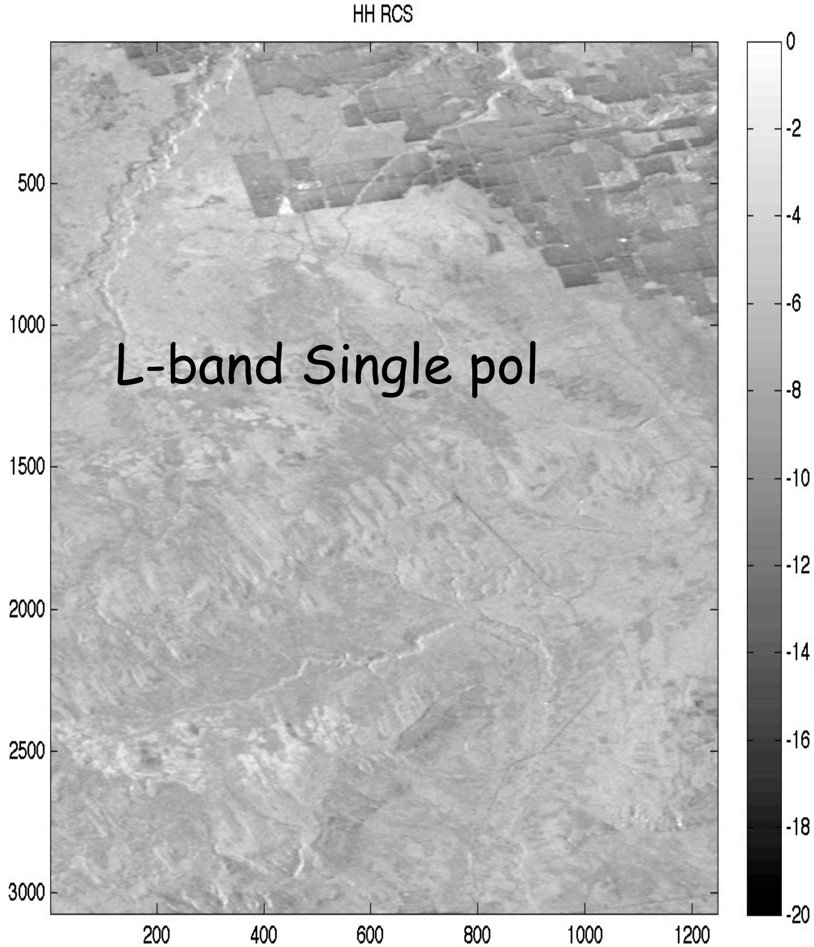
SAR for Fire Scars

- Traditional ways for getting information of fire damaged areas
  - ✓ Sketch mapping from small airborne platforms
  - ✓ GPS mapping from helicopters
  - ✓ Photo-interpretation
  - ✓ Landsat modified burn ratio (dNBR)

- Limitations
  - ✓ GIS wildfire polygon data varies in quality due to the limitations of traditional GIS technologies available at the time. Generally the older the data the less reliable it becomes.
  - ✓ Limited optical application due to adverse weather and illumination conditions
  - ✓ Field work is expensive, time consuming and too extensive for complete annual coverage

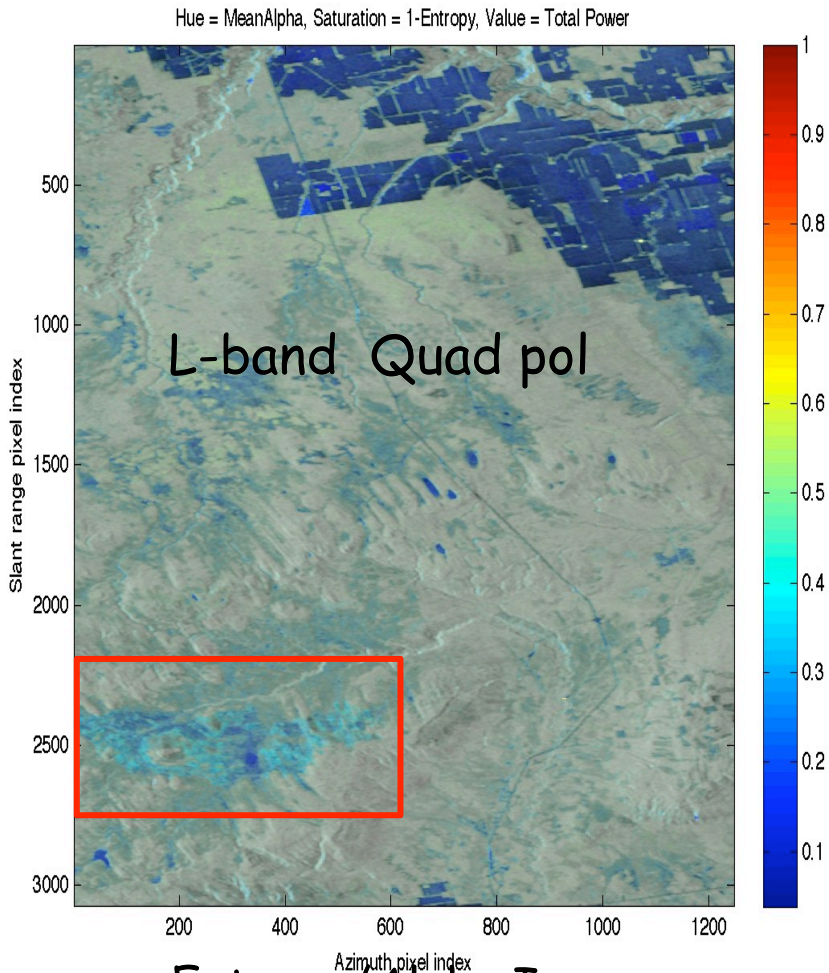
Polarimetry for Firescar detection

2 issues …how to establish automatic detection and then understand why quadpol gives such a strong signature not present in single pol image…



HH SAR Image

vs.



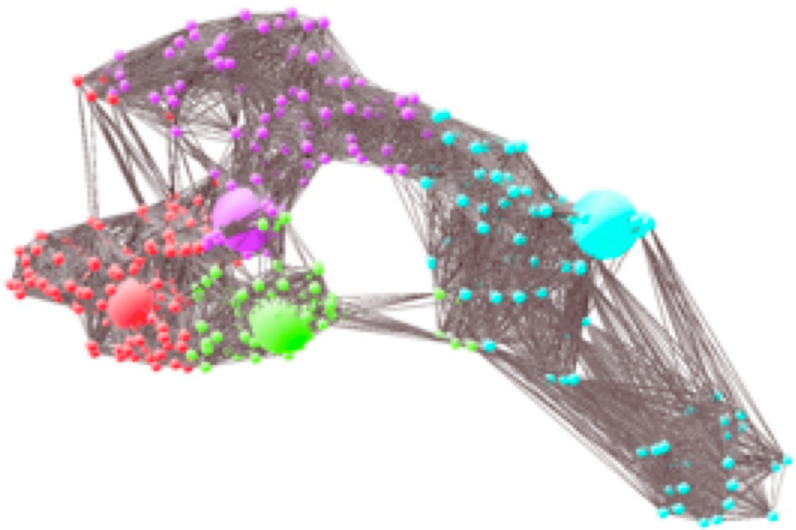
Entropy/Alpha Image

Fire Scar Classification:
New Unsupervised Manifold Method
- KNN Graph Clustering (KGC)*

A new unsupervised classification was devised.

- It is ***data driven***, with ***only one parameter (K).***
- It is intended to ***find clusters of arbitrary shape***.
- It ***doesn't directly assume the number of clusters***.
- It ***doesn't assume the data has any underlying parameterized distribution*** (e.g. Wishart).
- ***Is stable*** in terms of both the number of clusters,
  and the cluster shapes
  (with respect to the parameter K).

KGC uses an ***approximate manifold (the K Nearest Neighbor Graph)*** to describe arbitrary cluster shapes in N dimensions..here N = 3



*A. Richardson et al "Unsupervised Classification of Polarimetric SAR Data using the K-nearest Neighbour Graph", Proc. IGARSS 2010, Hawaii, USA, July 2010

KGC-Fire-Scar Application

- Binary classification results for two values of the parameter K (2002 burned area class).
- Increasing K (“blurring” the density estimate) resulted in less accurate class boundaries.
- For speed, only 1/30th of the 737x249 data points were used.
- A random algorithm was used to assign classes rapidly.
- Increased computational power will further improve the results.

General Polarimetric Coherence Detector

Stage 1 : convert C to T, in the Pauli basis..

Why?...this has the effects of putting all forest canopy terms along the diagonal and all surface returns from gaps etc. on the off-diagonal

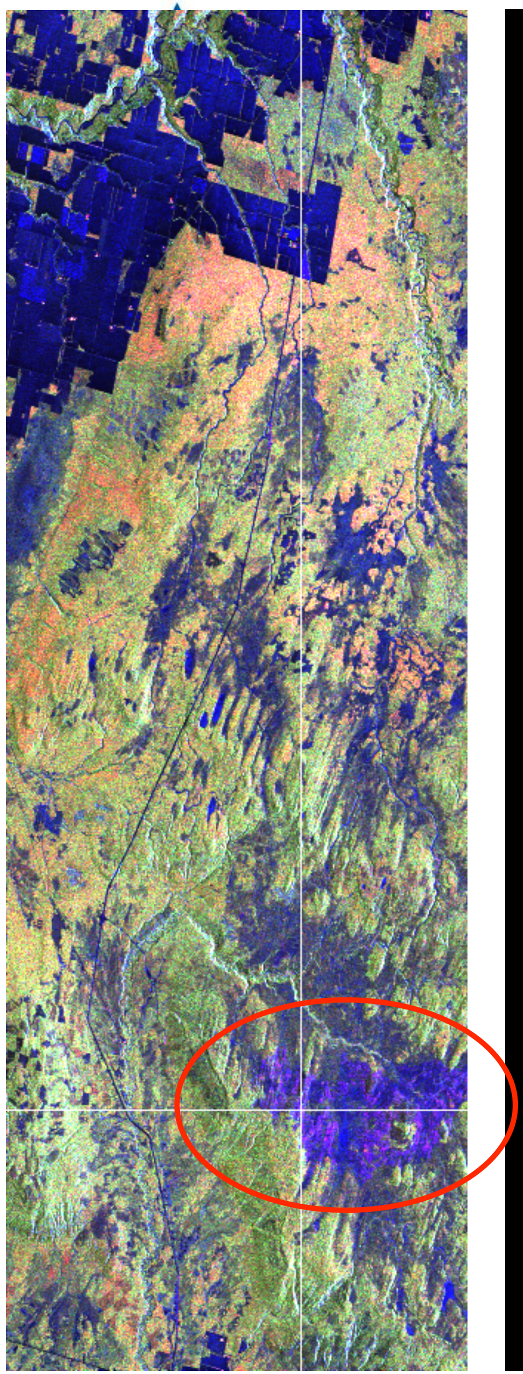
Stage 2 : vectorise upper diagonal terms of T to generate 6-dimensional vector $\underline{t}$

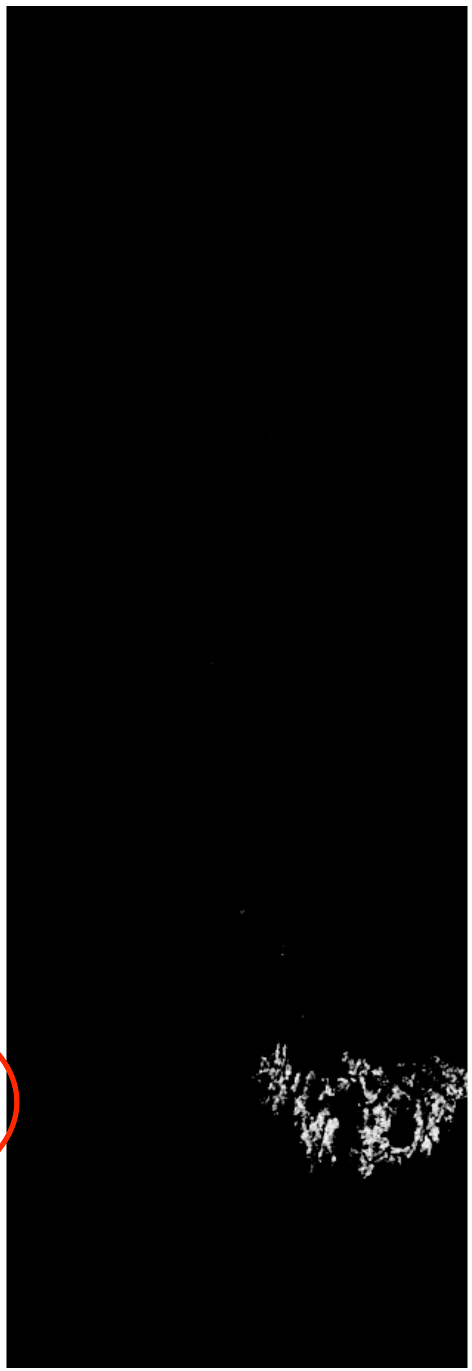
Why?...because then we can define a coherence which is only high when we have a firescar region...using a threshold G and a signal-to-clutter ratio scr

$$\gamma_c = \frac{1}{\sqrt{1 + R\left(\dfrac{\left\langle \underline{t}^{*T} \cdot \underline{t} \right\rangle}{\left\langle \left| \underline{t}^{*T} \cdot \hat{\underline{t}}_{FS} \right|^2 \right\rangle} - 1\right)}} \geq G \ , \qquad R = \frac{scr}{\left(\dfrac{1}{G^2} - 1\right)}$$

*A. Marino et al" New Classification Technique based on Depolarized Target Detection", Proc. IGARSS 2010, Hawaii, USA, July 2010

Supervised detection: historical fire scar





- Multi-look 1x5 in range azimuth
- Supervised Detection with a window 7x7

✓ The forest on the ancient fire scar is younger (8 years old) and with absence of understory.

✓ Its polarimetric return is different from the rest of the forest.

✓ The detector seems able to separate the fire scar from the rest

Understanding the Firescar Signature

RVOG (random-volume-over-ground) model allows us to separate forest canopy from surface returns..fully invertible from radar data..first generate rotated [T] matrix to compensate topography effects, then apply the following model for vegetated terrain:

$$\left[T_R\right] = [R][T][R]^T = \left[T_S\right] + \left[T_V\right] =$$

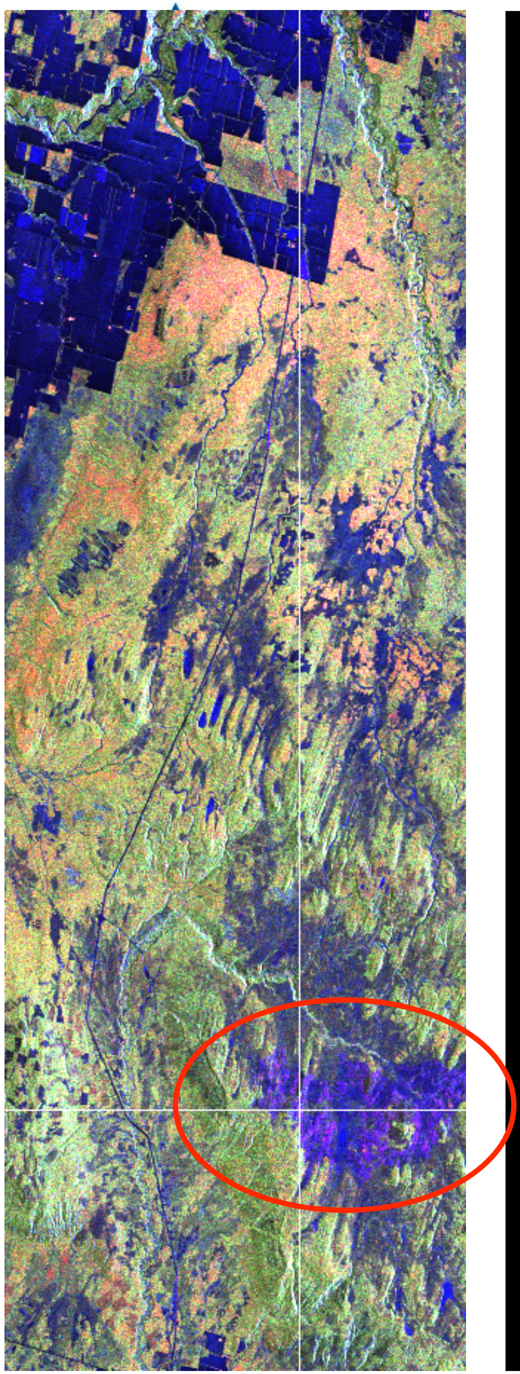
$$= m_S \begin{bmatrix} \cos\alpha & \cos\alpha\sin\alpha \cdot e^{j\varepsilon} & 0 \\ \cos\alpha\sin\alpha \cdot e^{-j\varepsilon} & \sin\alpha & 0 \\ 0 & 0 & 0 \end{bmatrix} + m_V \begin{bmatrix} F & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

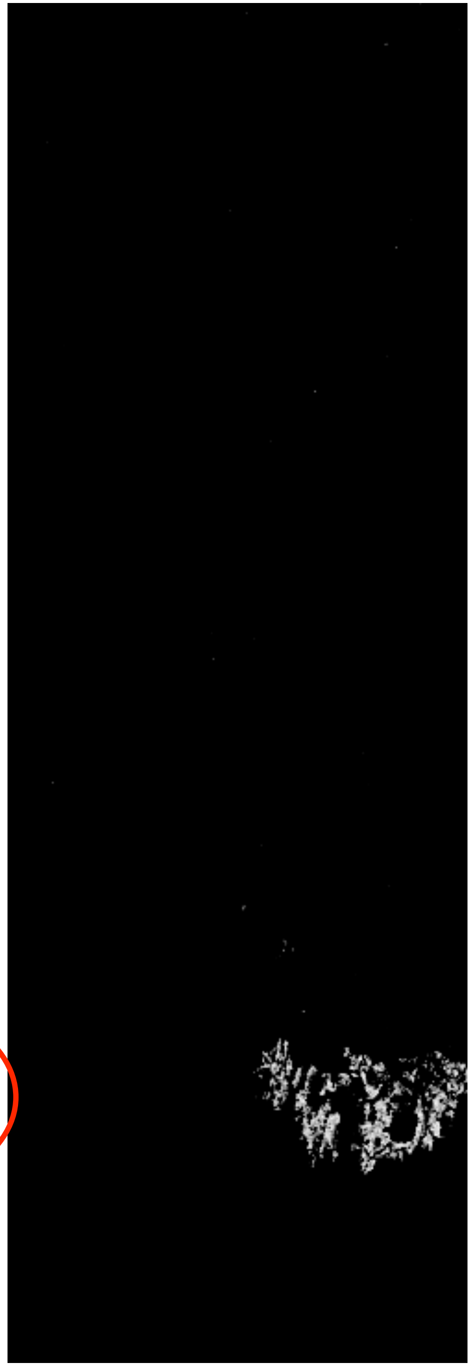
Three important parameters

$$\mu = \frac{m_s}{m_v} \qquad \alpha \qquad \mathrm{F}$$

Question is…does this model fit the data?

Unsupervised detection: ALOS-PALSAR





Good classification using only mean RVOG parameters for fire scar

$$\alpha = 19^\circ$$

$$\mu = 7.7dB$$

$$F = 2$$

Conclude that fire scar is composed of a pine forest (F=2) with a particular surface boundary condition (α = 19°) which is around 8dB higher than the canopy (open forest or low biomass)..

.can we use this idea to estimate biomass of forests directly using RVOG?

AEL consultants

Application 2: Forest Biomass Estimation

Estimating Volume/Biomass from μ

$$V = \frac{1}{\beta}\ln(1+\frac{R}{\mu})$$

..two model parameters to be set , R and β …3 ways to solve this:

1) Use regression against (at least 2) sites of known biomass in a scene

2) Use fixed values from the literature

e.g. for Sweden Boreal Forest, 42 stands, 1995-96,

$$L-band \quad \beta = 0.004 \quad R = 0.5$$
$$C-band \quad \beta = 0.0064 \quad R = 1$$

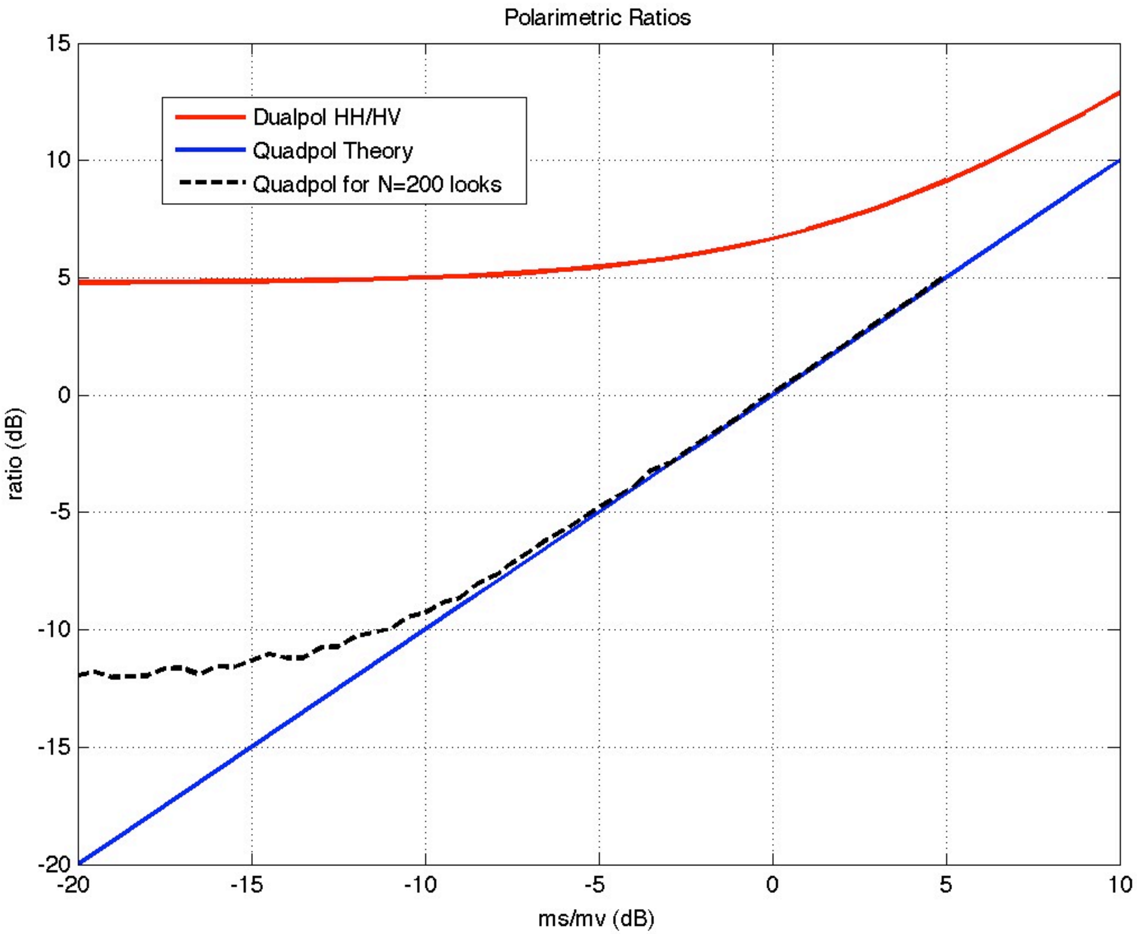
3) Fix β and estimate R from the data itself (using forest/non-forest mask)

Final step is then to relate V to Biomass e.g. For Boreal forest
B = 0.6V (e.g. 100m^3/ha = 60 t/ha) but other relationships can be employed as appropriate

Askne J., M Santoro, G Smith, J E S Fransson, "**Multitemporal Repeat-Pass SAR Interferometry of Boreal Forests**", IEEE Transactions on Geoscience and Remote Sensing, Vol. 41, pp. 1540-1550, July 2003

Biomass from Ratios:
The effect of speckle noise..

…first step is to estimate μ…the ratio of surface-to-volume scattering



Quadpol is much better than Dualpol (FBD mode of ALOS)

But speckle fluctuations combined with finite number of independent looks causes a low μ saturation which implies a Biomass saturation as well..

But at what level?

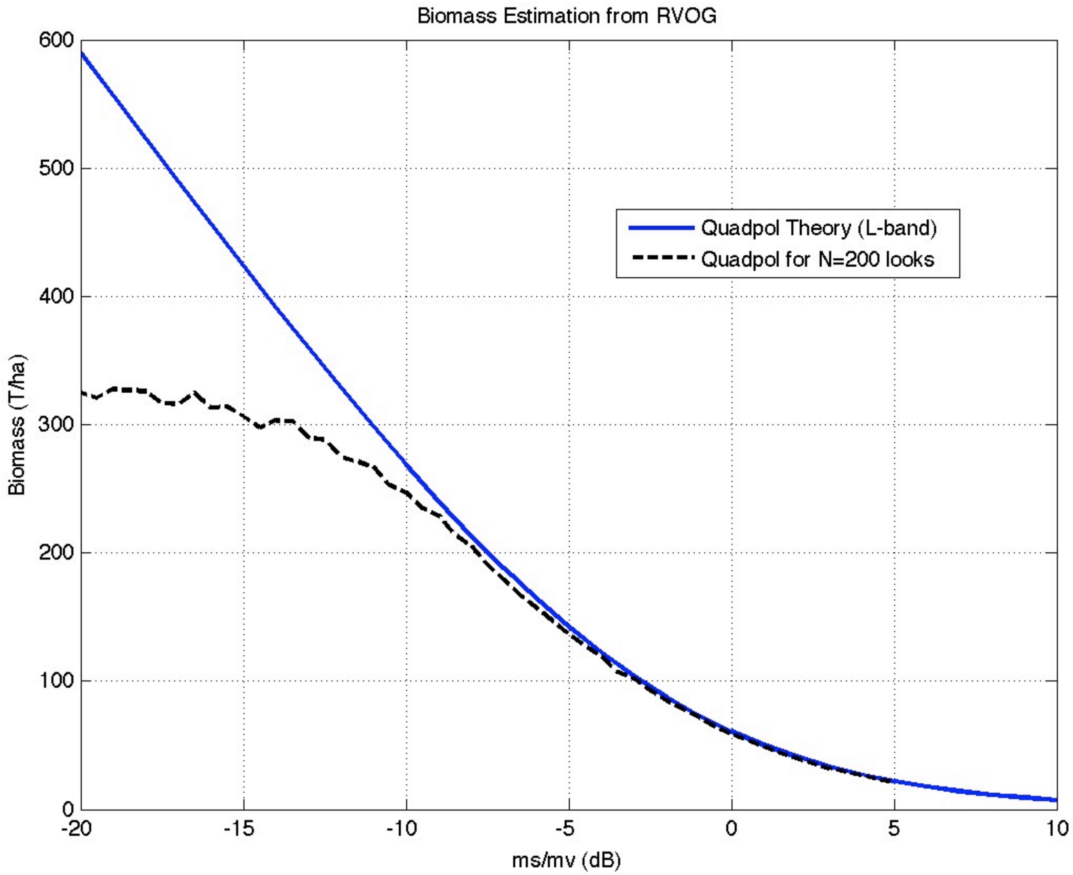
Forest Biomass Estimation:
L-Band

$$B = \frac{0.6}{\beta}\log(1+\frac{R}{\mu})$$

Need 2 parameters

$$R = \frac{\sigma_o^{surf}(\theta)}{\sigma_o^{veg}}$$

$$\beta$$



Saturation Level around 300 t/ha…much higher than conventional backscatter approach

Case Study : GVWD Victoria
L-band ALOS and C-Band Radarsat-2

The GVWD site is covered by temperate coastal rainforests with the forest stands composed of predominantly Douglas-fir (*Pseudotsuga menziesii*), Lodgepole Pine (*Pinus contorta*), Western Hemlock (*Tsuga heterophylla*) and Western White Pine (*Pinus monticola*). Much of this area of the watershed has been logged and reforested over the last 100 years, resulting in various stand age classes in this second growth forest

Quadpol Radar Data Used:

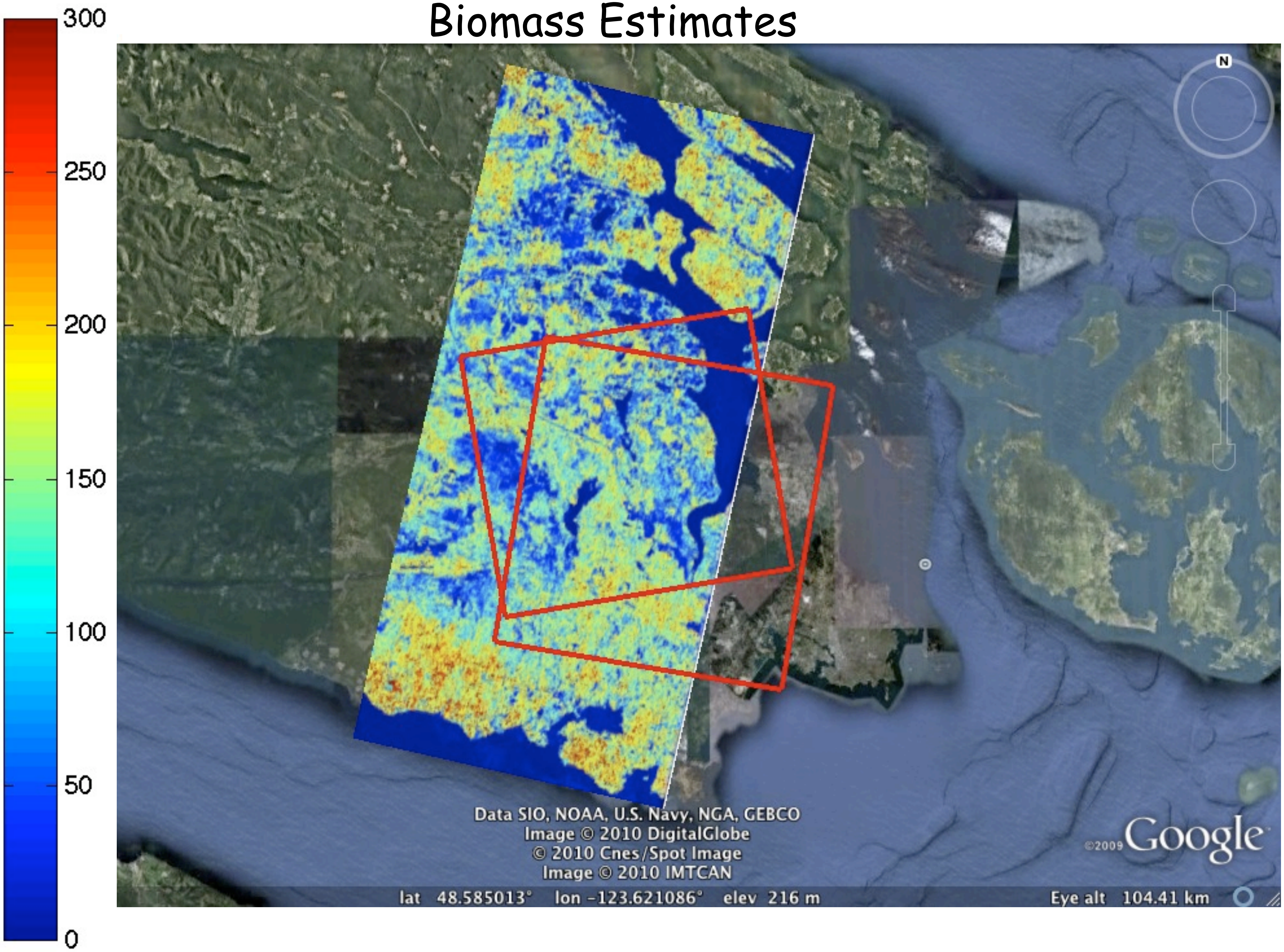
ALOS PALSAR: (L-Band)

11/01/2009 (large swath)

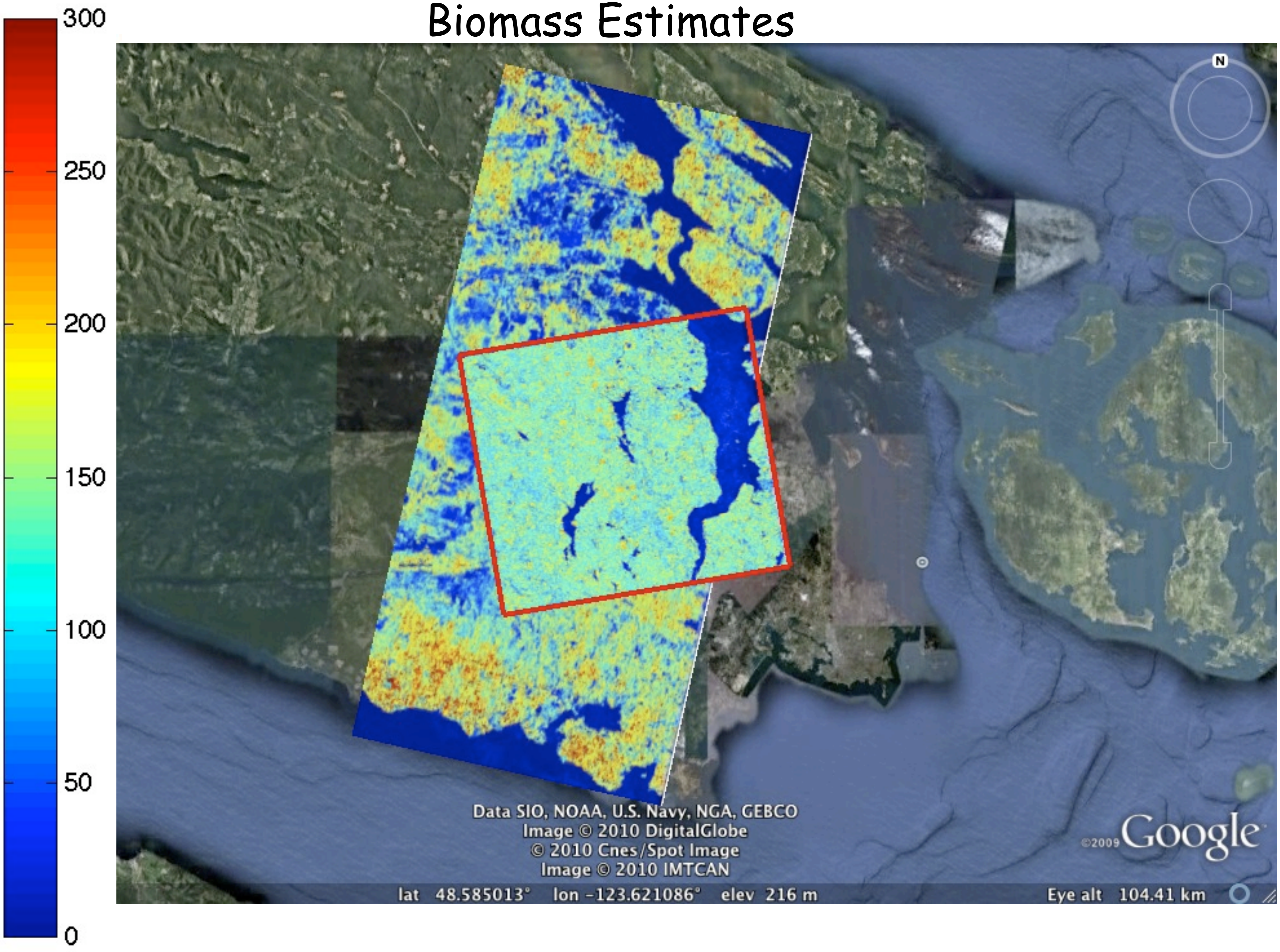
Radarsat-2 : (C-Band)

07/07/2008 (small swath)
25/02/2009

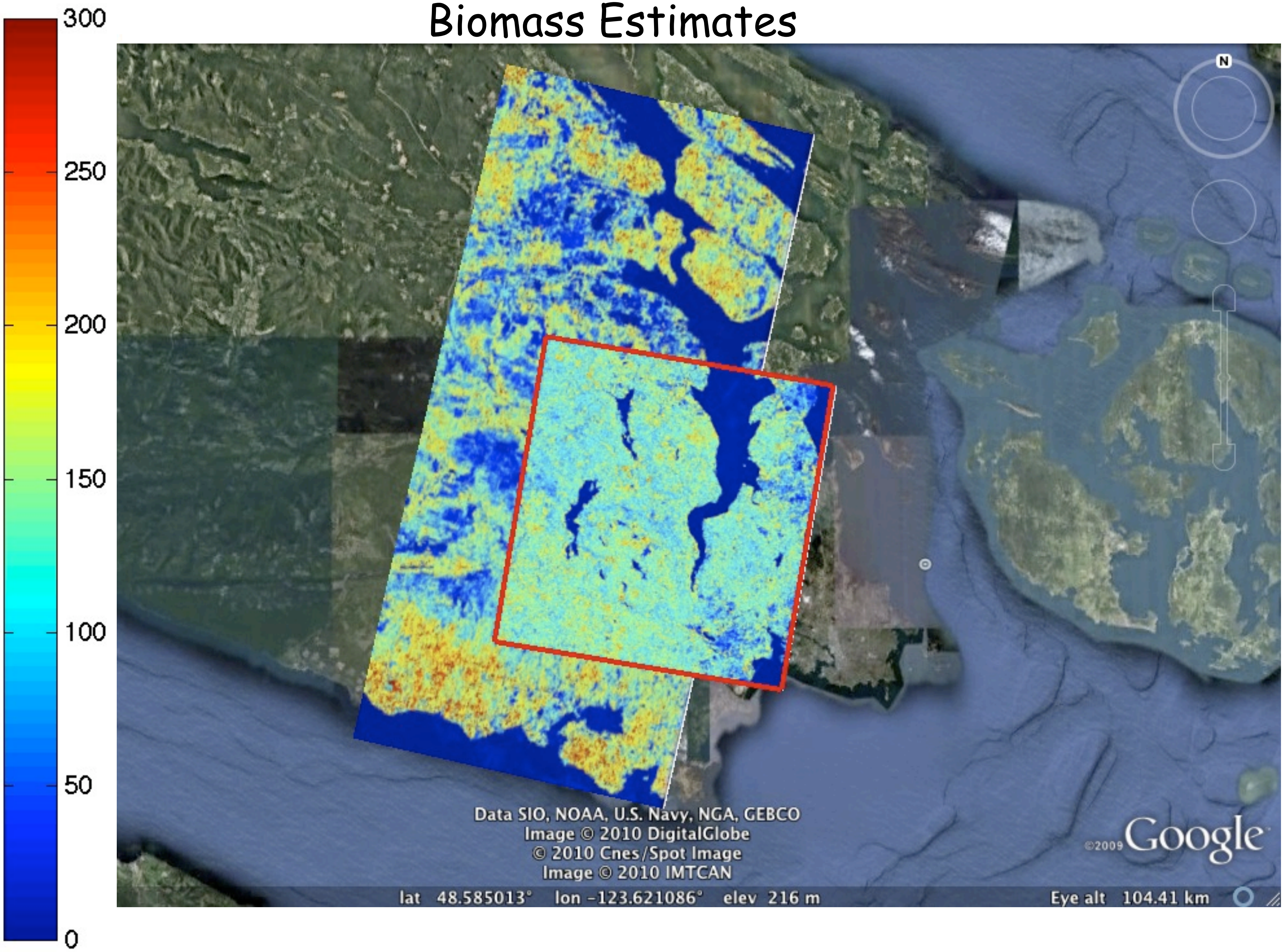
Biomass Estimates



Biomass Estimates



Biomass Estimates



Conclusions

• Quadpol Satellite Radars add a unique monitoring capability from space, with extra information channels through the 4x4 matrix [C] for each pixel

Our studies have focused on two main applications:

- Historical Fire scar detection, where Quadpol systems provide a characteristic signature not seen in conventional Radar monitoring

- Forest Volume/Biomass estimation, where Quadpol systems provide enhanced sensitivity to the balance of surface and canopy scattering.

• In both cases L-band Quad shows better performance than C-band, since the higher frequency results in higher depolarization, even from low biomass areas

Future work will address development of

- a fire scar ageing system
- validation of biomass estimates
- biomass change using multi-temporal acquisitions
- Forest Height estimation using single-pass POLInSAR from Tandem-X