Synthetic Aperture Radar (SAR)

Developments up to RADARSAT-2

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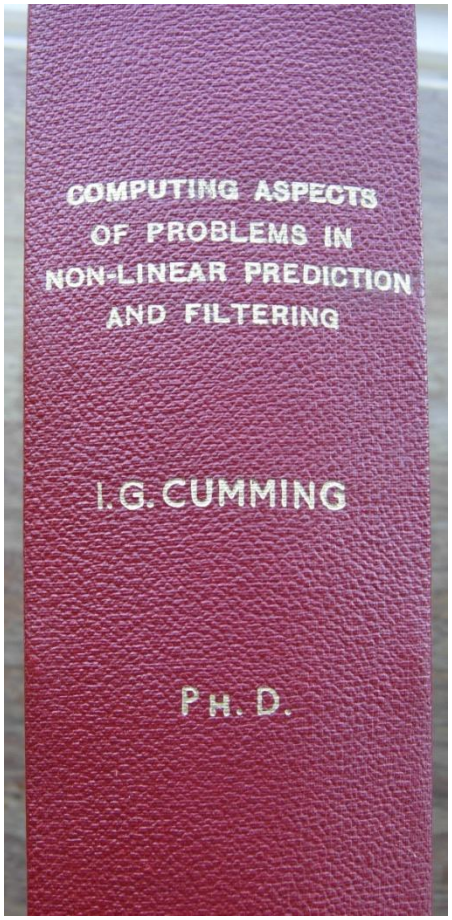
Outline of Talk

- Brief career outline
- What is SAR?
- SAR Signal Processing
- Satellite SAR
- RADARSAT-2: innovations and images

Career Outline

- B.A.Sc. Univ. of Toronto 1961
- Ph.D. Imperial College 1967
- Steel Mill Automation 1968-71
- Sonar Signal Proc. 1971-77
- SAR Signal Proc. 1977-93
  - first easterner hired by MDA
- DSP Prof. at UBC 1993-2006
  - MDA/NSERC Industrial Research Chair in Radar Remote Sensing

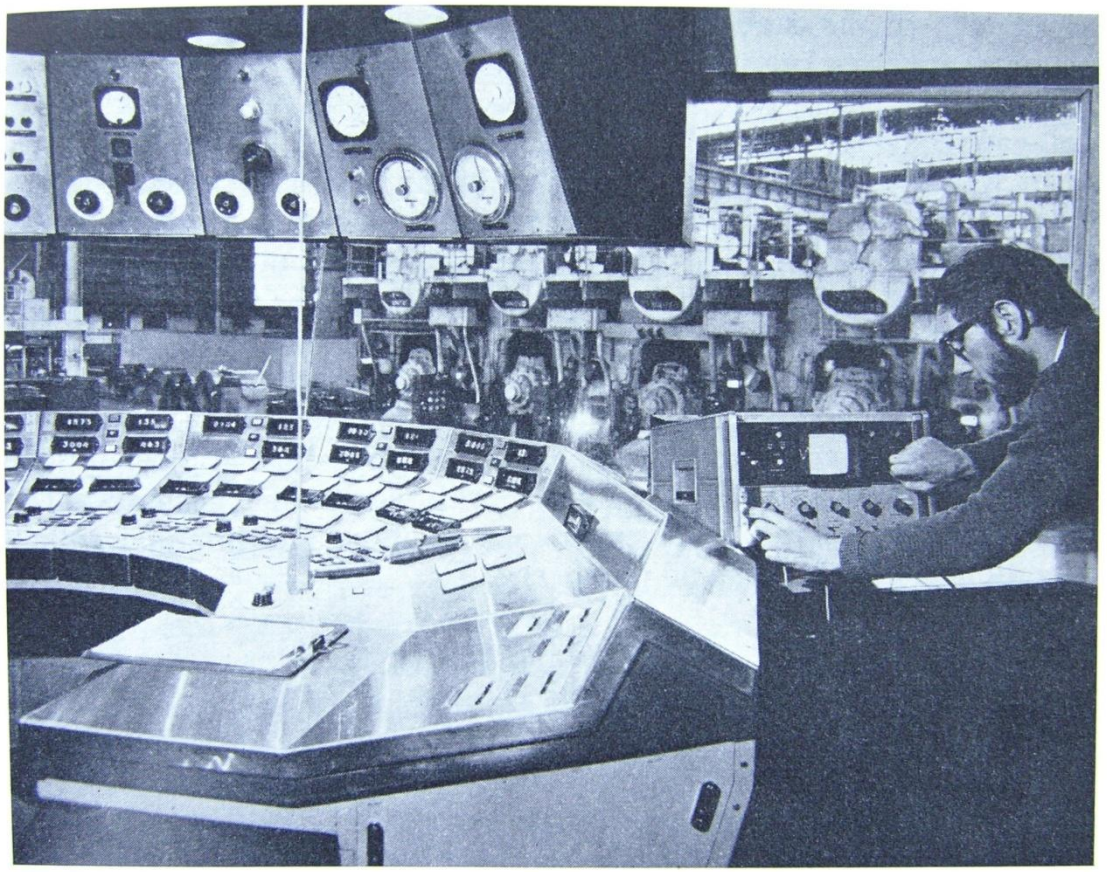
- Common thread…
  - Digital Signal Processing
  - Analysis of random data



Steel Mill Automation

- 5-stand cold rolling mill in Port Talbot, Wales
- Contract with GE to design mill control system
- Measured 5 roll speeds and 5 inter-roll tensions
- Controlled force on each roll by turning a screw
- Controlled torque of each motor by current
- These 10 variables all interact with each other

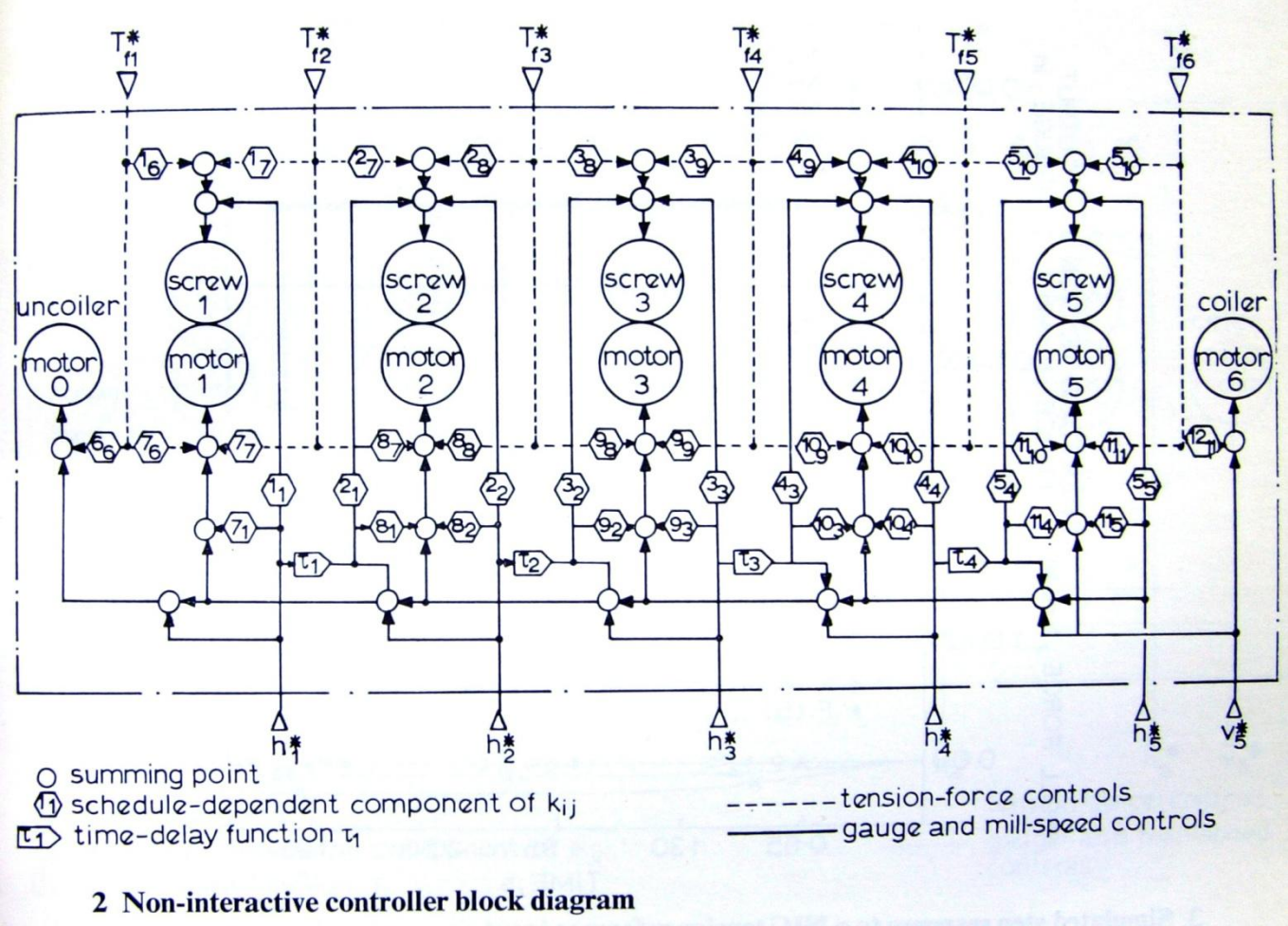
On-line identification of a tandem mill



2 British Steel Corporation's 5-stand tandem mill at Port Talbot as seen from the control pulpit

Non-interactive Control System

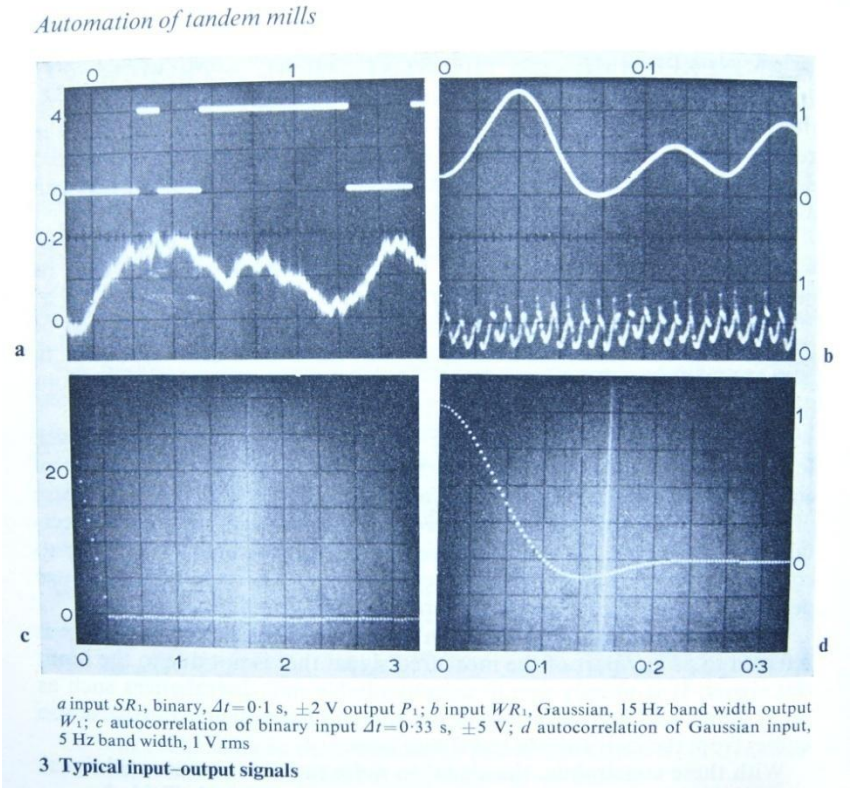
Best control can be achieved by adjusting the controls to affect one variable at a time



2 Non-interactive controller block diagram

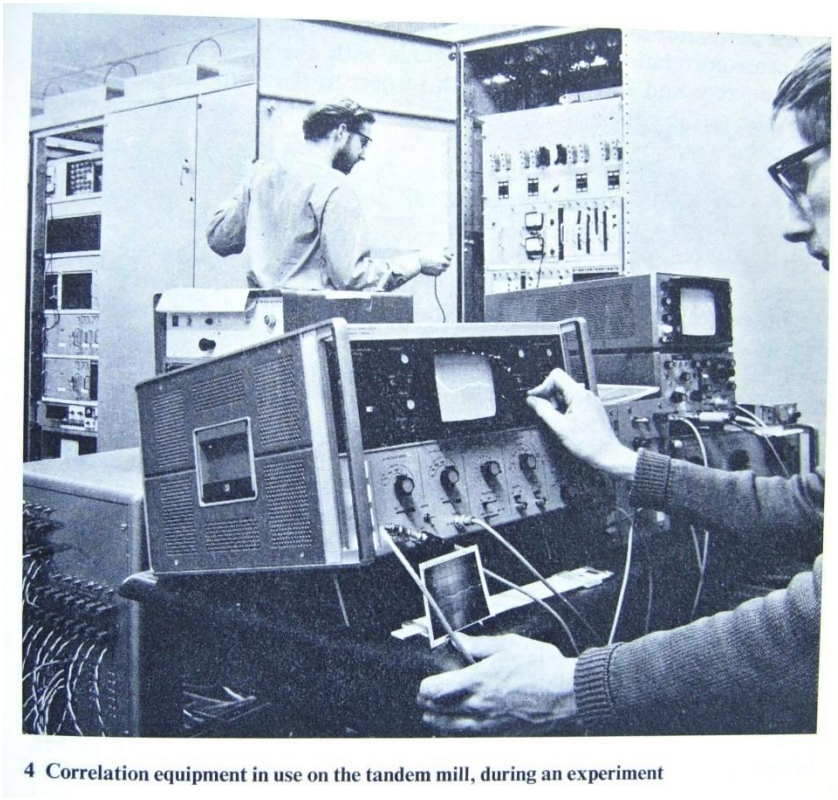
Identification of Mill Dynamics

- The mill dynamics must be estimated and a model built, to design the control system
- A pseudo-random binary sequence was used to perturb the motor torque
- An HP on-line digital correlator was used to measure the mill dynamics



a input SR_1, binary, $\Delta t = 0{\cdot}1$ s, ± 2 V output P_1; *b* input WR_1, Gaussian, 15 Hz band width output W_1; *c* autocorrelation of binary input $\Delta t = 0{\cdot}33$ s, ± 5 V; *d* autocorrelation of Gaussian input, 5 Hz band width, 1 V rms

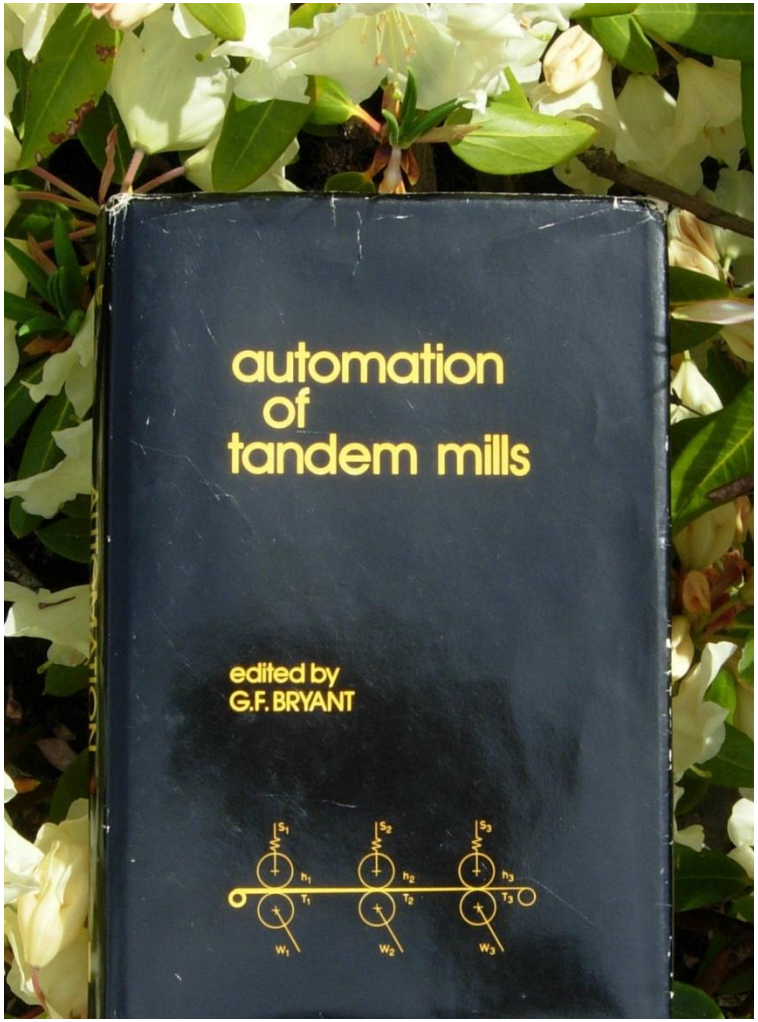
3 Typical input–output signals



4 Correlation equipment in use on the tandem mill, during an experiment

Installation on the Steel Mill

- The control system was installed in 1972, and improved the steel quality and reduced breakages
- A book was written describing the project:
  - published by the British Iron and Steel Institute in 1973



What is SAR?

- Specific Absorption Rate $$SAR = \frac{\sigma |E|^2}{2\rho}$$
  - a measure of how RF energy is absorbed by human tissue
- Search and Rescue
- Severe Acute Respiratory Syndrome (SARS)
- Synthetic Aperture Radar
  - active radar from airborne or spaceborne platforms
  - coherent processing to achieve very fine resolution

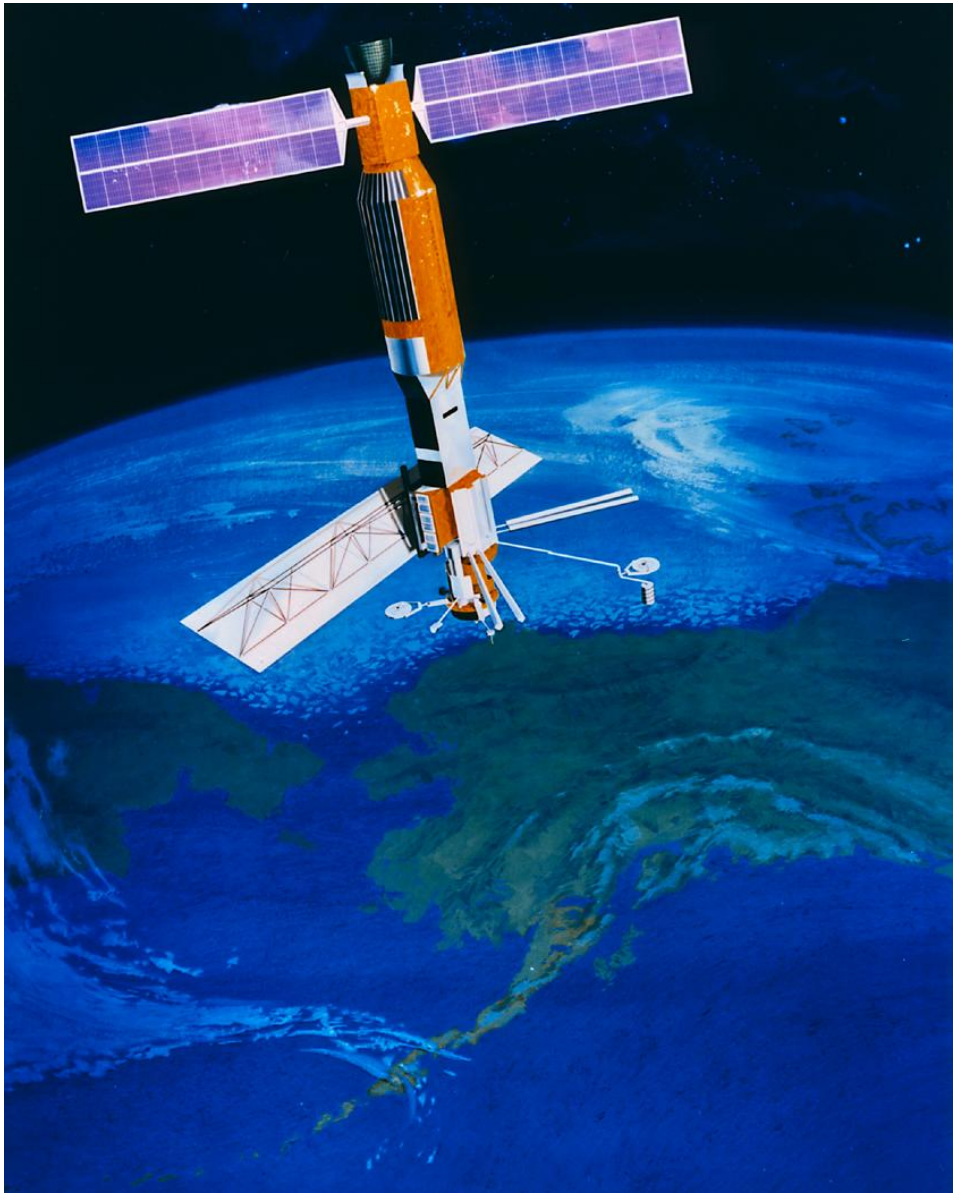
Synthetic Aperture Radar

- "Aperture" refers to the size of the sensor "opening"
  - e.g., camera lens, radar antenna
  - the bigger the opening, the better the resolution

- With "synthetic aperture", we use DSP to increase the aperture
  - Real aperture – is the length of the radar antenna, D
  - Resolution = beam footprint = $R\lambda/D$ or many km from a satellite
  - R is the range, e.g., 1000 km for a satellite, λ is the radar wavelength
  - Synthetic aperture – is the length of the beam footprint, X
  - Resolution = $R\lambda/2X = D/2$ or a few meters with typical satellite parameters

- Using DSP, the phase of each echo is adjusted to equal what it would be if there were a physical antenna the length of the beam footprint

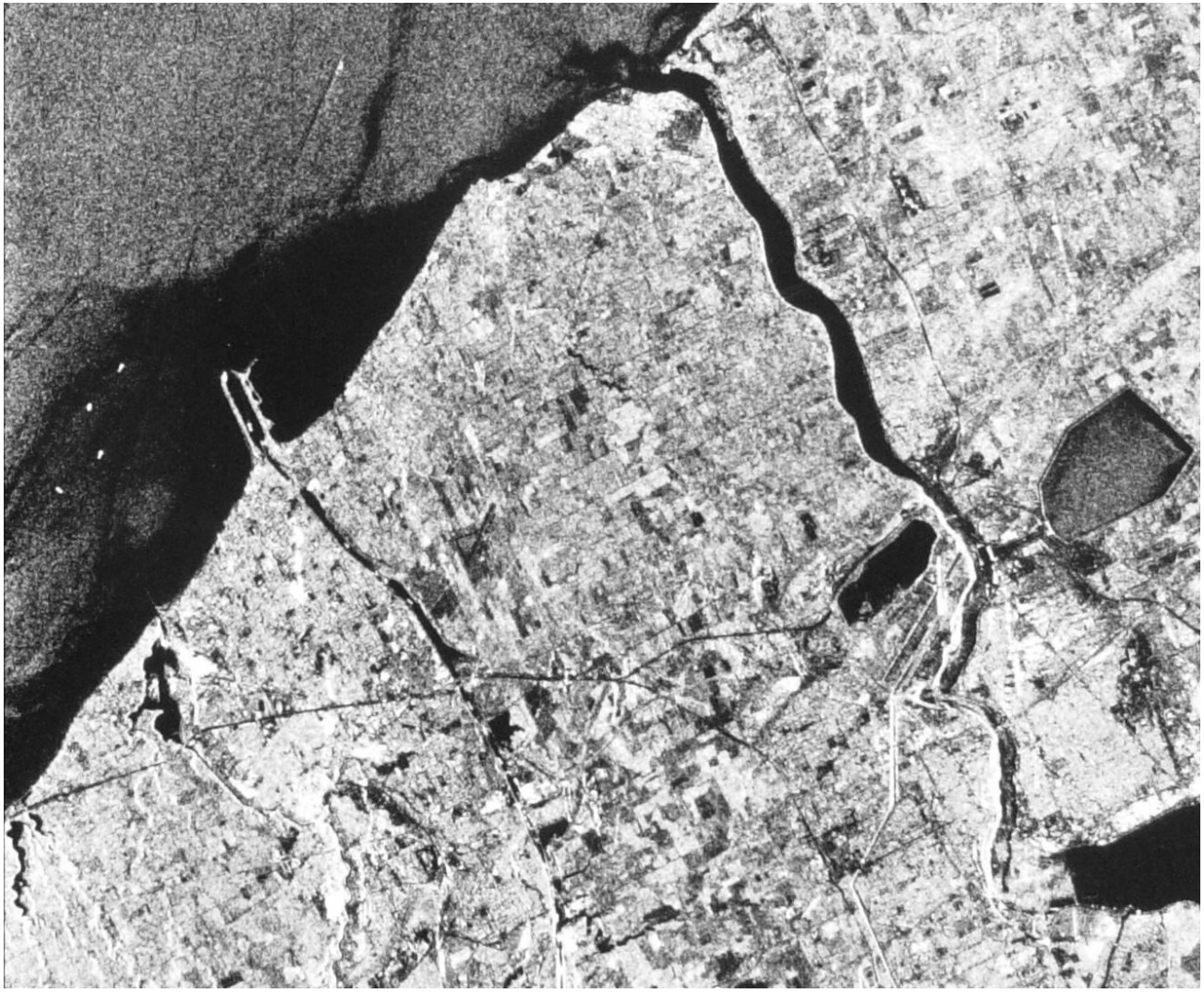
SEASAT – the beginning



- JPL/NASA program
  - launched October 1978
  - first civilian satellite SAR
- Canada a program partner
- MDA contracted to build a ground station and processor
- A small team was formed at MDA to build the SAR processor
  - began research in 1976
  - first image in early 1979
  - also had an airborne SAR project

First SEASAT Image

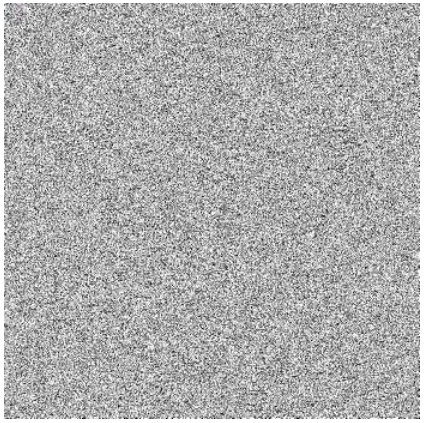
Niagara Falls and Welland Canal, data from Oct 1978



- The MDA team were the first in the world to produce a SEASAT image digitally
- Image published in "Aviation Week" Feb 1979
- Subsequently, processors were designed for SIR-B, SIR-C, ERS-1, J-ERS-1, RADARSAT-1 and ENVISAT
- RADARSAT-1 launched in 1995
  - prime: SPAR Aerospace
  - still operating after 13 years

A Word on Digital SAR Processing

- When data received, it is in the form of a hologram, where the information is in the phase rather than the amplitude of the signal
  - the received data looks like pure noise
  - the reflections from a single point on the ground is spread over 2000 x 2000 samples
  - energy from many scatterers is mixed together in the received signal



- A 2-dimensional, space variant, matched filter is used to focus the data
  - Done with a 2-dimensional correlation, implemented using FFTs
- 4 million operations/sec are needed to process the data in real time
  - data is collected at the rate of 10 million samples/sec
  - the first software processor took 40 hours to process a 40 x 40 km image
  - MDA have built real-time hardware processors
  - current ground stations have software processors running about 1/10 real time

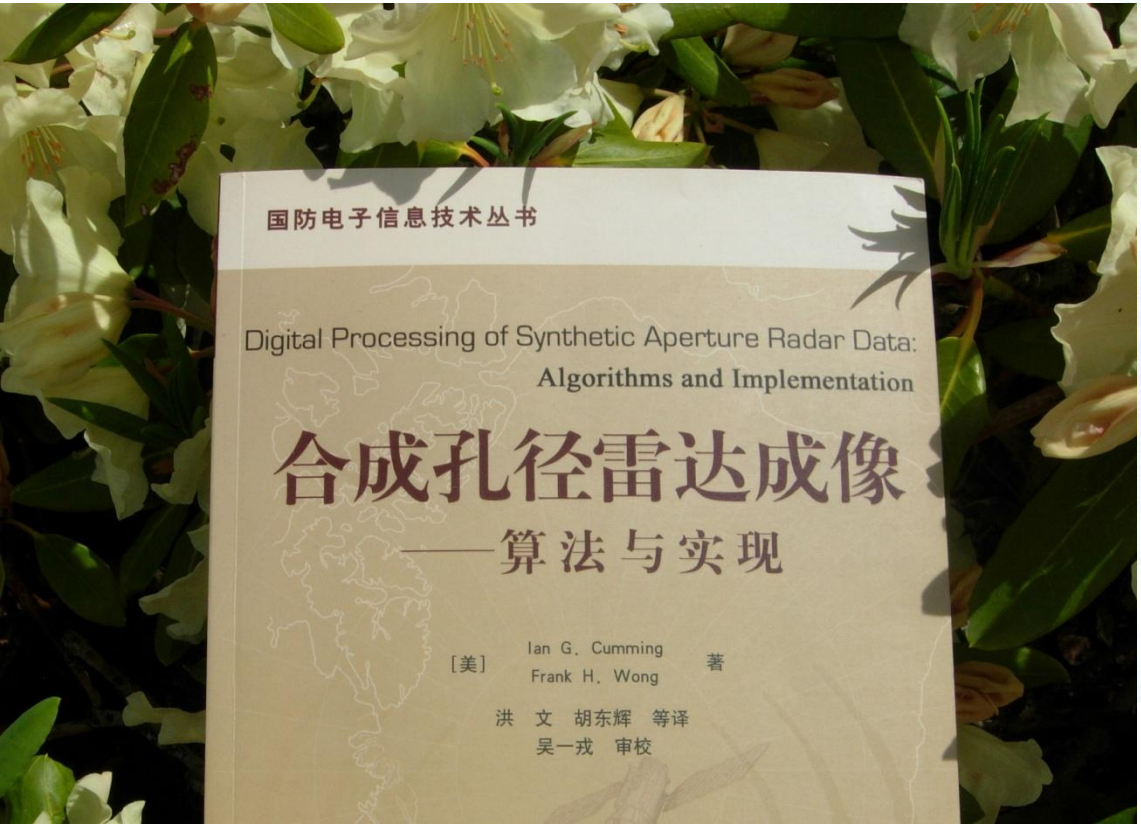
SAR Processing Book

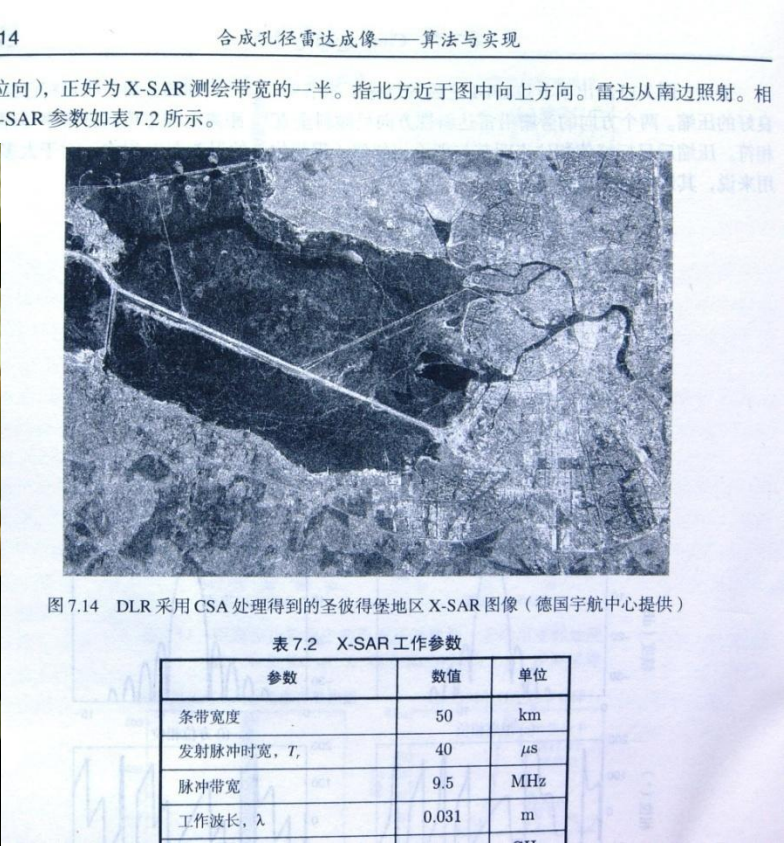
- In all, teams at MDA developed 3 out of the 4 common SAR processing algorithms in use today
  - Range/Doppler
  - Chirp scaling
  - SPECAN
- "Digital Processing of Synthetic Aperture Radar Data", Artech House, Boston, 2005

SAR Processing Book – 2

A Chinese edition was published in 2007 by:

Publishing House of Electronics Industry, Beijing





214 合成孔径雷达成像——算法与实现

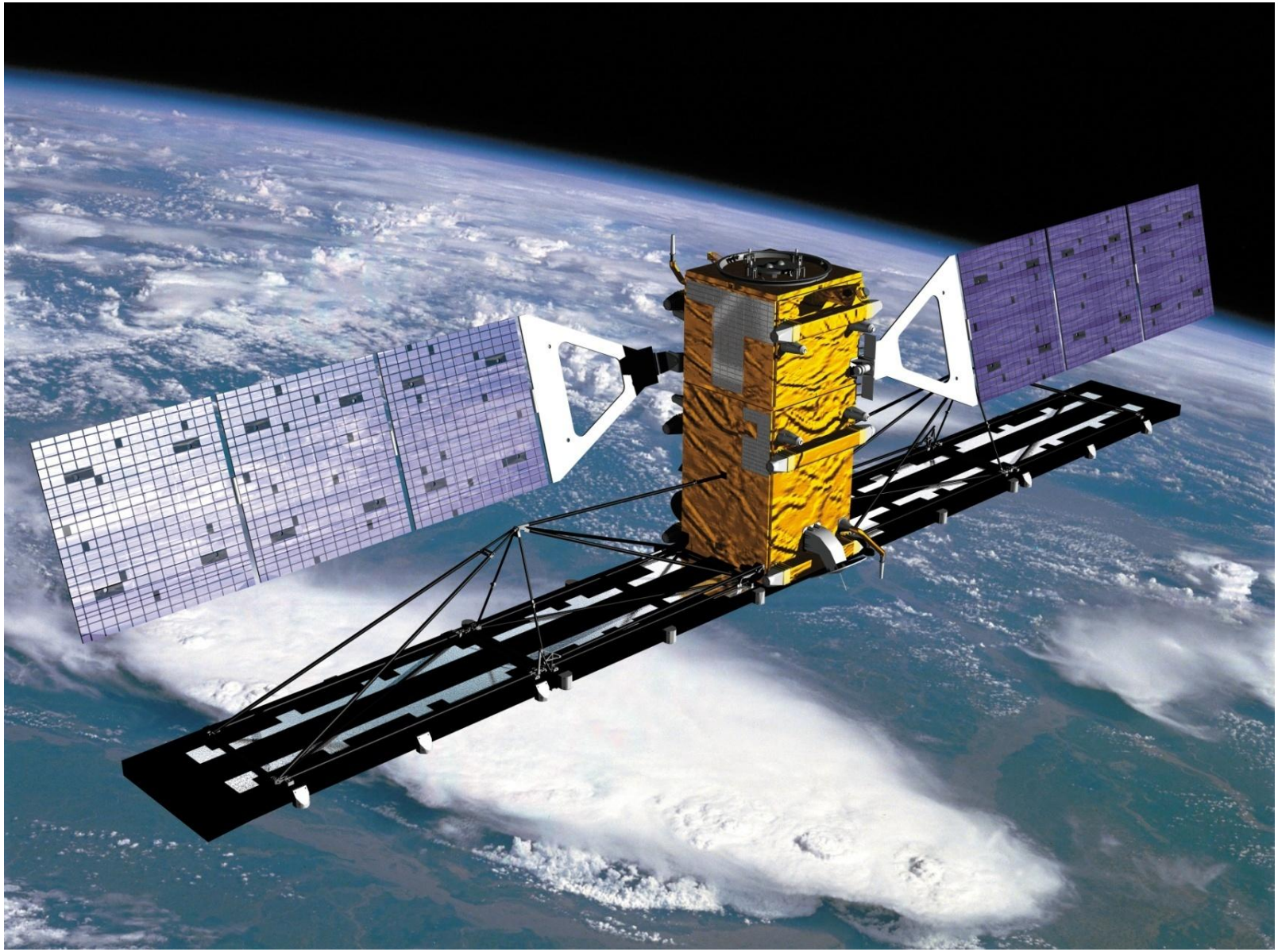
（方位向），正好为 X-SAR 测绘带宽的一半。指北方近于图中向上方向。雷达从南边照射。相关 X-SAR 参数如表 7.2 所示。

图 7.14 DLR 采用 CSA 处理得到的圣彼得堡地区 X-SAR 图像（德国宇航中心提供）

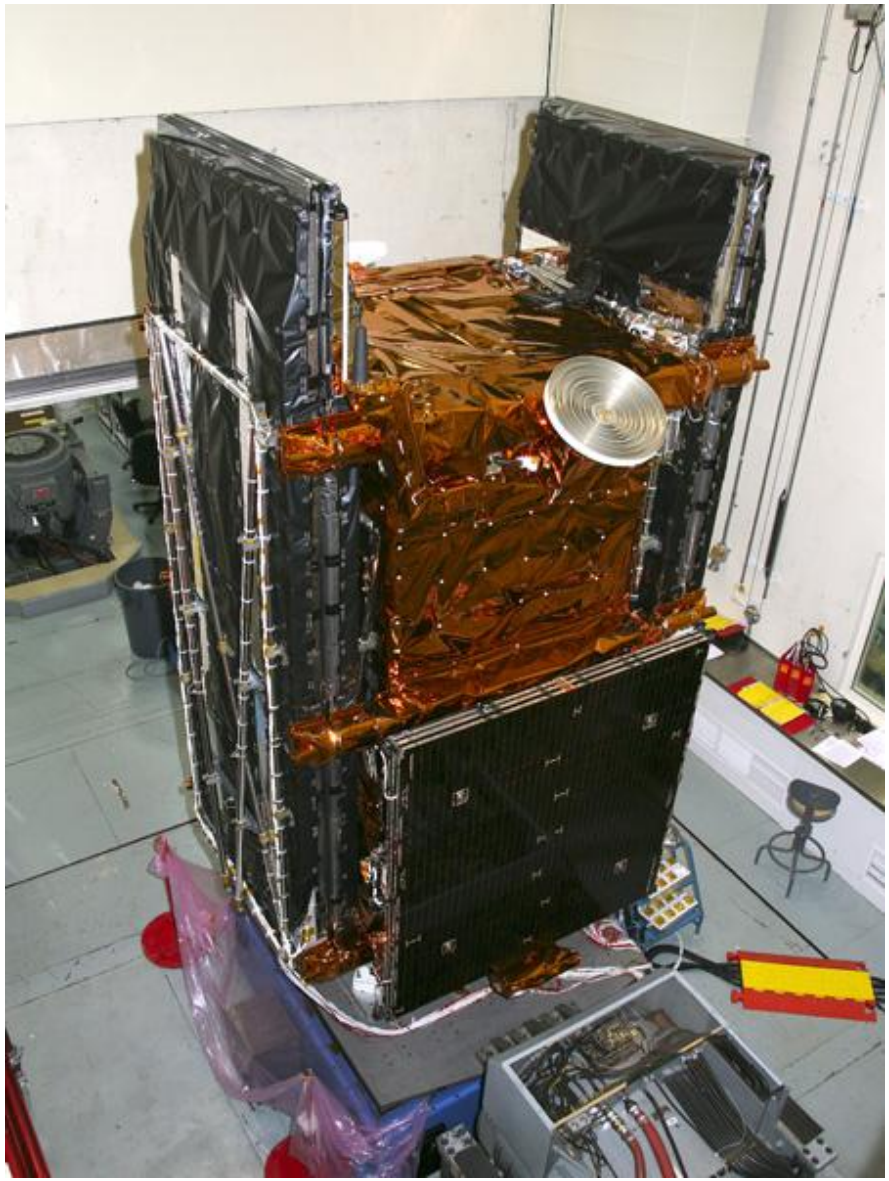
表 7.2 X-SAR 工作参数

参数	数值	单位
条带宽度	50	km
发射脉冲时宽，T_r	40	μs
脉冲带宽	9.5	MHz
工作波长，λ	0.031	m

RADARSAT-2 – 2007



RADARSAT-2



- MDA is the prime contractor:
  - managed the program
  - built the payload (formerly SPAR)
  - built the satellite software
  - built the ground stations and SAR processors
  - MDA/GSI operates the satellite
- Assembled, integrated and tested in the David Florida Laboratory in Ottawa
- Image shows vibration testing at DFL
- SAR antenna and solar panels are folded up in launch configuration

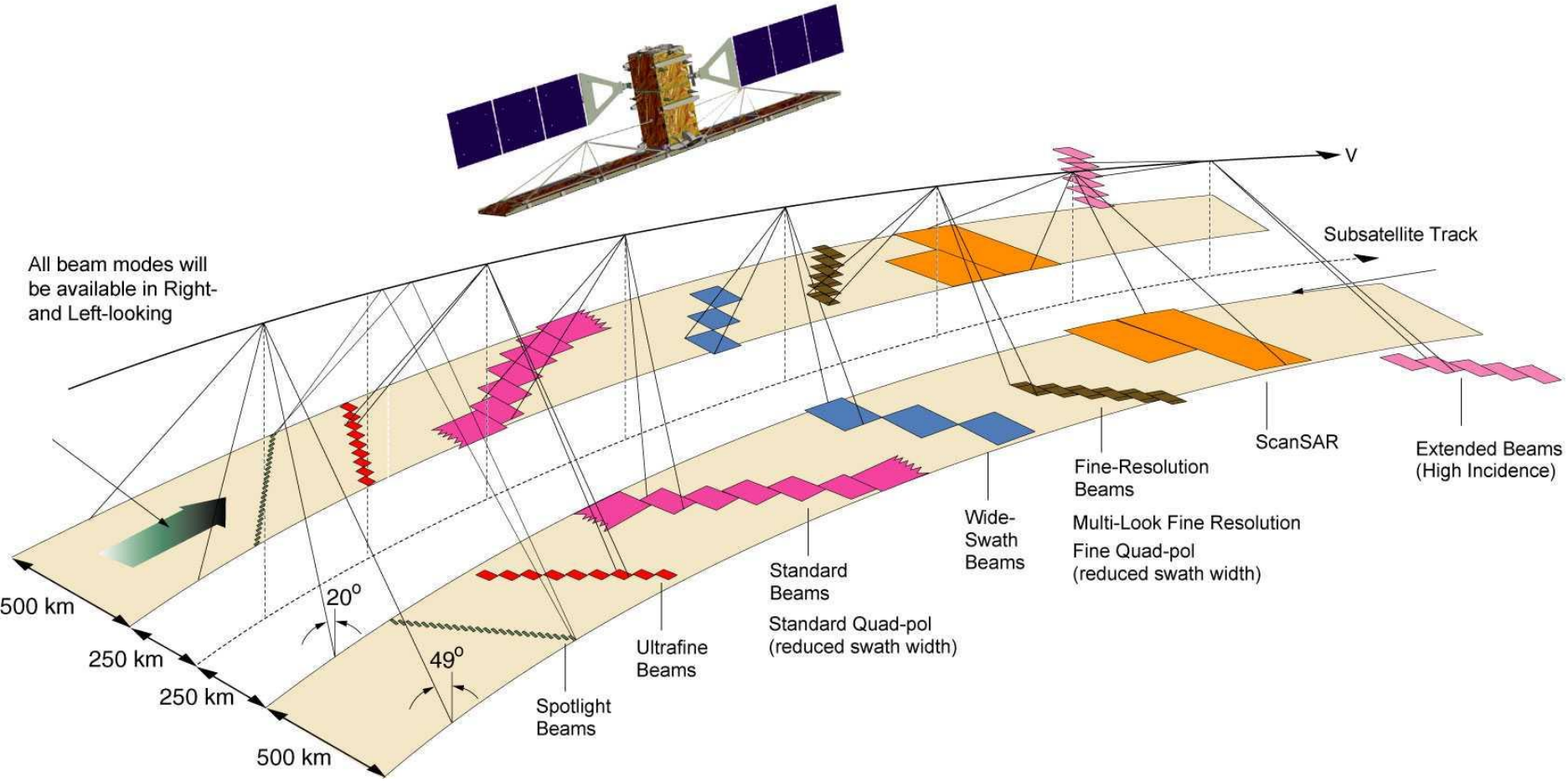
RADARSAT-2

- Launched December 14, 2007
  - aboard a Russian Soyuz FG launch vehicle
  - at 19:17 local time
  - at the Baikonur Cosmodrome in Kazakhstan
- Now fully operational:
  - after a successful calibration phase that ended April 27, 2008
  - C-band, multi-mode SAR
- Planned 7-year lifetime, with uses:
  - sea ice mapping and ship routing,
  - iceberg detection,
  - agricultural crop monitoring,
  - marine surveillance for ship and pollution detection,
  - geological and land use mapping,
  - wetlands mapping, topographic mapping.
- More images and launch video:
  - http://www.asc-csa.gc.ca/eng/satellites/radarsat2/images.asp
  - http://www.radarsat2.info/about/gallery/

RADARSAT-2 Innovations

- Many new modes in RADARSAT-2
  - Ultra-Fine – 3 m resolution
  - Spotlight – 1 m resolution
  - Single, dual and quad polarization
  - Left and right looking beams
- Accurate image location, using on-board GPS (100 m)
- Solid-state data recorders
- Faster beam selection via uplinked programming

RADARSAT-2 Beam Modes



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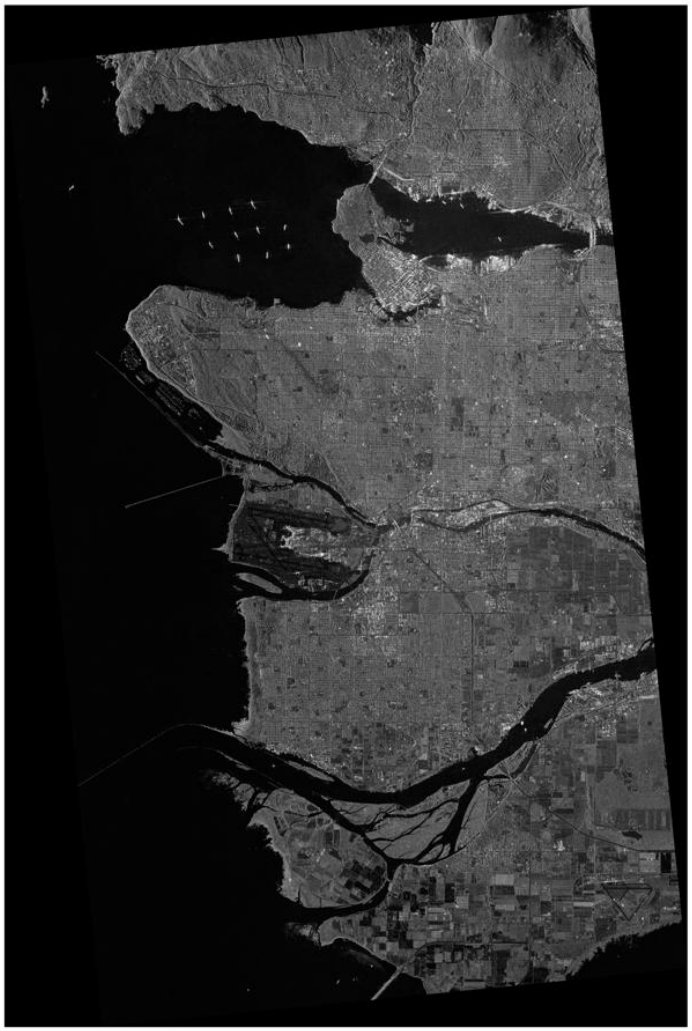
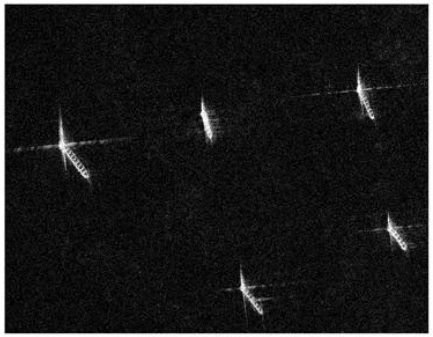
RADARSAT-2 – Ultra-Fine Mode

January 6, 2008 – 3 m resolution



20 km x 36 km, HH polarization

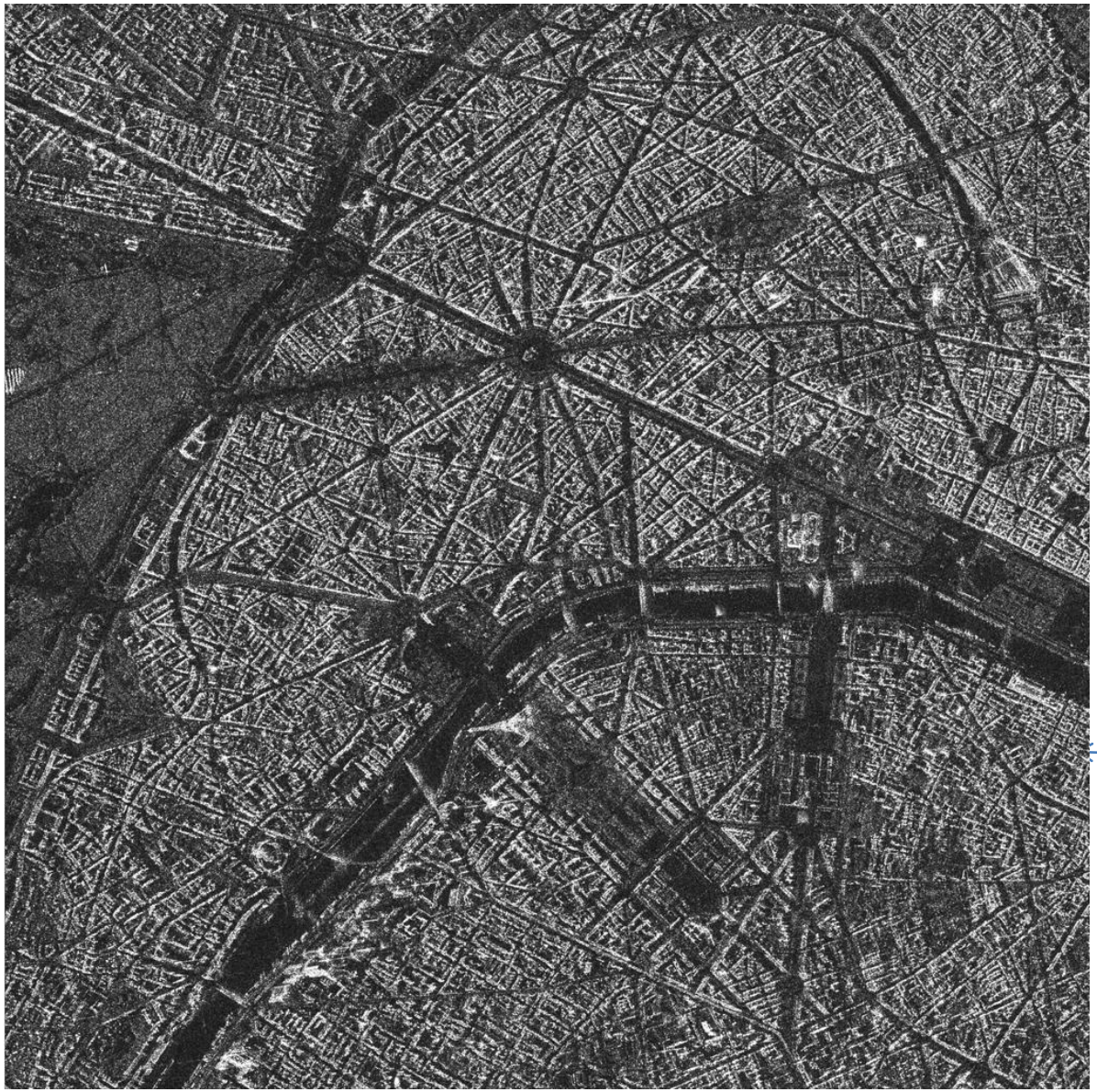


Canada Line

- Ships in English Bay
- Some superstructure details are visible
  - http://www.radarsat2.info/about/gallery/

Agriculture fields in Ladner

RADARSAT-2 – Ultra-Fine Mode



- Paris, France
- January 9, 2008
- 3 m resolution
- 6 x 6 km image

- HV Polarization
  - shows some city features better

Eiffel Tower

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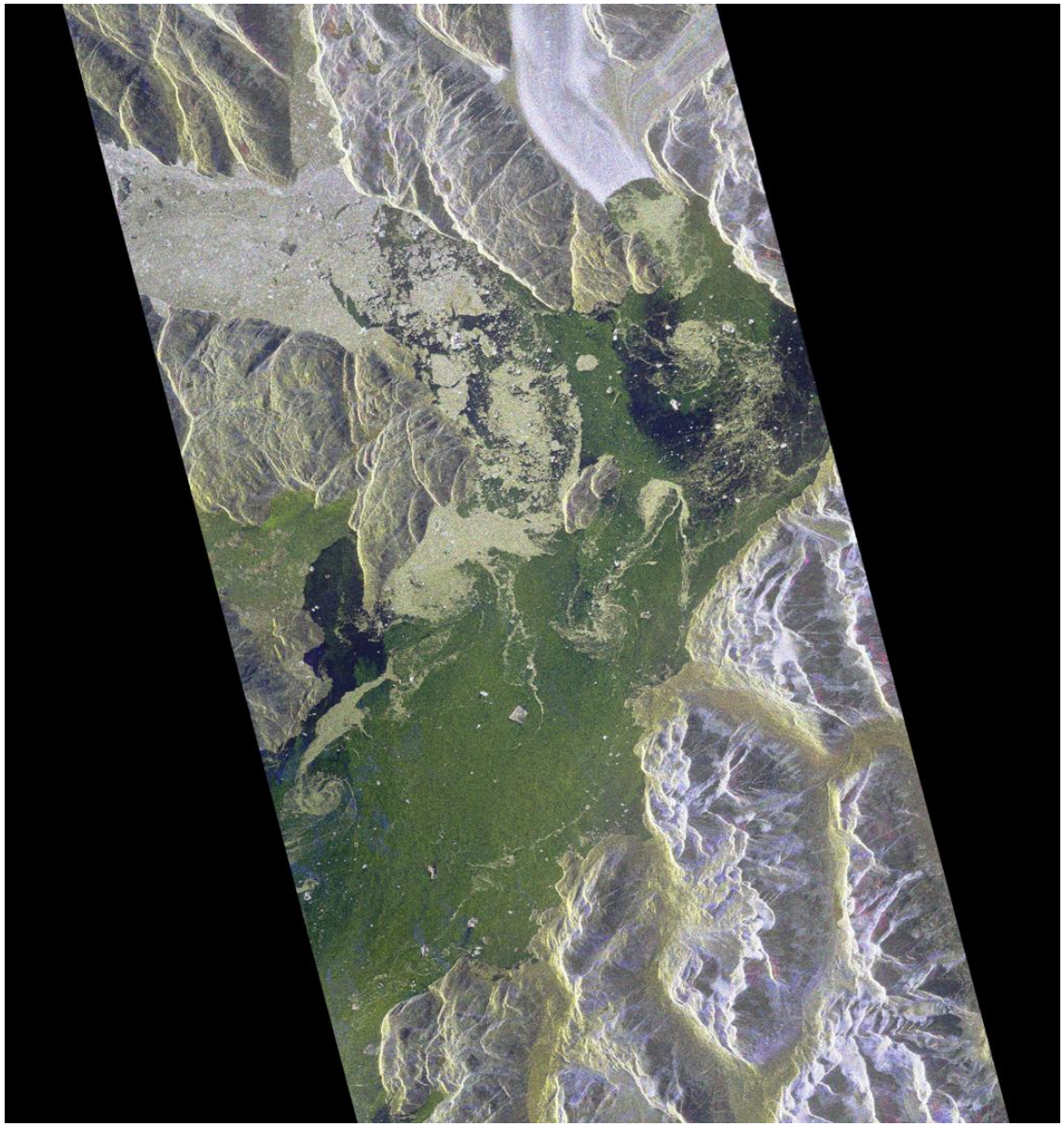
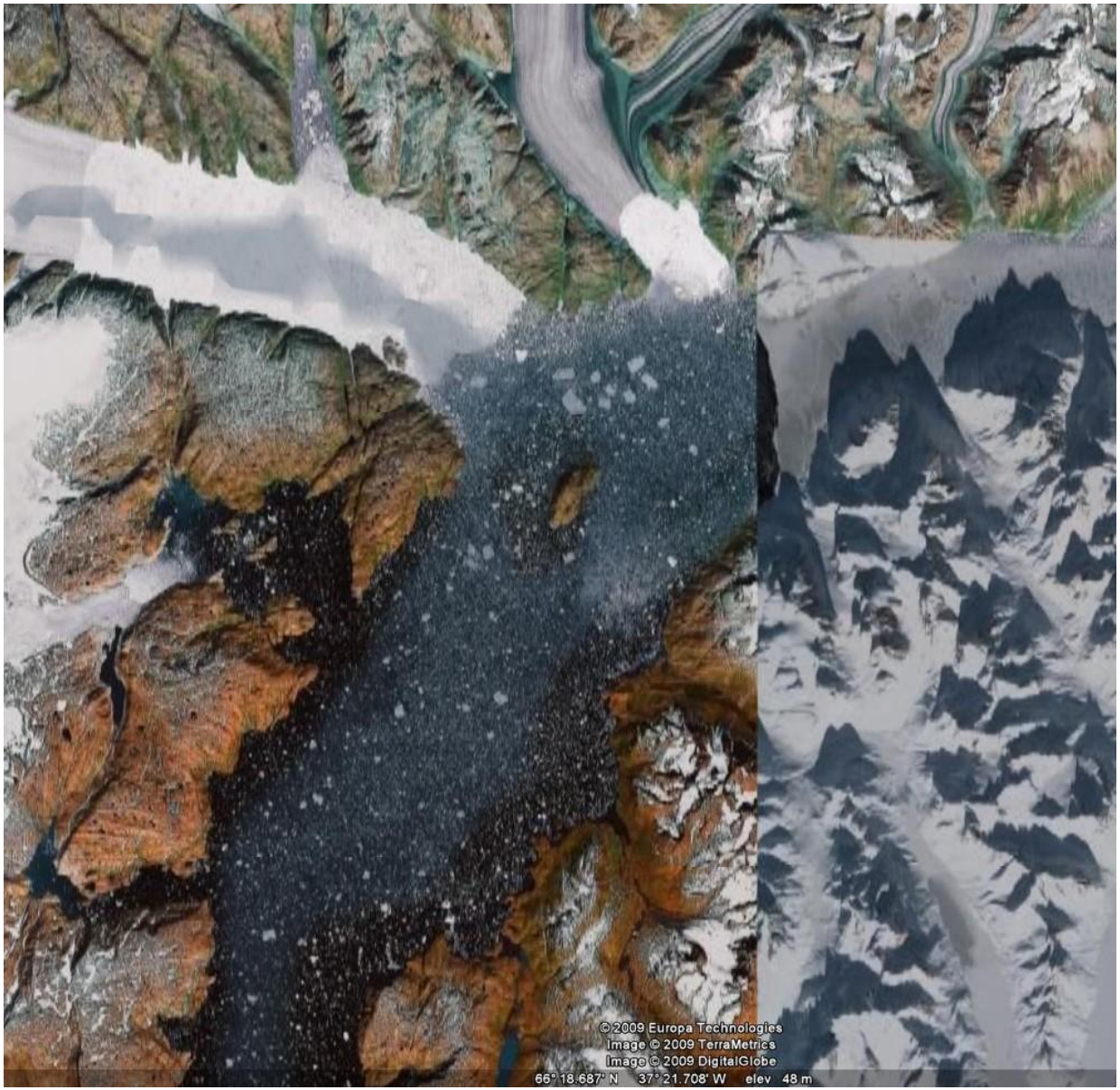
RADARSAT-2 Polarization



- Sermilik Fjord
- East Coast, Greenland
- 66.2 N, 37.5 W
- Std. Quad-Pol Mode
- Dec 18, 2007 (+4 days)
- (HH, VV, HV) = (R, G, B)

Google Earth Comparison



- Sermilik Fjord
- East Coast, Greenland
- Different seasons
  - Inset - Feb 26, 2006
- SAR has better ice discrimination

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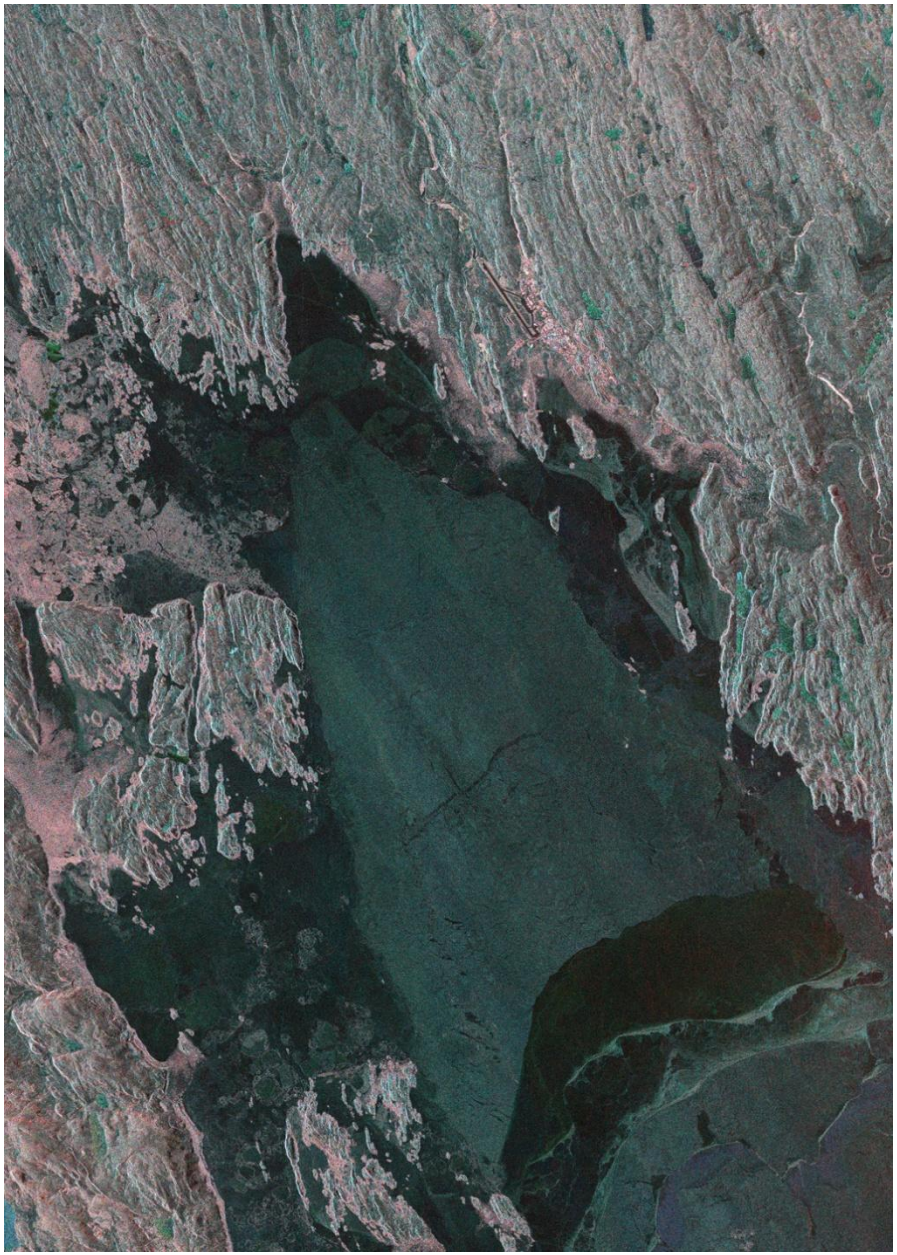
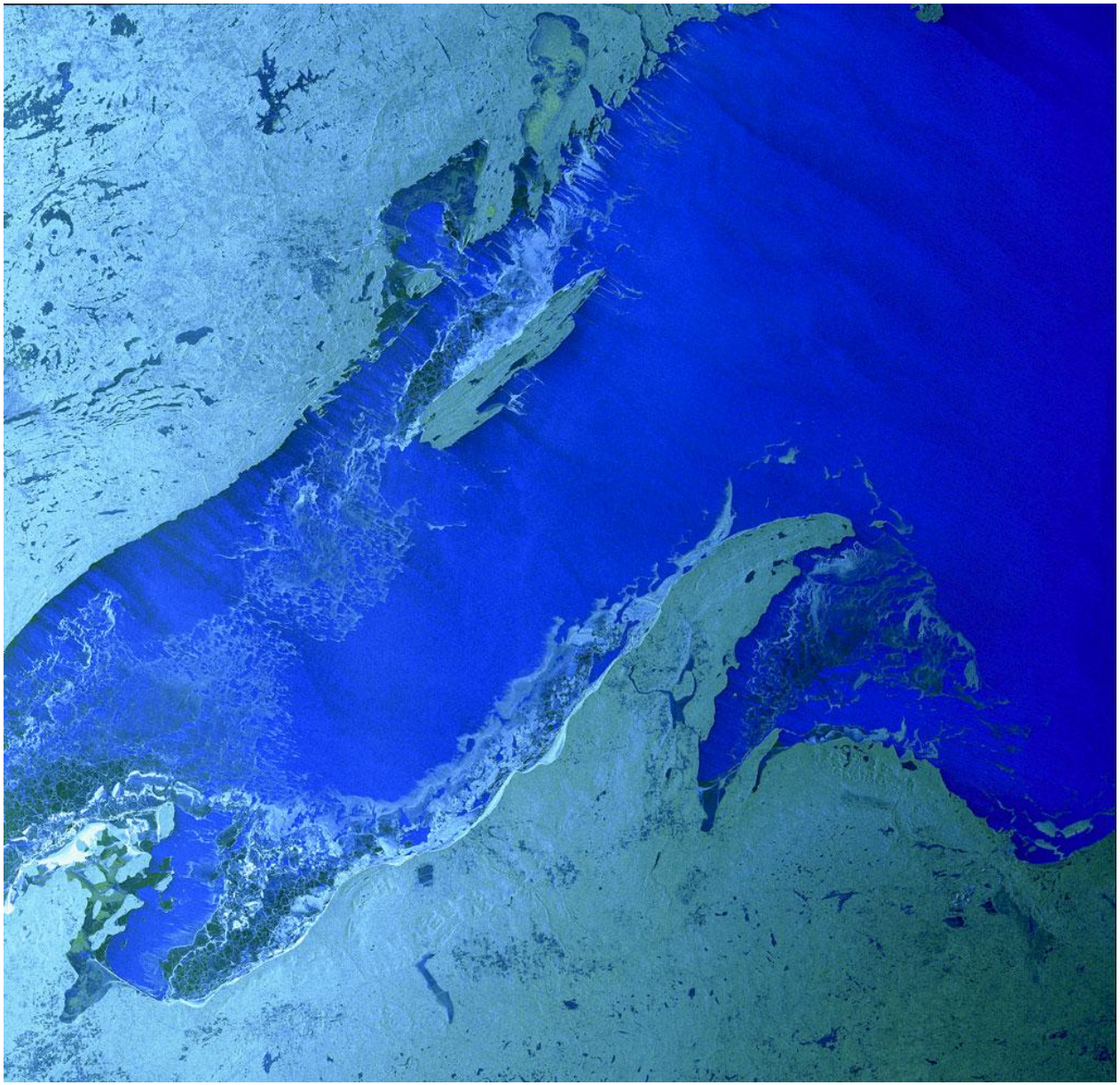
RADARSAT-2 Polarization



- Iqaluit, Baffin Island
- Frobisher Bay
- 66.2 N, 37.5 W
- Std. Quad-Pol Mode
- Dec 18, 2007 (+4 days)
- (HH, VV, HV) = (R, G, B)

RADARSAT-2 Polarization



- Thunder Bay, Ontario
- 47.7 N, 88.6 W
- March 3, 2008

- ScanSAR Narrow
- 300 x 300 km

- Dual Pol – (VV, VH)
- VV shown in blue

RADARSAT-2 Mode Comparison

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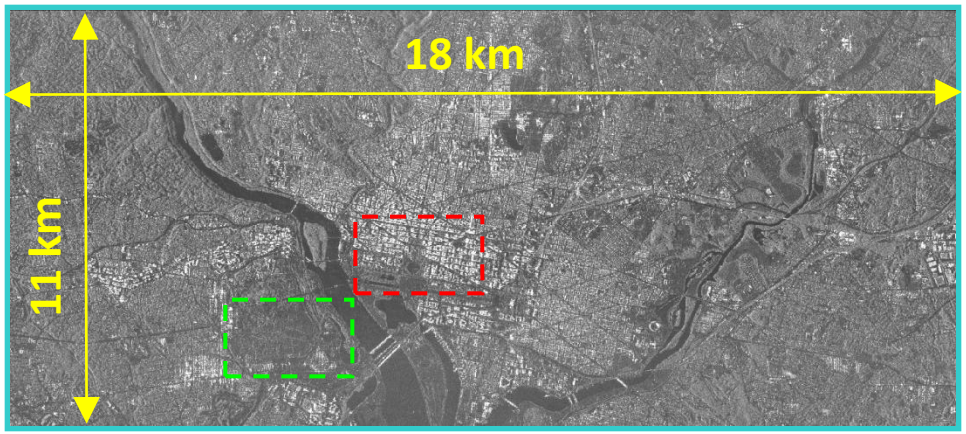

Spotlight Mode Product (right-looking ascending)

Spotlight Mode

- 0.8 m x 3.0 m resolution

Sub-images

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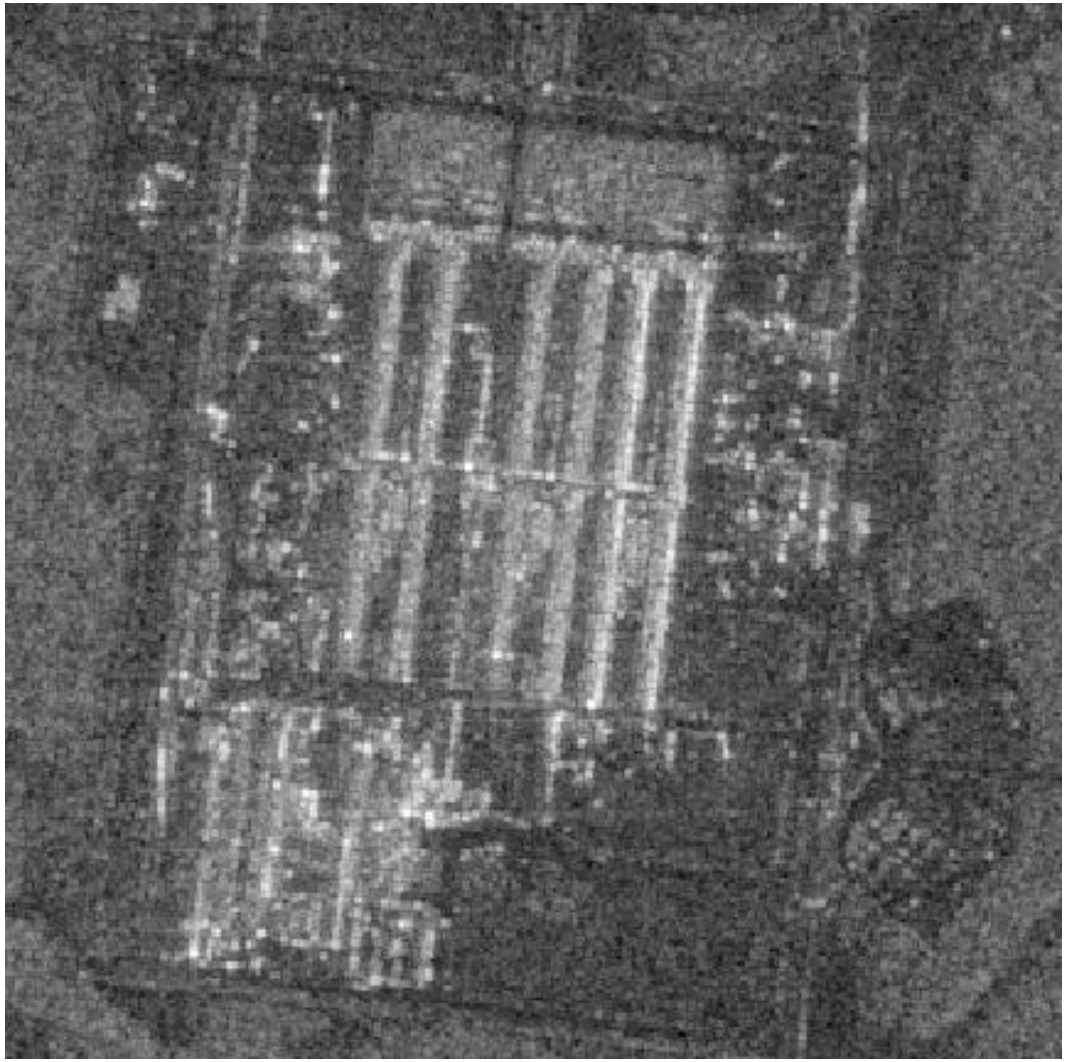
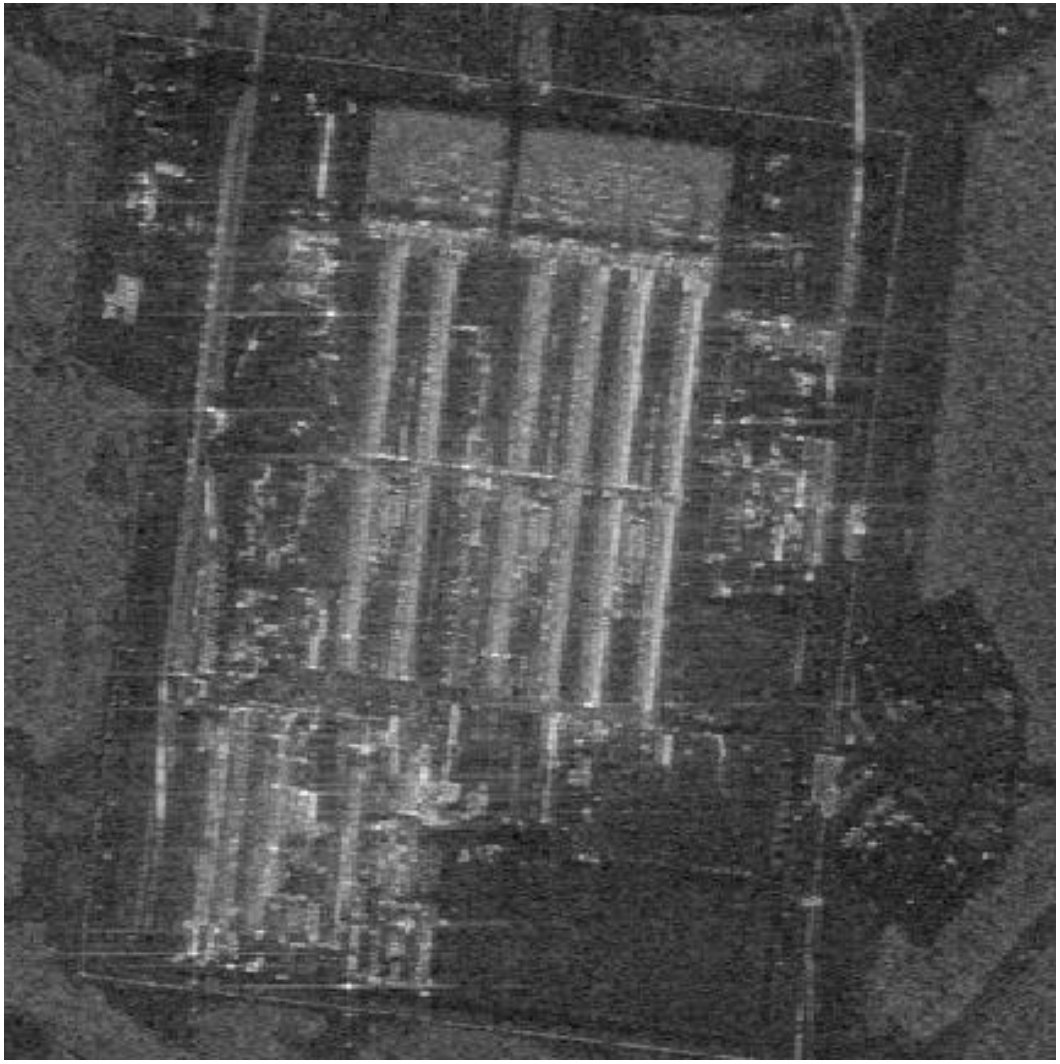
Comparison of Spotlight with Ultra-fine Resolution



Ultra-fine

Sub-Image
(1 km x 1 km)

Comparison of Spotlight with Ultra-fine Resolution



Spotlight

Sub-Image
(1 km x 1 km)

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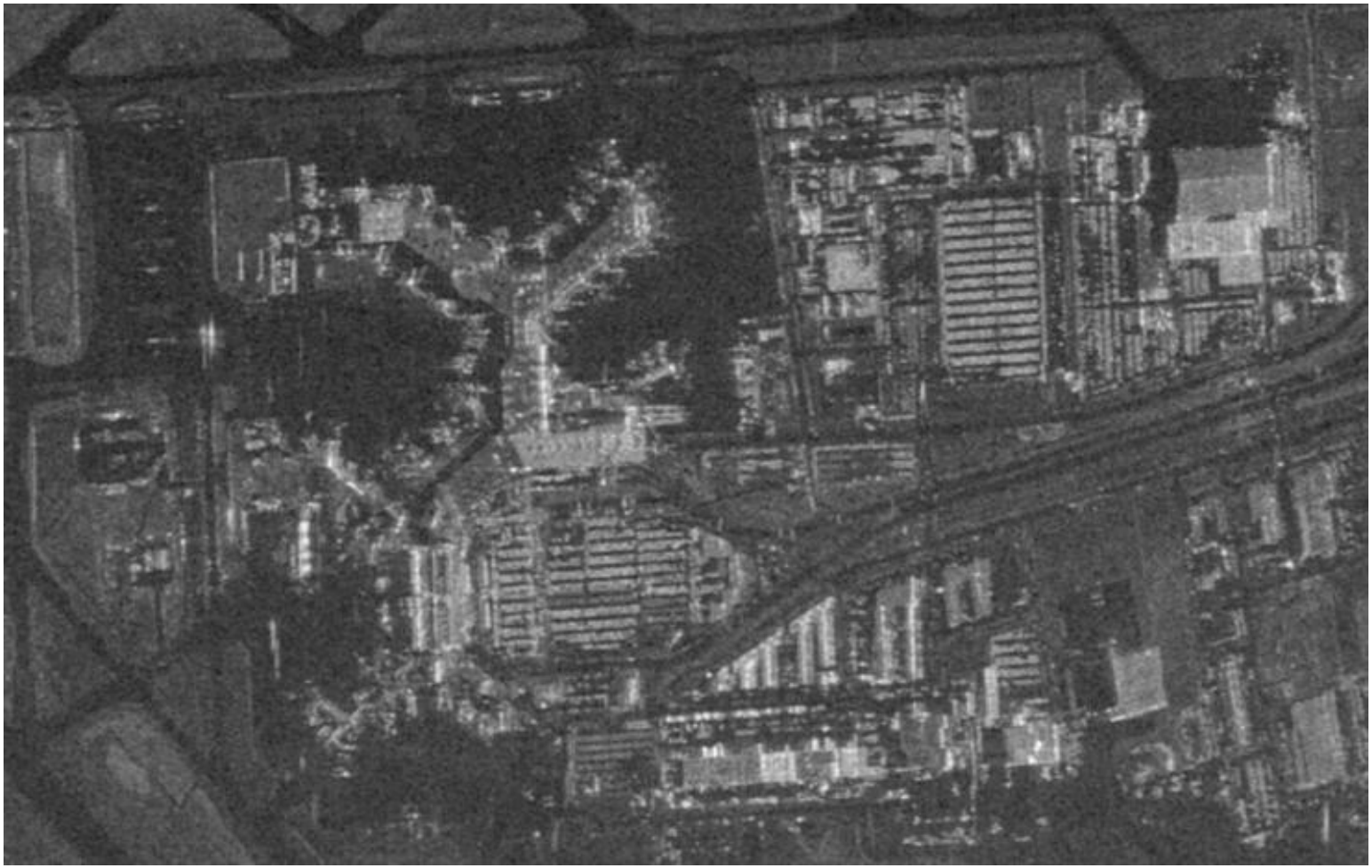
RADARSAT-2 Spotlight – Vancouver Int'l Airport



Closing Comments

- RADARSAT-2 is a brilliant accomplishment for a Canadian company
  - In June 2008, MDA wins the British Columbia Technology Industry Association Impact Award for Best Application of Technology for RADARSAT-2 SAR satellite.
- Proud to have played a role in SAR developments in Canada
  - SAR signal processing algorithms (image formation algorithms)
  - Doppler centroid estimation (beam pointing estimation)
- Proud to be a member of the IEEE
  - Member since 1962
  - Chairman, Vancouver Electronics Chapter, 1967-69
  - IEEE has served me well in my technical career
    - conferences, publications, local meetings