Canadian Space Agency | Agence spatiale canadienne

RADARSAT-1 Image Quality and Calibration Performance Maintained Beyond 12 Years of Operation

Satish K. Srivastava, Stéphane Côté
Canadian Space Agency, Longueuil, Canada
Email: Satish.Srivastava@space.gc.ca

Bob Hawkins
Canada Centre for Remote Sensing, Ottawa, Canada

2008 Civil Commercial Imagery Evaluation Workshop
Fairfax, VA, 25 – 27 March 2008

Canadian Space Agency | Agence spatiale canadienne

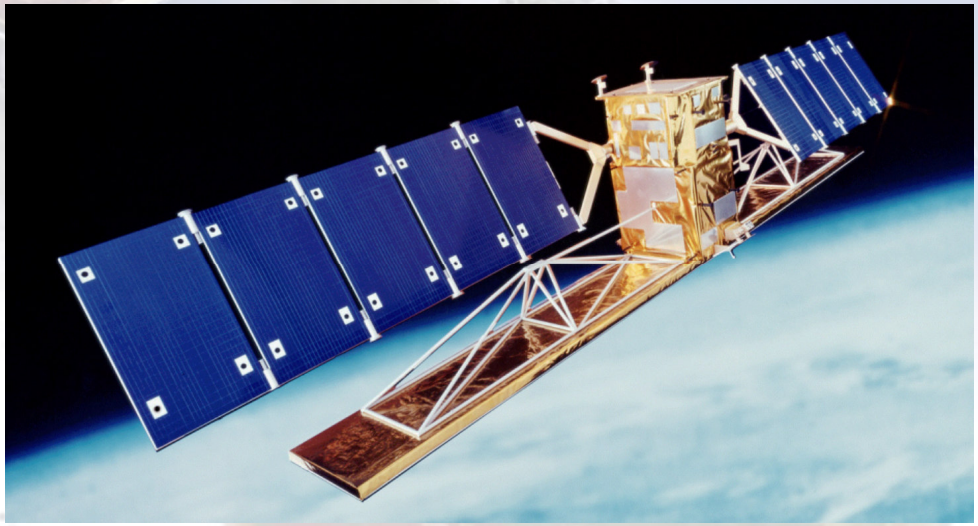
The RADARSAT-1 System

Canada's first operational EO satellite
HH Polarized C-Band Right-Looking SAR
Launched November 4, 1995
Mission Design Life: 5.25 years (completed in Early 2001)
Started thirteenth year of operation
Data received and processed at 38 ground stations with 25 archive facilities globally

Orbit

- Sun-synchronous
- Dawn–Dusk

- Altitude: 798 km
- Period: 100.7 minutes
- Repeat Cycle: 24 days
- Orbits per day: 14



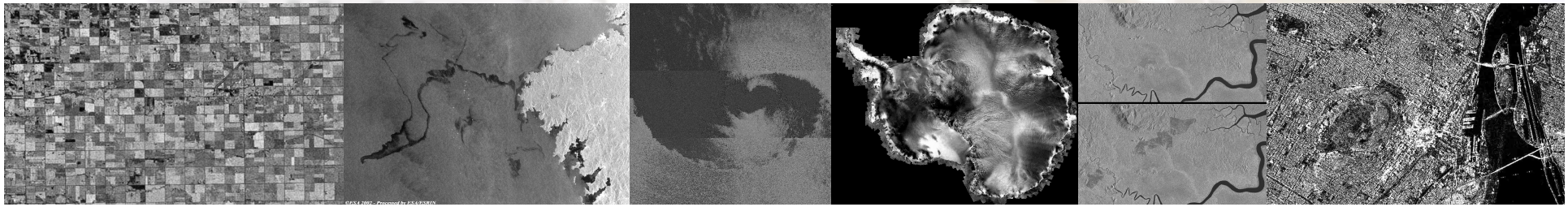
Canadian Space Agency | Agence spatiale canadienne

RADARSAT-1 Applications

- Ice Monitoring
- Pollution Monitoring
- Disaster Watch – International Charter Space Major Disasters
- Forestry
- Crop Monitoring
- Antarctic Mapping Missions (1997 & 2000)

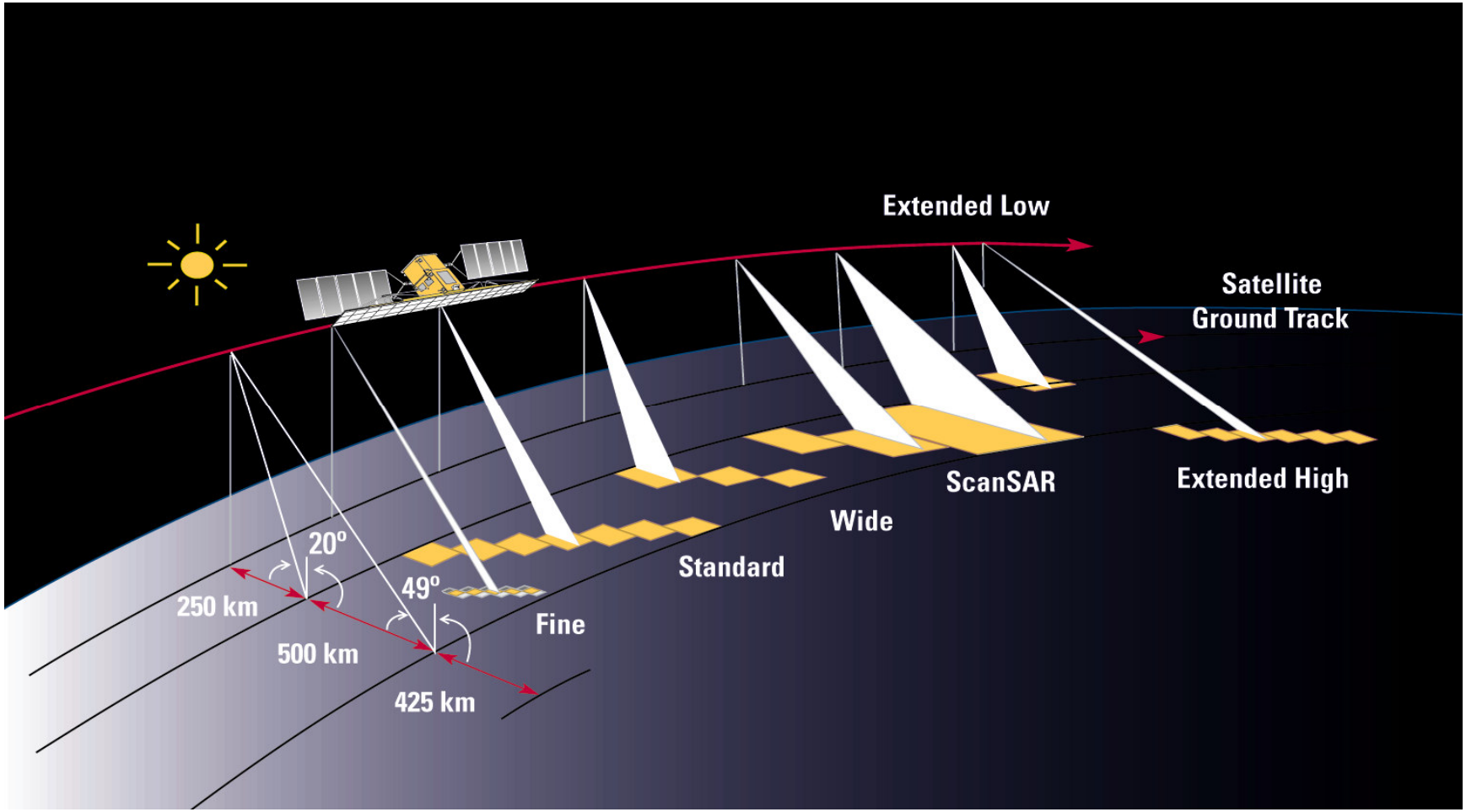
As of Jan. 1, 2008

Acquired minutes of SAR data:	571,100
Number of orbits completed:	63,461
Number of user requests:	293,183
Average system performance:	> 95%



Canadian Space Agency | Agence spatiale canadienne

RADARSAT-1 Imaging Beams/Modes



SAR Sensor Calibration Maintenance Plan

(started in 1997 after initial calibration)

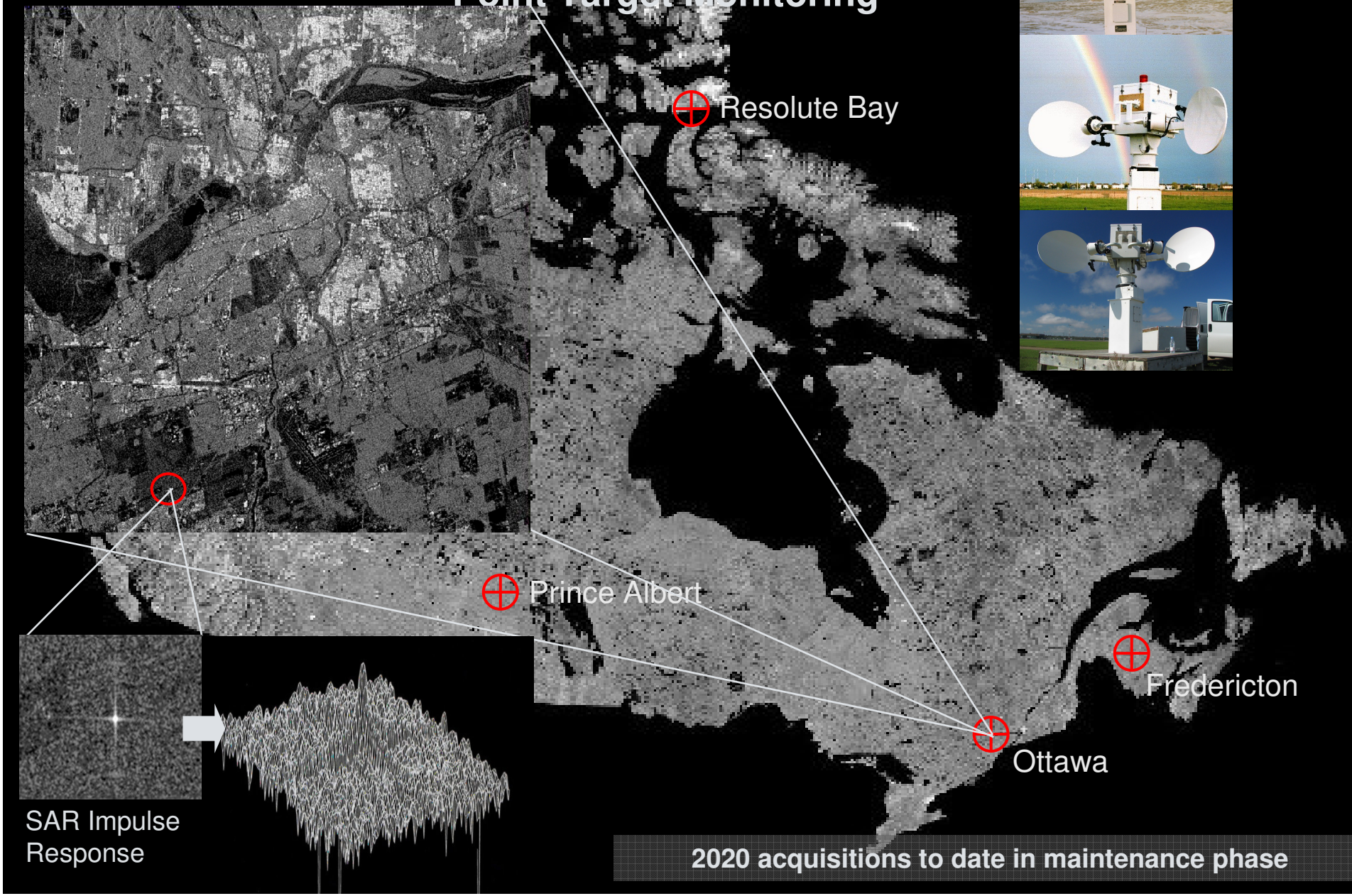
Objectives

- **Characterize, monitor and maintain image quality and SAR calibration throughout the mission**
- **Provide stable, quantifiable image products to users**

Calibration Type	Measurements	Methodology
External	Point Target Monitoring Impulse response parameters	Imaging of RADARSAT-1 Precision Transponders (RPTs) Sites 16 acquisitions/24-day cycle
	Distributed Target Monitoring Relative intensity of any point in image	Imaging of Amazon Rainforest 13 acquisitions/24-day cycle
Internal	On-Board Monitoring Gain Changes Embedded in SAR subsystem components	Replica measurements during transmit Mixer, IF, Receiving Circuits Off-line special processing Pre and Post-Image Operations

Canadian Space Agency
Agence spatiale canadienne

RADARSAT-1 Precision Transponders Point Target Monitoring



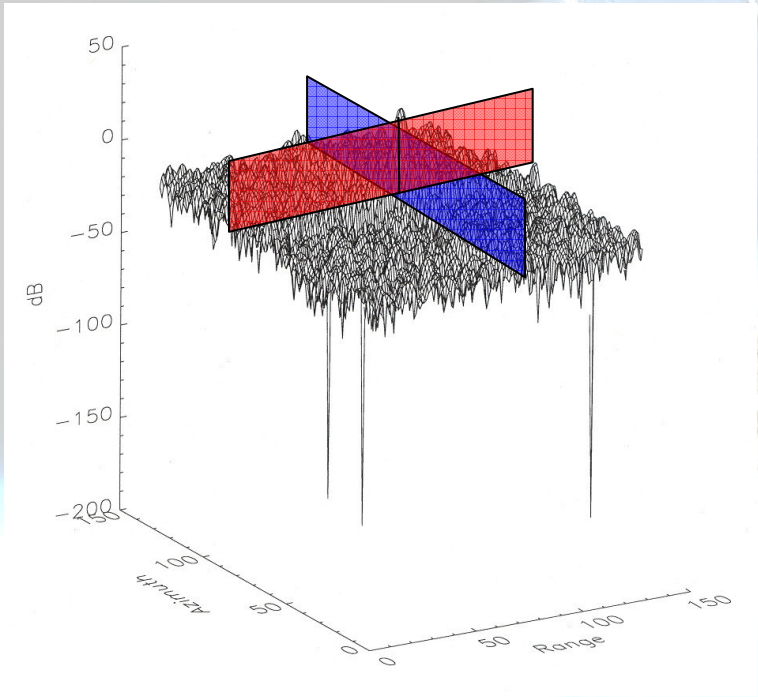
2020 acquisitions to date in maintenance phase

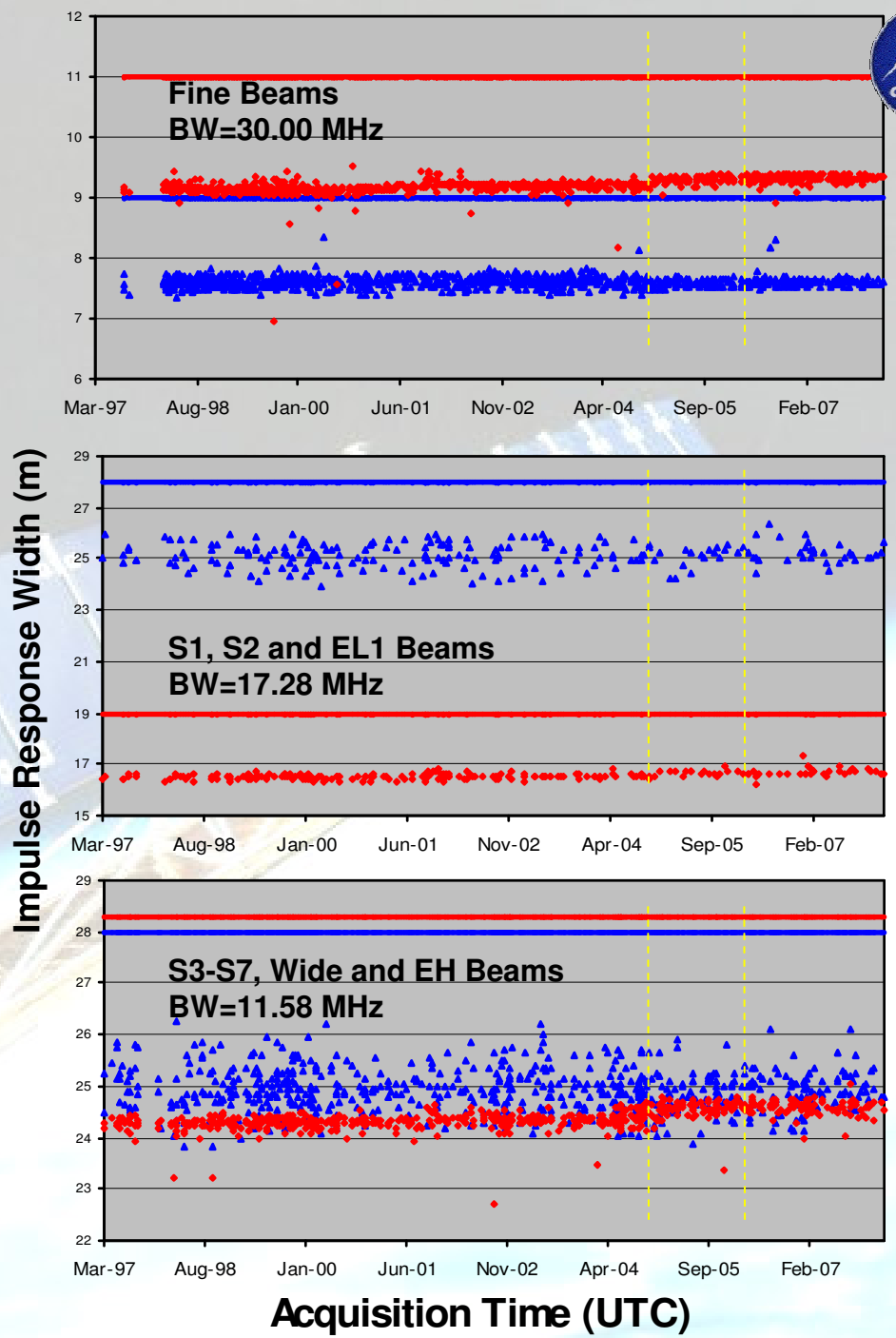
Canadian Space Agency | Agence spatiale canadienne

Impulse Response Parameters

3dB Impulse Response Width
in Range
in Azimuth

⇒ **Spatial Resolution**





Canadian Space Agency | Agence spatiale canadienne

Impulse Response Parameters

Peak Side Lobe Ratio (dB)
in Range
in Azimuth

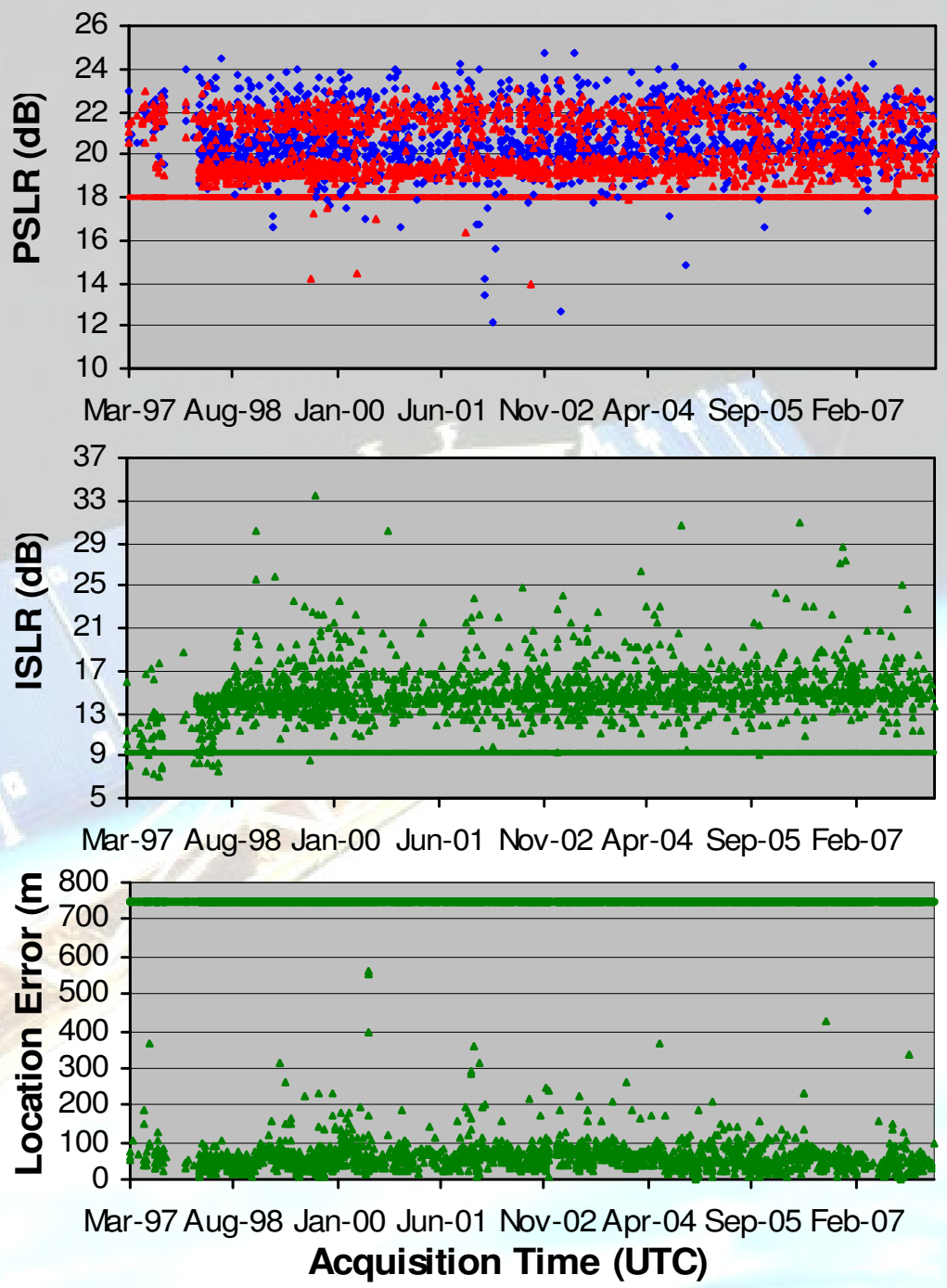
⇒ Focusing

2D Integrated Side Lobe Ratio (dB)

⇒ Energy Concentration in Main Lobe

Absolute Location Error (m)
Based on predicted orbit data

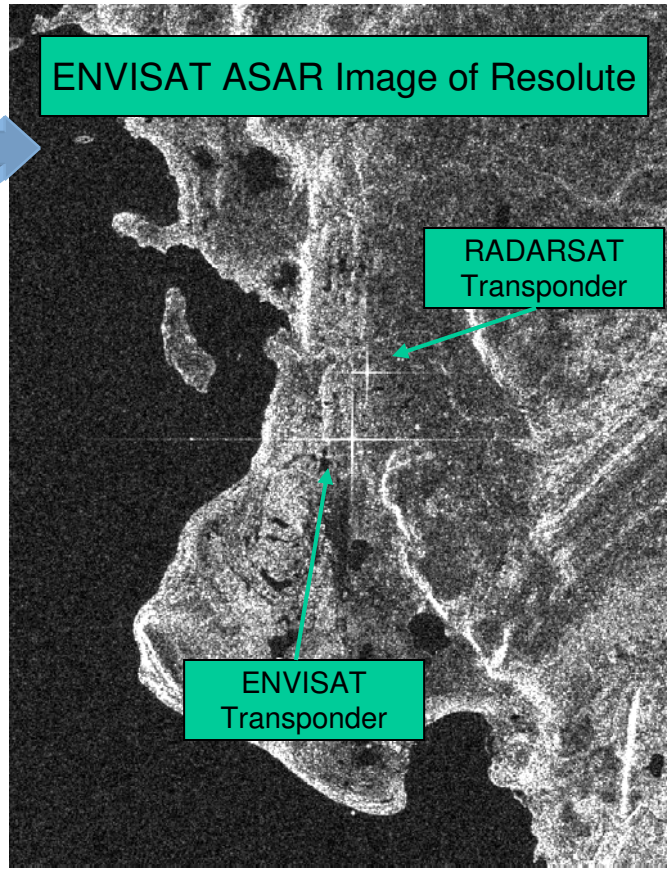
⇒ Geometrical Registration



Calibration Transponder Sites

Multi-Agency Transponder Sites in Canada

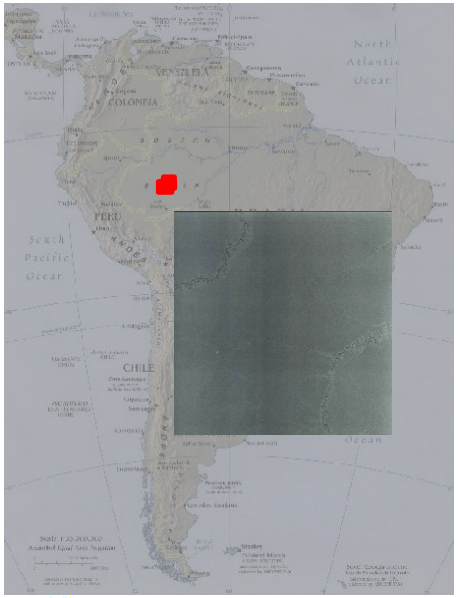
- In Fall 2006, ESA relocated an ENVISAT ASAR Transponder in Resolute Bay in vicinity of a RADARSAT Transponder
- Both transponders can be used simultaneously by ENVISAT
- In 2007 another ENVISAT ASAR Transponder was relocated in Ottawa, again in vicinity of another RADARSAT Transponder



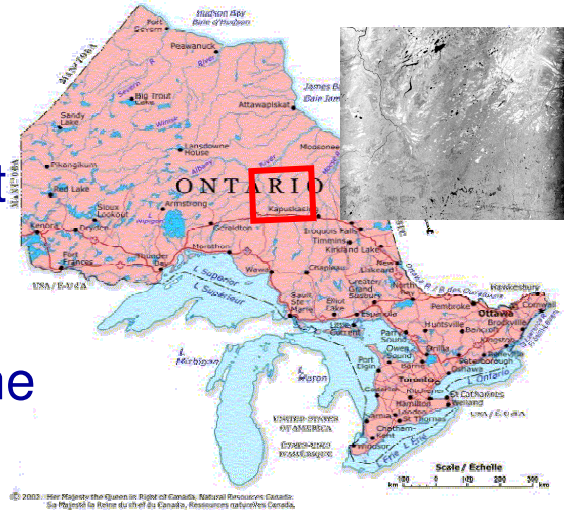
- Two potential sites in Canada for inter-sensor comparisons for C-band SARs (e.g., RADARSAT-1, RADARSAT-2, ENVISAT)

Natural Calibration Sites

- **International Amazon Rainforest Site**
  - A CEOS radiometric calibration reference site
  - Data routinely collected and analyzed for calibration monitoring of SAR satellites including RADARSATs
  - Radiometry of the site remains stable



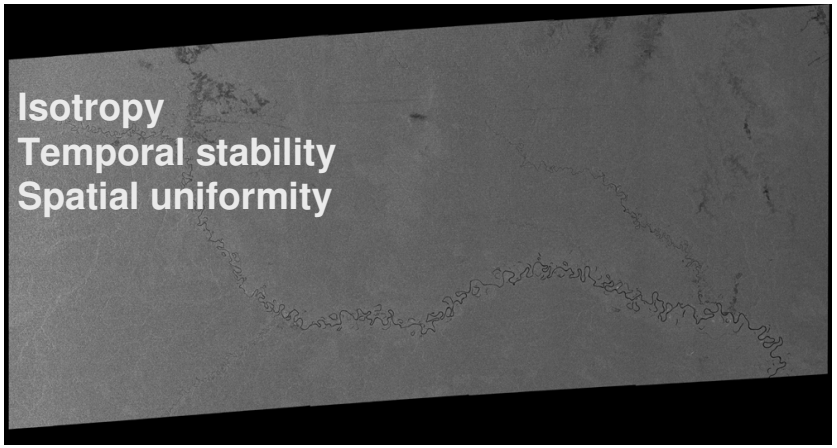
- **Canadian Boreal Forest Site**
  - Radiometric characterization completed at C-band using RADARSAT-1 data
  - Site seasonally dependent
  - Can be used as a complimentary site to the Amazon but with reduced radiometric accuracy



Canadian Space Agency | Agence spatiale canadienne

Radiometric Calibration: Amazon Rainforest

Rainforest Properties

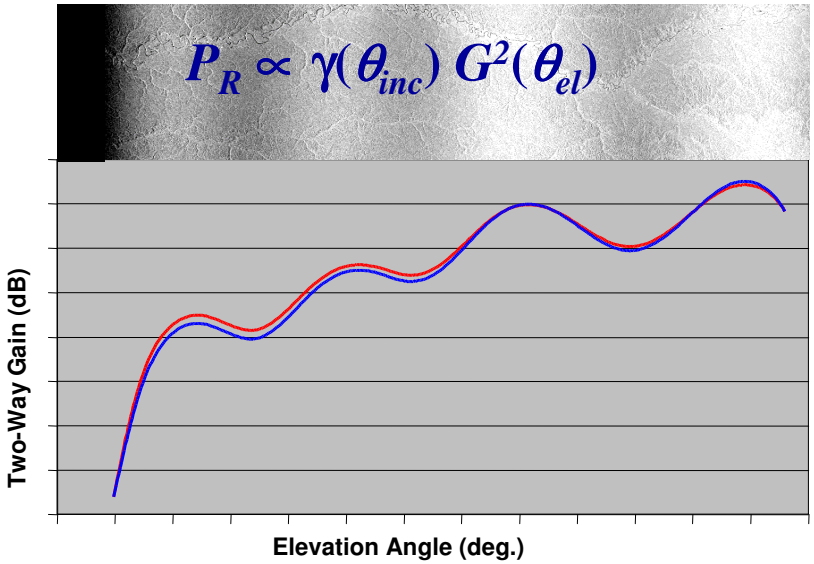


Well characterized radiometrically

Recognized distributed target reference

1991 ERS-1 (C)
1992 ERS-2 Scatterometer (C)
1994 SIR-C (X)
1992 JERS-1 (L)
1996 RADARSAT-1 (C)
2002 ENVISAT (C)
2008 RADARSAT-2 (C)

Use of Amazon imagery (uncorrected)



- Extraction of In-Flight Elevation Beam Pattern from Amazon Rainforest images (Antenna pattern correction off)
- Range averaging → Elevation beam pattern
- Comparison against Calibrated Pattern (reference stored in processing)
- Calculate pk-pk deviation: 1 dB tolerance

Canadian Space Agency | Agence spatiale canadienne

Amazon Rainforest Site - Distributed Target Monitoring

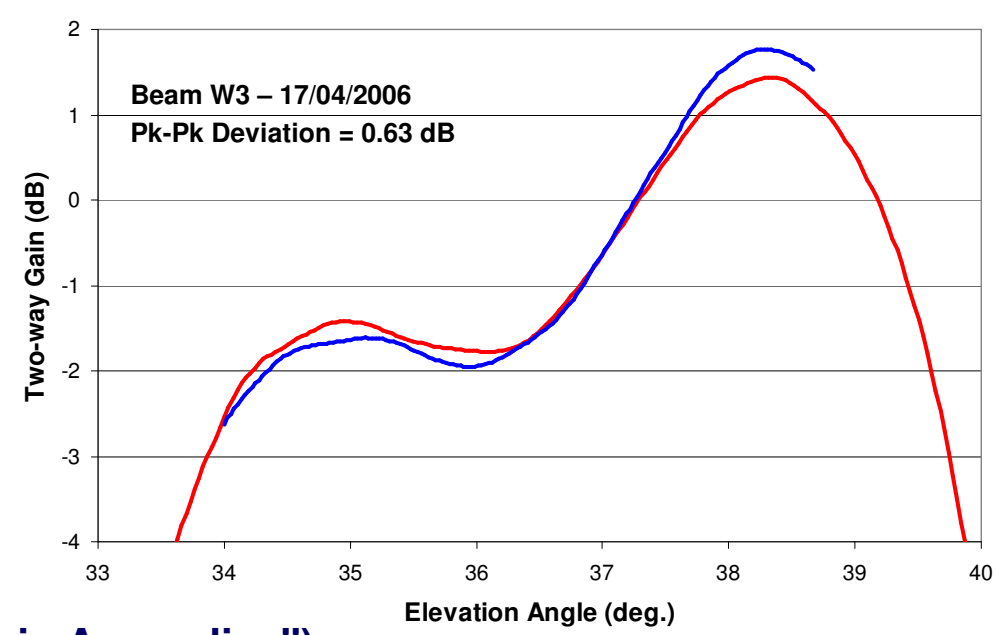
More than 1600 acquisitions to date in maintenance phase

Products calibrated to reflectivity in slant range (βº)

- Natural observable of a radar
- Requires no knowledge of local incidence angle

Comparison against Calibrated Pattern:

- Stored in Payload Parameters File (processing)
- Design Goal: Pk-pk deviation from Calibrated Pattern < 1 dB
- Worst case ever registered: 2.2 dB in 1998 (W1)



Antenna Pattern Changes ("Radiometric Anomalies")

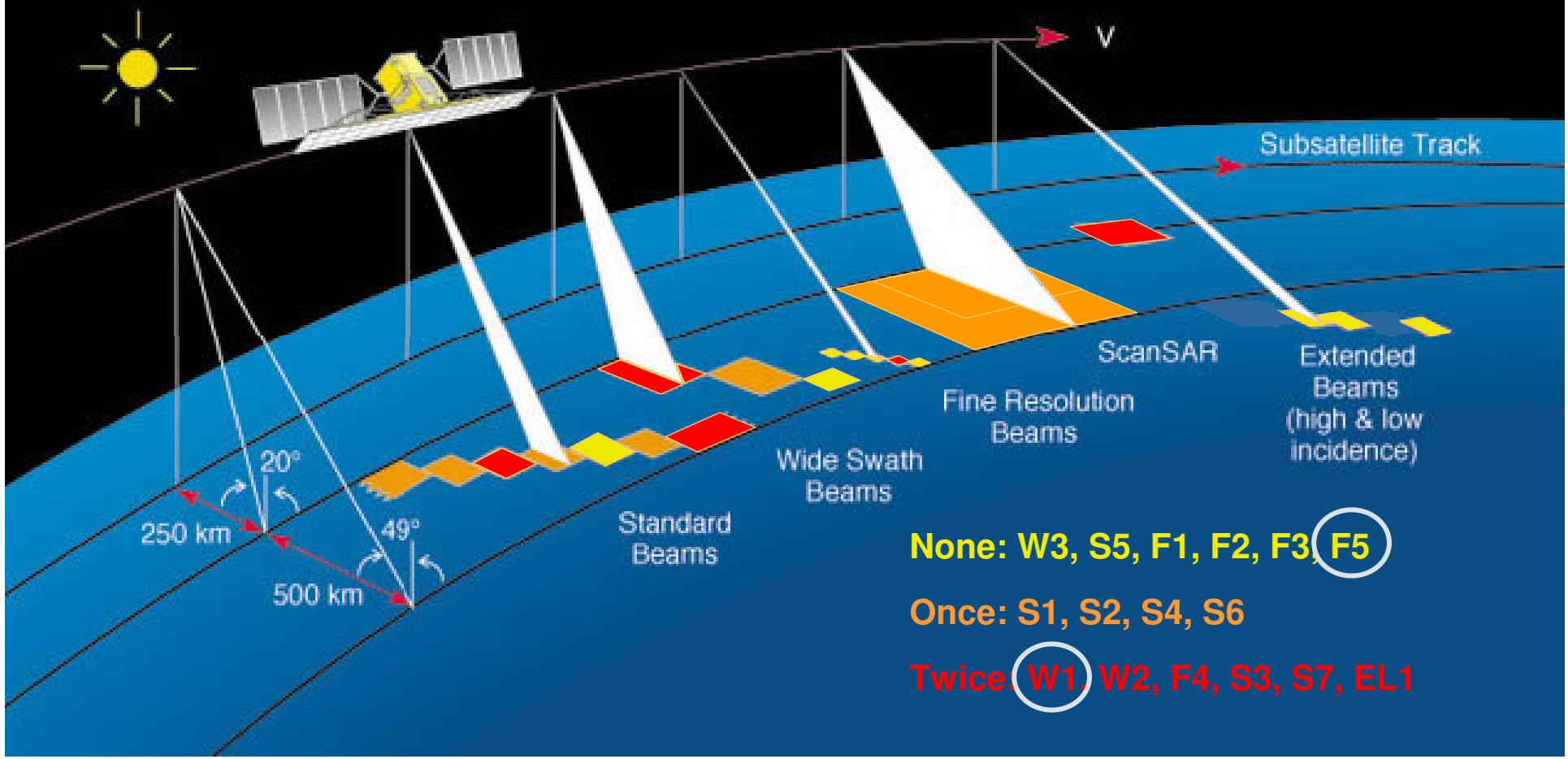
- Occurred gradually since 1998
- Variable Phase Shifters (VPS) investigation, 2001
- Likely due to changing performance over time, not temperature
- Stable since last recalibration in December 2002

Canadian Space Agency | Agence spatiale canadienne

RADARSAT-1 Radiometric Recalibrations

Pattern Shape Recalibrations Since 1998

Update of Payload Parameters File with new calibrated elevation pattern



None: W3, S5, F1, F2, F3, F5

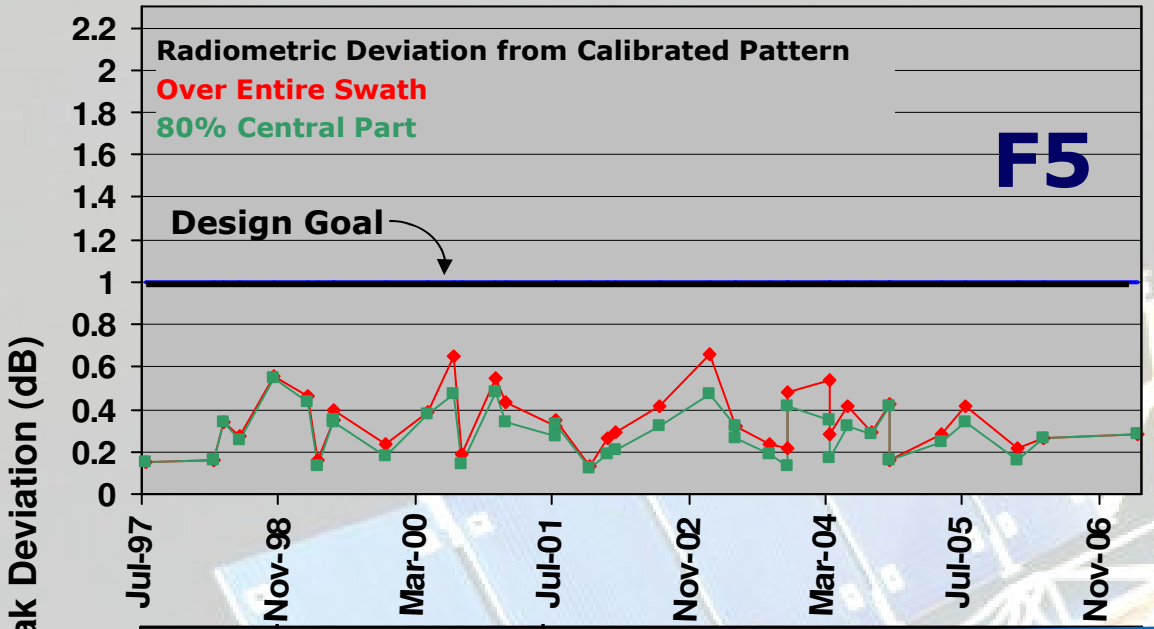
Once: S1, S2, S4, S6

Twice: W1, W2, F4, S3, S7, EL1

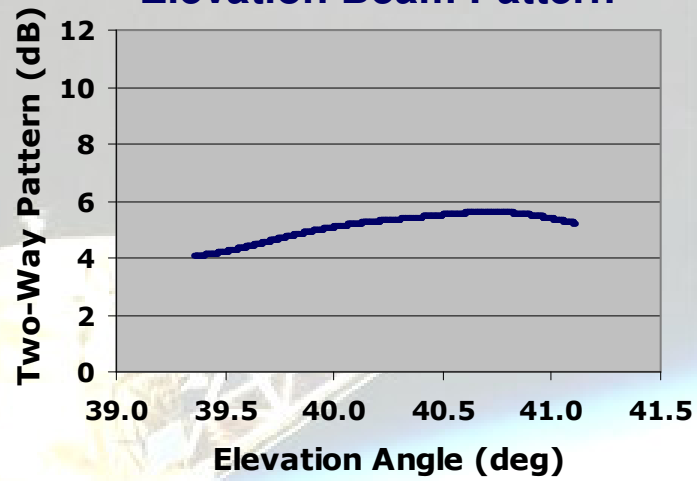
Canadian Space Agency | Agence spatiale canadienne

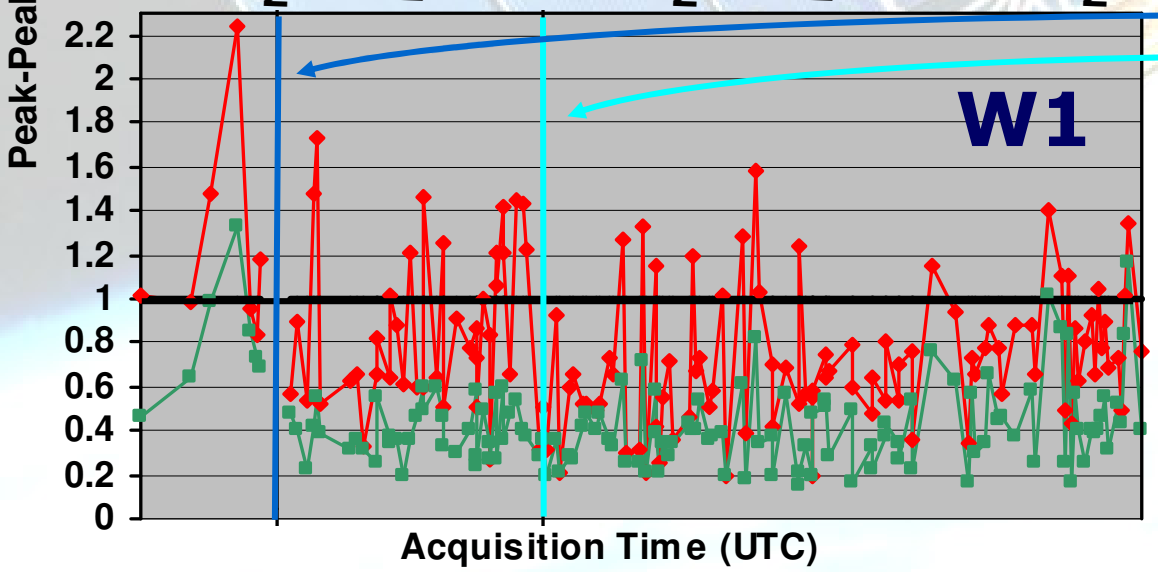
RADARSAT-1 Recalibration Examples - Beams F5 and W1

Radiometric Monitoring History

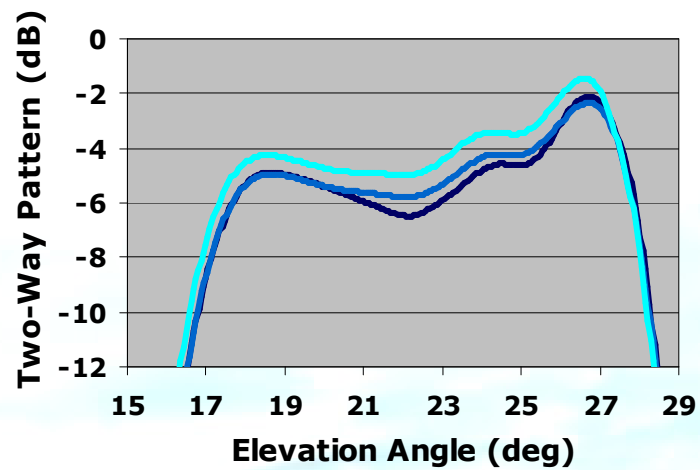


Elevation Beam Pattern





Original Calibration – Feb 97
First W1 Recalibration – Dec 98
Second W1 Recalibration – Jul 01



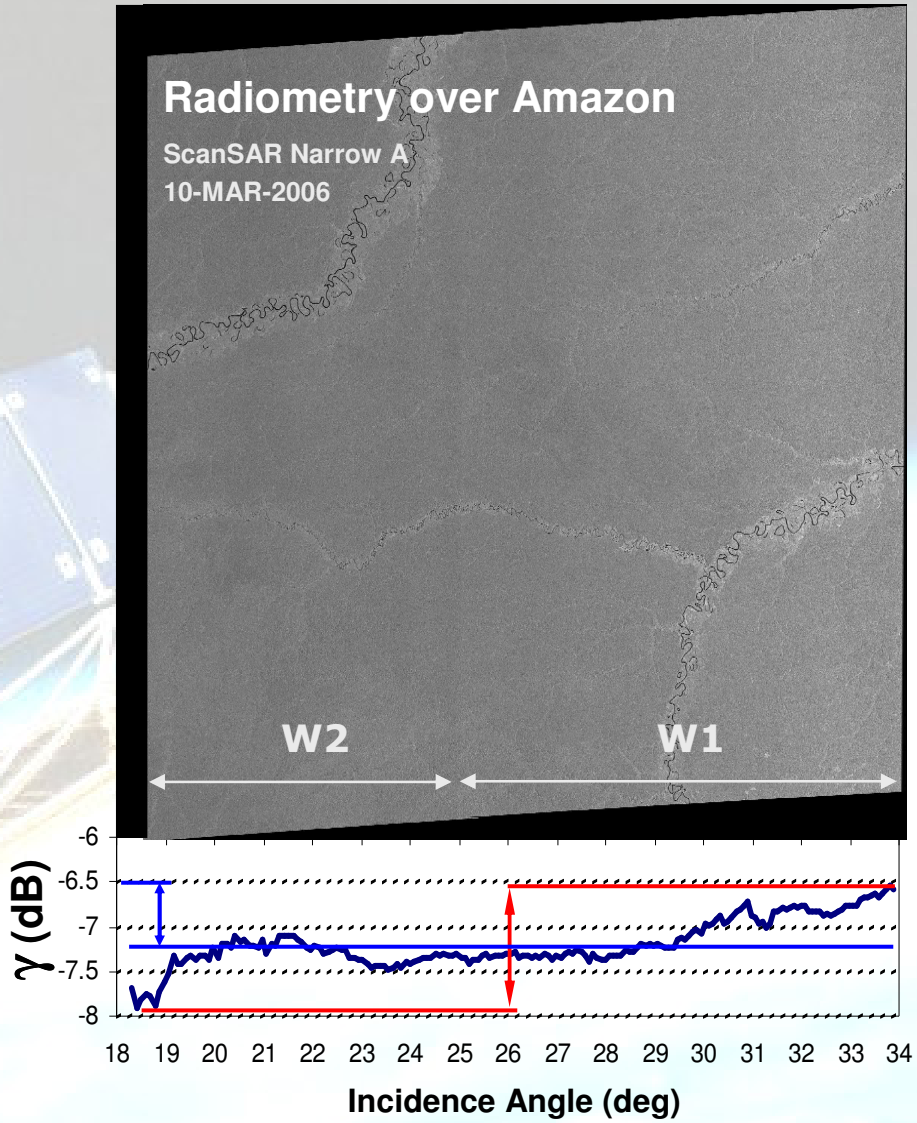
Canadian Space Agency | Agence spatiale canadienne

RADARSAT-1 ScanSAR Calibration

Mode	Composite Beams	Coverage (km)
SCNA	W1-W2	300X300
SCNB	W2-S5-S6	300X300
SCWA	W1-W2-W3-S7	500X500
SCWB	W1-W2-S5-S6	450X450

Accuracy (dB)	Worst Case	Typical
Absolute	± 1.35	± < 1
Relative	2.78	< 2

Radiometric calibration to brightness coeff. β^o effective Feb 1, 1999 for all ScanSARs

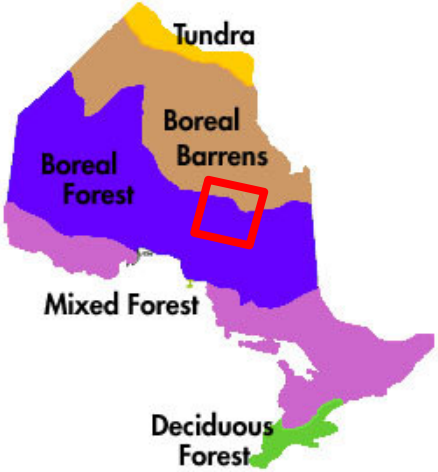


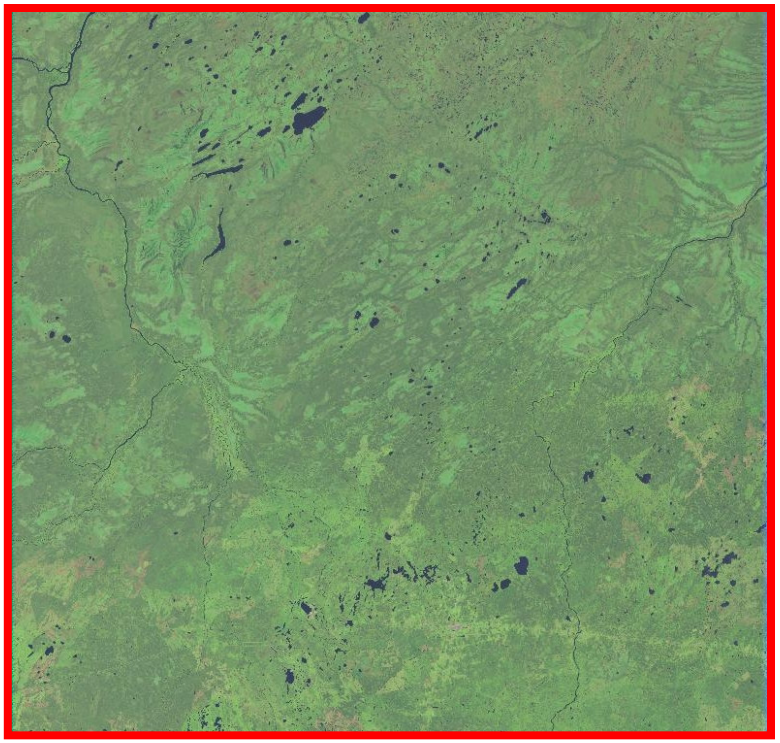
Canadian Space Agency | Agence spatiale canadienne

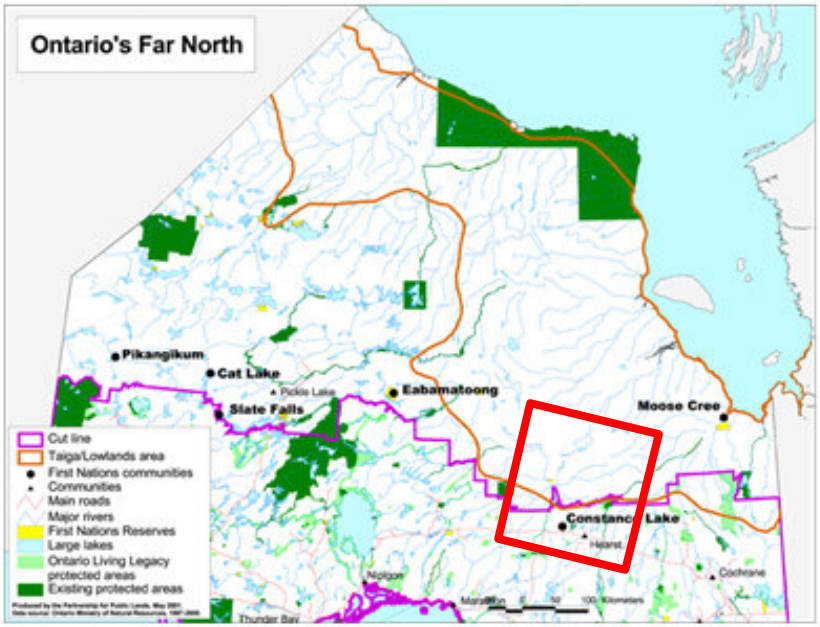
Canadian Boreal Forest - Hearst Site

- **Northwestern Ontario landmass (Hudson Bay basin)**
- **Boreal Forest-Barrens transition**

  boreal spruce, balsam fir, jack pine, poplar, birch, tamarack, cedar
- **Seasonal Variations**



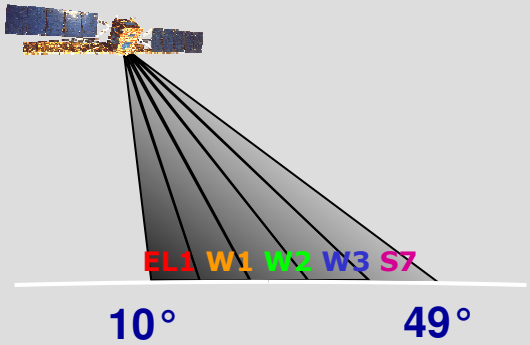


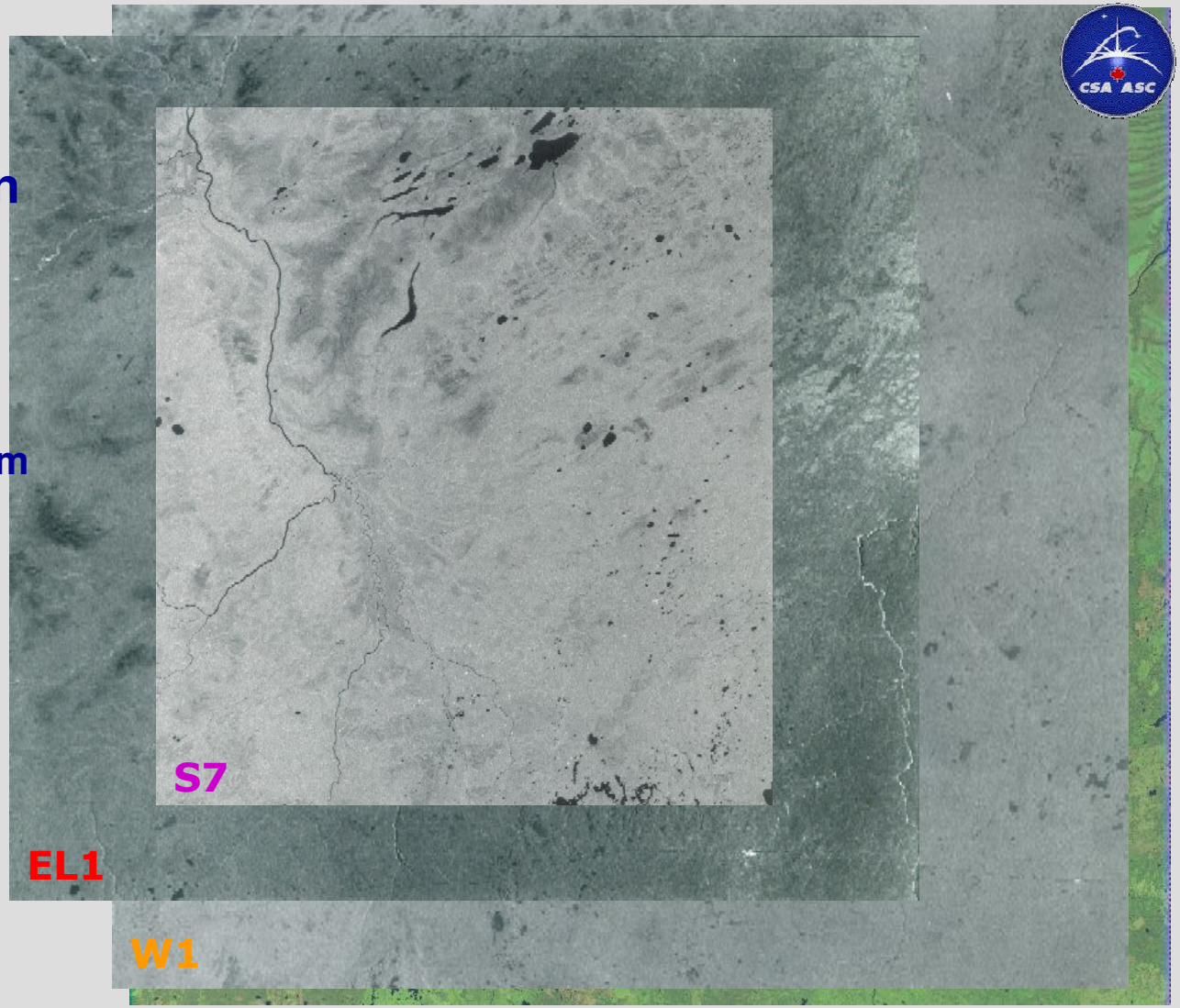


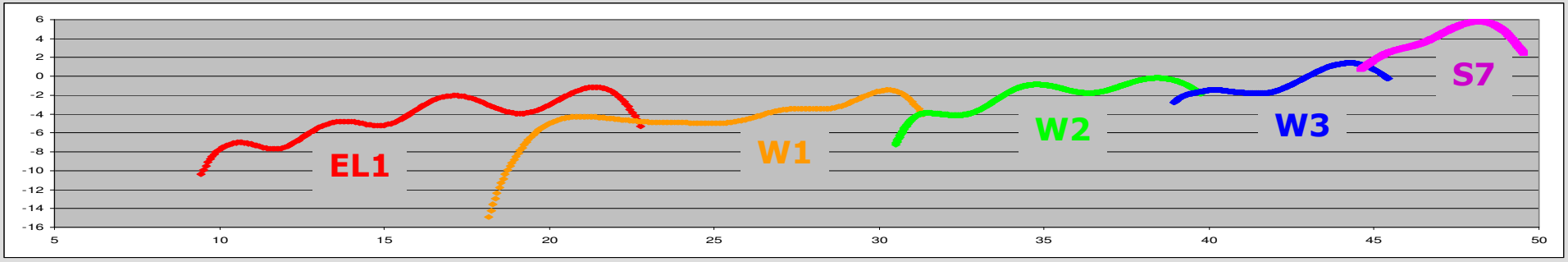
Canadian Space Agency | Agence spatiale canadienne

RADARSAT-1 Measurement Campaign

- Started in January 2003
- Covering entire range of incidence angles (5 beams)
- 2 to 4 products of each beam every 24-day cycle





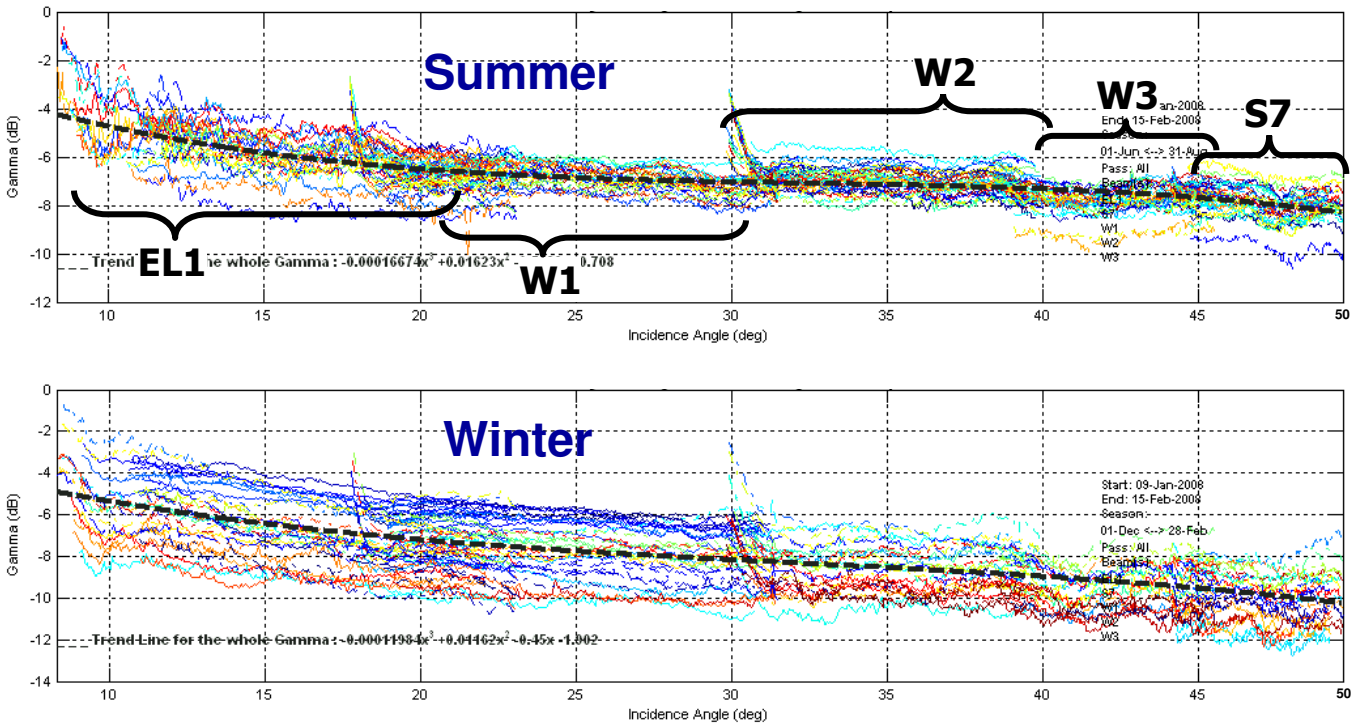


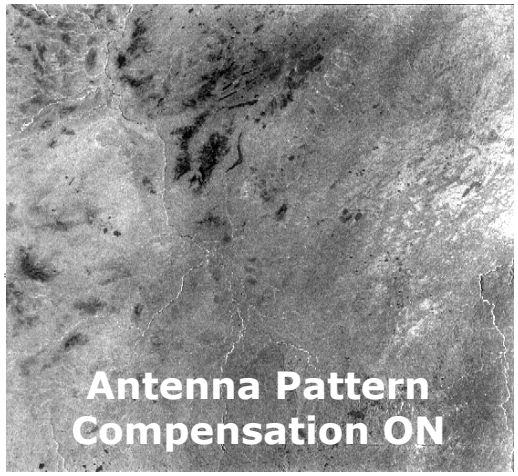
Canadian Space Agency | Agence spatiale canadienne

Boreal Forest: Seasonal Reflectivity

Extractions of $\gamma(\theta_{inc})$ from Boreal Forest images

- Assuming beams remain calibrated during acquisitions





γ ~ centered around Rainforest value (-6.5 dB)

γ dependence conforms to clutter models

Large variation of reflectivity levels, especially in winter

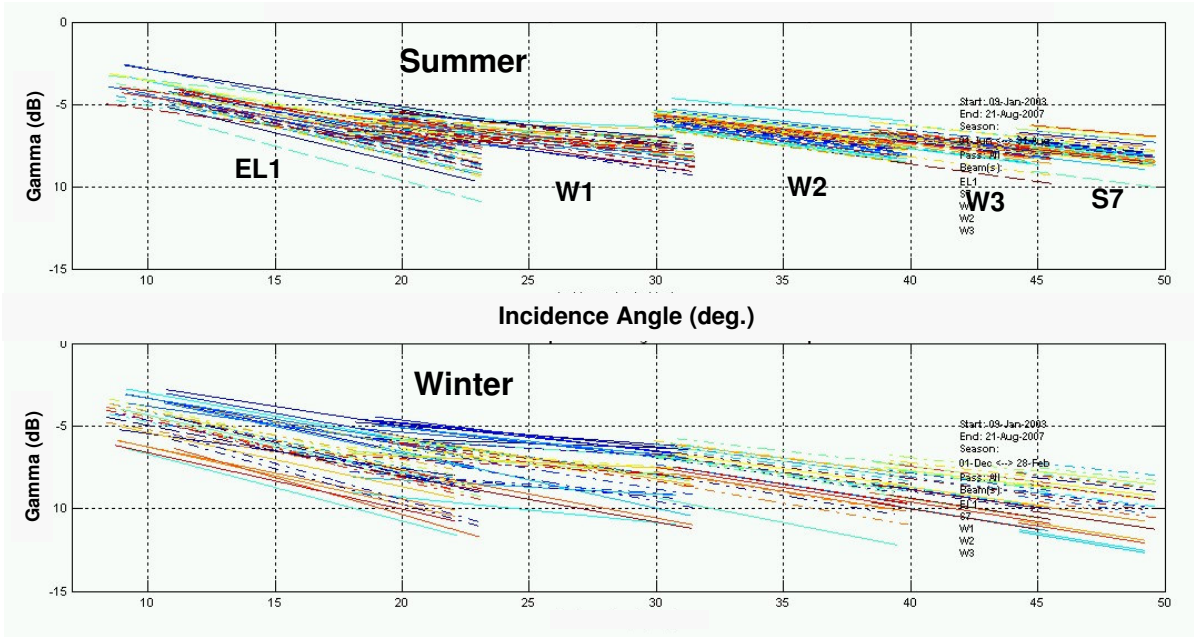
Boreal Forest: Deriving Reflectivity Estimates

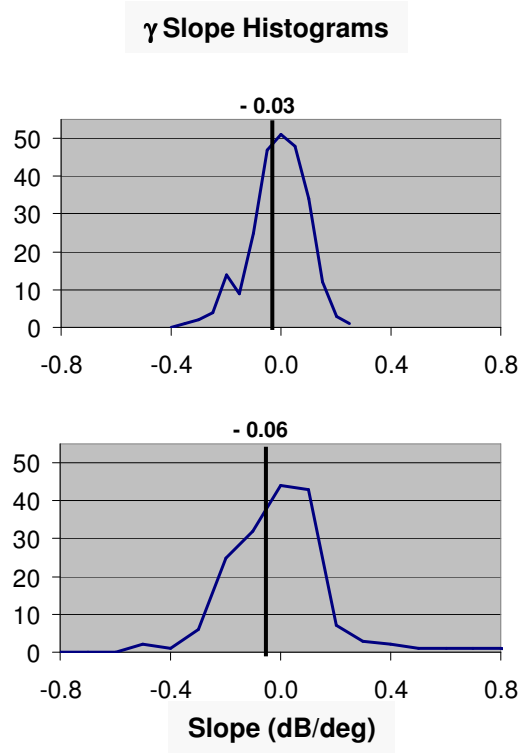
Assumptions:

- Seasonally stable
- Linear anisotropy over each beam range

Model

$\gamma \sim k\,\theta_{inc}$ over incidence angle range of each tested beams





Elevation Beam Pattern Extraction Tests

Derived a beam-wise linear reflectivity estimate $\hat{\gamma}(\theta_{inc})$, for both reference periods

$$G^2(\theta_{el}) \propto P_R / \hat{\gamma}(\theta_{inc})$$

In analysis software, substitute constant Rainforest reflectivity with 'summer' or 'winter' $\hat{\gamma}$ reference, for the given beam

Procedure (as with Amazon imagery):

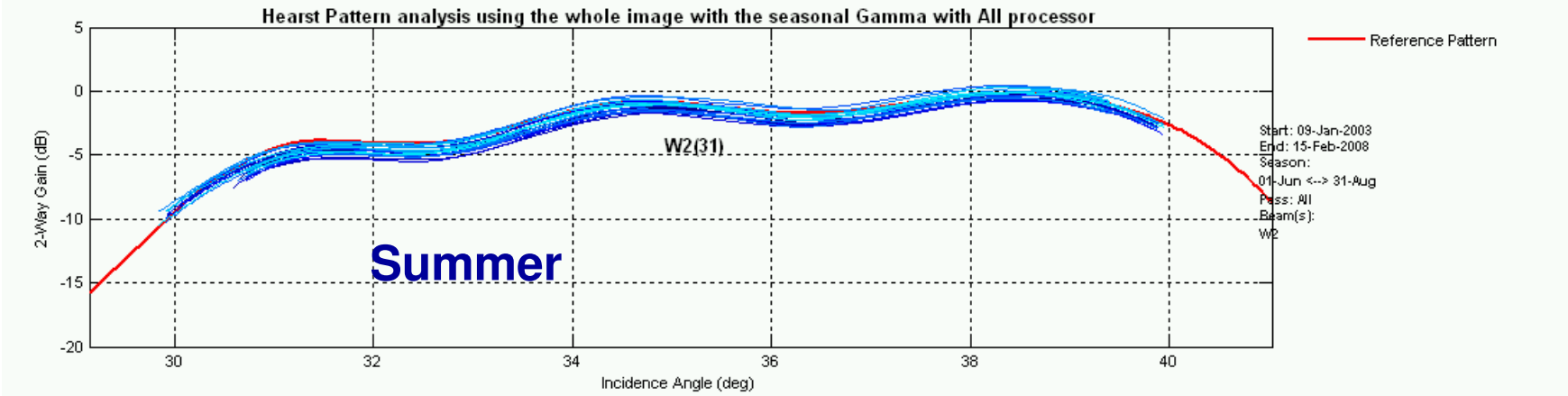
1. Extract beam pattern
2. Compare with calibrated pattern in Payload Parameters File
3. Measure radiometric deviation: peak-peak of pattern difference (dB)

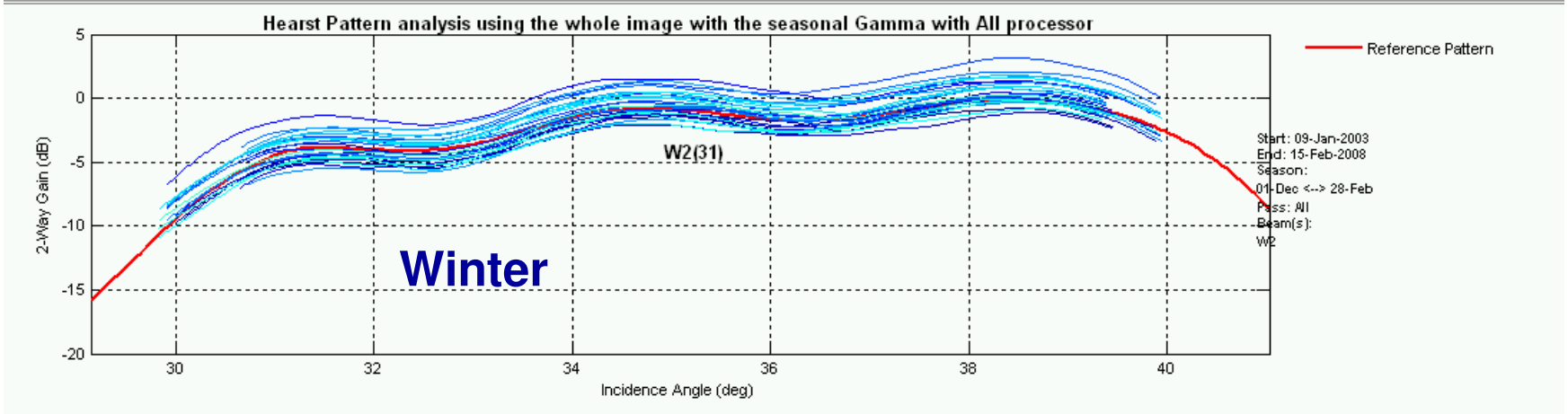
	Average peak-peak pattern difference (dB) 100% swath	
	'Summer'	'Winter'
EL1	1.4	1.8
W1	1.1	1.5
W2	1.0	1.4
W3	0.8	1.3
S7	0.8	1.3

Canadian Space Agency | Agence spatiale canadienne

Boreal Forest Extracted Pattern Plots

Beam W2



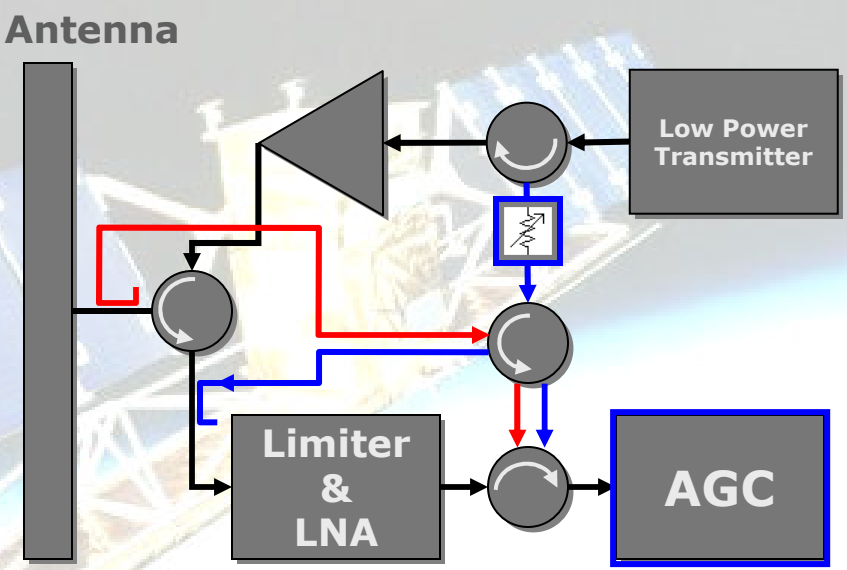


Internal Calibration Subsystem

Monitoring of the SAR instrument subsystem components for gain variations/linearity

- High-Power Amplifier, Limiter, LNA, Mixer, IF, AGC

- Pulse Replicas used for on-line compensation (processor)
- Internal Calibration Path used to test RX linearity
  - On-board subsystem equipped with stepped attenuator



From 1999 to 2006: 8 (annual) tests carried out

- Testing all stepped attenuator settings + AGC attenuator settings (~40 dB)
- Results very similar over the years: marginal variations - no apparent trends
- Latest results of last test in Fall 2006 consistent with past series
- One additional test in Spring 2006, No indication of any seasonal variations

Summary

RADARSAT-1 from early maintenance phase (1997) to present:

- **Image quality consistently maintained better than specification (point target measurements)**
- **Radiometric calibration routinely monitored and maintained through recalibrations using Amazon site**
- **ScanSAR calibration – stable and mature**
- **Radiometric calibration supported by Boreal Forest RT data**
- **Spacecraft health and resource utilization appear to indicate a continuation of operation until March 31, 2009 (current end date of operation as approved by the Government of Canada)**