Satellite Photogrammetry / Radargrammetry with High Resolution Images for Topographic Mapping and Updating

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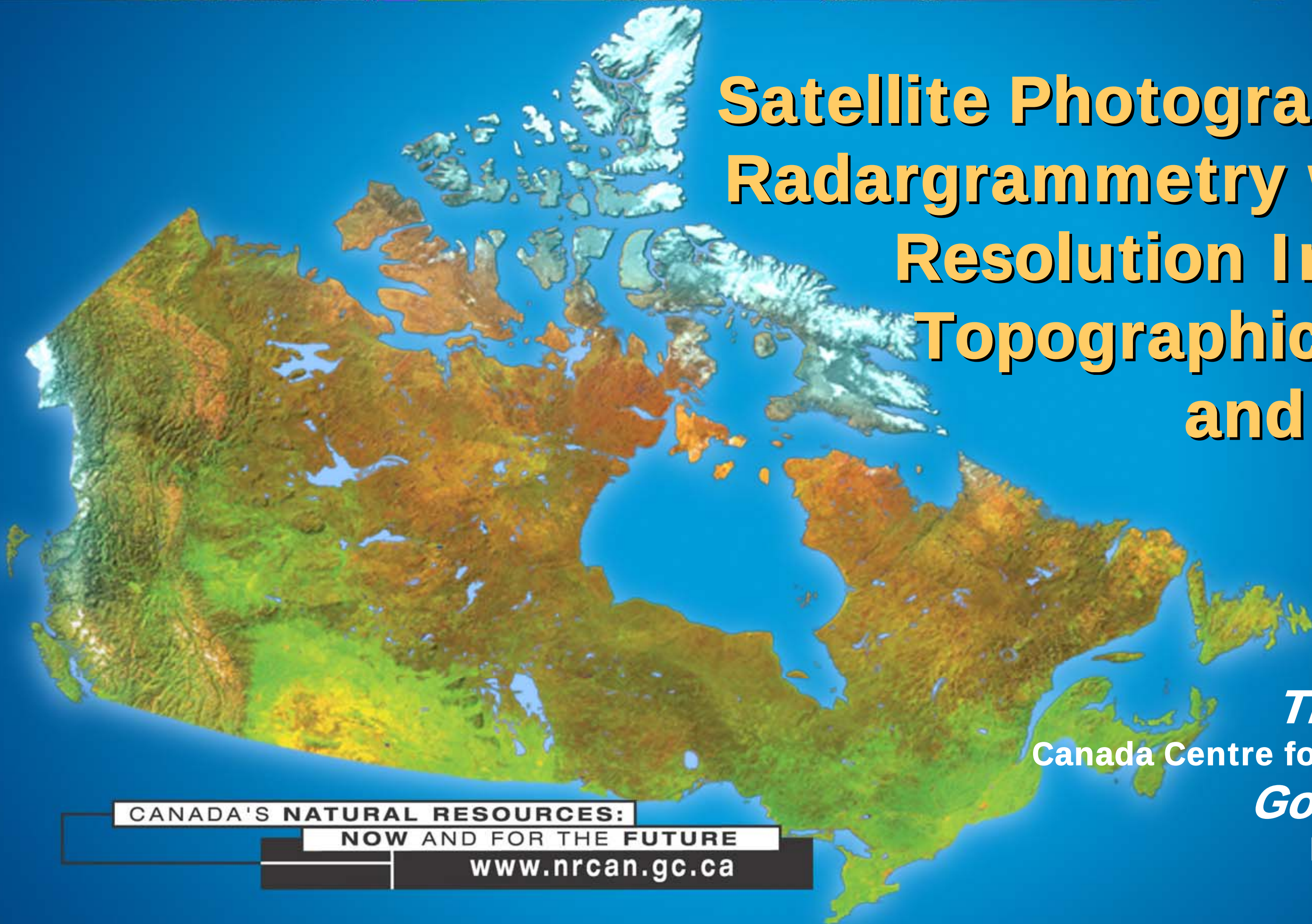
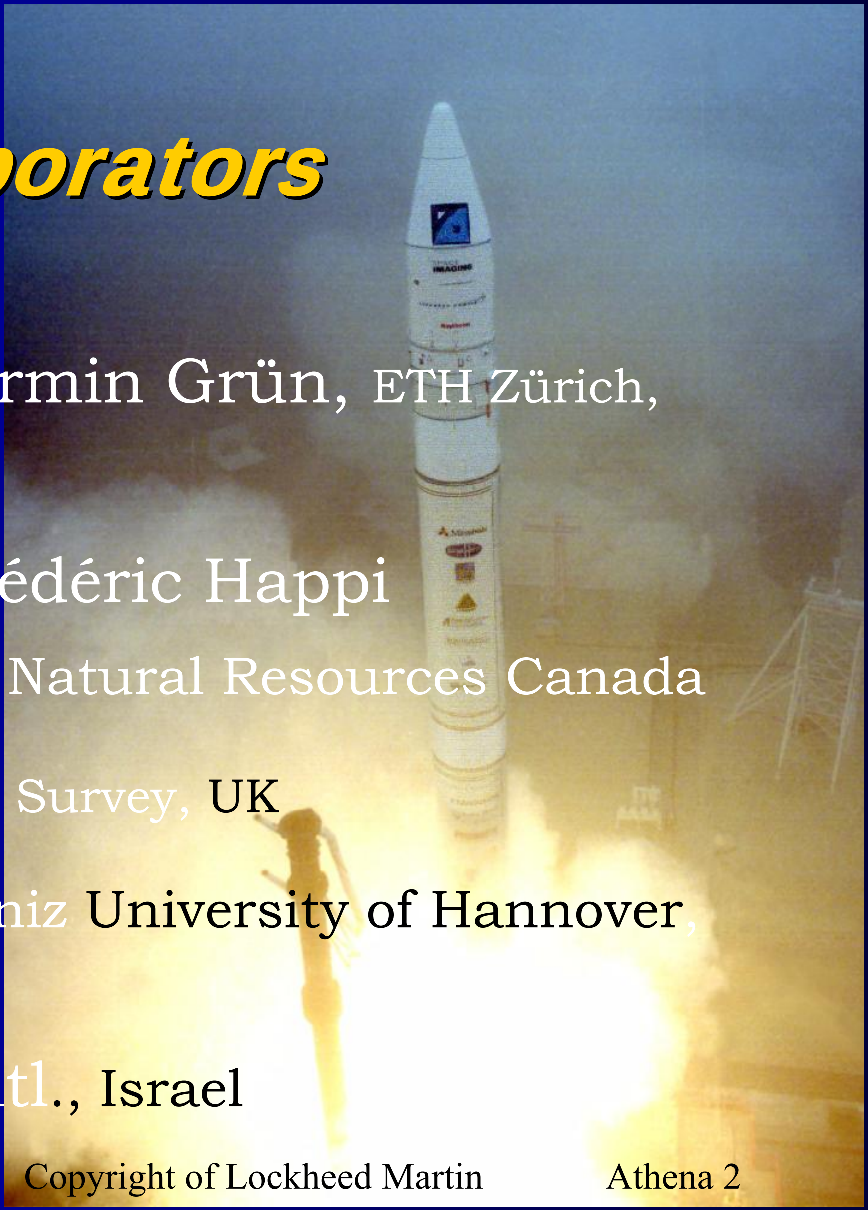


Launch of collaborators



- Dr. Manuel Baltsavias & Armin Grün, ETH Zürich, Switzerland
- Dr. Pierre-Jean Alasset, Frédéric Happi Mangoua, Daniel Clavet Natural Resources Canada
- Dr. David Holland, Ordnance Survey, UK
- Dr. Karsten Jacobsen, Leibniz University of Hannover, Germany
- Rani Hellerman, ImageSat Intl., Israel

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Tutorial Summary

- Introduction
- High-spatial resolution sensors
- Geometric issues
- Radiometric issues
- 3D topographic mapping
- Map updating

- Radarsat-2 with MDA
- Stereo Radarsat-2 UF mode with PCI OrthoEngineSE

Introduction

Photogrammetry and radargrammetry

1. Satellite photogrammetry/radargrammetry consists of the theory and techniques of photogrammetry/radargrammetry where the sensor is carried on a spacecraft and the sensor's output (in the form of images usually) is utilized for the determination of coordinates of the planet being investigated (*Light et al., 1980*).
2. Satellite photogrammetry/radargrammetry is thus characterized by the fact the *geometry* is of major interest and the *nature* of the object imaged is of minor interest. On the other hand, remote sensing and its applications are mainly interested in the nature of the object imaged.
3. Satellite photogrammetry/radargrammetry, in turn, can be divided into two sub-categories:
   - Planimetry (2D) in which only the horizontal geometry of the object is investigated,
   - Topography (3D) in which the three dimensions of the object are investigated.

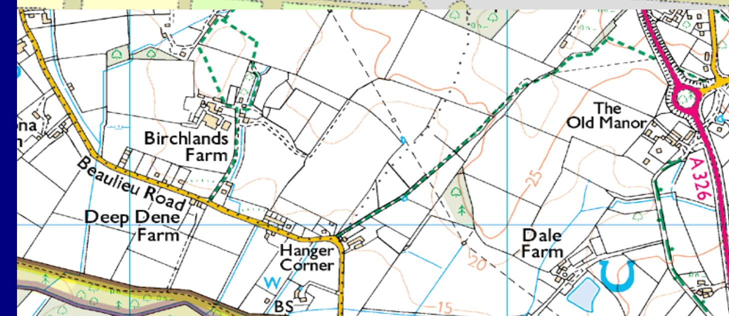
Introduction

High spatial resolution satellite sensors

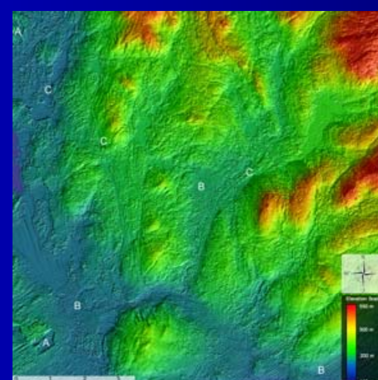
1. For a long time spaceborne remote sensing, especially fine at spatial resolutions, remained in the military domain (*Aplin et al. 1997*).
2. In 1986, a breakthrough was realized with the launch of first French satellite SPOT carrying sensors with spatial resolution as fine as 10 m.
3. Later on to re-enforce the presumed US leadership in civil satellites, the US Land Remote Sensing Policy Act of 1992 allowed the commercialization of satellites carrying up to 1m resolution sensors, and subsequently IKONOS, the first civilian satellite (0.81m resolution), was launched in September 1999.
4. Because a little less than twenty civilian satellites have been now launched within 0.5—10 m resolution range, a better distinction between these sensors is required:
   - Fine spatial resolution (FSR) for 1—10 m
   - Very fine spatial resolution (VFSR) for 1 m and below

Introduction

3D topographic mapping and map updating

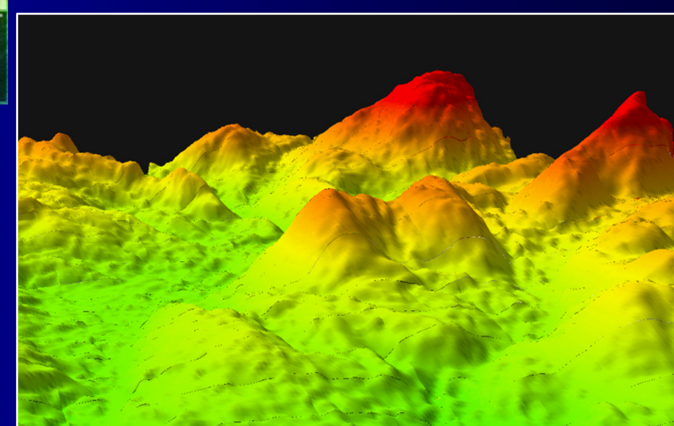


1. Large scale topographic data (1:1 250, 1:2 500, 1:10 000)
2. Small scale (tourist) mapping (1:50 000 and 1:25 000)
3. Change intelligence
4. Identifying areas of change



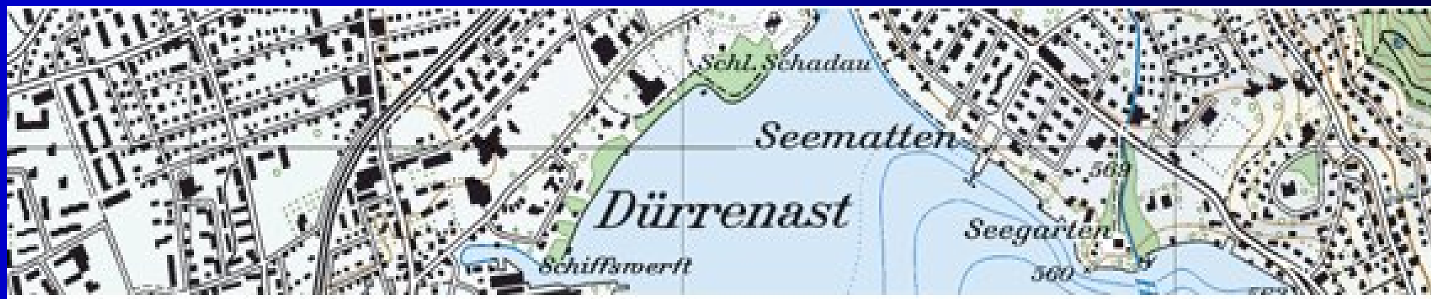
Two aspects to be addressed:

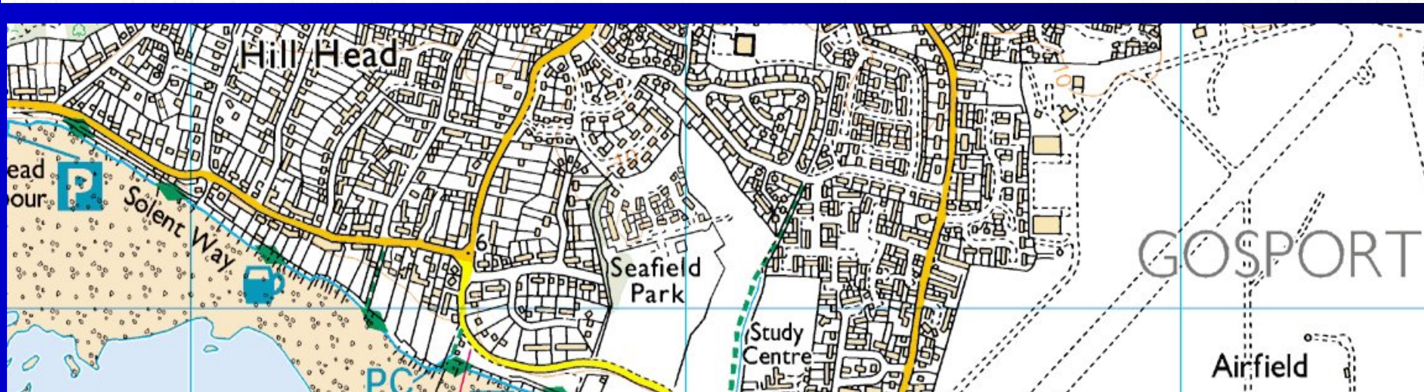
Accuracy (horizontal, elevation)
Information content
Standard, specs & context



Introduction

3D topographic mapping and map updating





Not all maps are the same…Swiss and British 1:25 000 maps: no standardization

➽ No standardization in the methods and algorithms: different processes and tools should be developed depending on information content, standard, context, specification… for each country

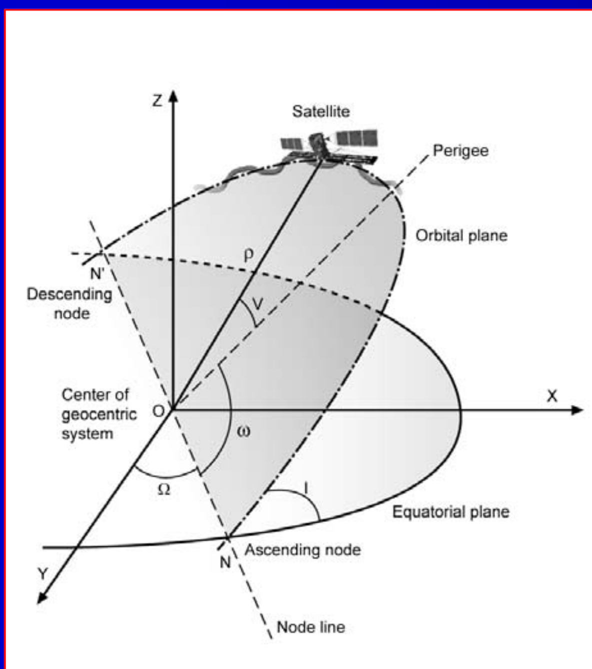
High-spatial resolution satellite sensors

1. Orbital considerations
2. Push-broom scanners: some generalities
3. Existing HSR/VHSR sensors and examples (SPOT-5, EROS-A/B, Ikonos, QuickBird)
4. SAR systems and examples (Radarsat-2, Terra-SAR-X)
5. Geometric and radiometric comparisons
6. Stereo acquisition

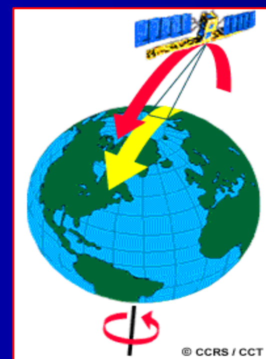
Orbital considerations

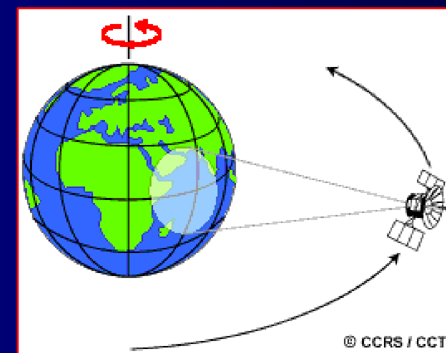
Satellite is not an UFO!

It follows celestial mechanic laws: an osculatory elliptic movement



Telecommunication satellites follow geostationary, far-Earth, equatorial orbit.





Remote sensing satellites follow:

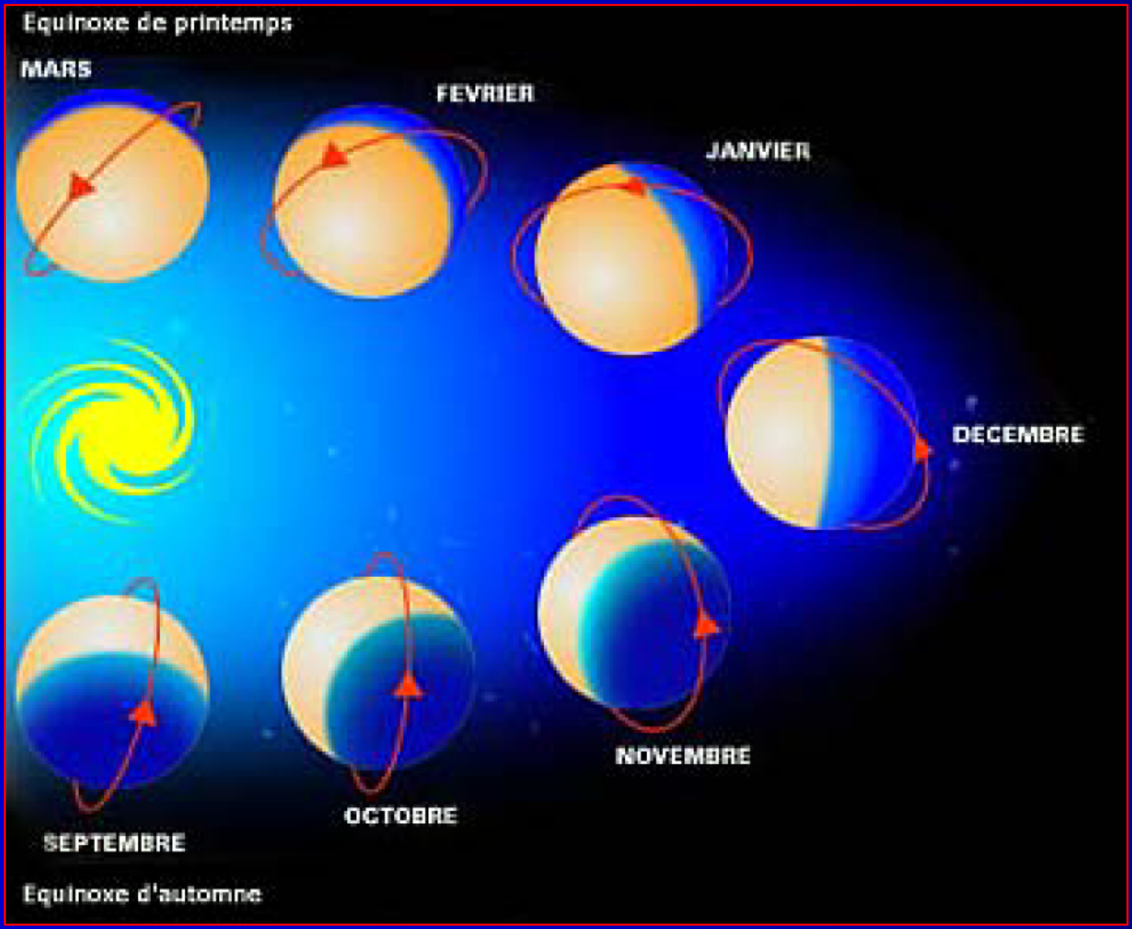
- near-Earth orbit (>300km altitude)
- retrograde orbit (90-180° inclination)
- helio-synchronous (same illumination)
- geosynchronous (repeating track)
- quasi-circular (small eccentricity)
- quasi-polar orbit (crossing poles)

http://spaceplace.jpl.nasa.gov/goes/goes_poes_orbits.htm

http://physics.nad.ru/Physics/English/sat_txt.htm

Canada

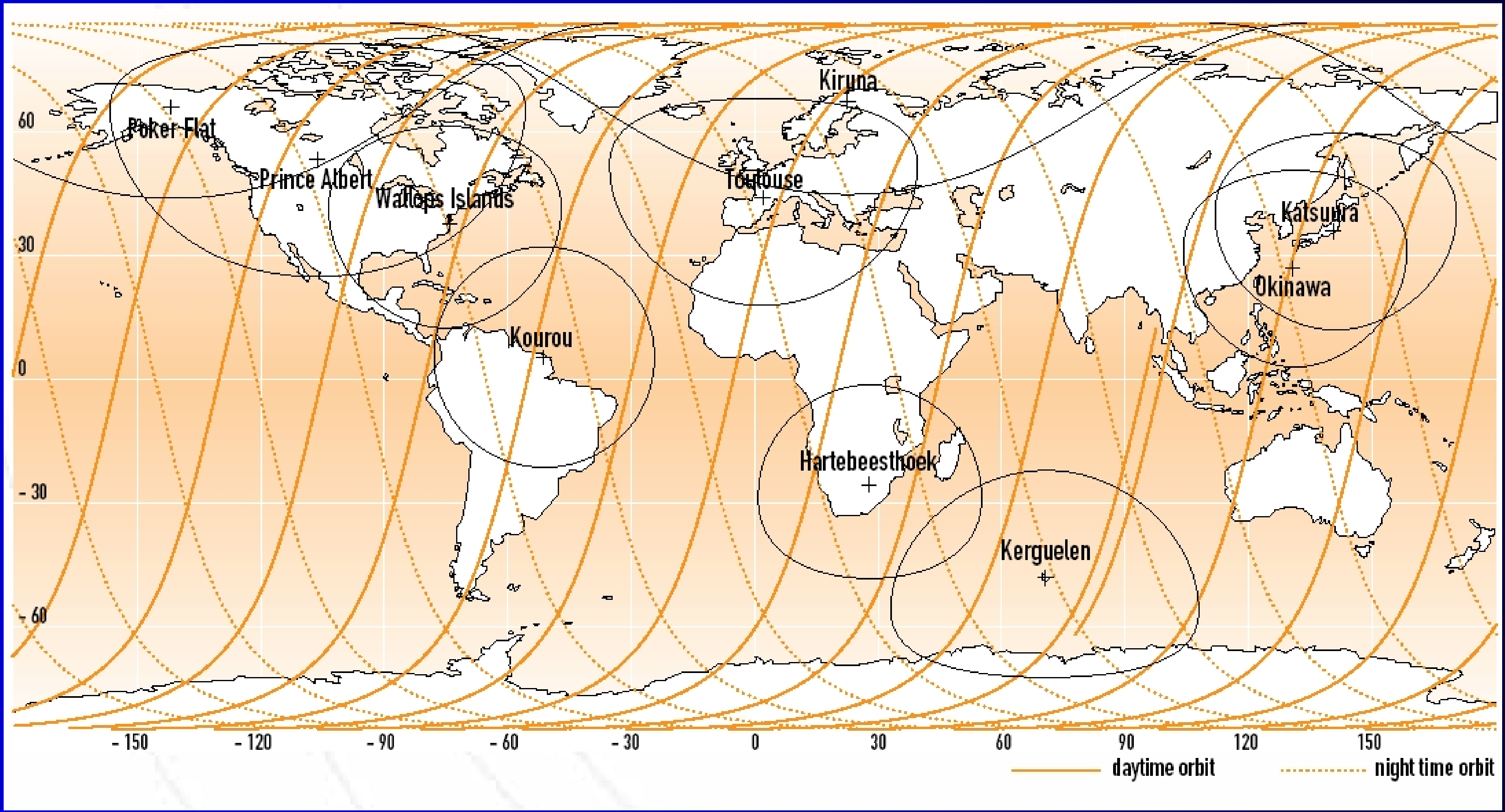
Orbital considerations



Because the valid comparison of images of a given location ***acquired on different dates*** depends on the similarity of the illumination conditions, the orbital plane must also form a constant angle relative to the sun direction.

This is achieved by ensuring that the satellite flies over any given point at the same local time, which procures a helio-synchronous orbit.

Orbital considerations



Helio-synchronous orbits

High-spatial resolution satellite sensors

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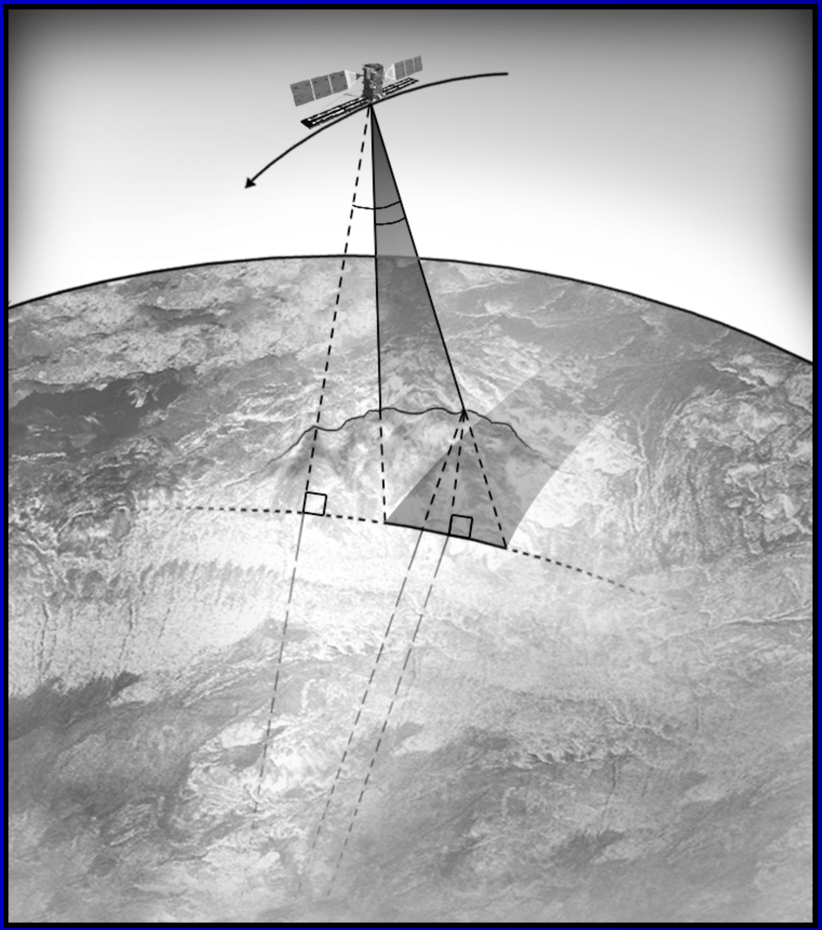
Push-broom scanners



Push-broom scanner is a sensor formed with "aligned" charge coupled devices (CCD)

The second scan direction is generated by the movement of the platform

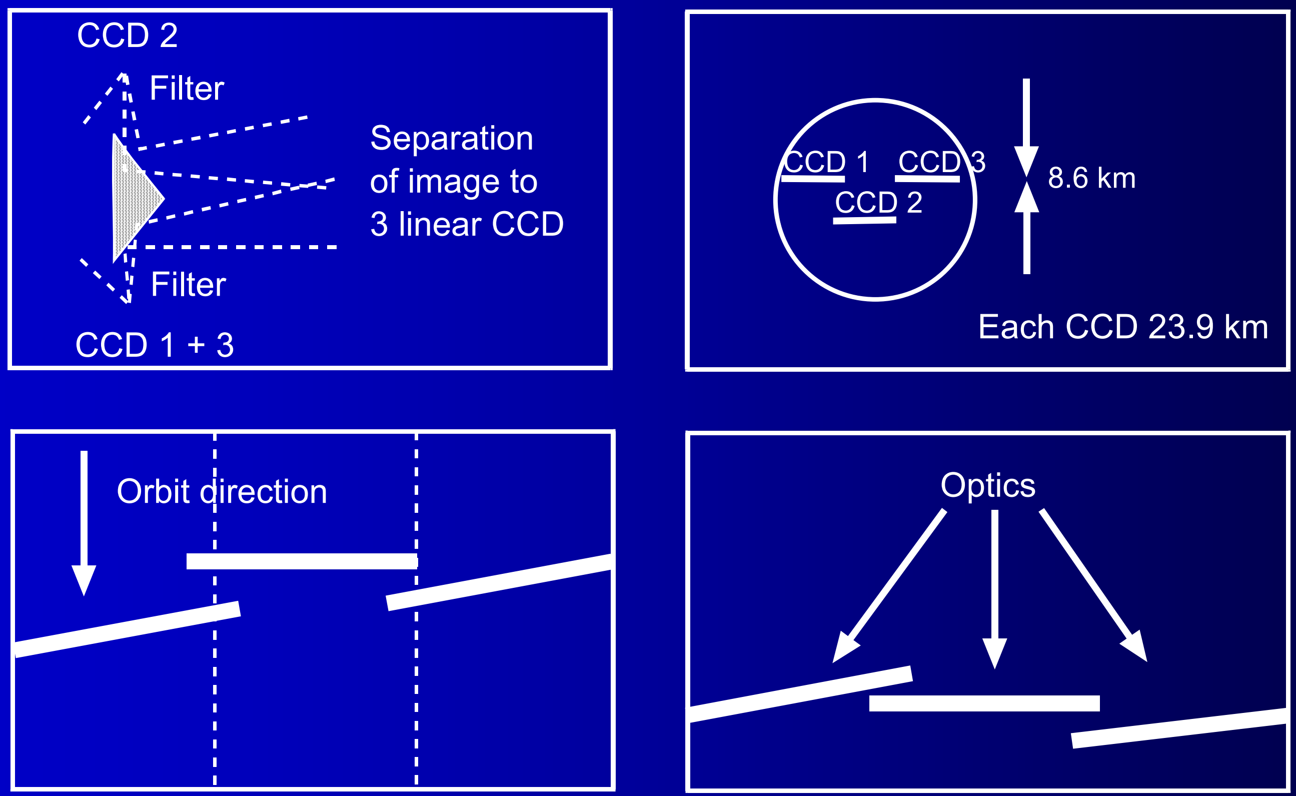
Agile scanner can point in any direction

Other scanner can only point in one direction:

- nadir (Landsat);
- across-track (SPOT5, IRS);
- along-track (SPOT5, ALOS)

Push-broom scanners: IRS-1C/D

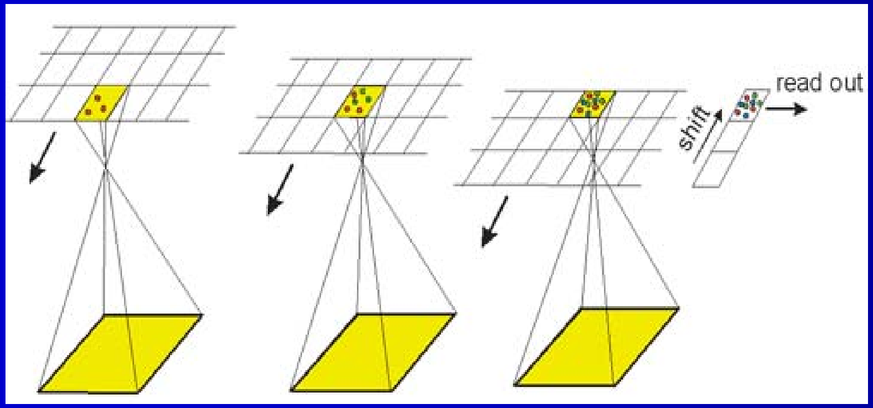
Description of IRS-1 focal plane using 3 CCDs
for covering larger swath



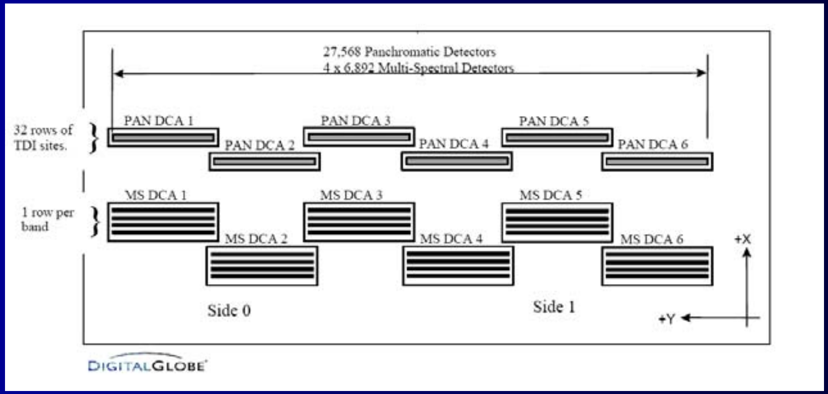
Agile push-broom scanners

Transfer delay and integration (TDI)

Integration of received energy over several pixels: relative speed of satellite

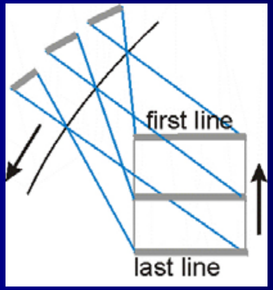


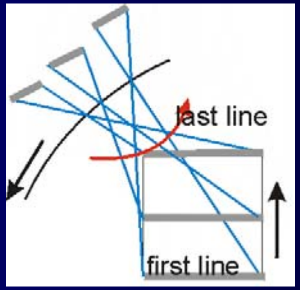
Butted CCDs



Flexible view direction &

Forward and reverse scanning





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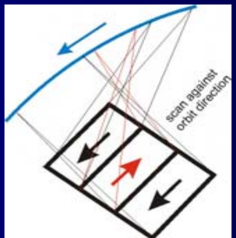
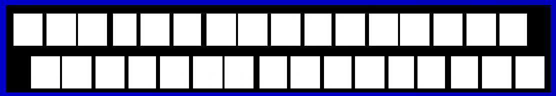
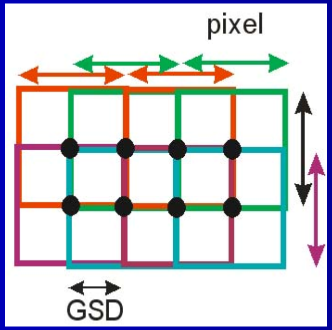


Staggered CCDs

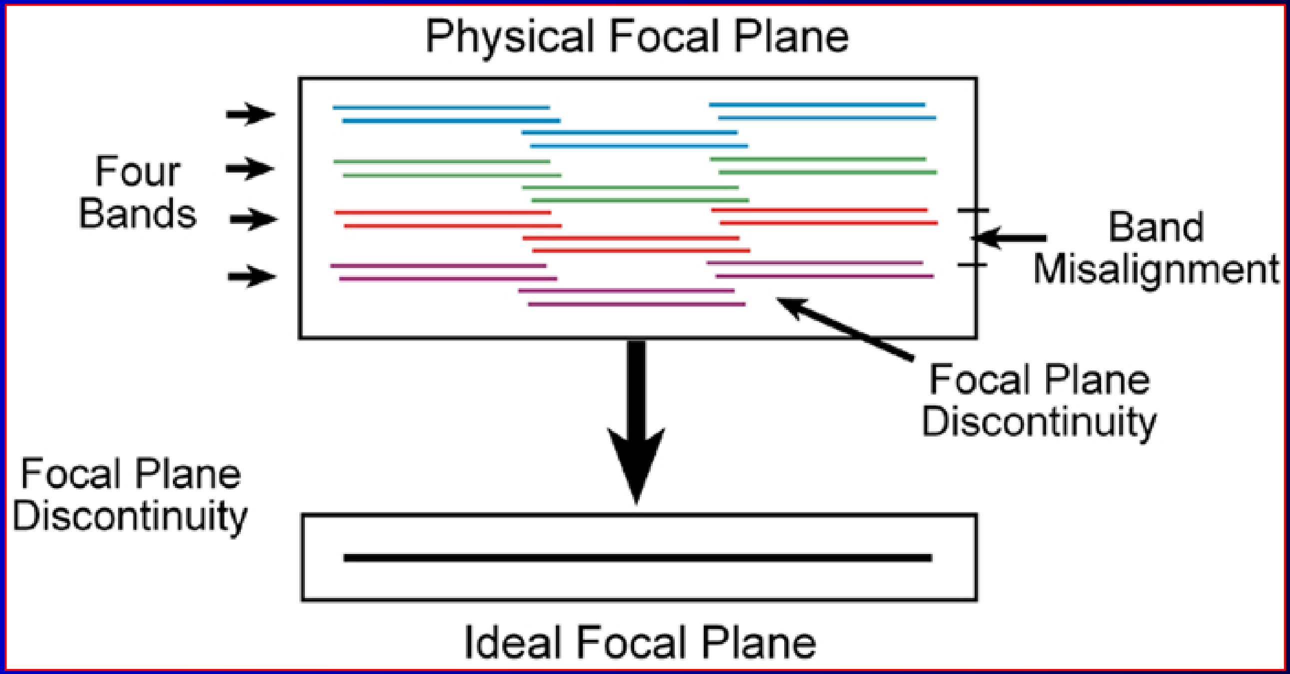


Two CCD arrays with 50% over-sampling



Agile push-broom scanners

Combining Staggered & Butted & TDI CCDs in the focal plane to increase the imaging capability requires a pre-processing to generate an “ideal focal plane”



High-spatial resolution satellite sensors

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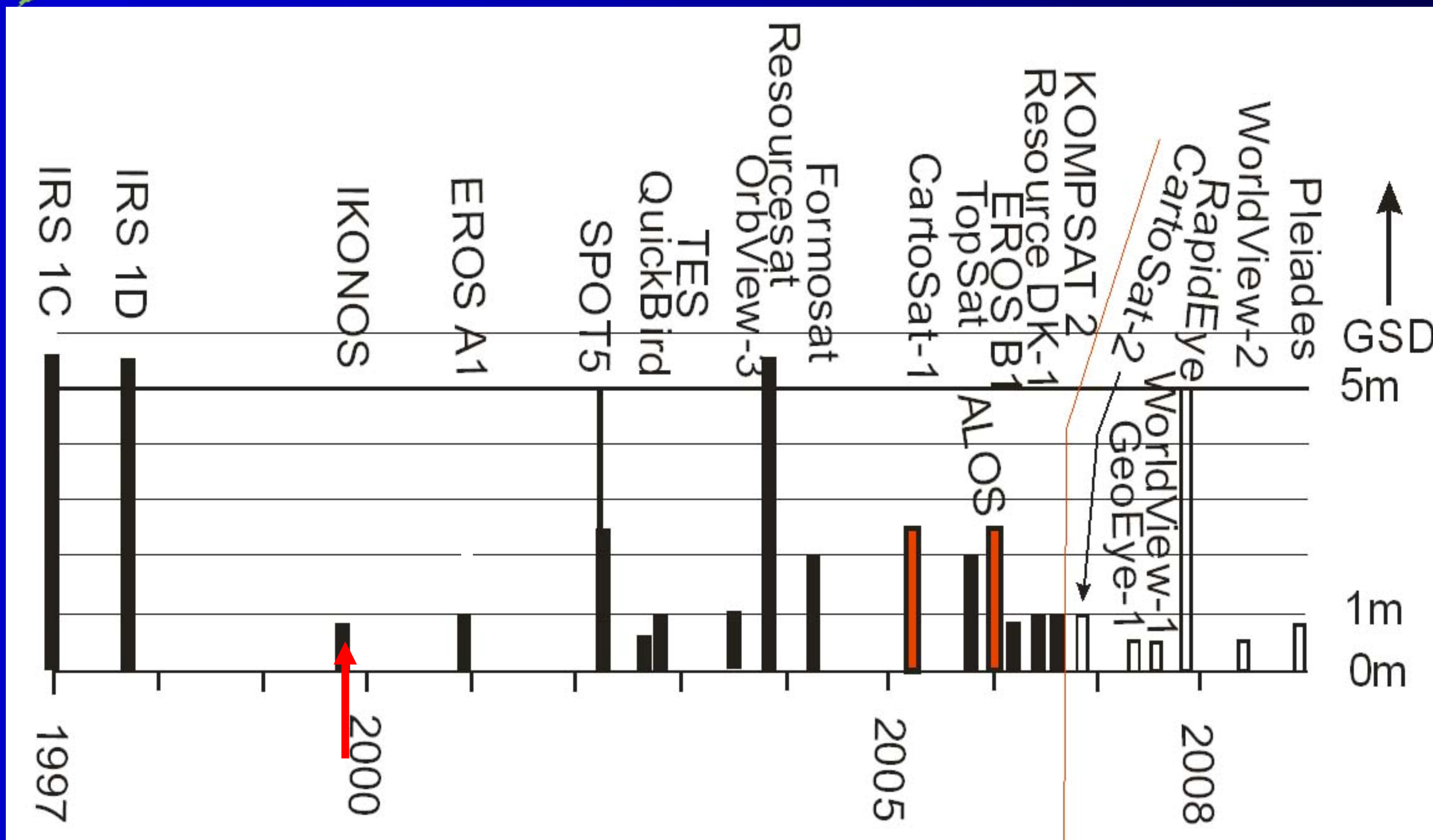
Agile & push-broom scanners

Platform Sensor	Country Year	Height (km) / Inclination (º)	GSD (m) / Nb of CCDs	MB / GSD (m)	FOV (º) / Swath (km)	Field of regard (º)	Revisit time (days)	Stereo B/H	Nb. of bits
IRS-1C/1D PAN	India 1995/97	817/98.6	5.8/12,288	None	4.9/70	±26 across	5	Across Up to 1	6
IKONOS-2 OSA/TDI	USA 09/1999	680/98.2	0.8[A]/13,816	4/4	0.93/11	45[A] (at 360º)	2—3.5	Agile Variable	11
Kompsat-1 EOC	Korea 12/1999	685/98.13	6.6/2,592	None	1.4/17	±45[C] across	3	Across Up to 1.1	8
EROS A1 PIC/TDI	Israel 12/2000	480/97.4	1.8[B]/7,800	None	1.5/13[B]	45 (at 360º)	2—4	Agile Variable	11
QuickBird-2 BHRC60/TDI	USA 10/2001	450/52	0.61/27,568	4/2.44	2.12/16	45 (at 360º)	1—3	Agile Variable	11
SPOT-5 HRG	France 05/2002	822/98.7	(5/3.5)/ 12,000[D]	4/10	4.2/60	±27 across	3—6	Across Up to 1	8
Orbview-3 OHRIS	USA 06/2003	470/97	1/8,000	4/4	0.97/8	50 (at 360º)	1-3	Agile Variable	11
Formosat-2 RSI/TDI	Taiwan 05/2004	891/99.14	2/12,000	4/8	1.5/24	45 (at 360º)	1	Agile Variable	8
Cartosat-1 PAN (2)	India 05/2005	618/97.87	2.5/12,288	None	2.16/30	±26 across	5	Along 0.62	10
Beijing-1 CMT	China 10/2005	686/98.2	4/(6 000)	None	2/24	±30 across	4	Across Up to 1.1	8
TopSat AOC/TDI	UK 10/2005	686/98.2	2.5/6,000	3/5	1.2/15	±30 across	4	Across Up to 1.1	11
ALOS PRISM (3)	Japan 01/2006	692/98.16	2.5/14,000	None	2/35	±1.5 across	46	Along 0.5/1.0	8
EROS B PIC-2/TDI	Israel 04/2006	~500/97.4	0.7/20,000	None	0.8/14	45 (at 360º)	1—3	Agile Variable	10
Kompsat-2 MSC	Korea 07/2006	685/98.13	1/15,000	4/4	1.3/15	30 along 56 across	2	Agile Variable	10
Cartosat-2 PAN	India 01/2007	635/97.92	0.8/12,000	None	0.59/9.6	45 (at 360º)	1-4	Agile Variable	10
WorldView-1 PAN/TDI	USA 09/2007	496/97.2	0.5/35,000	8/2	2.12/17.6	45 (at 360º)	2-6	Agile Variable	11
CBERS-2B HRC	China-Brazil 11/2007	778/98.5	2.5/10,368	None	2.1/27	Few	5	Along Up to 1	8

Agile & push-broom scanners

sensor	country	GSD (nadir) [m]	swath [km]	pointing in-track	pointing across
SPOT 5	France	5 (2.5) / 10	60	-	+/-27°
SPOT 5 HRS	France	5 x 10	120	+20°, -20°	-
IRS-1C/1D	India	5.8 / 23.5	70 / 142	-	+/-26°
Resourcesat	India	- / 5.8	70	-	+/- 26°
KOMPSAT	S. Korea	6.6	17	-	+/-45°
IKONOS	USA	0.82 / 3.2	11.3	free view direction	
EROS A	Israel	1.8	12.6	free view direction	
QuickBird	USA	0.61 / 2.44	16.4	free view direction	
EROS B	Israel	0.7	14	free view direction	
FORMOSAT 2	Taiwan	2 / 8	24	free view direction	
IRS-P5 Cartosat-1	India	2.5	30	26° fore, 5° after	free view to side
TopSat	UK	2.5 / 5	15 / 10	free view direction	
Beijing-1	China	4 / 32	/ 600	free view direction	
ALOS	Japan	2.5	35 (70)	-24°, 0°, +24°	free view to side
KOMPSAT-2	S. Korea	1 / 4	15	free view direction	
Resource DK1	Russia	1 / 3	28	free view direction	
IRS Cartosat-2	India	<1	9.6	free view direction	
WorldView-1	USA	0.45	15.8	free view direction	
CBERS-2B	China/Brasil	2.5 / 20	27 / 120	free view direction	
IRS Cartosat-2A	India	1	10	free view direction	

Agile and push-broom scanners

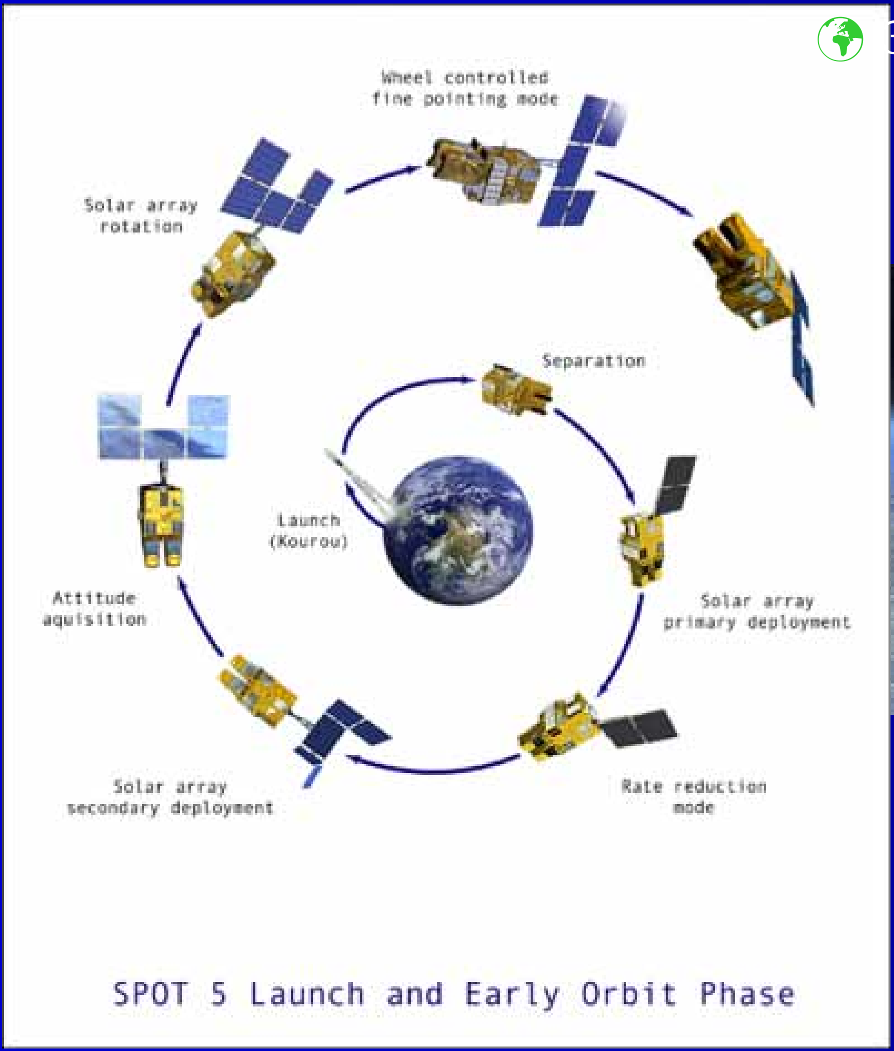


Less than 20 optical satellites and three SAR are available for mapping application: first with Ikonos in 2000, and now 6 civilian or dual use VHSR sensors and more will follow soon

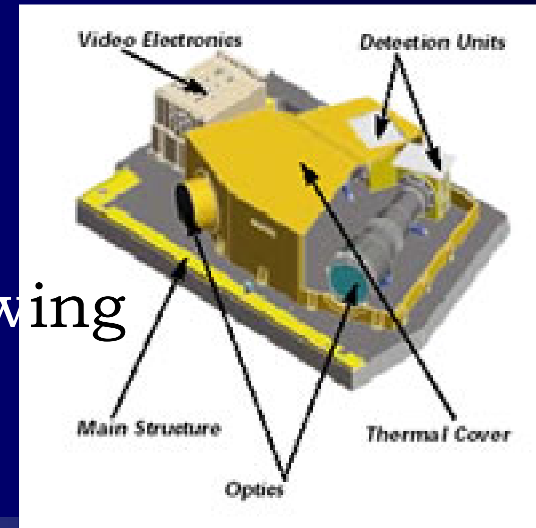
CNES- SPOT-5

Launched in 2002 by French Ariane-4 rocket

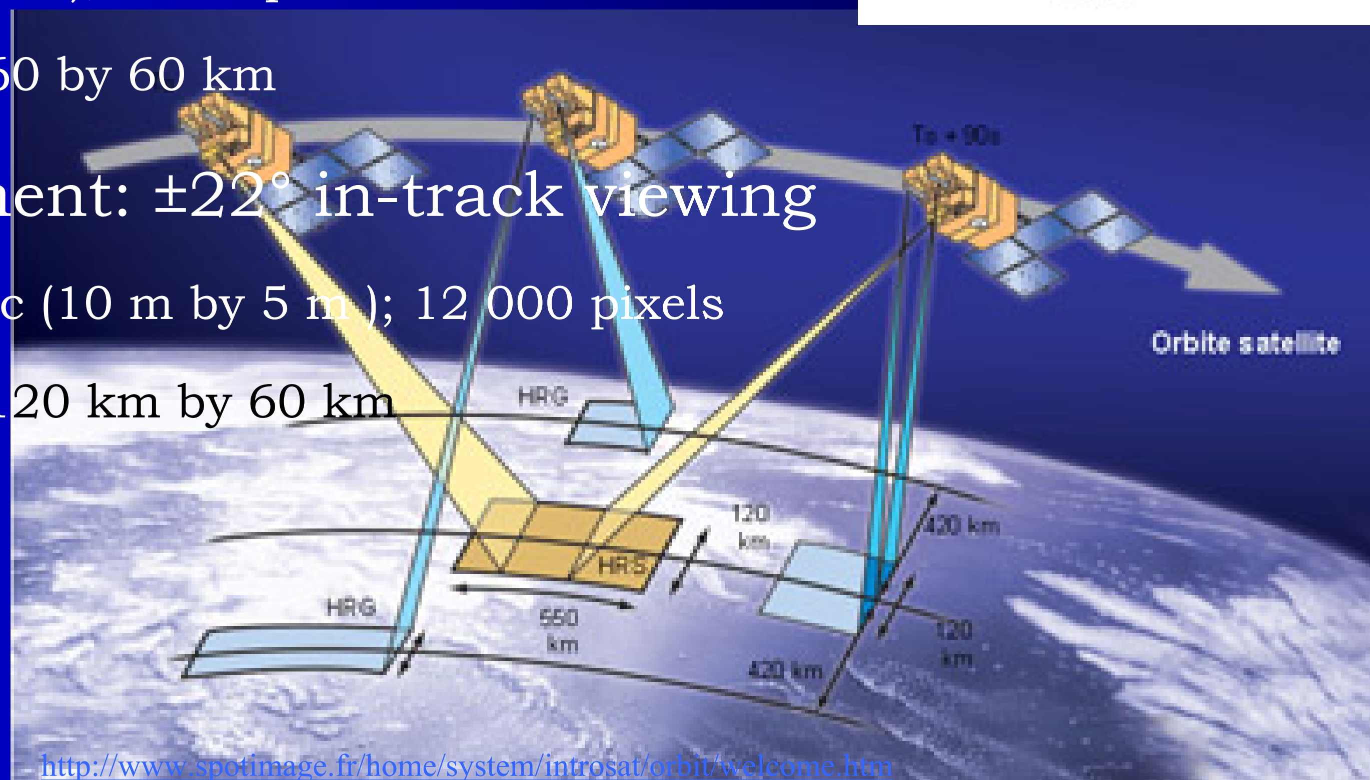
- 3000kg; 3.1 x 3.1 x 5.7 m; 5 years lifetime
- 820 km, 97.2° inclination



CNES-SPOT-5



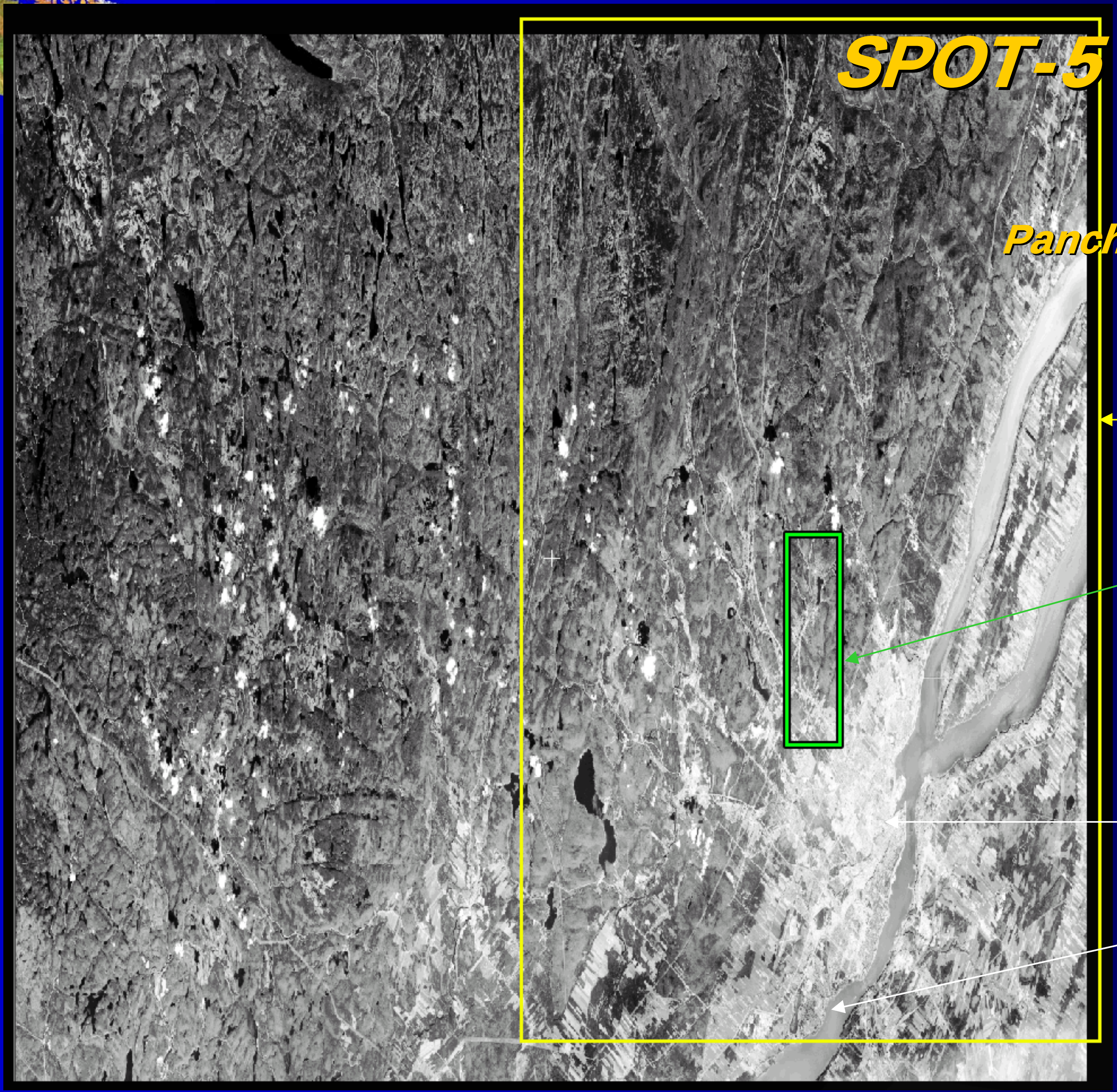
- HRG instrument: ±27° across-track viewing
  - Panchromatic (2.5 m); 24 000 pixels and multiband (10 m); 6 000 pixels
  - FOV of ±2°, 60 by 60 km
- HRS instrument: ±22° in-track viewing
  - Panchromatic (10 m by 5 m); 12 000 pixels
  - FOV of ±4°, 120 km by 60 km



http://www.spotimage.fr/home/system/introsat/orbit/welcome.htm

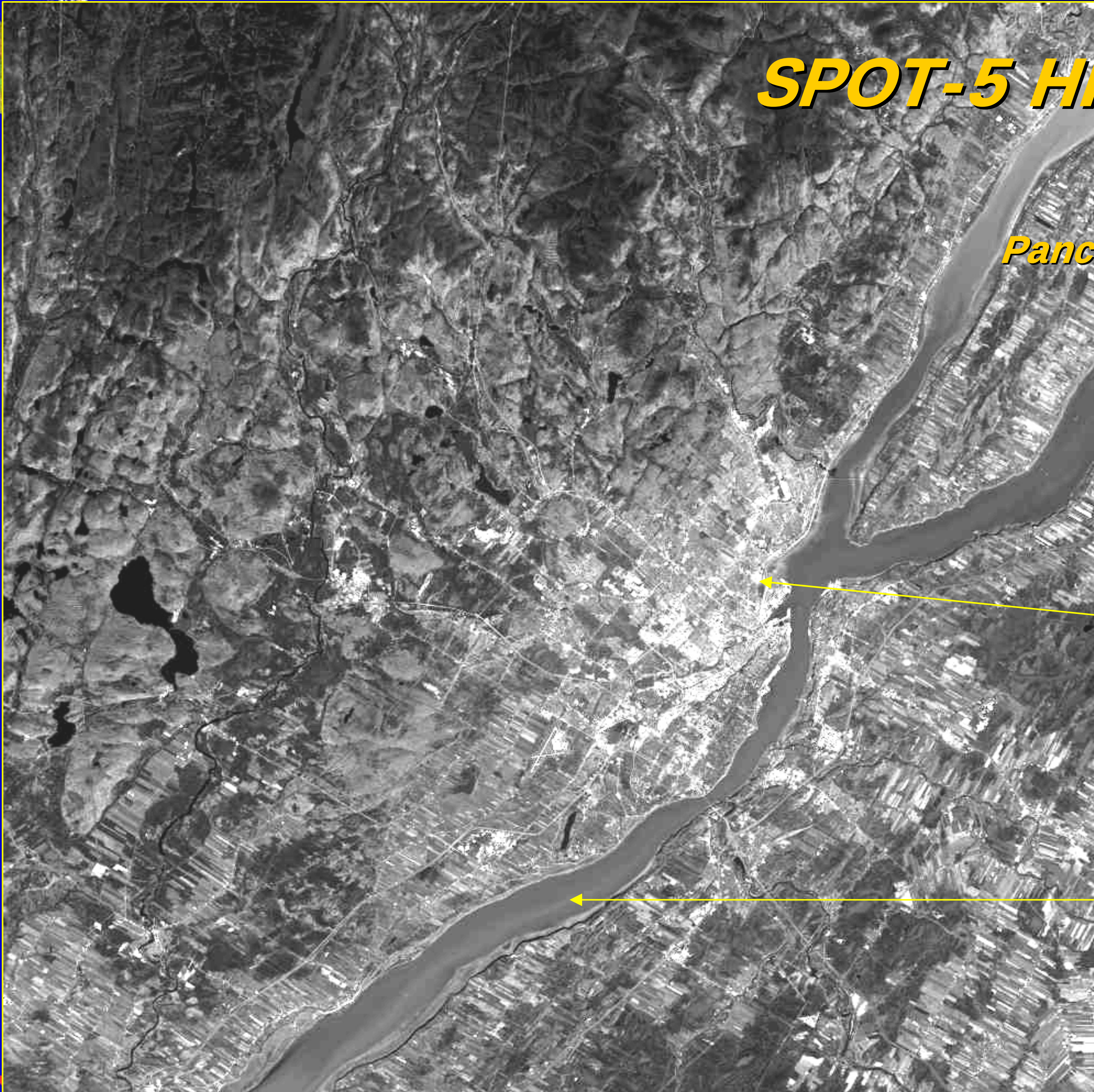
SPOT-5 HRS Image

Quebec
120 by 60 km
Panchromatic (10 by 5 m)



SPOT-5 HRG Image

Quebec
60 by 60 km
Panchromatic (2.5 m)



ImageSat Intl.- EROS-A

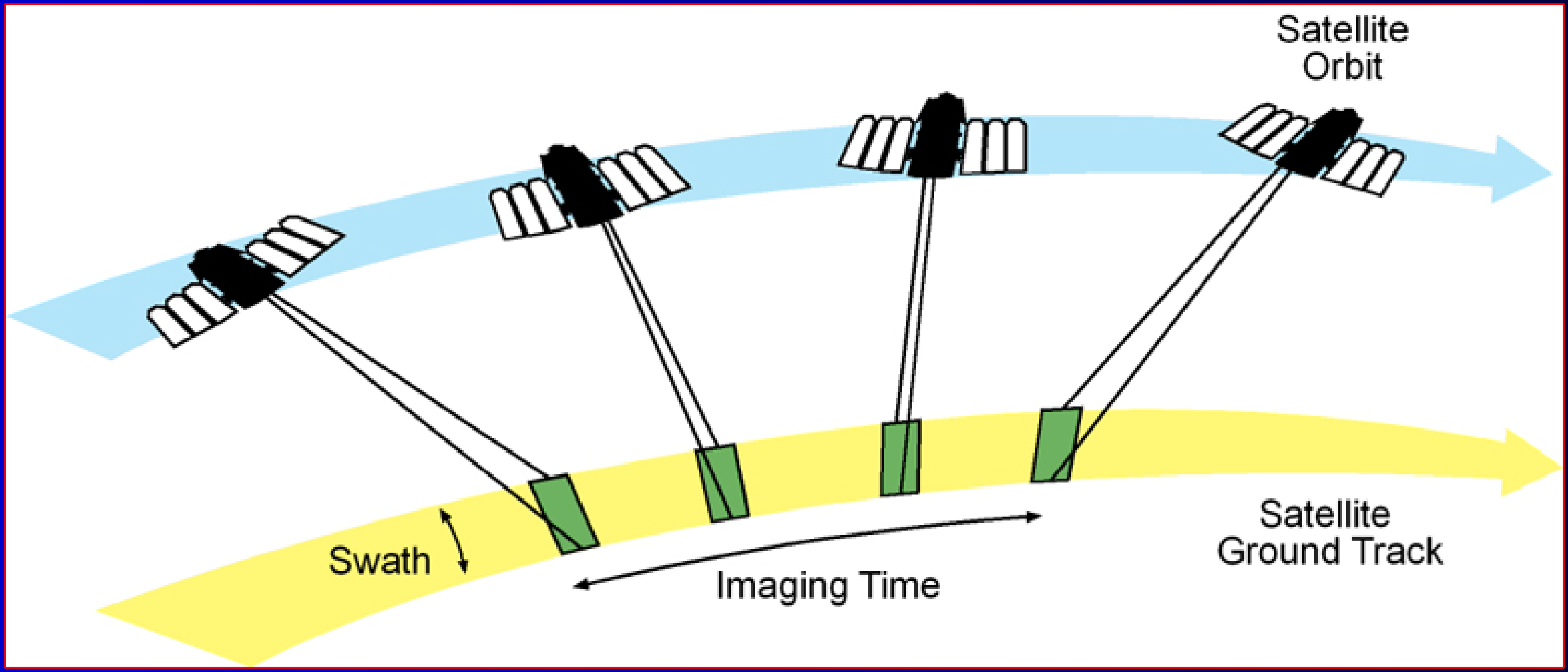
- Launched in 2000 by Russian Start-1 launcher
  - 250kg; 3.1 x 3.1 x 5.7 m; 7 years lifetime
  - 480 km, 97.3° inclination
- CCD agile asynchronous instrument: 45° viewing in any direction
  - Panchromatic (1.8 m); 7000 pixels
  - FOV of ±1.8°, 13.5 by 13.5 km

EROS-A Satellite

... is too fast ...

EROS-A Satellite

The ground satellite velocity is much higher than the ground scanning velocity. The satellite attitude pitch has to compensate for this variation during the image acquisition.

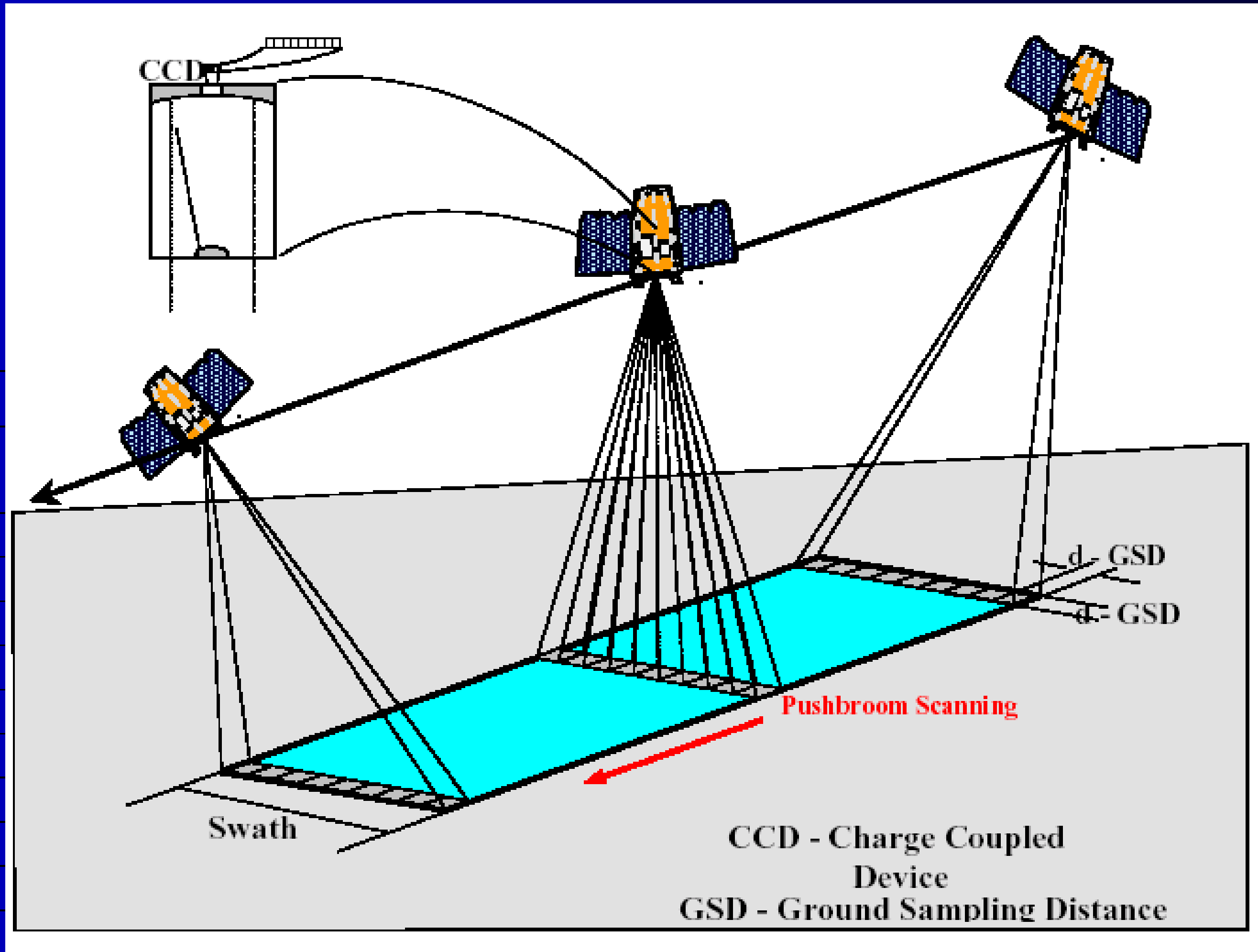


http://www.imagesatintl.com/customersupport/techarticles/Tutorial_SatelliteImaging_Non-synchronousMode.pdf

EROS-A Satellite

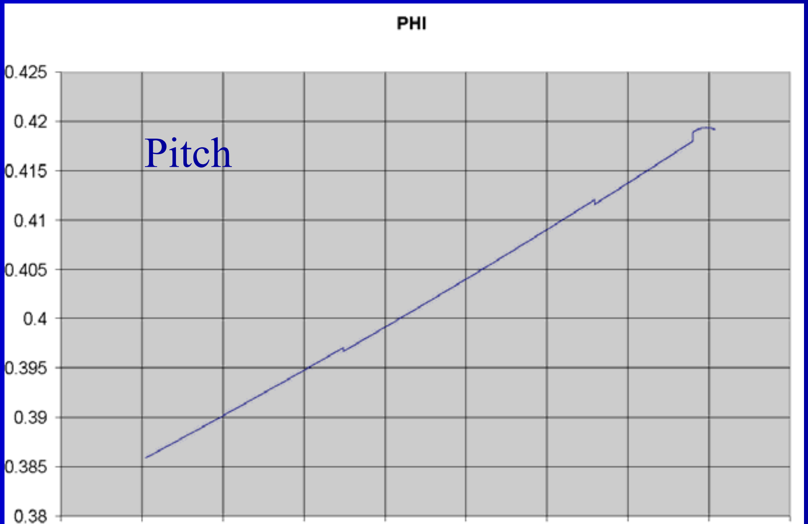
EROS is thus continuously pitching backward and yawing during the image acquisition

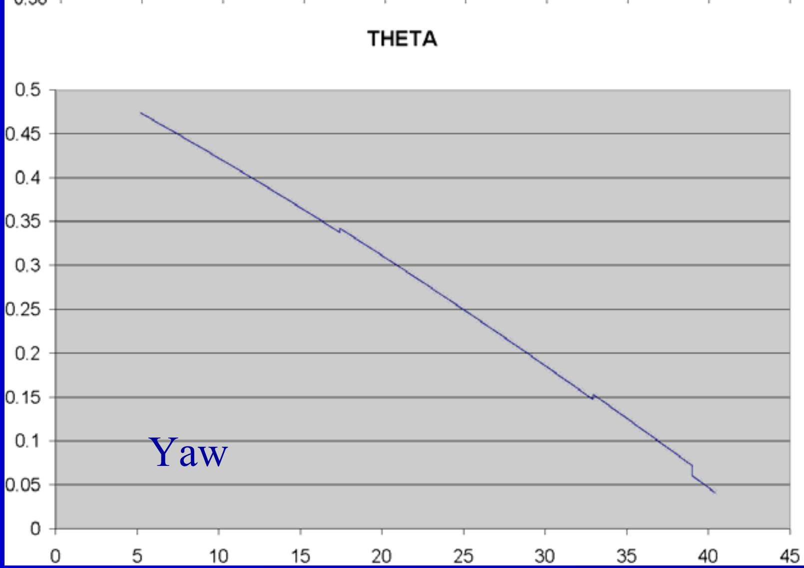
Scanning Angle, (Deg.)	Resolution (metre)	
	Along Scanning	Cross Scanning
0	1.80	1.80
5	1.81	1.81
10	1.83	1.86
15	1.86	1.93
20	1.92	2.04
25	1.99	2.19
30	2.08	2.40
35	2.20	2.68
40	2.35	3.07
45	2.55	3.60

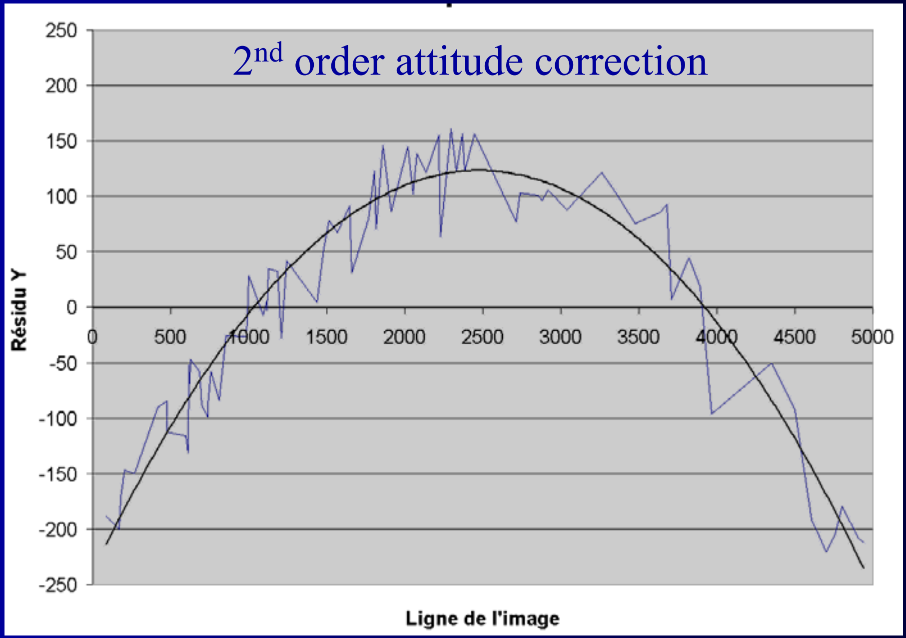


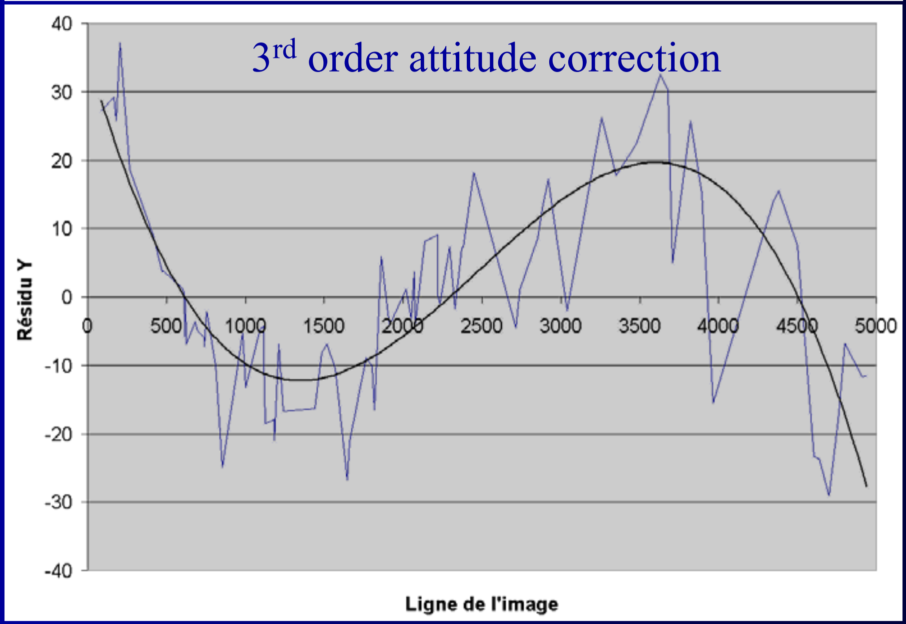
http://www.apogee.com.au/images/satellites_nimble_anim.gif

EROS Attitude





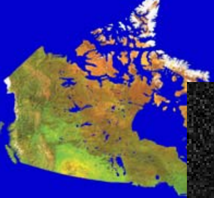




EROS-A Image

Tokyo Downtown
Aft image (25°)

Effect of the great viewing angle (more than 45°)



EROS-B Image

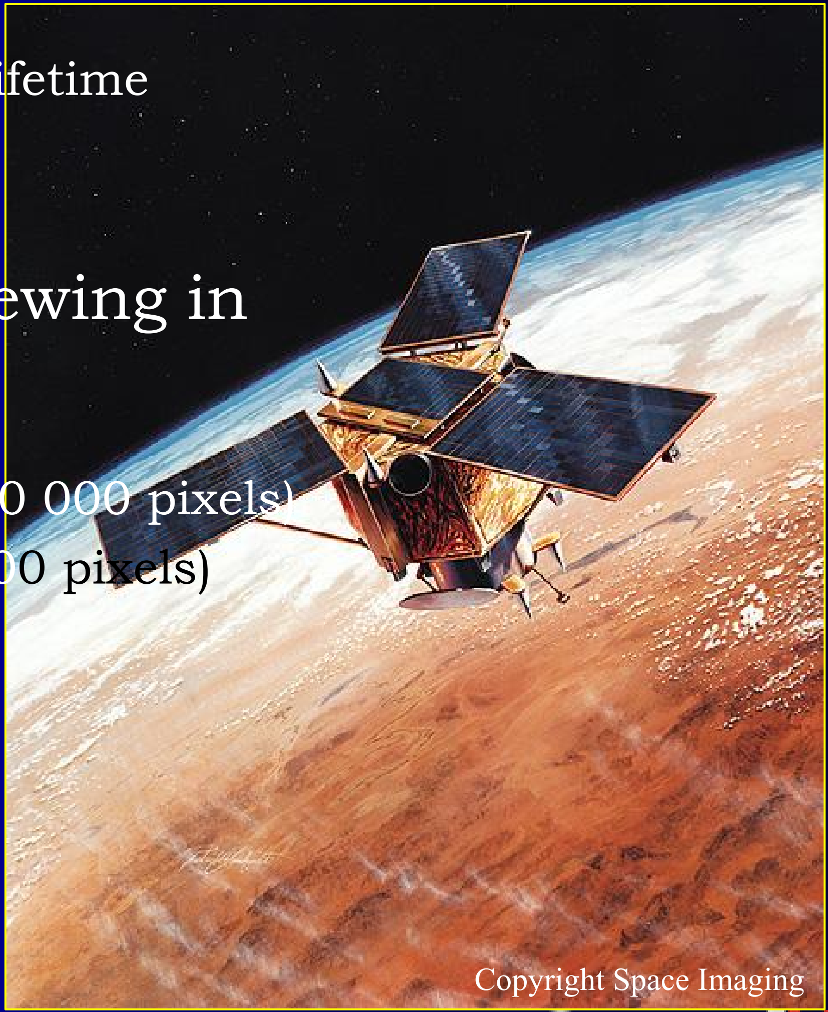
La Habana

EROS-B Image

La Habana Vieja

Space Imaging-IKONOS

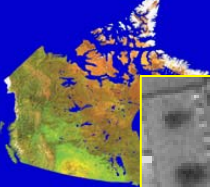
- Launched in 1999 by Athena 6 rocket
  - 820kg; 1.8 x 1.8 x 1.6 m; 7 years lifetime
  - 680 km, 98.1° inclination
- CCD agile instrument: 60° viewing in any direction
  - Panchromatic (0.82 m up to 30°; 10 000 pixels) and multiband (3.26 m up to 30°; 2500 pixels)
  - FOV of ±0.9°, 10 by 10 km



IKONOS Image

Toronto

Industrial area



Canada

IKONOS Image

Beauport

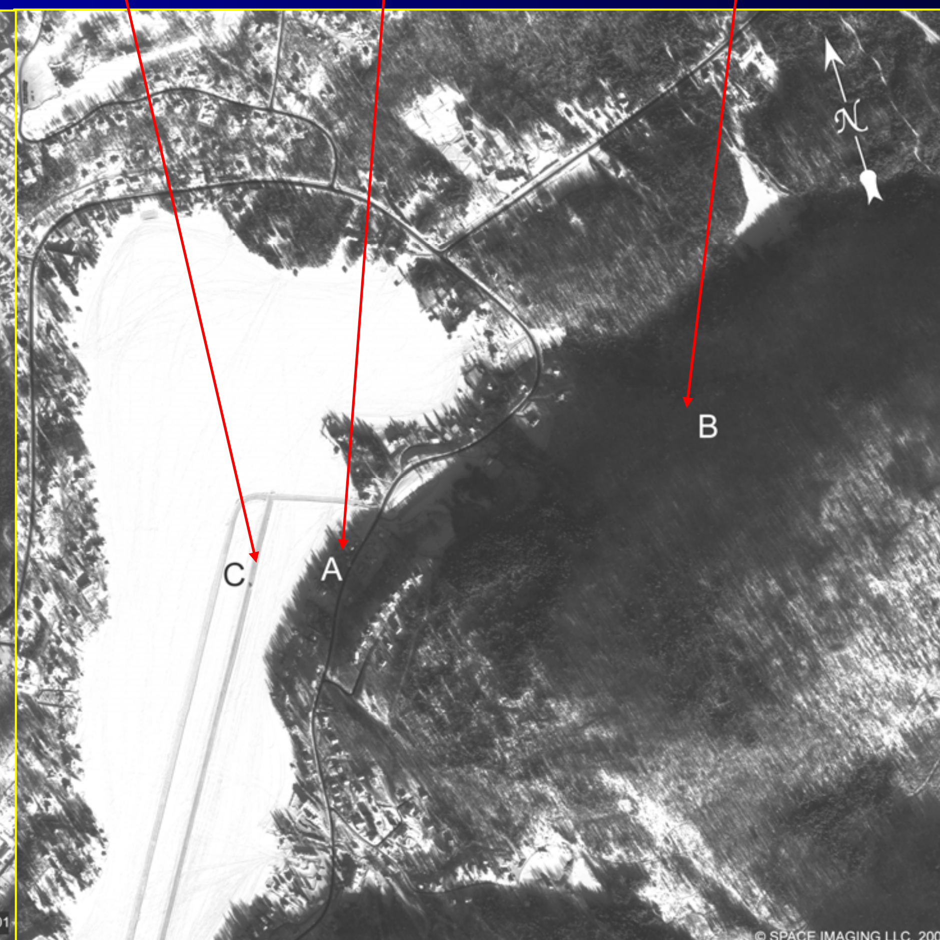
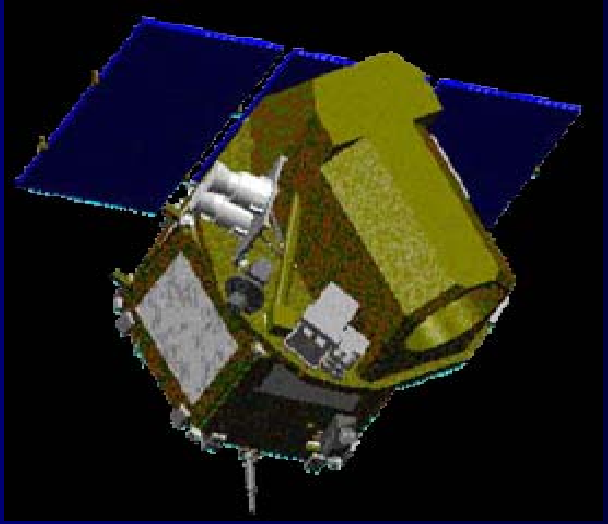


Image size: 2 km x 2 km

Formosat-2



SATELLITE

- Satellite owned by NSPO (Taiwanese Space agency)
- Space segment manufactured by EADS/ASTRIUM
- NSPO has appointed Spot Image as exclusive worldwide distributor

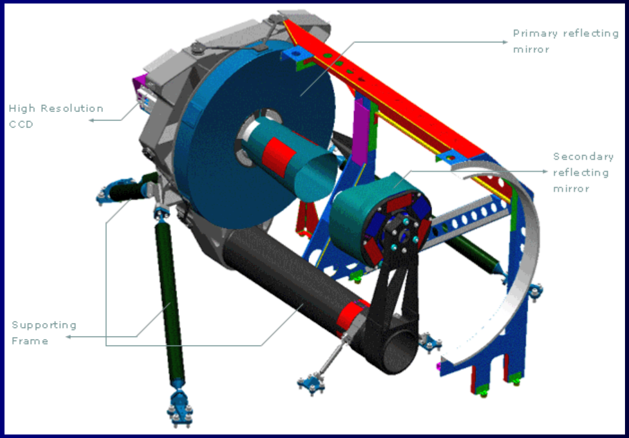
A SPECIFIC ORBIT

- 891 km: sun-synchronous & geo-synchronous
- 14 orbit per day
- □Daily revisit for accessible areas, always under the same roll angle
- 9h30 am Local Time at descending node

CHARACTERISTICS

- 2-m pan / 8-m colors@ Nadir
- Swath @ NADIR: 24 km
- 4 spectral bands (R.V.A., PIR)
- On board memory: 40 Gbit
- High agility: stereo along the track and fast roll
- More than 8 minutes imaging per orbit

Formosat-2 RSI

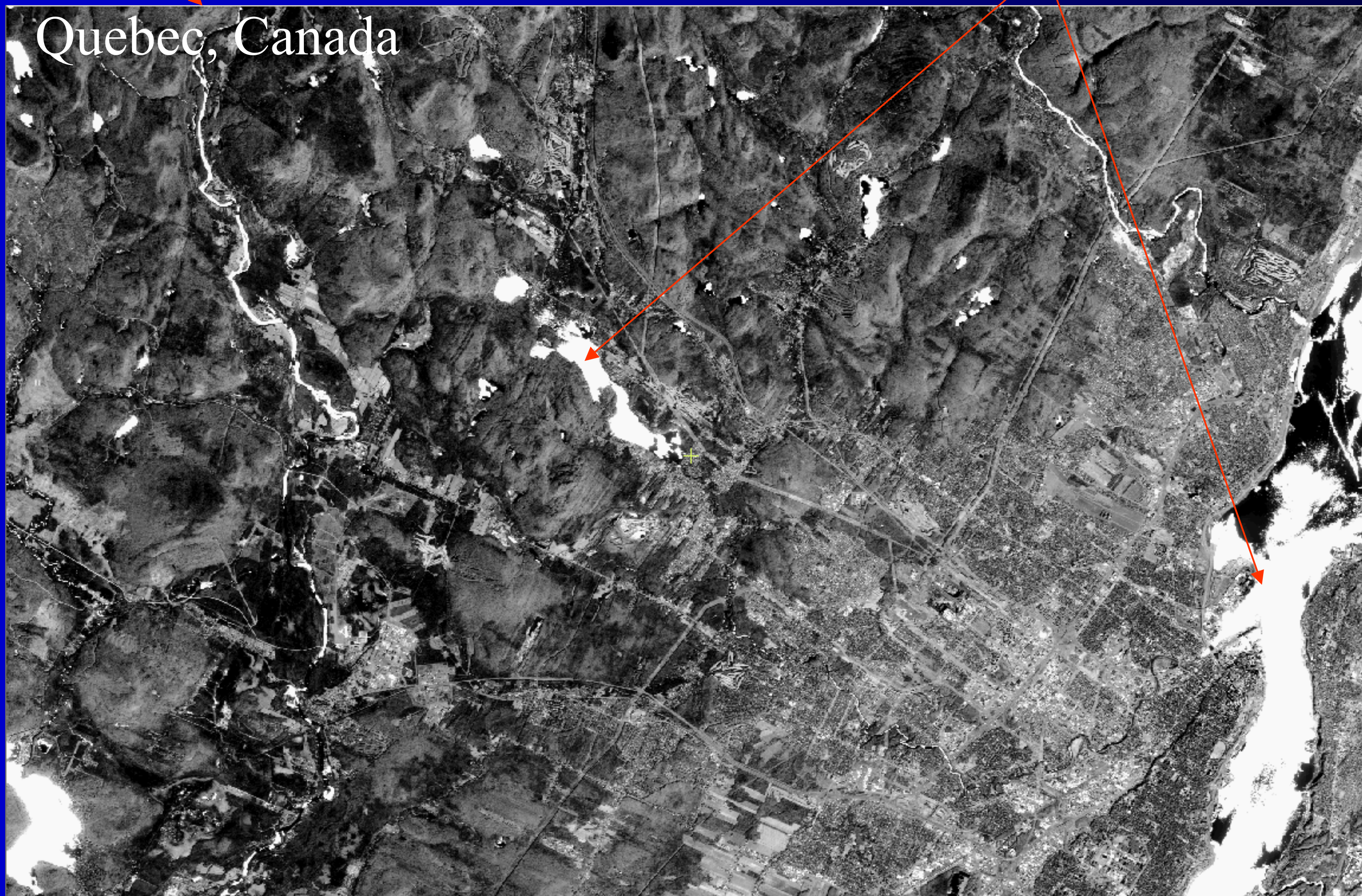


- Remote Sensing Instrument
  - Earth observation optical camera, which simultaneously provides high-resolution panchromatic imagery and multi-band imagery
  - Single focal plane with four CCDs
  - Stereo is obtained by pitching the sensor

Multi-band + panchromatic	450 ~ 900 nm
Sensor Resolution	2 m (panchromatic) 8 m (multi-band)
Image Swath	24 km
Stereo	along-track (B/H ≈ 1)

Formosat-2

Specular reflection on water bodies



Formosat-2

Quebec, Canada

Copyright 2008 NSPO, Taiwan

Kompsat-2

Satellite

- Satellite belonging to KARI (Korean Space Agency)
- Space segment developed by KARI with support from : KAI, Korean Air; ASTRIUM (platform and system support) ; ElOp (instrument)
- Launched in July 2006

Orbit

- 685 km: sun-synchronous
- 3 days revisit with angle 30° (every day with angle of 56°)
- 10:30am Local Time at ascending mode

Technical features

- 1m pan / 4m colors(1m pan-sharpened)
- 10 bits
- Swath @ NADIR: 15 km
- Off track viewing up to 30°
- On board memory: 64 Gbit

Digital Globe-QuickBird

- Launched in 2001 by Boeing Delta II rocket
  - 950kg; 3.1 x 3.1 x 5.7 m; 5 years lifetime
  - 450 km, 97.2° inclination
- HRG instrument: ±27° agile viewing
  - Panchromatic (0.6 m; 27 550 pixels) and multiband (2.4 m; 6 900 pixels)
  - FOV of ±1.3°, 16.5 by 16.5 km

QuickBird CCDs

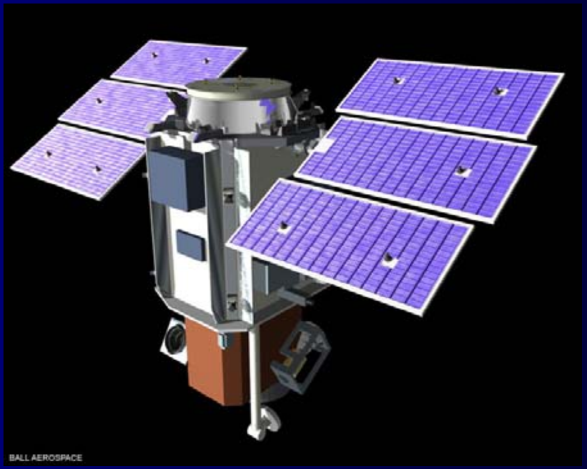
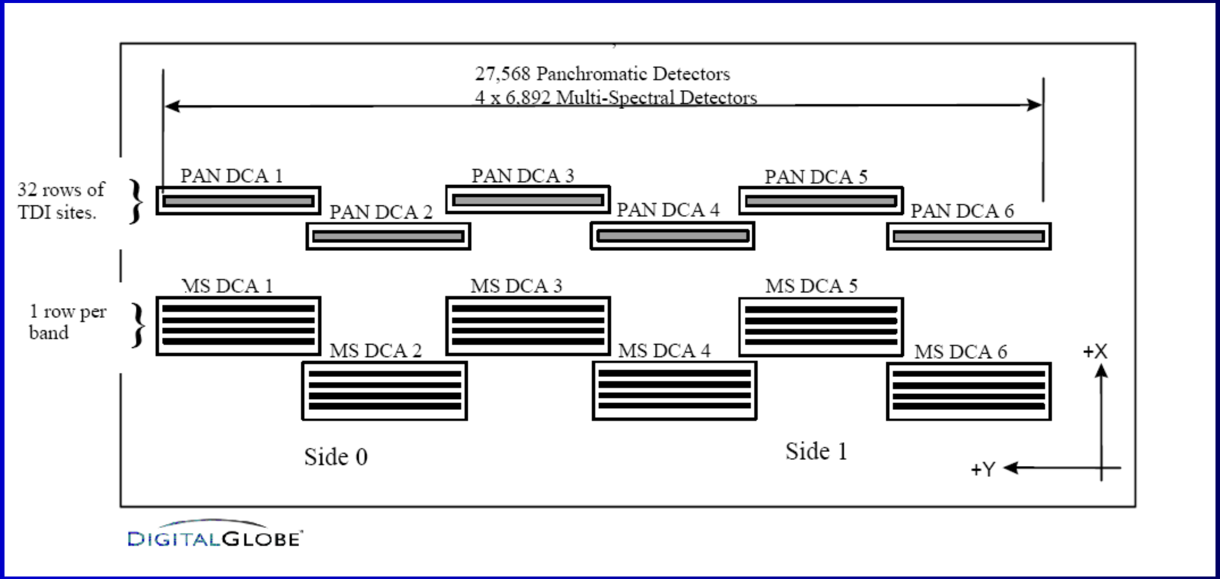


Image acquisition is discontinuous in the cross-track-direction (pixel)direction



6 butted/staggered pan arrays with 32 TDI stages each

6 butted/staggered XS arrays with four linear arrays each

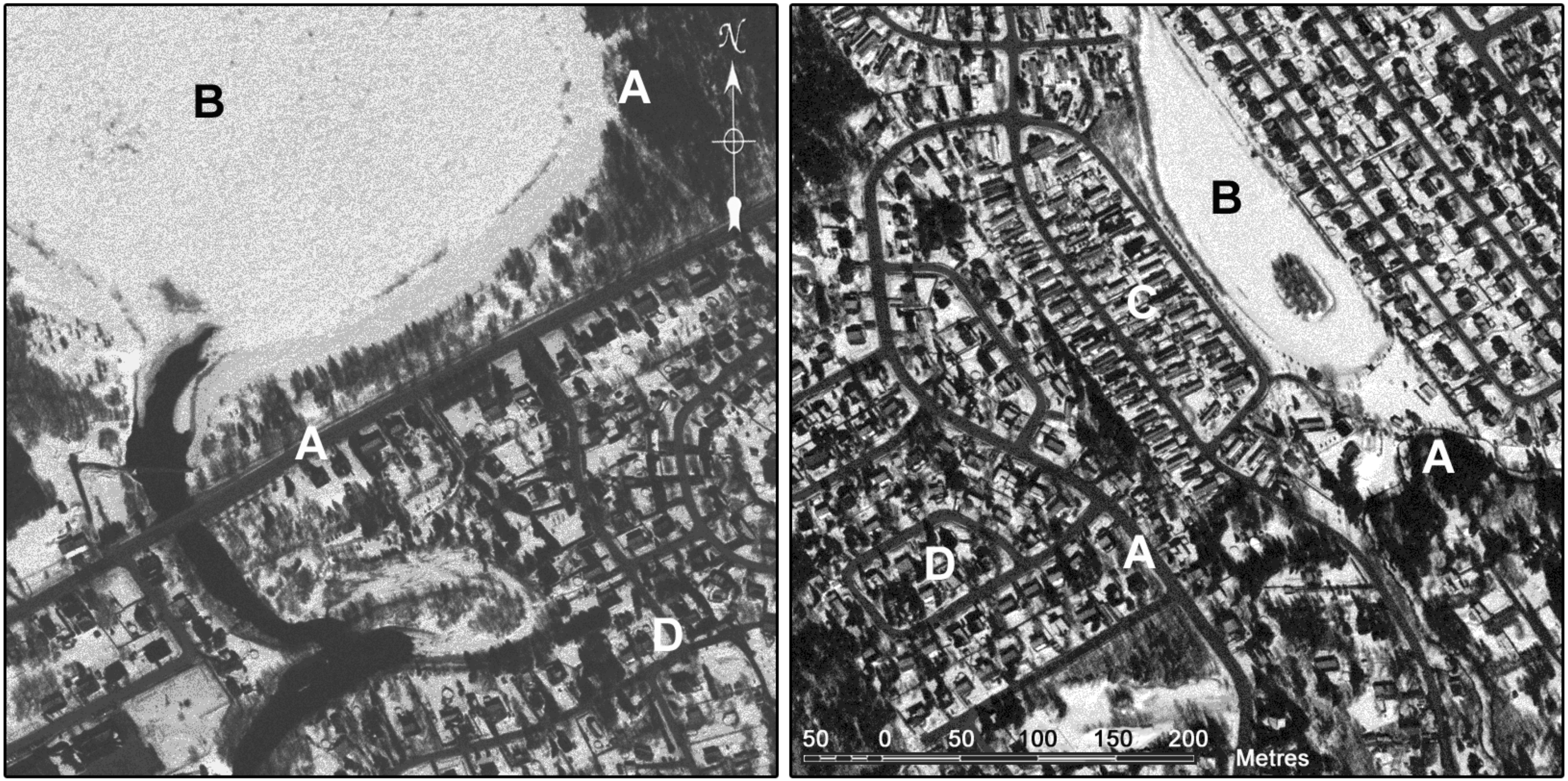
QuickBird Images

A Sand pits
B Lakes
C Bare soils
D Power corridors
E Ski station

QuickBird Images

Beauport

A: Shadows of trees or houses; B: Snow-frozen lake;
C: Mobile homes; D: 2-storey residential houses



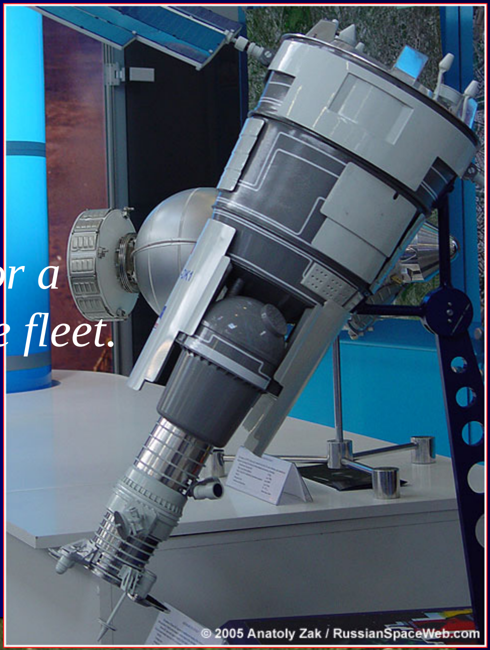
QuickBird Image

Texas

0.61 m pixel spacing

0.10 m pixel spacing

Resurs-DK1



The first digital frame cameras DK-1 *were launched 15 June 2006 for a three-year mission on the newest member of Russia RESURS satellite fleet.*

<u>Specifications</u>

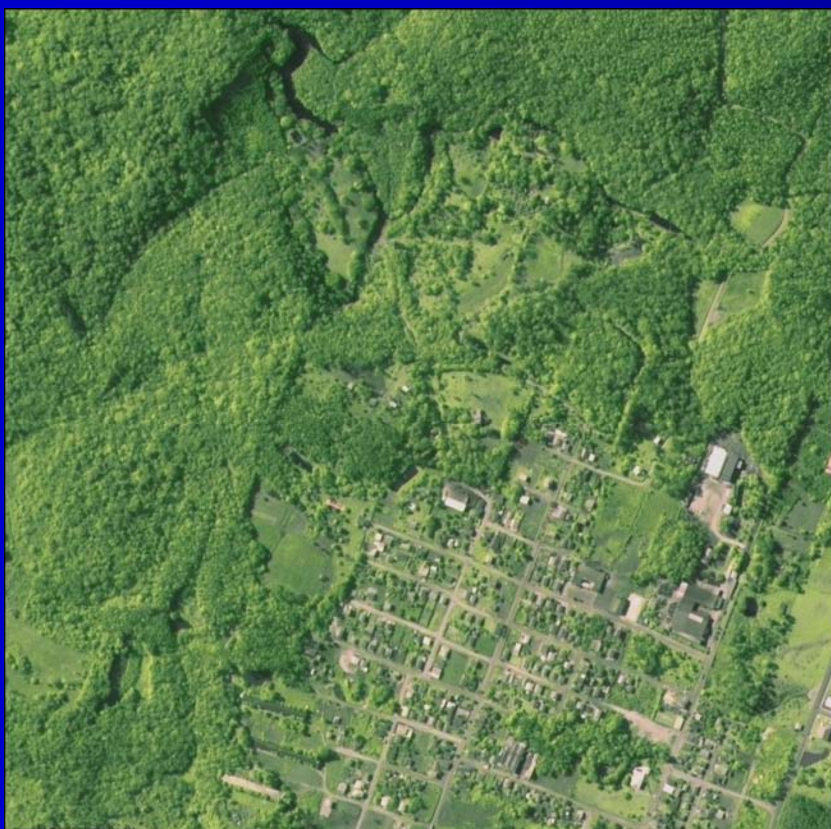
CCD “Kruiz” chip of 9 x 9 µm 1024 pixel by 128 lines
Four arrays with 36 CCD “Kruiz” chips and 128 horizontal TDI rows each
- *Pan: (580—800 nm) 1 m GSD,*
- *VNIR: (green 520—600 nm, red 600—700 nm, NIR 700—800 nm), 2—3-m GSD*

28.3 km swath and 40 km at 30°
up to 105,000 km2 imaging capacity daily.
body-pointing capability of ±30° across-track
448 km field of regard
360—690 km altitude
extensive on-board memory,
high-speed real-time downlink system
GLObal Navigation Satellite System (GLONASS).

Concepcion, Chile

Resurs-DK1

The first digital frame cameras DK-1 were launched 15 June 2006 for a three-year mission on the newest member of Russia RESURS satellite fleet. Spatial resolution is below 1 m but images are sampled at 1 m.



Santa Catarina, Brazil

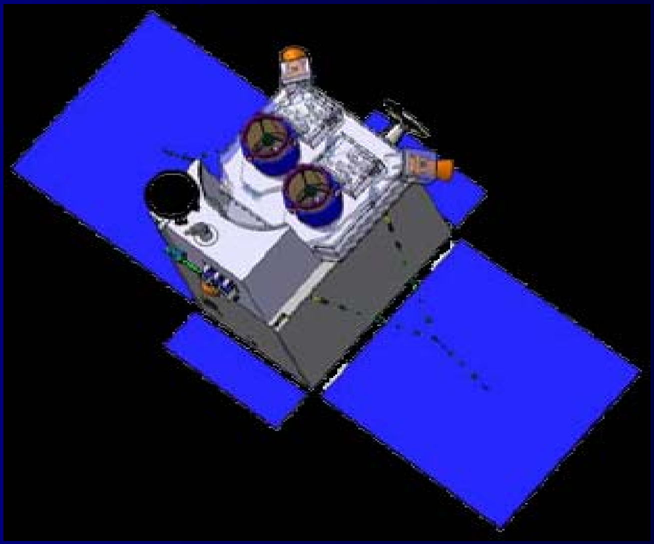
Jiddah, Saudi Arabia

Pleiades

Characteristics

- 2 satellites (P1 + P2)
- Manufactured by EADS/ASTRIUM & Alcate
- Resolution: 50 cm Pan + 2m XS GSD (16 bits)
- Swath @ NADIR : 20 km
- Localization (without GCP): 12 m @ 90%
- Daily revisit (when 2 satellite and 45° angle)
- Up to 450 images/day (20 km x 20 km)
- On board memory (250 images)
- Very high agility : Control Moment Gyros (4)
- Launch (2010 + 2011)

Astroterra

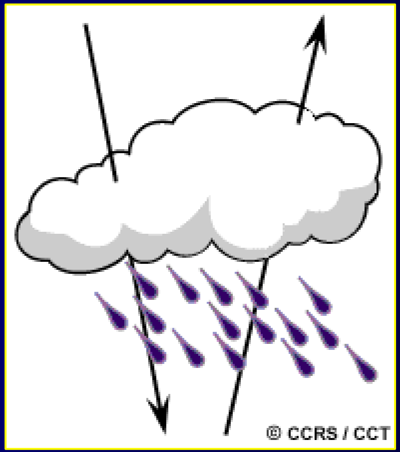


Providing *continuity* to the Spot 5 mission, funded by Spot Image and EADS Astrium: will be the future SPOT 6 and SPOT7

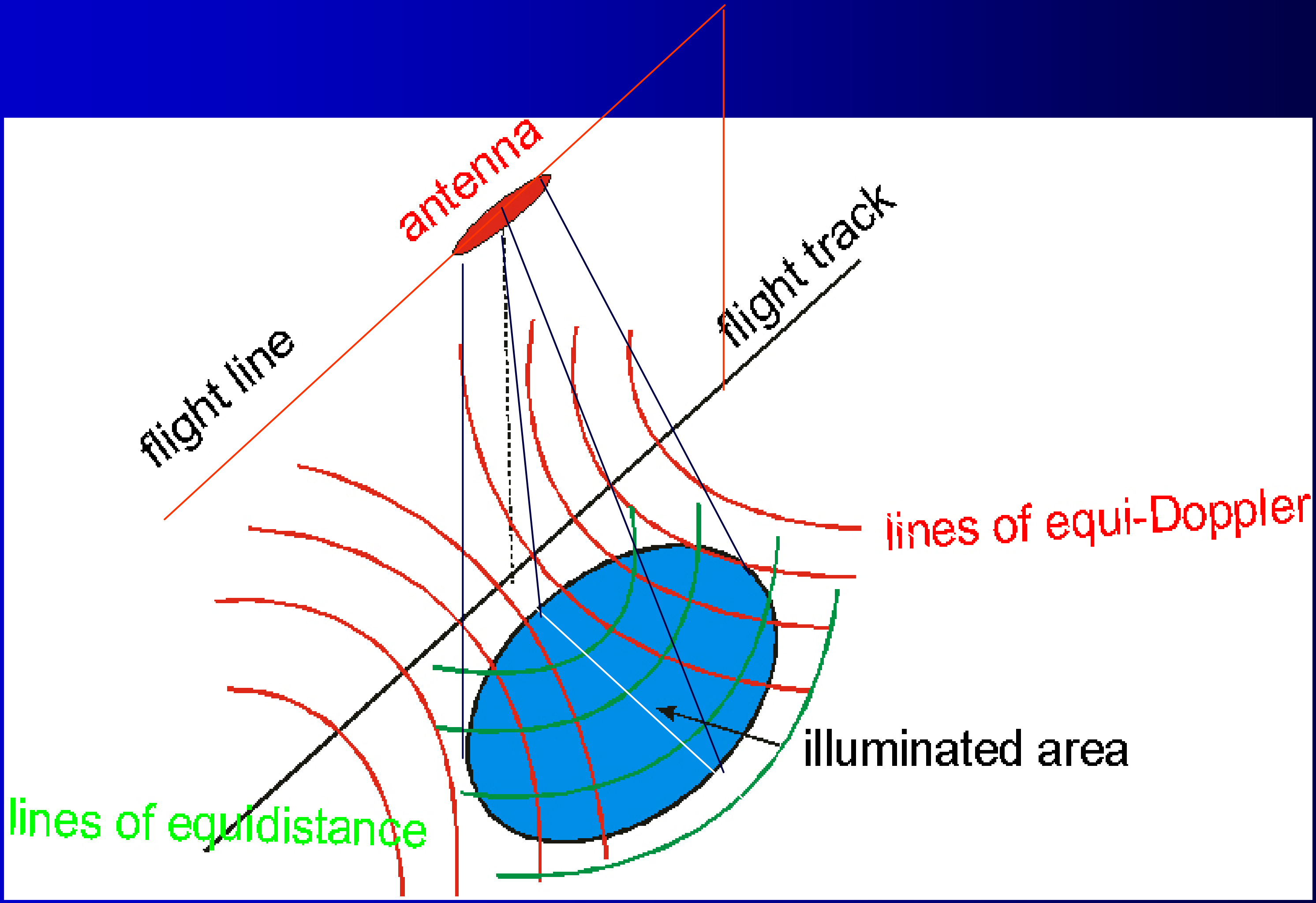
- **System based on agile mini-satellite (400 kg class)**
- **2 instruments, 4 multispectral bands (blue, green, red, NIR)**
- **Resolution: < 2m B&W; 8 m Colour**
- **Swath: 60km**
- **Altitude: 700 km**
- **Extreme agility (CMG)**
- **Acquisition capacity: > 2,5 Million km²/day (similar to SPOT 5)**
- **Stereo capability: along track; and 3-stereo**
- **System Architecture & Design held with ASTRIUM & CNES**
- **Launch date: end 2011**
- **life time: 7 years**

High-spatial resolution satellite sensors

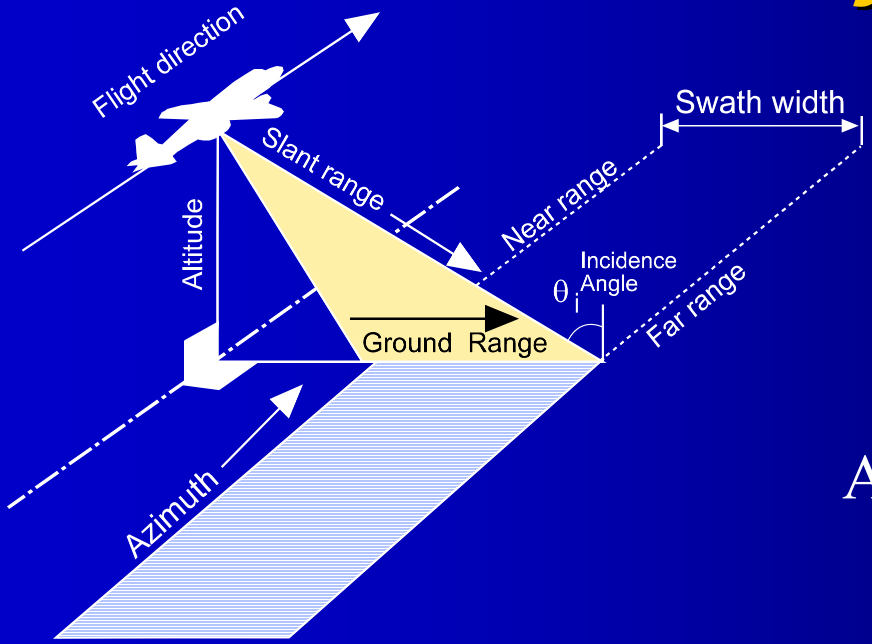
1. Orbital considerations
2. Push-broom scanners: some generalities
3. Existing HSR/VHSR sensors and examples (SPOT-5, EROS-A/B, Ikonos, QuickBird)
4. **SAR systems and examples (Radarsat-2, Terra-SAR-X)**
5. Geometric and radiometric comparisons
6. Stereo acquisition



SAR systems

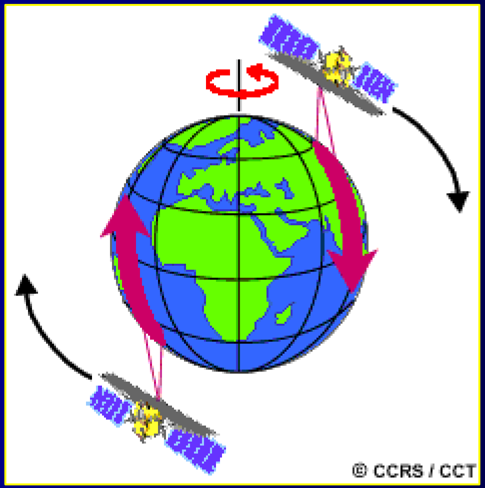

antenna
flight line
flight track
lines of equi-Doppler
illuminated area
lines of equidistance

SAR systems



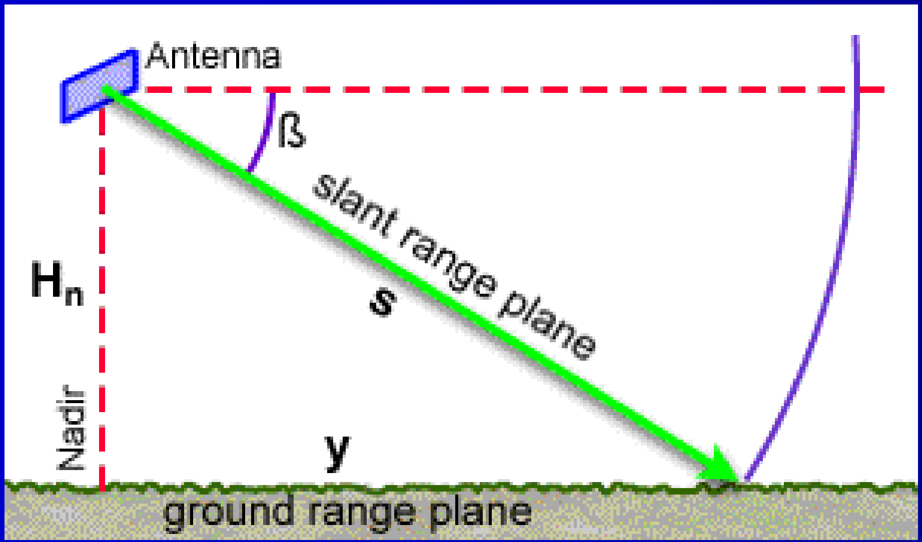
Basic geometry of SAR image acquisition

Ascending and descending acquisition

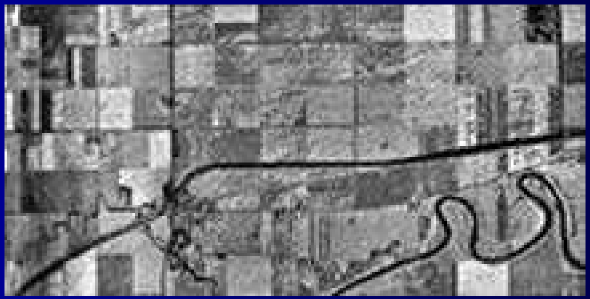


SAR systems

Slant versus ground range



Slant range

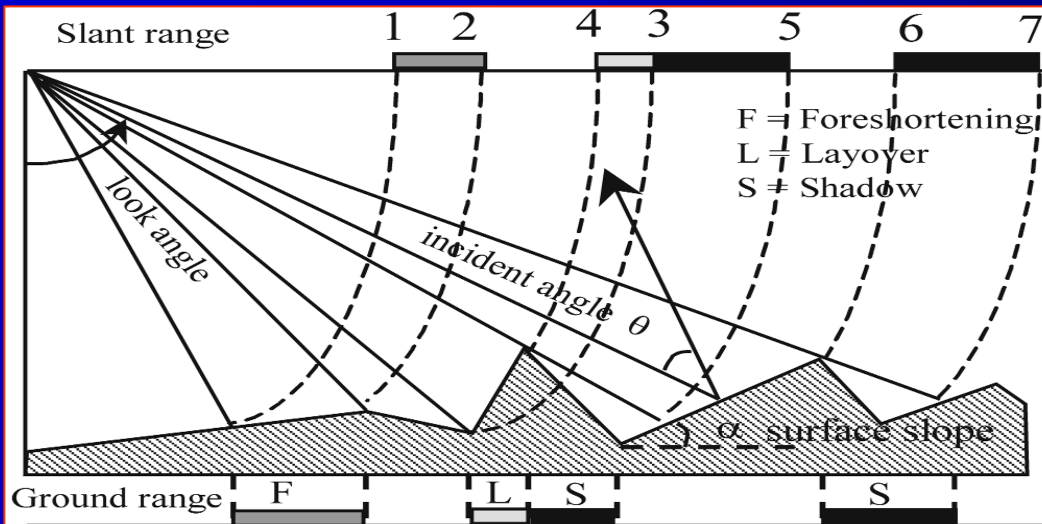


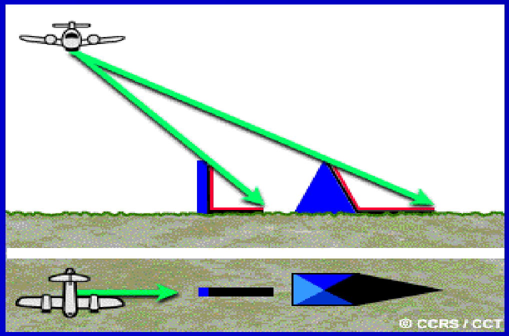
Ground range

SAR systems

The specific geometry of SAR image:

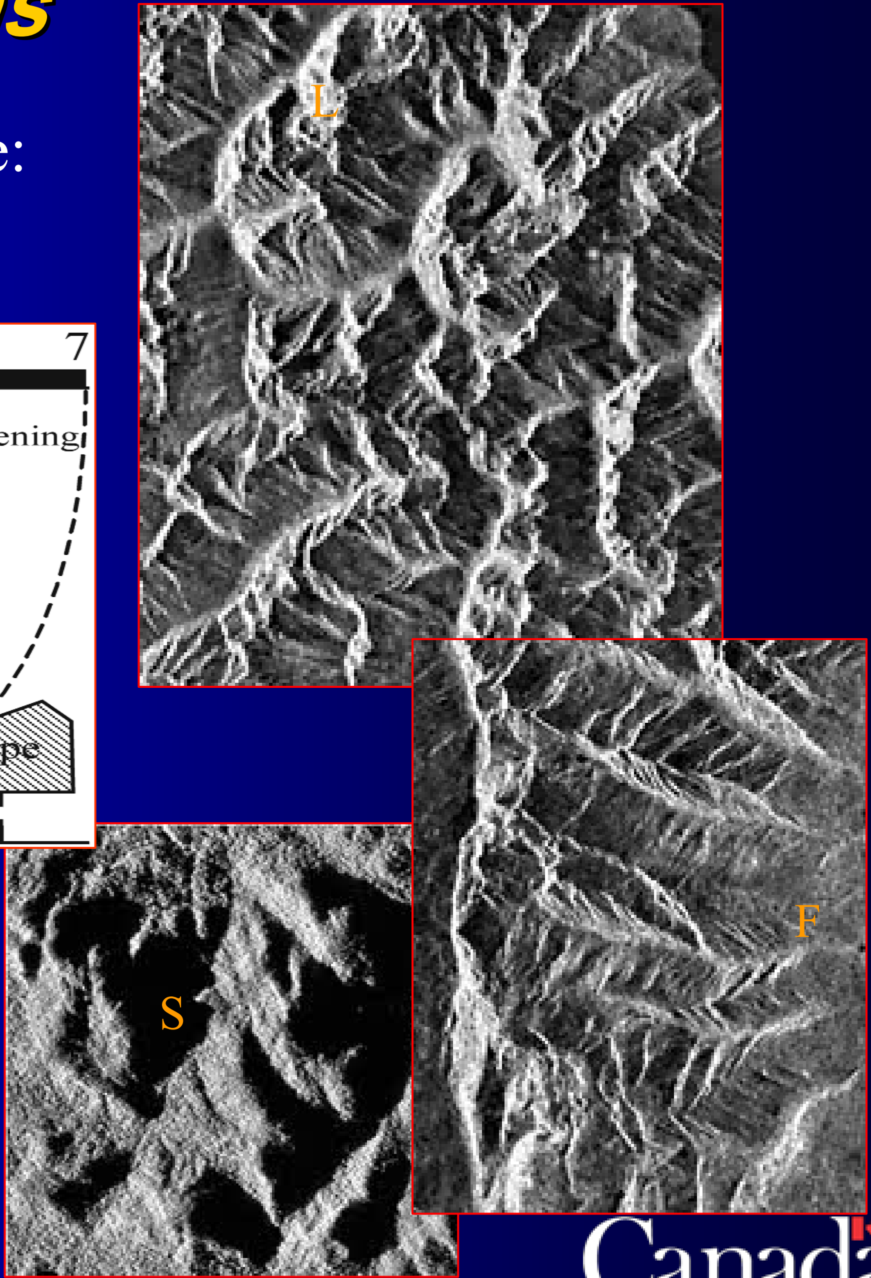
F = foreshortening; L = layover; S = shadow





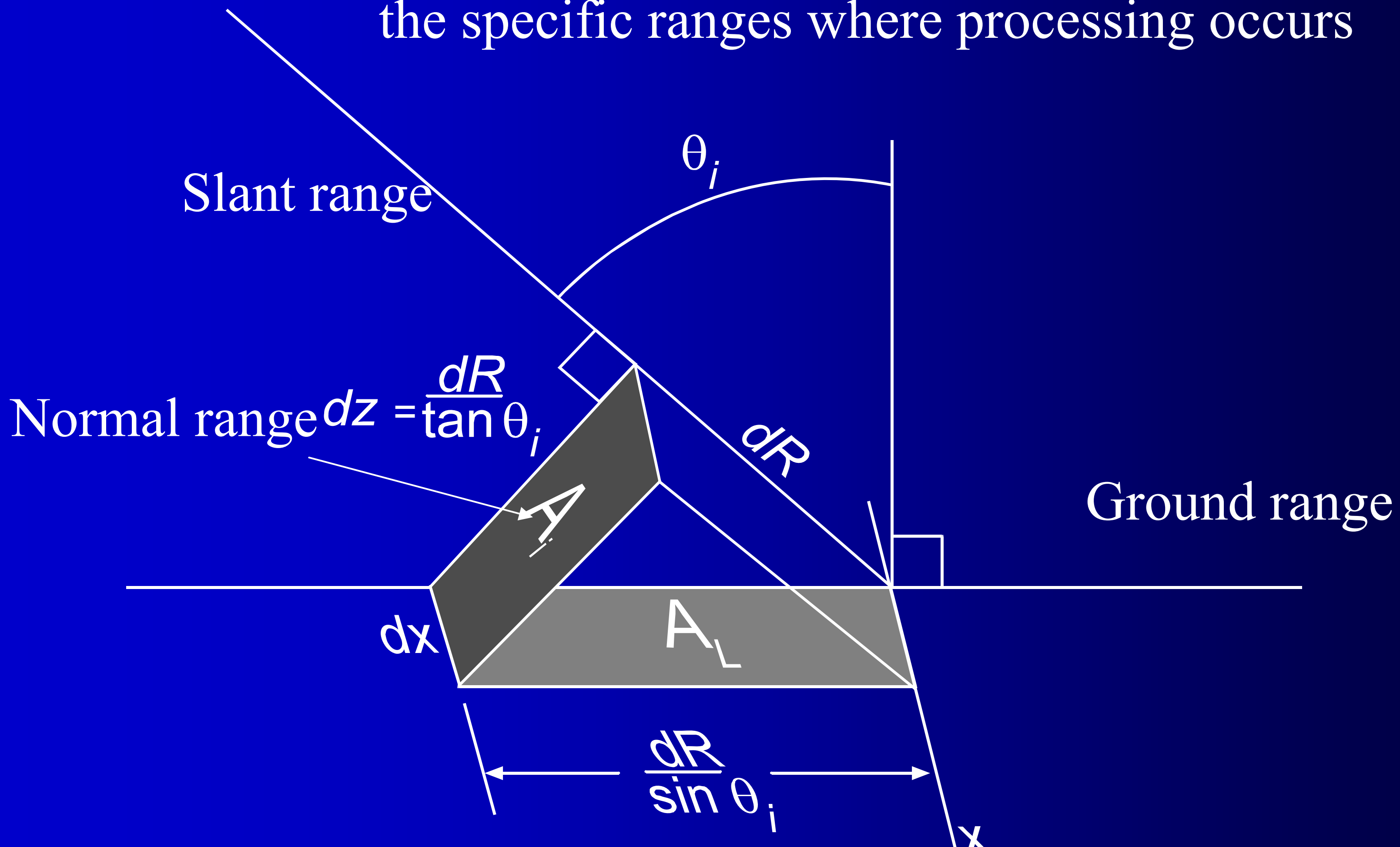
Foreshortening and layover are most severe for small incidence angles.

Shadow is most severe for large incidence angles.



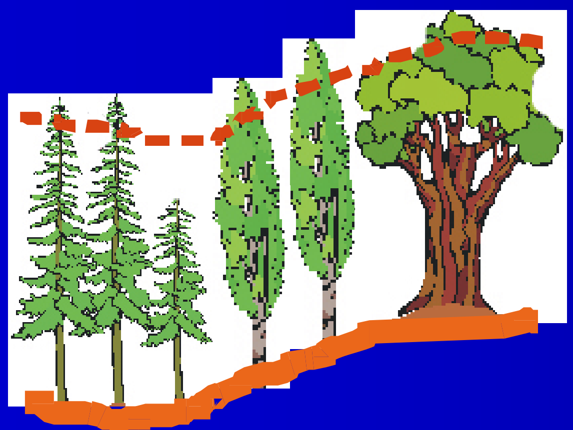
SAR systems

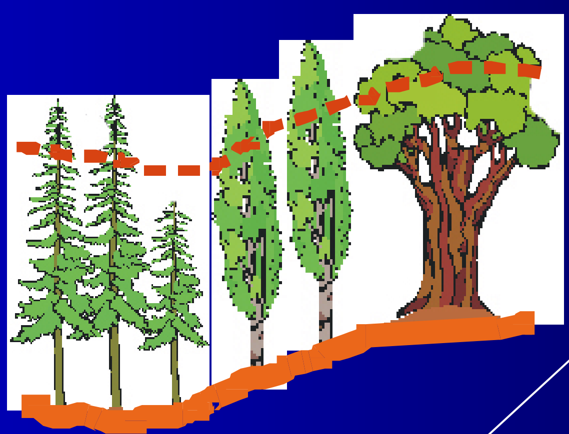
Radiometric calibration must be performed in the specific ranges where processing occurs

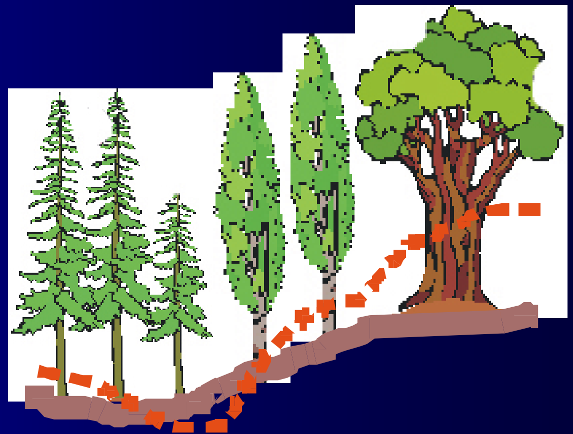


SAR systems

X-band	C-band	L-band
2.4 – 3,75cm	3.75 – 7.5 cm	15 – 30cm
reflection close to top surface	reflection close to top	close to

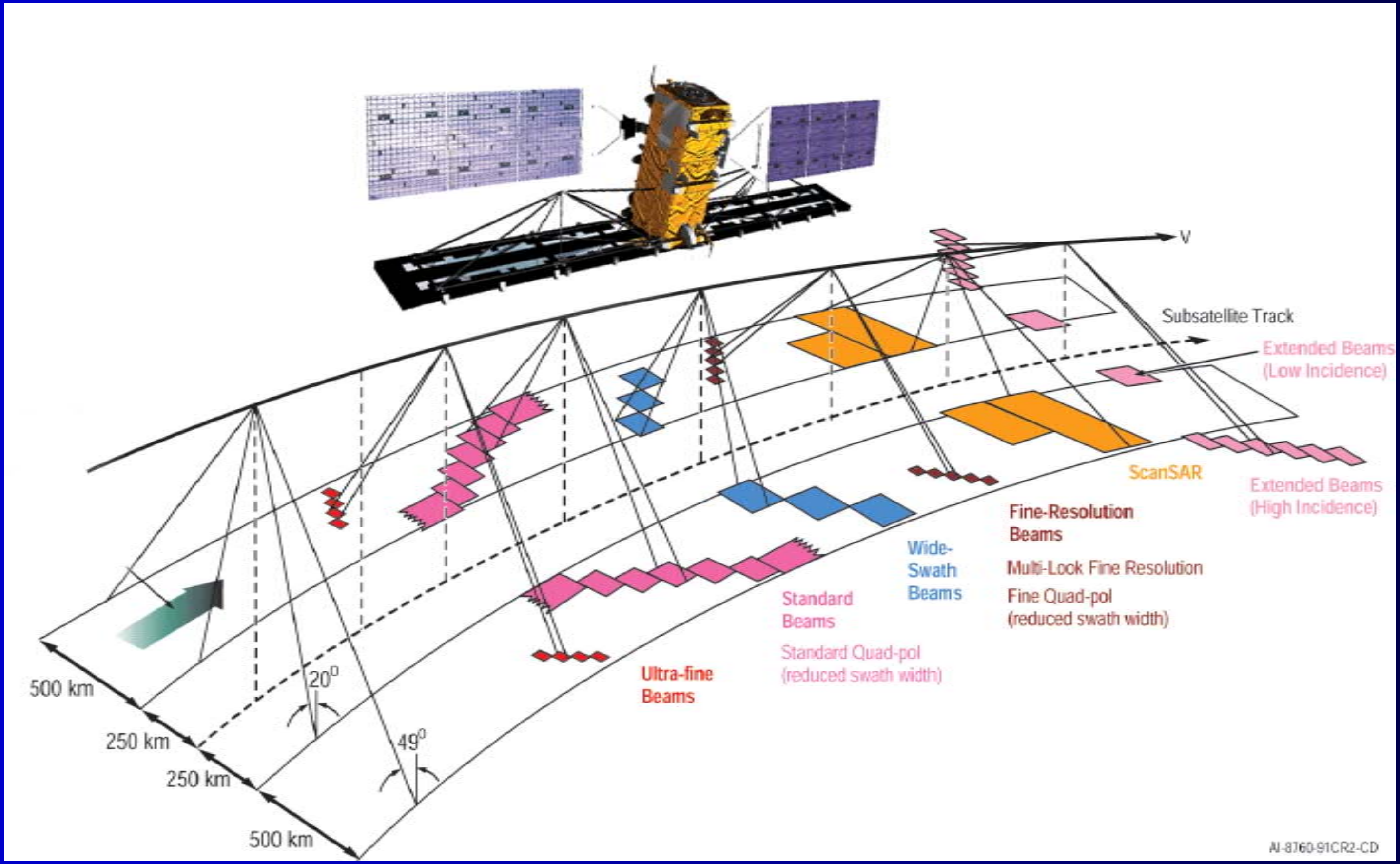






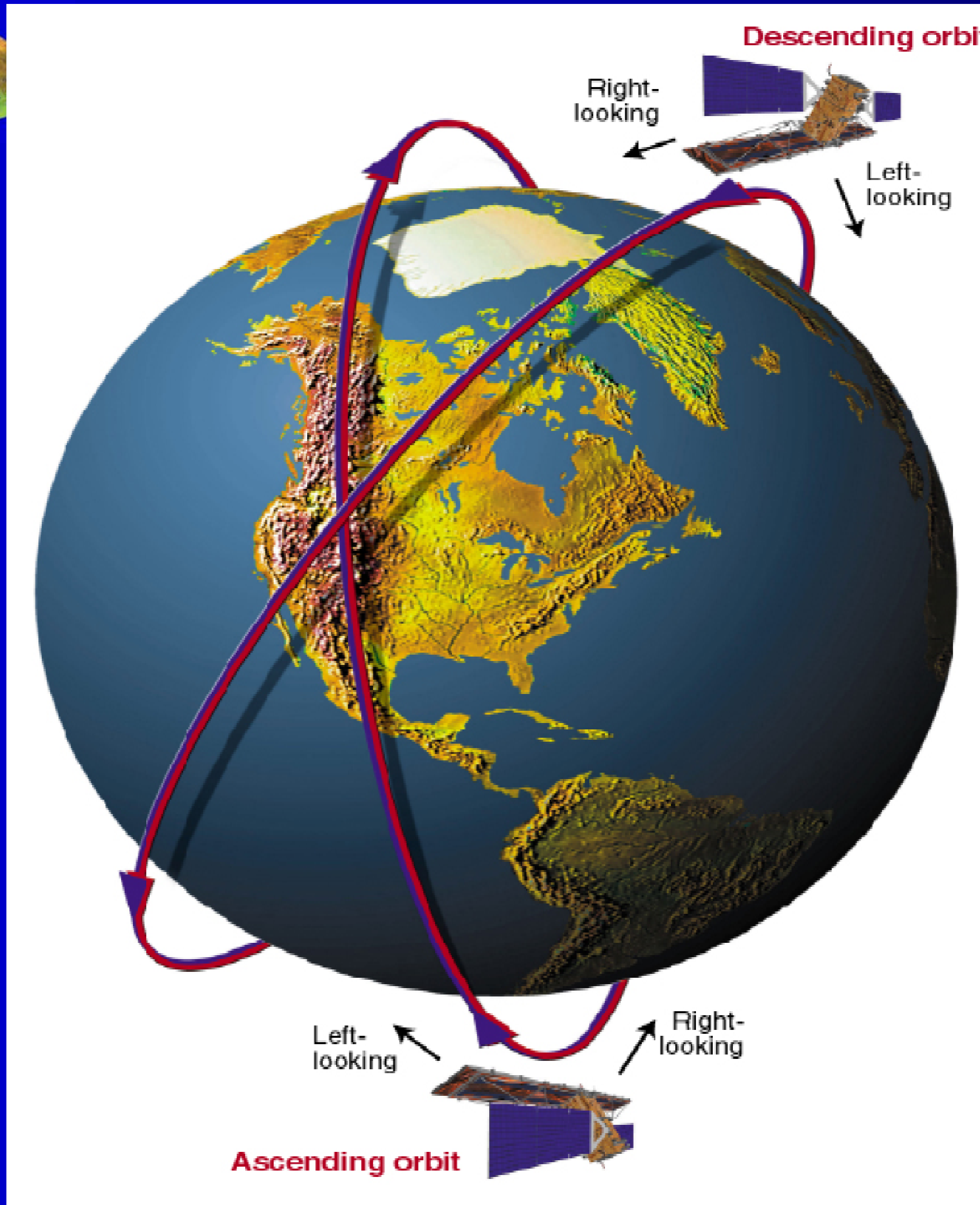
dense conifers ~ 6m above ground
young trees ~ surface
clear cut – penetration of mud ~0.5m

SAR systems



RADARSAT OPERATING MODES

Radarsat-2 orbit

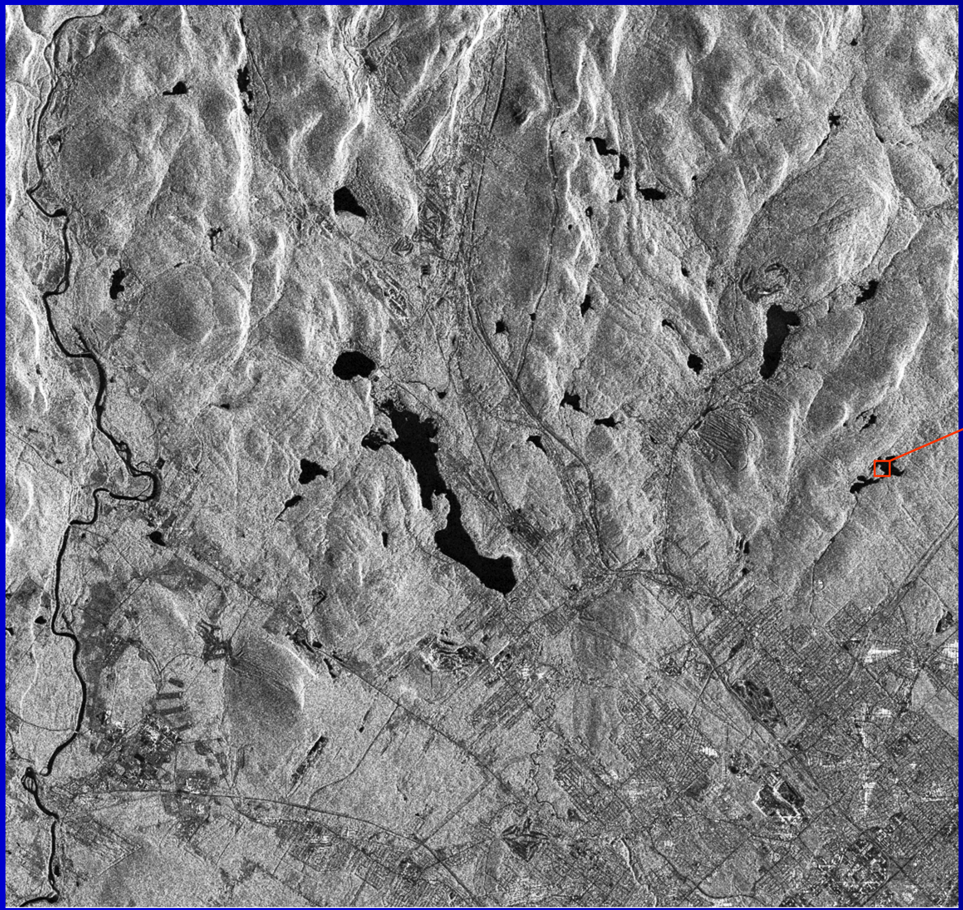


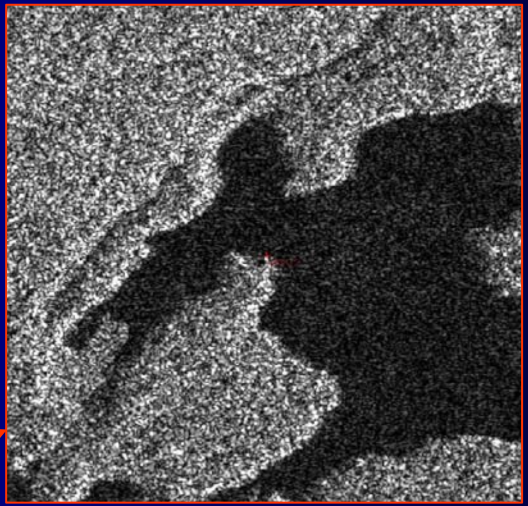
ORBIT CHARACTERISTICS	
Altitude (average)	798 km
Inclination	98.6 degrees
Period	100.7 minutes
Ascending node	18 hrs (± 15 min)
Sun-synchronous	14 orbits per day
Repeat cycle	24 days

COVERAGE ACCESS USING 500 KM SWATH WIDTH	
North of 70°	Daily
North of 48°	Every 1-2 days
Equator	Every 2-3 days

SAR systems

Beauport, Quebec

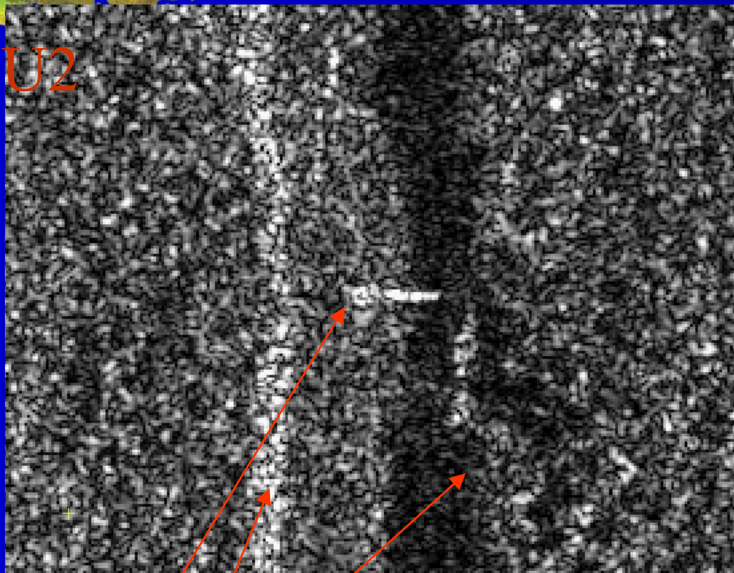


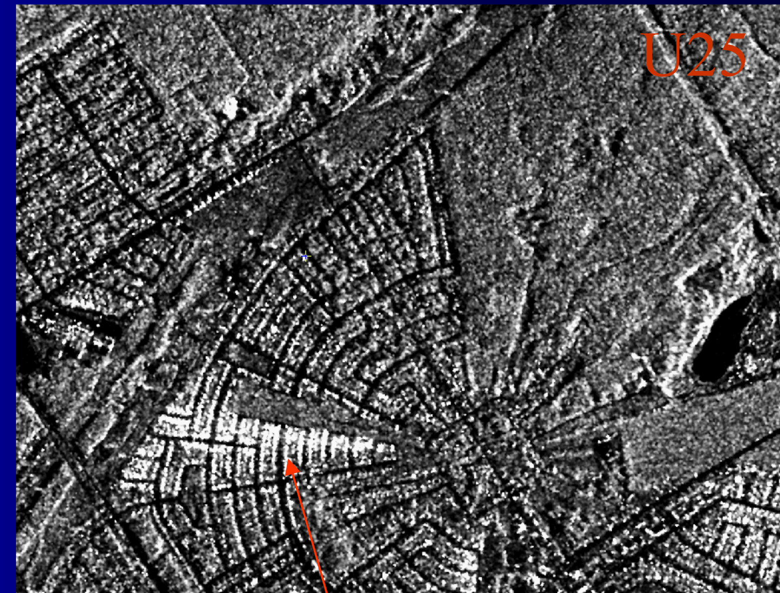


RADARSAT2 ultra-fine mode image

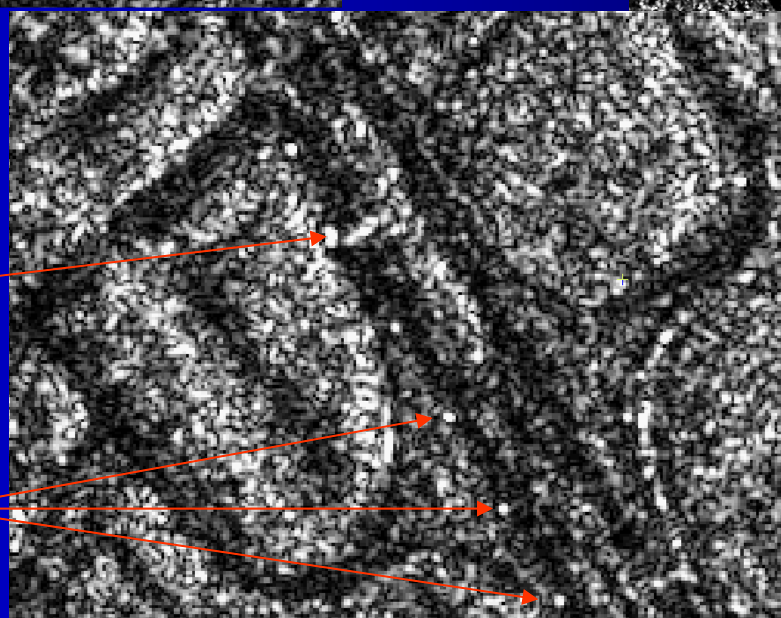
- 3 by 3 m resolution
- 30° viewing angle
- descending orbit
- right viewing
- ground range

Ghosts of Backscatter





Power line & corridor

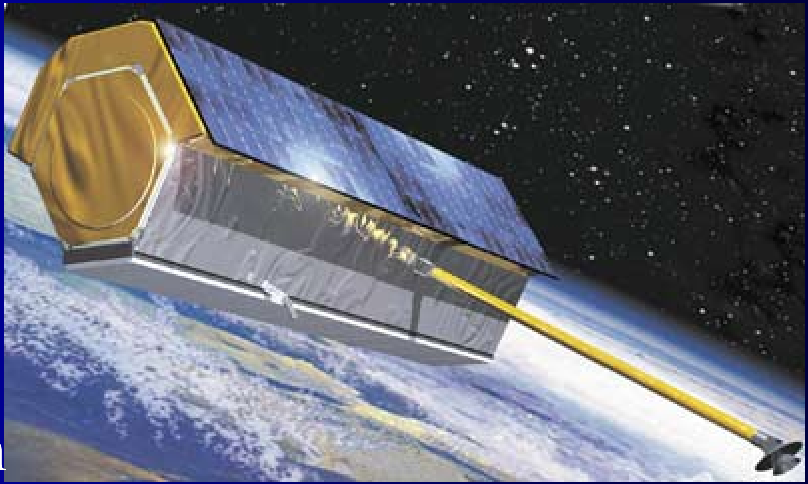


Direction sign

Power poles

Cardinal effects due to strong double bounce backscatter with streets aligned in range

TerraSAR-X



TerraSAR-X is a German satellite that uses an X-band SAR to provide high-quality topographic information for commercial and scientific applications.

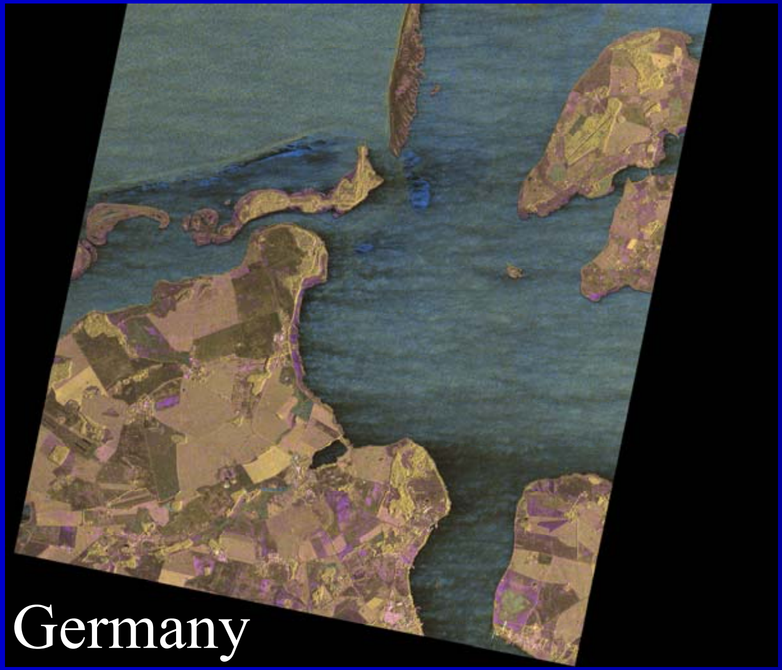
Launched June 15 2007 aboard a Dnepr rocket from Baikonur, it produced preliminary imagery on June 19 2007. TerraSAR-X has a **revisit interval of 11 days**. However, its ability to view on either side of the ground track means it sees any point on the globe at least every **4½ days**, and every **2 days** in 90% of cases.

TerraSAR-X

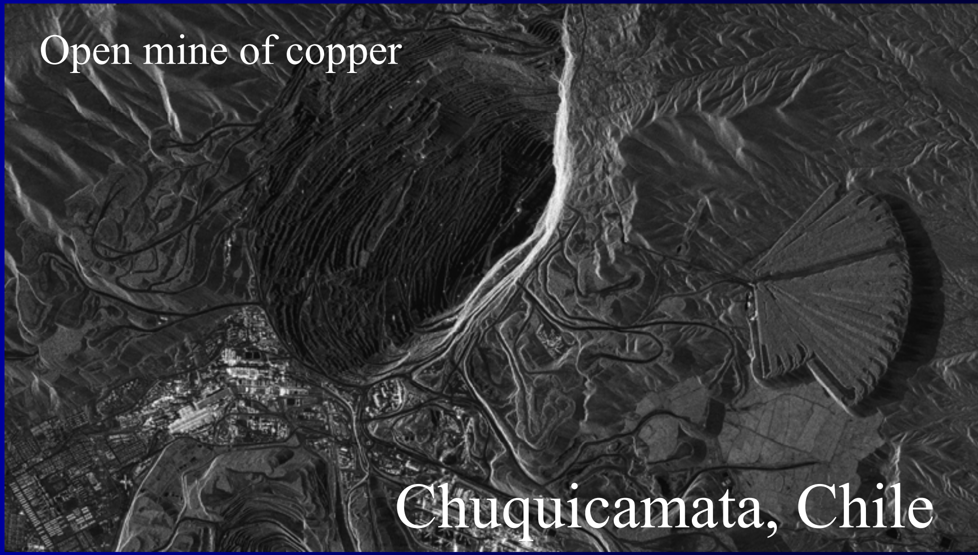
TerraSAR-X with the twin Tandem-X, to be launched in 2009, will provide interferometric data for accurate DEM generation. It is the first commercial 1-m resolution SAR satellite

Open mine of copper

Credit: DLR; date: July 7, 2007, 5:24 UTC; original resolution: 3 metres (reduced image); mode: StripMap mode; polarisation: VV and HH

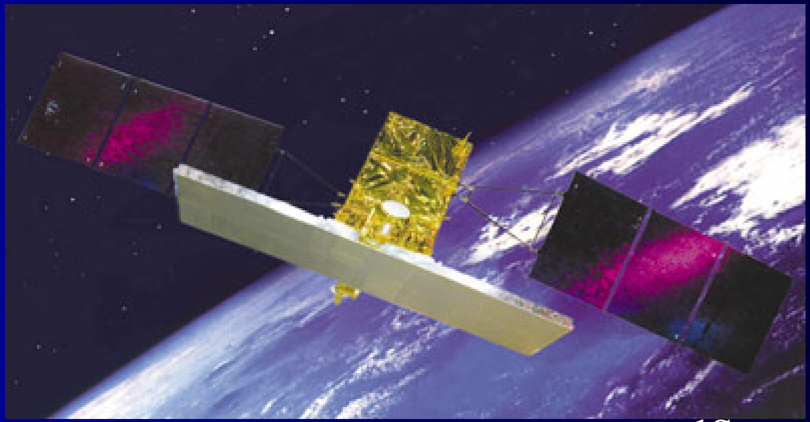


Credit: DLR; date: July 1, 2007, 23:00 UTC; original resolution: 1 metre (reduced image); mode: High Resolution Spotlight Mode, polarisation: HH.



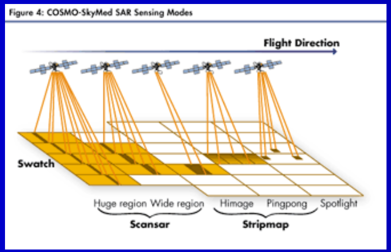
Chuquicamata, Chile

Cosmo-SkyMed

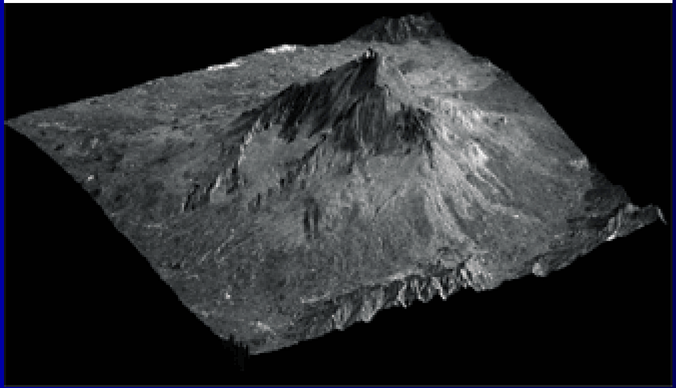


COSMO-SkyMed **(Constellation of Small Satellites for Mediterranean basin observation)** **IS** an Earth observation program of the Italian Space Agency (ASI) developed by Alenia Spazio. Three were already launched in 2007-08.

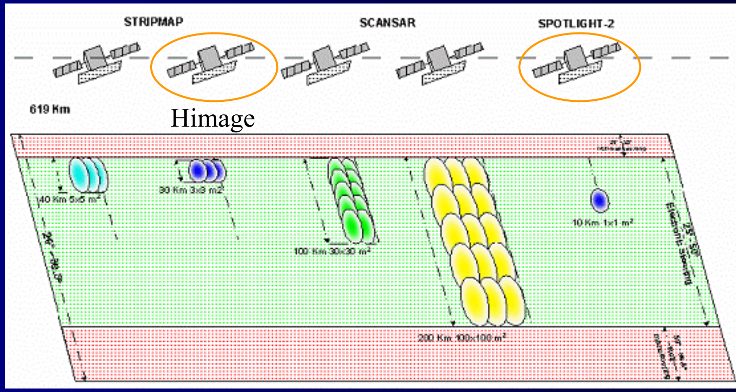
The four satellites are at 620 km and phased at 90°, which gives a revisit time of less than 12 hours. The field of regard is 1300 km with left/right 20-60° viewing angles. SAR sensor has multi-pol and interferometric capability.



Interferometric DEM



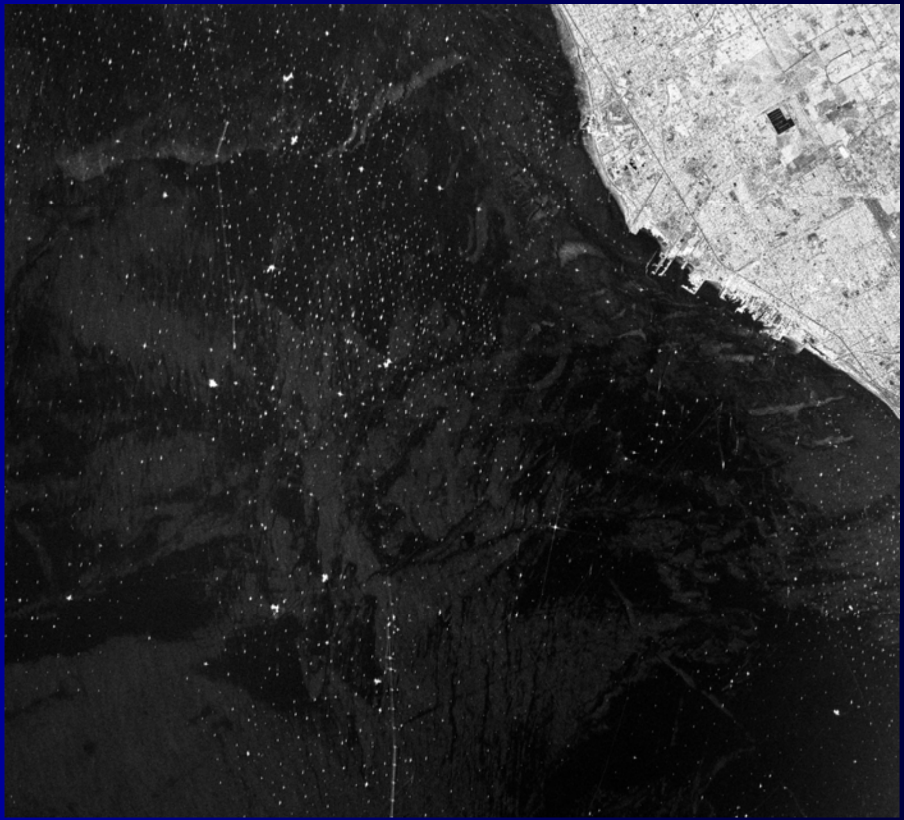
Cosmo-SkyMed



The HR modes are:

- Spotlight: single pol, 1-m resolution, 10x10 km
- Himage: single pol, 3-m resolution, 30x30 km

Chuquicamata, Chile



Maracaibo Lake, Venezuela

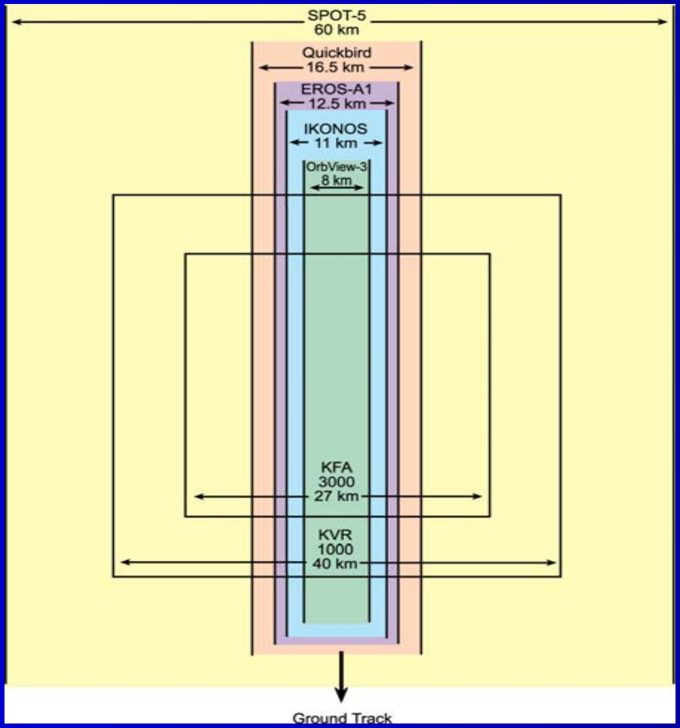
High-spatial resolution satellite sensors

1. Orbital considerations
2. Push-broom scanners: some generalities
3. Existing HSR/VHSR sensors and examples (SPOT-5, EROS-A/B, Ikonos, QuickBird)
4. SAR systems and examples (Radarsat-2, Terra-SAR-X)
5. Geometric and radiometric comparisons
6. Stereo acquisition

Geometry

For push-broom scanner SPOT-5 has the largest swath.

In addition, the acquisition is continuous, which enables long strip to be generated.



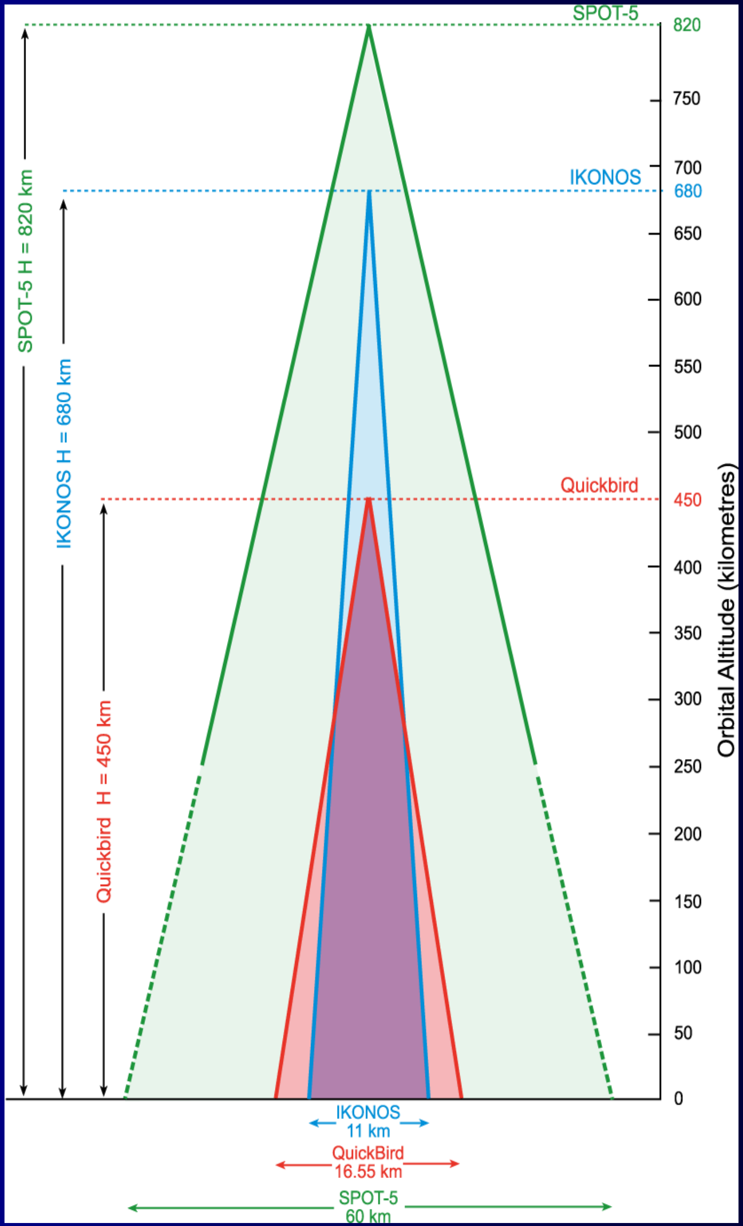
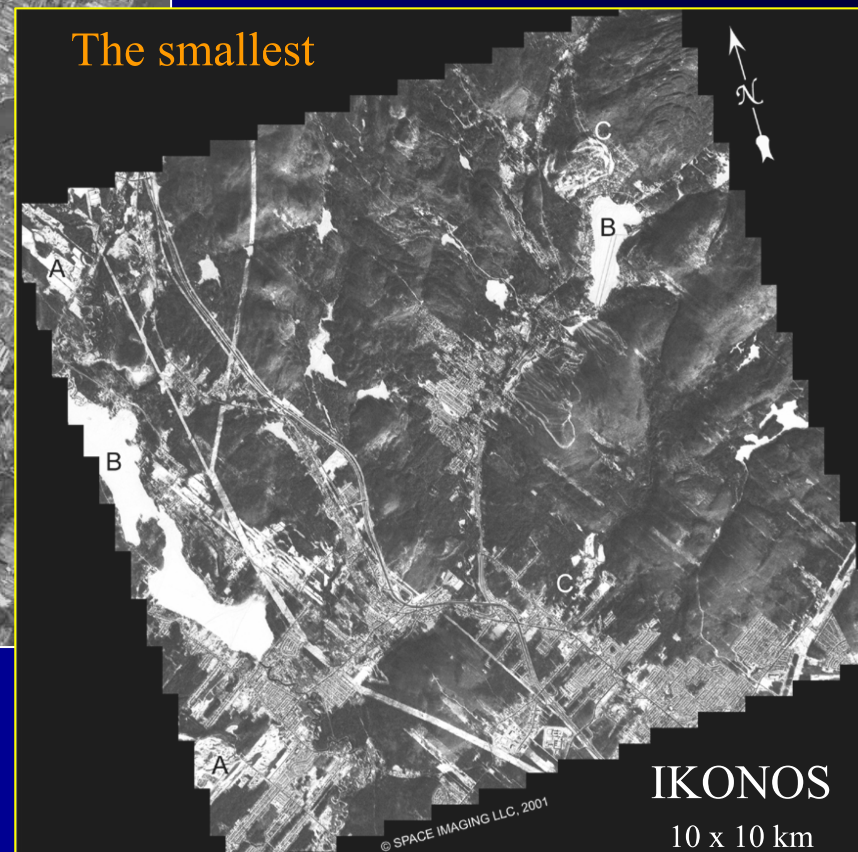


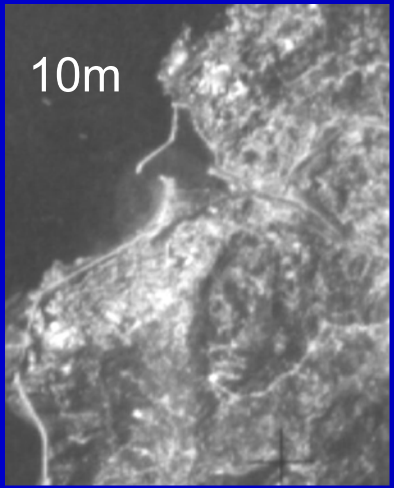
Image sizes

SPOT-5 versus IKONOS



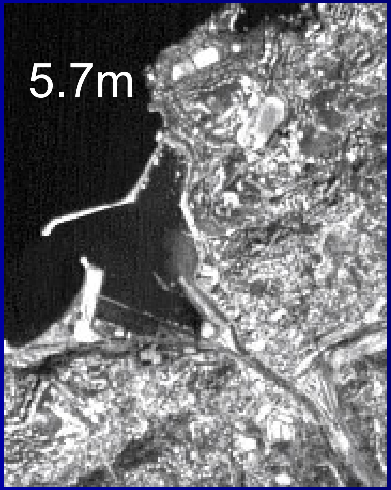
36 IKONOS for 1 SPOT-5

Geometry: FSR



TK 350 photo

KOMPSAT-1



IRS-1C

SPOT-5 HRG

FSR data acquired over the test field Zonguldak (*Jacobsen et al*.)
Small increase in sensor resolution does not improve feature characterization: radiometry should also be considered

Geometry: FSR

Better radiometry

SPOT-5

2.5 m pixel

EROS

1.8 m pixel

Fuzzy aspect due satellite movement

SPOT © 2002 CNES 2002

EROS © 2001 ImageSat 2001

Geometry and Radiometry

←OrbView 3

IKONOS →

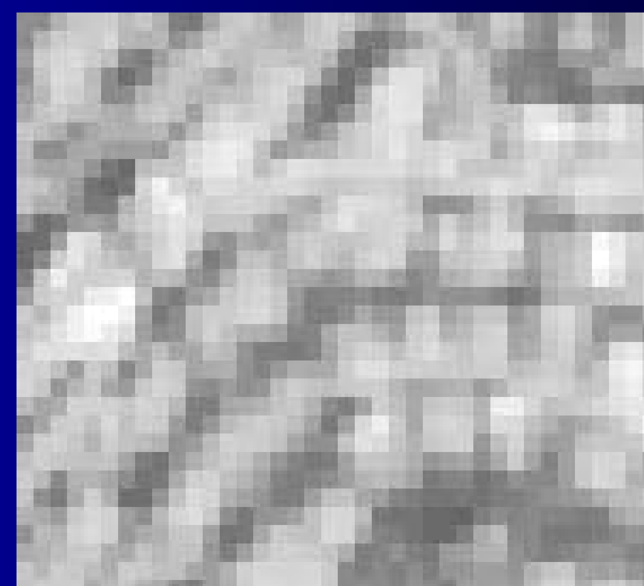
both 1m GSD

← QuickBird

0.62m GSD

SPOT 5 →

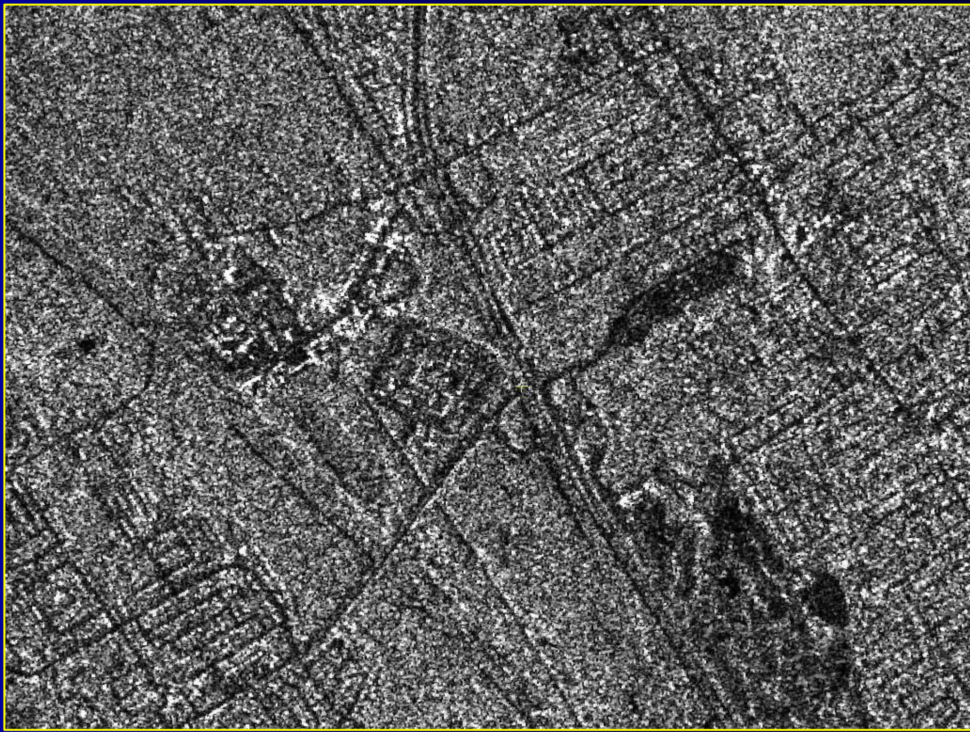
5m GSD



Geometry: Fine quad versus Ultra fine

Radarsat-2 UF25 HH
3-m resolution

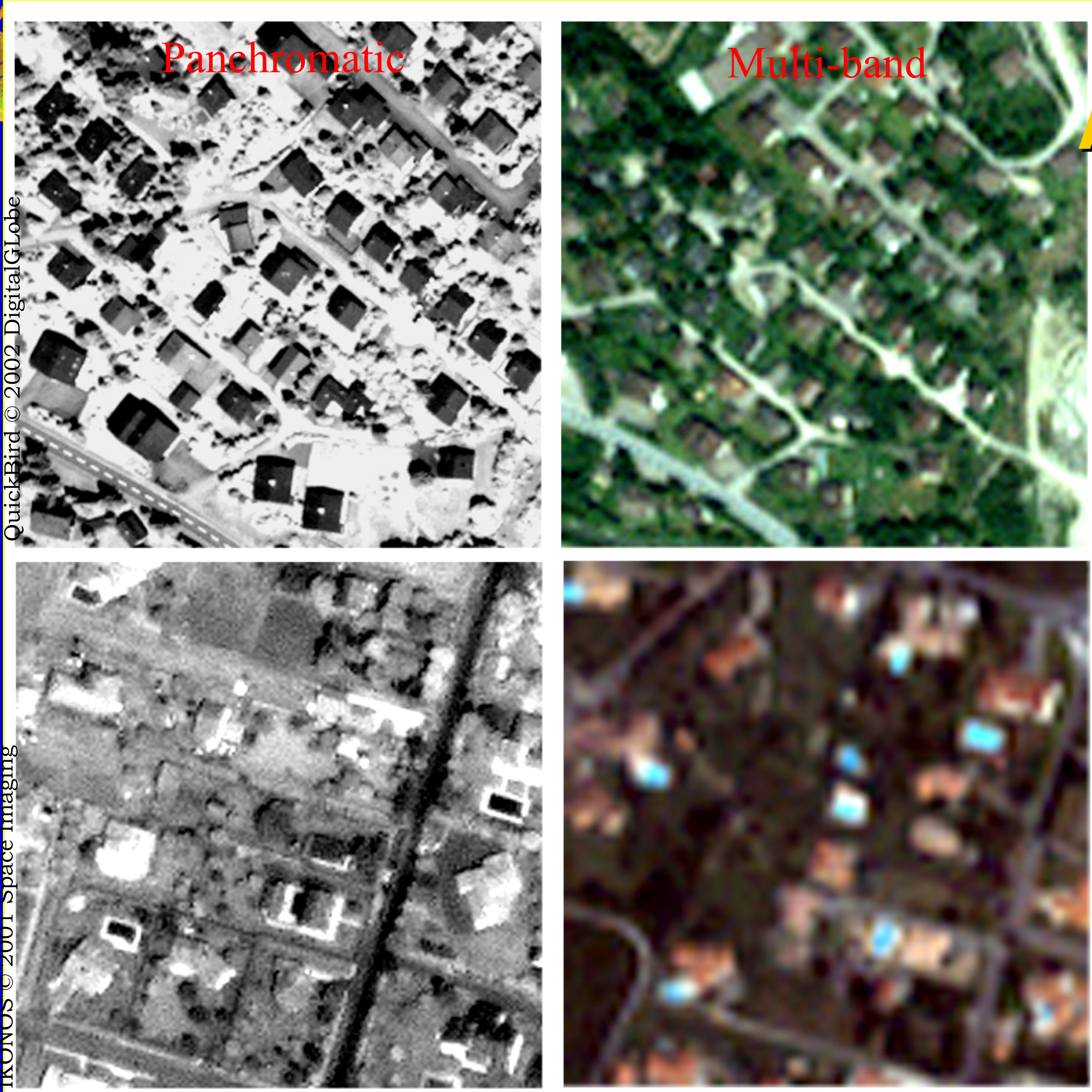
Radarsat-2 FQ18 HH
5-8-m resolution



Same coverage, same geometry, same polarization, single look

different geometric resolution and cartographic features

Geometry & Radiometry:
Pan vs XS



QuickBird

P: 0.6 m pixel

XS: 2.4 m pixel

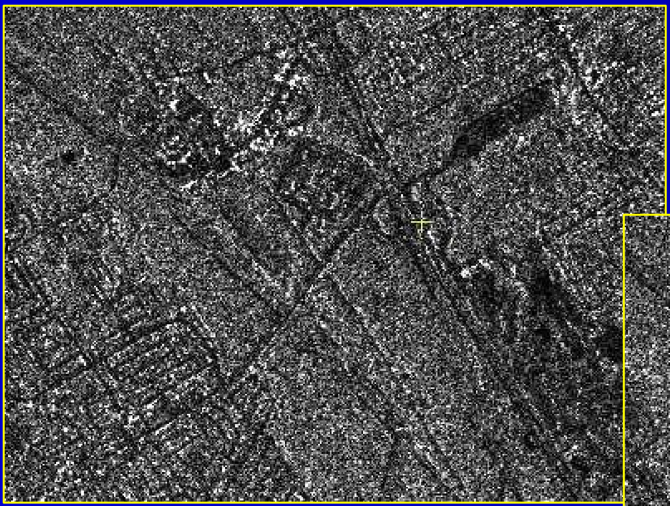
IKONOS

P: 1 m pixel

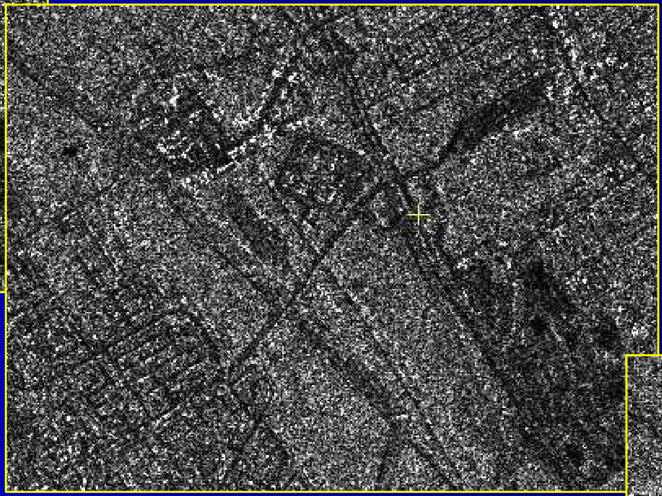
XS: 4 m pixel

Radiometry: *HH versus VV versus HV*

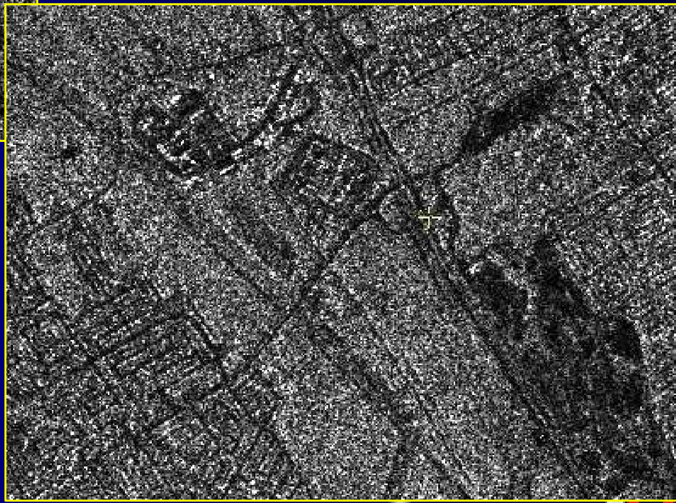
Radarsat-2 FQ18 HH
5-8-m resolution



Radarsat-2 FQ18 VV
5-8-m resolution



Radarsat-2 FQ18 HV
5-8-m resolution



Same coverage, same geometric, single look
and different radiometric resolution

Radiometry

Optical image based on chemical characteristics, radar images based on physical characteristics (cf. *Jacobsen*)

Aerial color photo

TerraSAR- X

In **rural areas** information contents on similar level, but different contents.

Electrical poles are well identifiable in SAR.

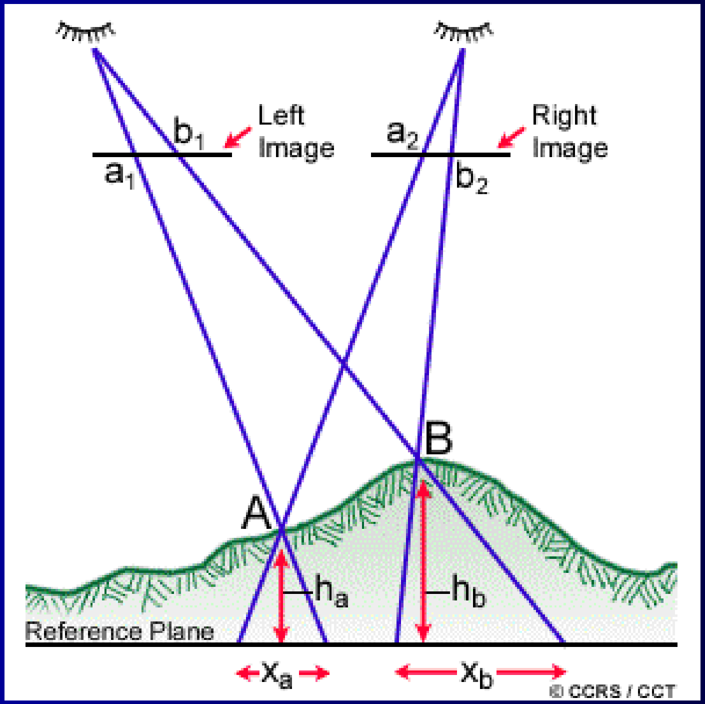
High-spatial resolution satellite sensors

1. Orbital considerations
2. Push-broom scanners: some generalities
3. Existing HSR/VHSR sensors and examples (SPOT-5, EROS-A/B, Ikonos, QuickBird)
4. SAR systems and examples (Radarsat-2, Terra-SAR-X)
5. Geometric and radiometric comparisons
6. **Stereo acquisition**

Stereoscopy

Satellite image stereo pairs are generated when a satellite collects data with two different viewing angles or two different beam positions of the same area

X parallax, X_a or X_b, known as the stereoscopic parallax, is caused by a shift in the position of observation and is proportional to elevation, h_a or h_b

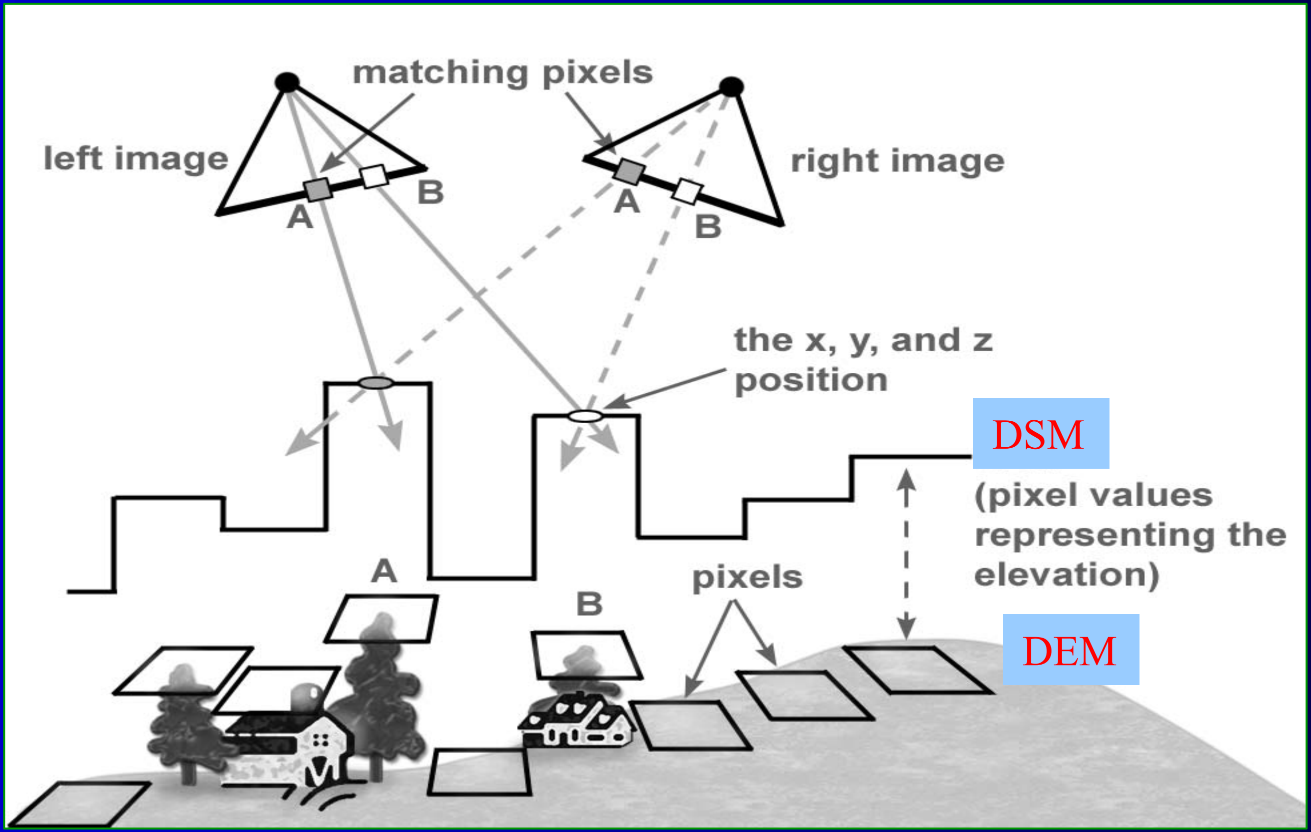


Advantages of Stereoscopy

Can convey information about slopes, shapes of landforms, and elevations much more clearly than 2-D representation

Useful to extract information: 3-D planimetric and elevation features (DEM)

DSM versus DEM

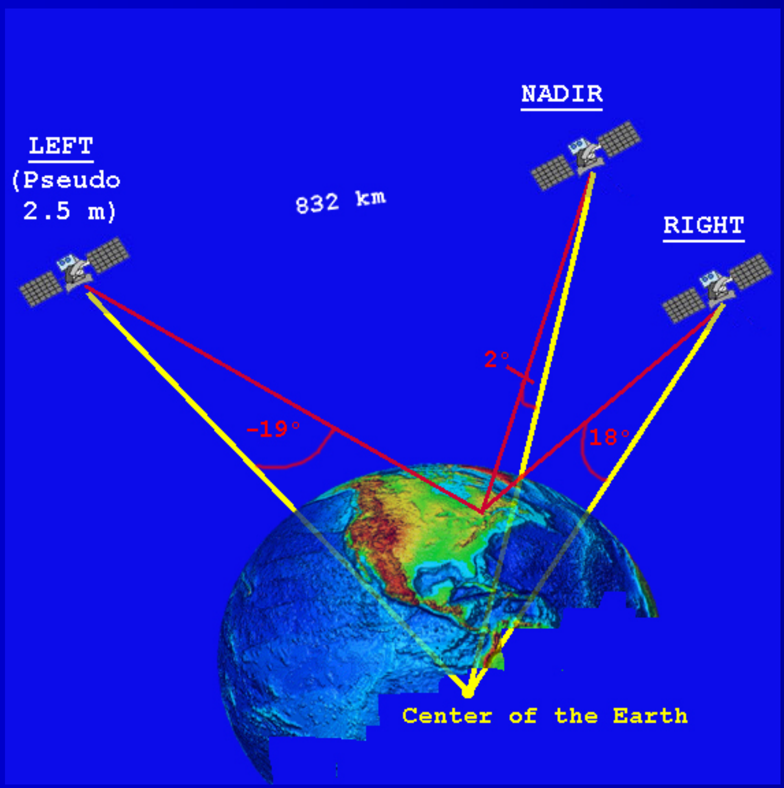


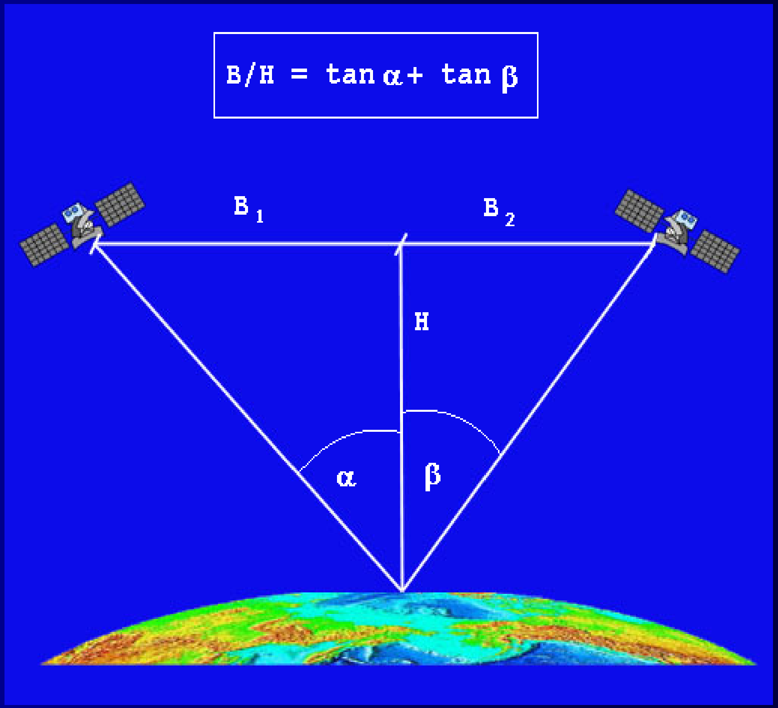
DSM takes into account the height of natural/artificial surfaces
DEM represents the bald Earth

⇒ DSM – DEM = Heights

Stereo image acquisition

Satellite images can be acquired from different view points in space geenraton different stereo viewing geometry





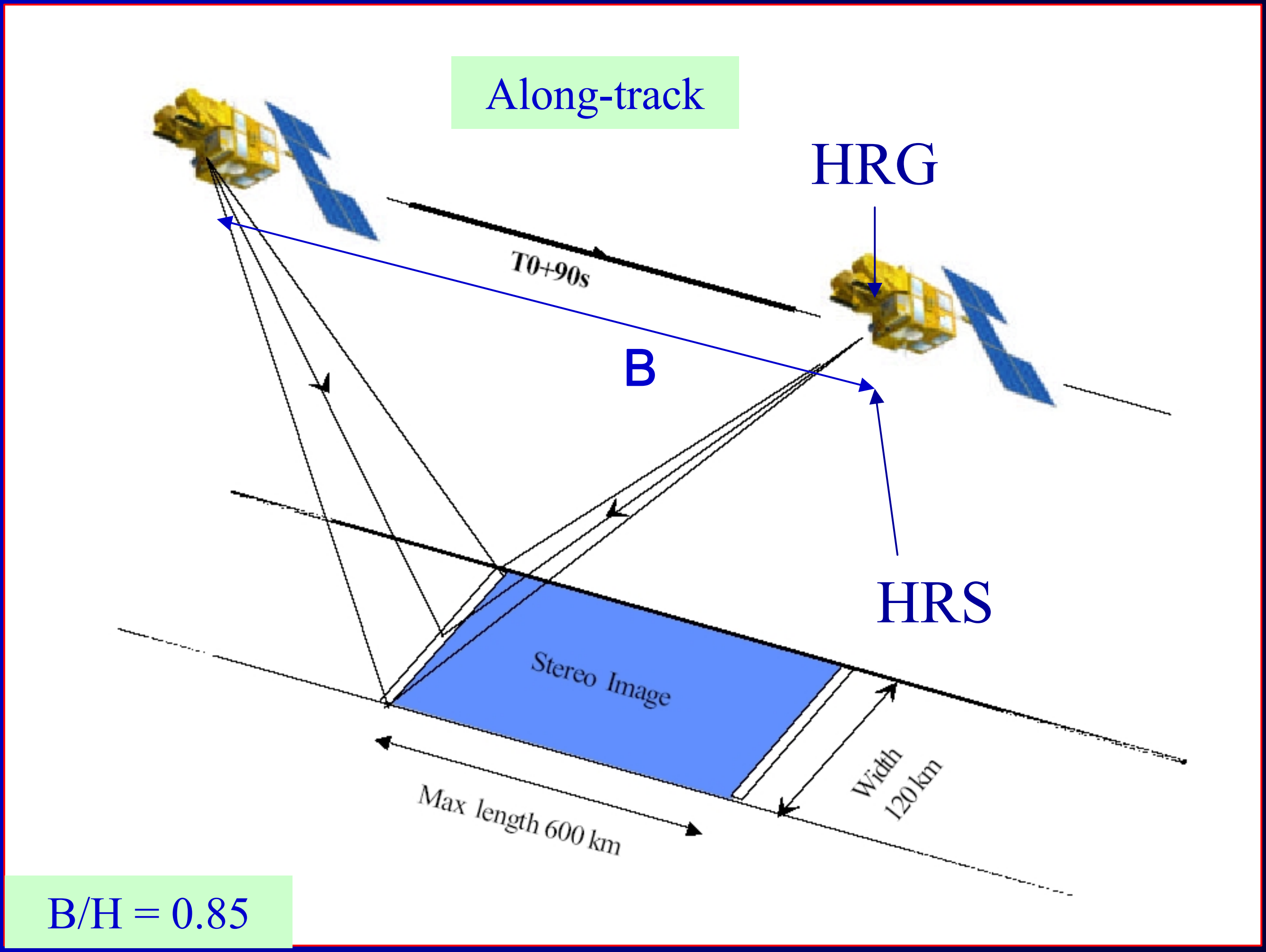
The most accurate stereo-geometry is with B/H of around one

Stereo image acquisition

In addition, SPOT-5 HRS can also acquire along-track stereo images only for DEM

⇓

No temporal variations in radiometry & good geometry



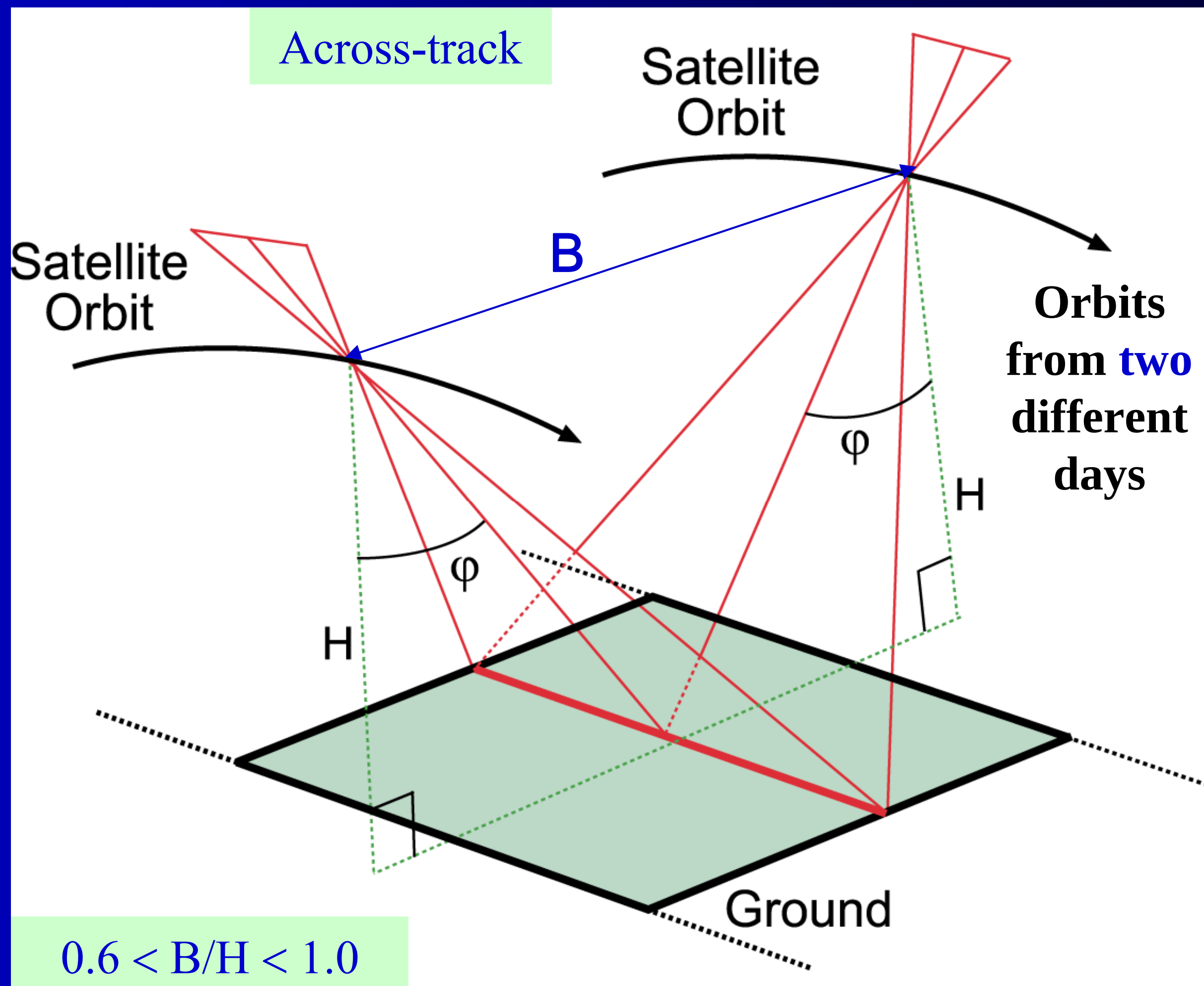
JERS-1 OPS, MOMS, ASTER, Cartosat, SPOT5-HRS

Stereo image acquisition

Other push-broom scanners (SPOT-5 HRG, IRS-1C) can only acquire multi-date across-track stereo images

⇓

Temporal variations in radiometry & variable geometry



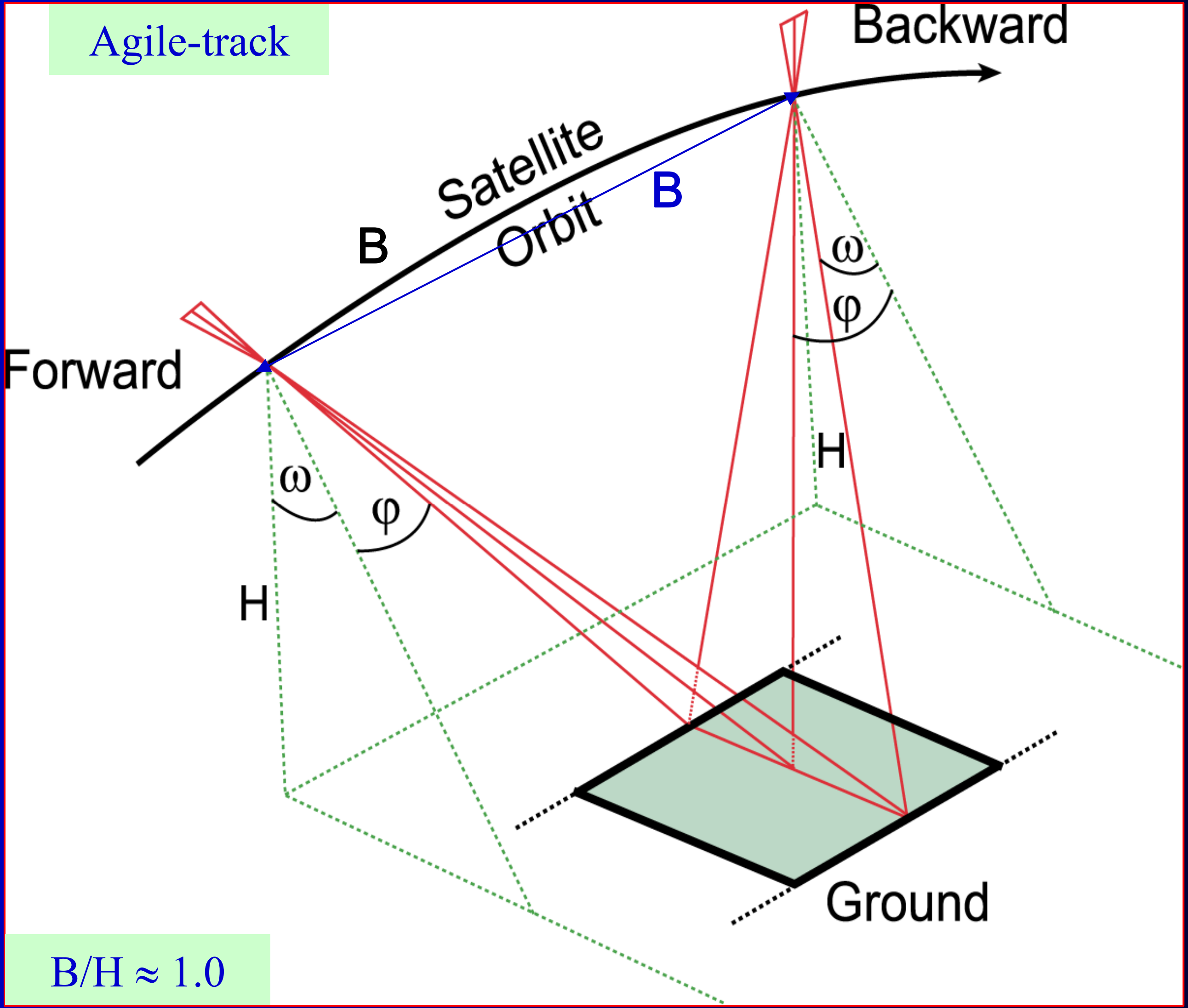
SPOT1-5, IRS1-C

Stereo image acquisition

Agile satellites (EROS, IKONOS & QuickBird) can acquire same-date stereo images in any direction

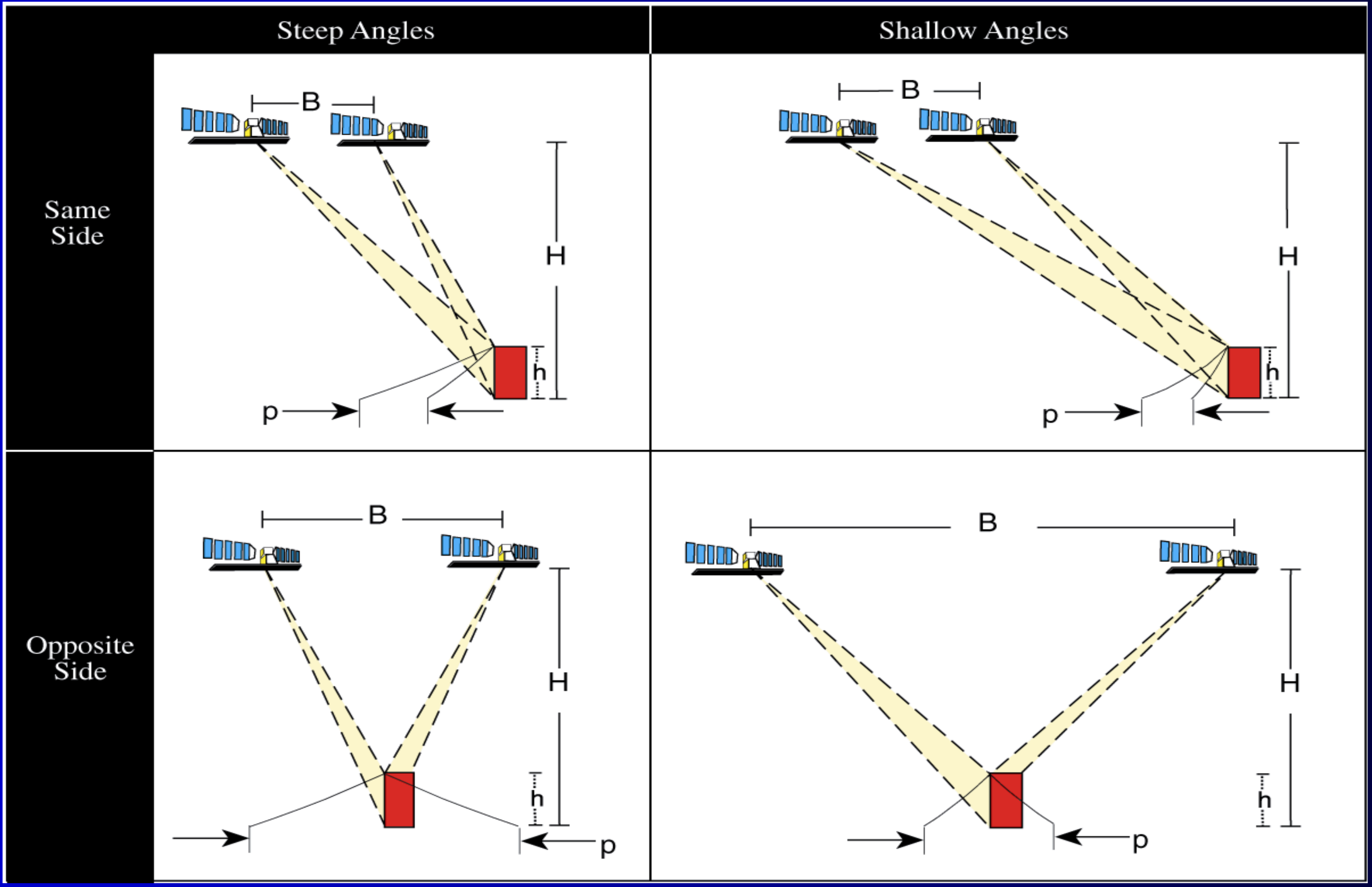
⇓

No temporal variations in radiometry & good geometry



EROS, Formosat, Kompsat, Ikonos, QuickBird, OrbView, WorldView, GeoEye

SAR stereo image acquisition

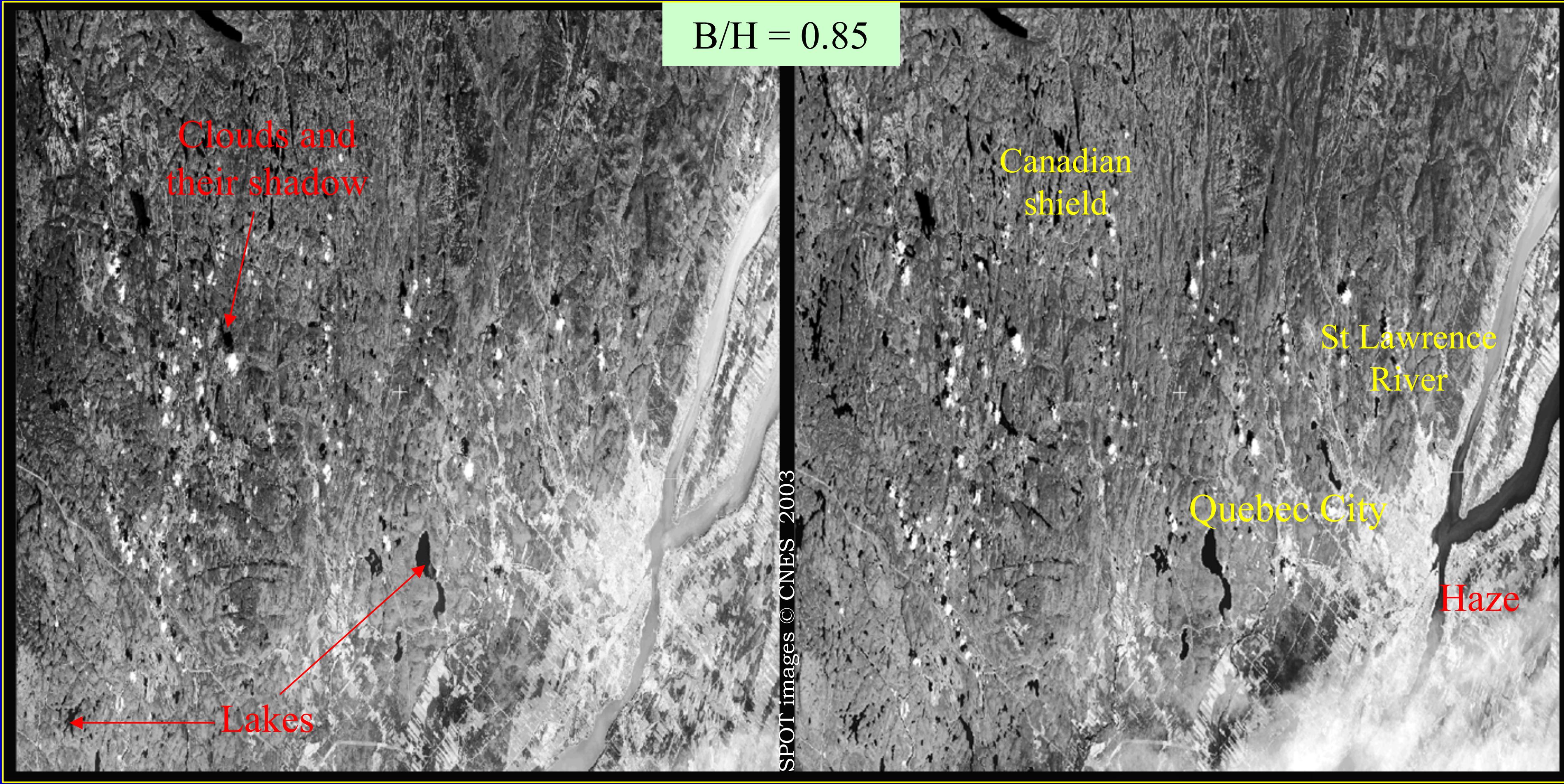


SAR stereo image acquisition: general guidelines for R-1 & R-2

Terrain Relief Slopes	Flat 0° - 10°	Rolling 10° - 30°	Mountainous 30° - 50°
Radiometric Disparities	Small	Medium	Large
Geometric Disparities	Large	Medium	Small
Compromises	Opposite-side with steep look angles	Same-side with large intersection angle *or* (Opposite-side with shallow look angles)	Same-side with small intersection angle and shallow (or steep) look angles
Stereo RADARSAT Configurations	S1desc-S1asc F1desc-F1asc	S1-S7 (desc or asc) F1-F5 (desc or asc) *or* S7 desc-S7 asc F5 desc-F5 asc	S1-S4 (desc or asc) F2-F5 (desc or asc) S4-S7 (desc or asc) F1-F4 (desc or asc)

Stereo acquisition: SPOT HRS

September 18, 2003; ±22°, along-track same-date



10m x 5m pixel; 120km x 60 km

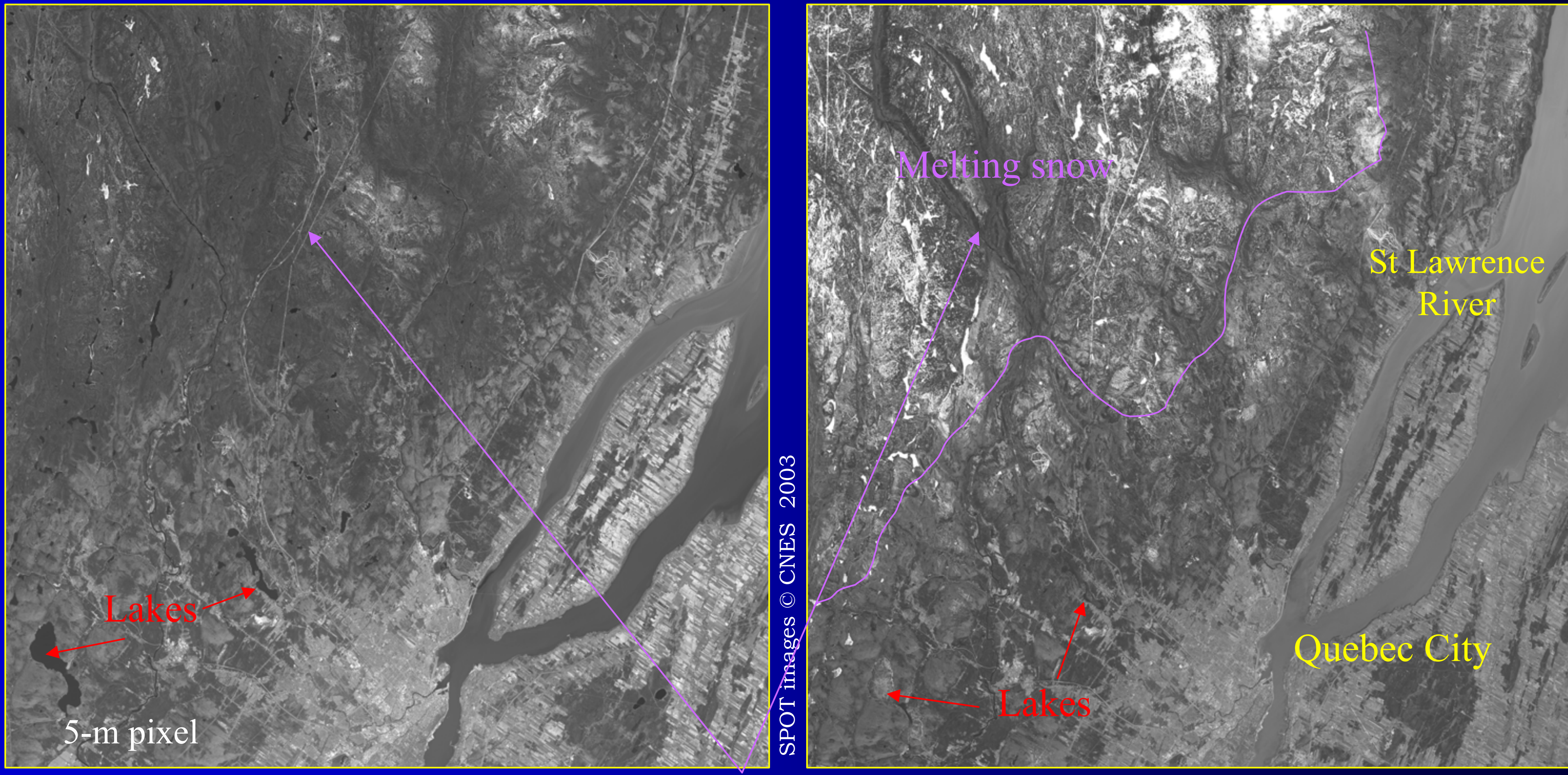
No temporal variation with same-date acquisition

Stereo acquisition: SPOT HRG

May 25, 2003; -19°

across-track multi-date

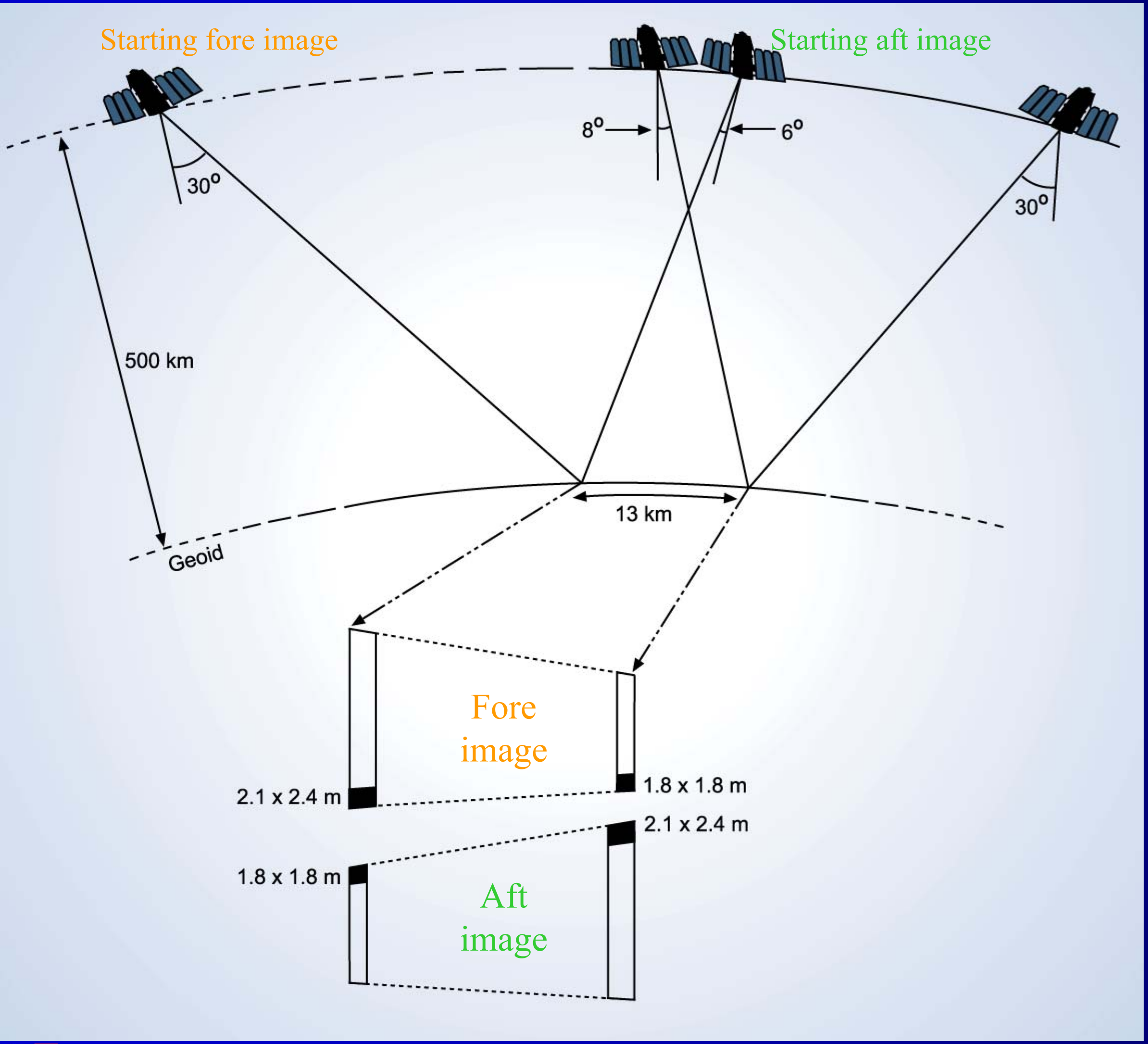
May 5, 2003; +23°



Temporal variation due to multi-date acquisition

Stereo acquisition: EROS-A

Agile, same-track, same-date



Effect of the viewing angles difference

As EROS asynchronous satellite generates large pitch variations during imaging time, the pixel/line spacing and image shapes are very different in the images and between the images.

This asynchronous process generates large geometric and radiometric disparities

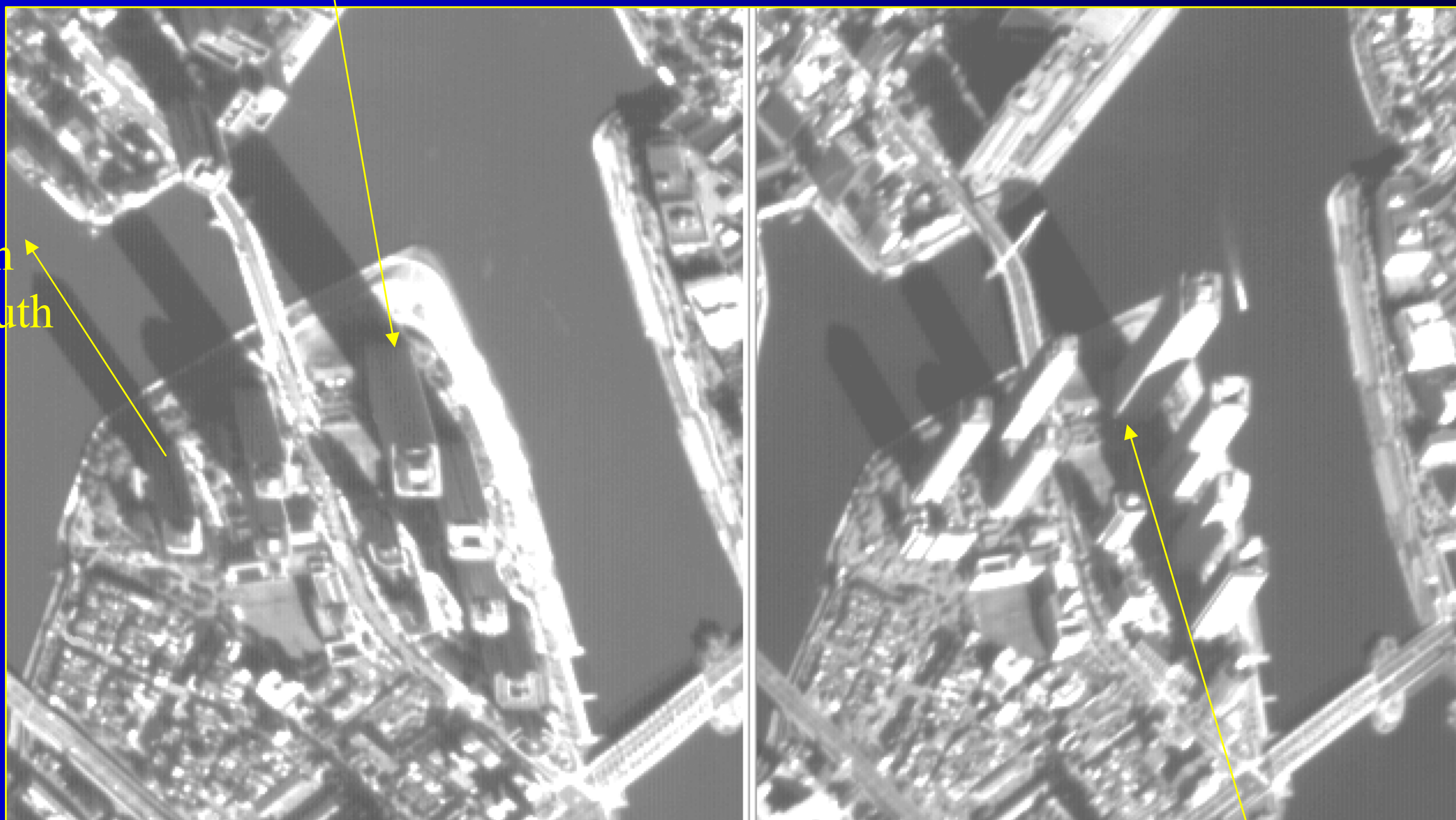
Stereo acquisition: EROS-A

Tokyo Downtown
Stereo images

Satellite velocity

Satellite viewing
for fore image

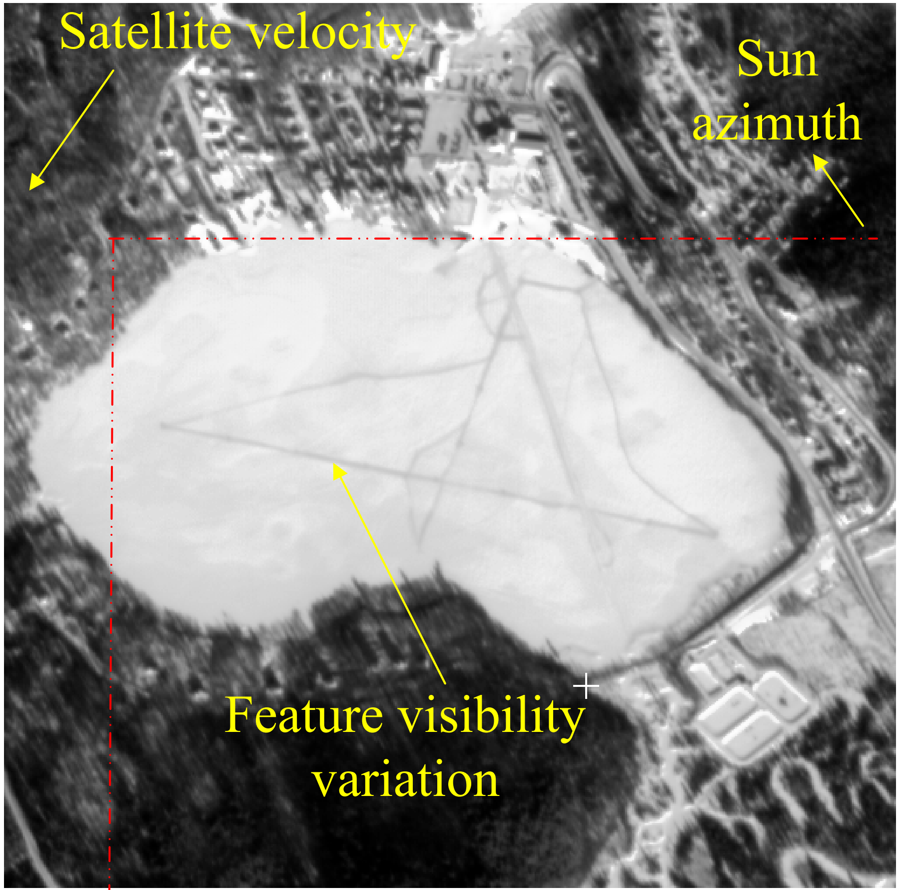
Sun
azimuth

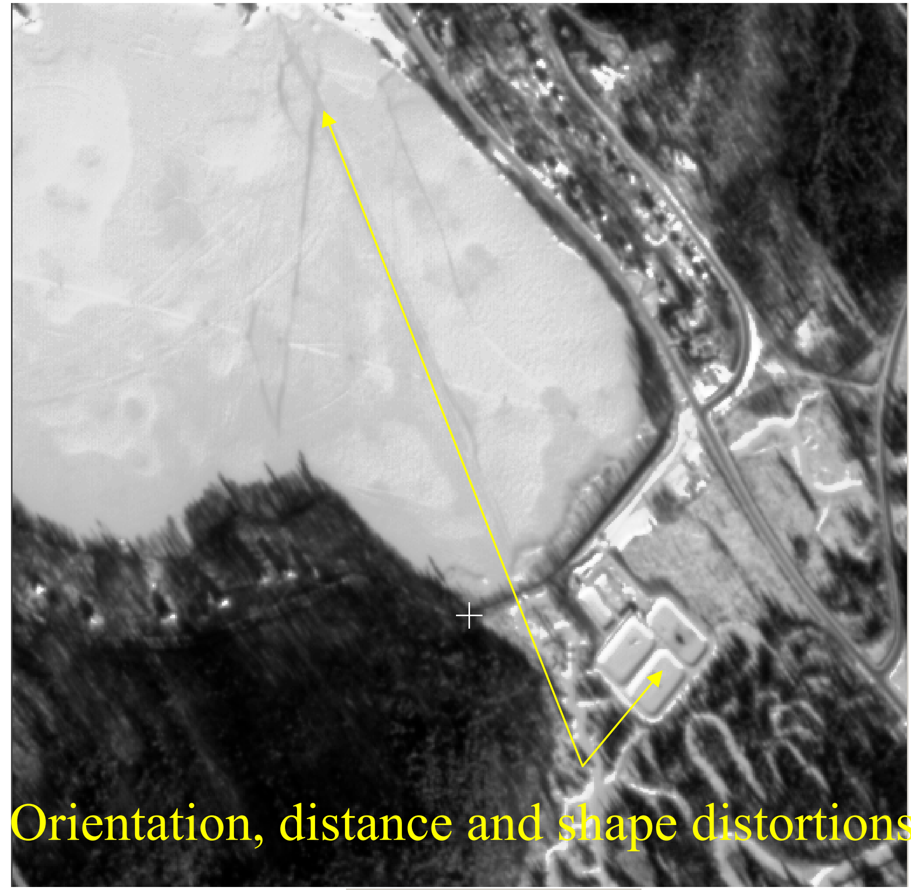


Agile, same-track, same-date

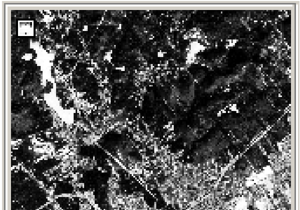
Satellite viewing
for aft image

Stereo acquisition: EROS-A





View Angle = 37°



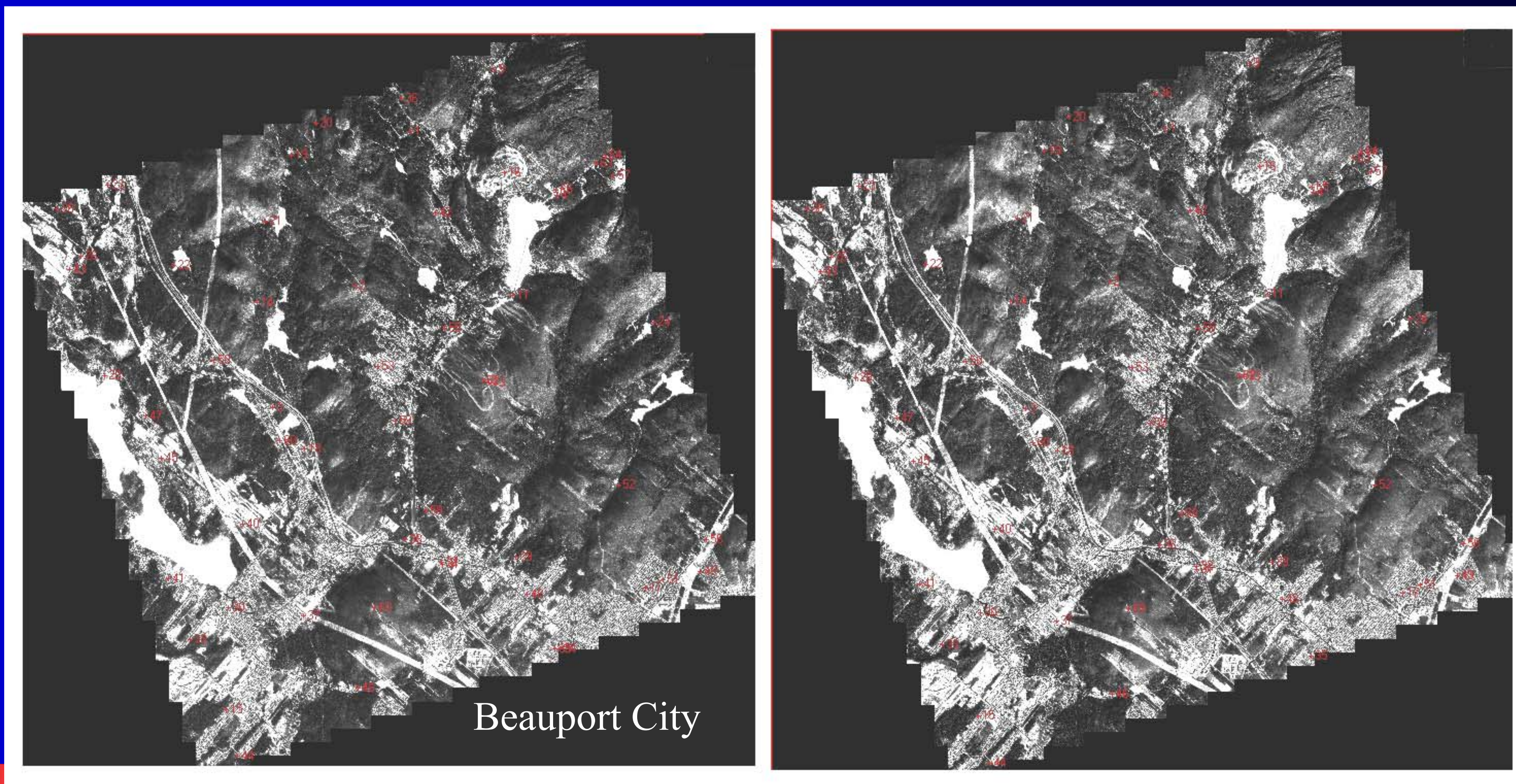
Pixel spacing: 2.8 m vs 2.2 m

Line spacing: 2.3 m vs 2.0 m

View Angle = 25°

Stereo acquisition: *Ikonos*

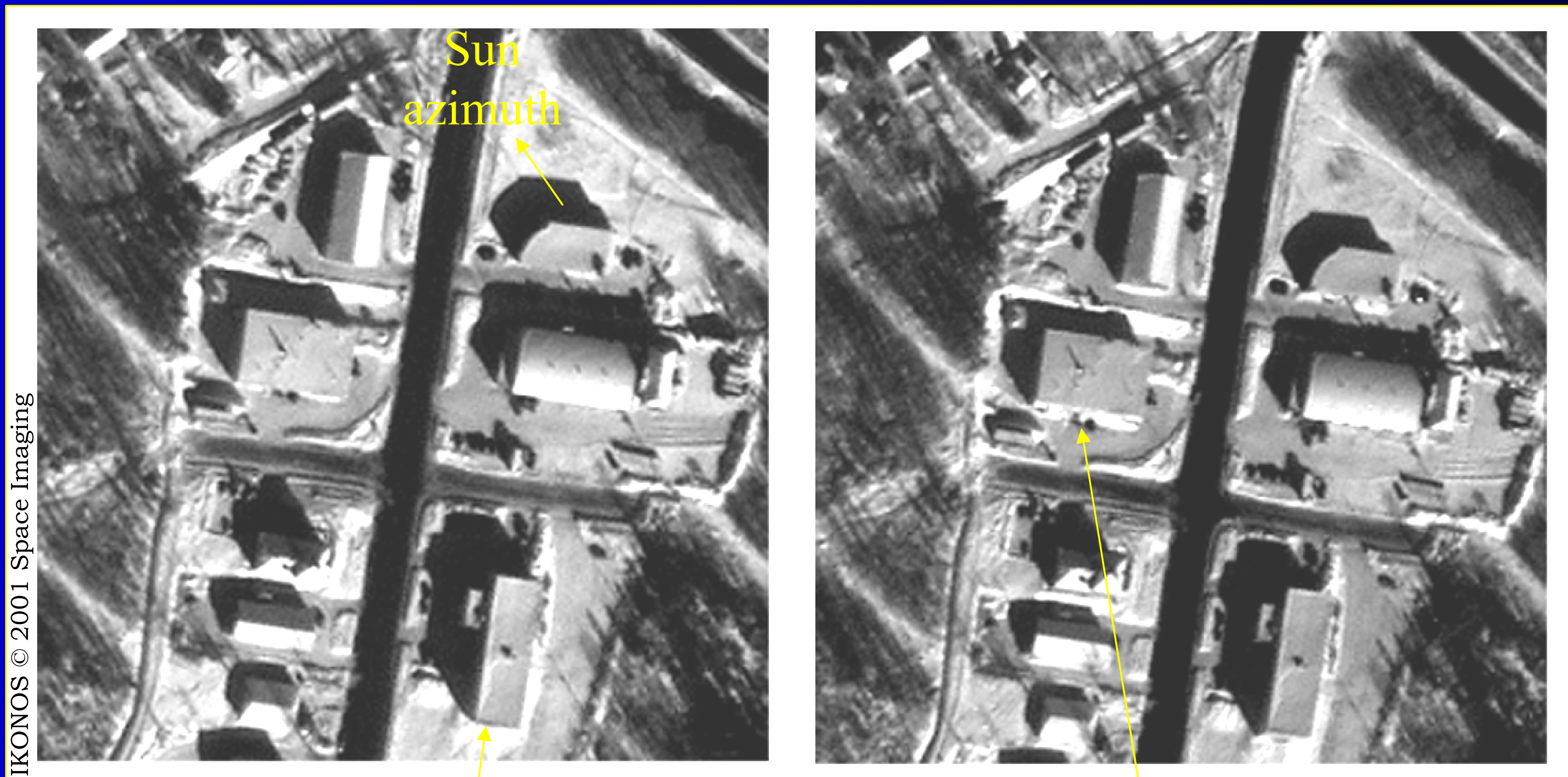
Stereo Ikonos images are directly provide in the quasi-epipolar geometry, where all geometric distortions were corrected, only elevation parallax remains. Consequently geometry and radiometry were transformed and radiometry degraded. Elevation parallaxes are only in the column direction.



Stereo acquisition: *Ikonos*

Beauport

Satellite velocity



No temporal variation except the occluded areas

Satellite viewing for aft image

Stereo acquisition: EROS-B

Santiago, Chile

Stereo acquisition: EROS-B

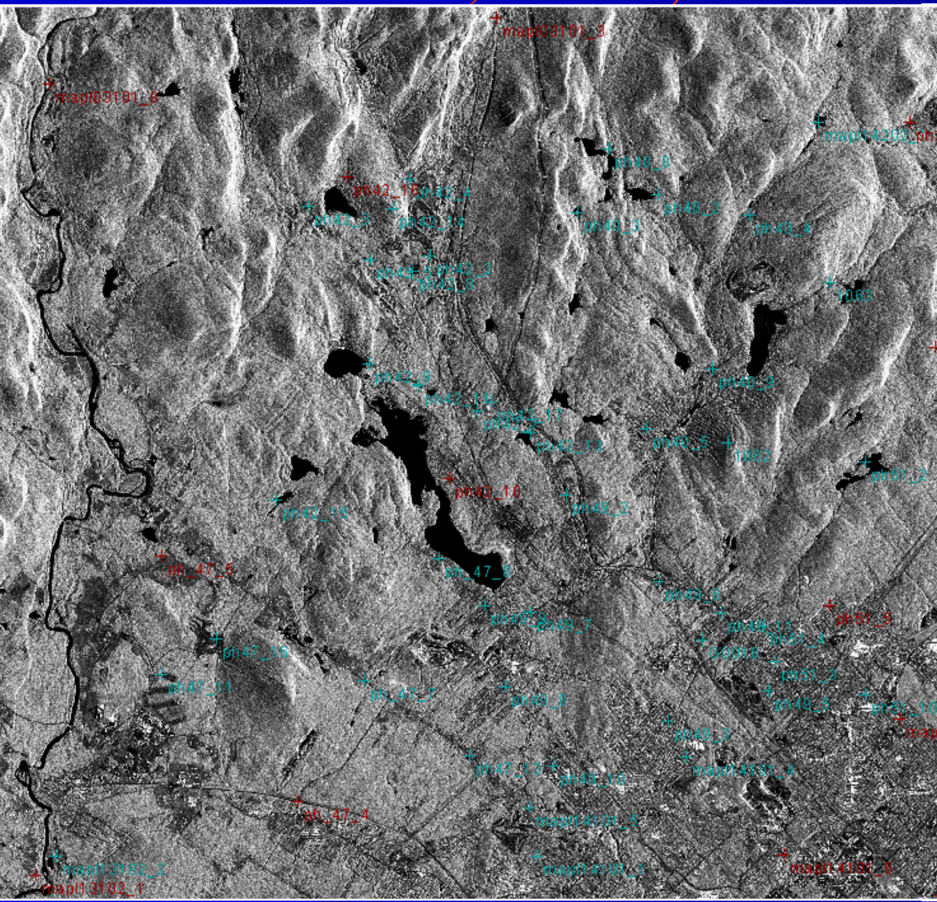
Santiago, Chile

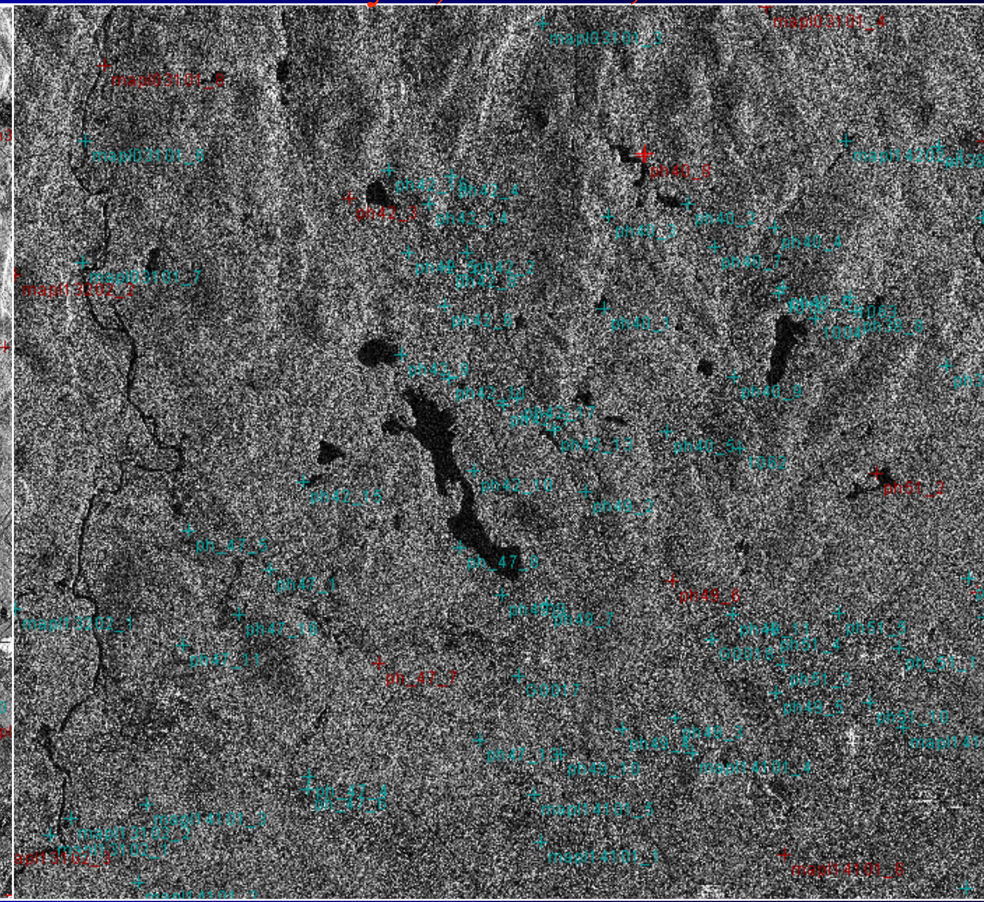
Geometric distortions between the two images due to the different viewing angles are more obvious

Stereo Radarsat-2 Ultra-fine mode

U2: June 30; 31°-32°; 1.56 m

U25: July 4; 47°-48°; 1.56 m



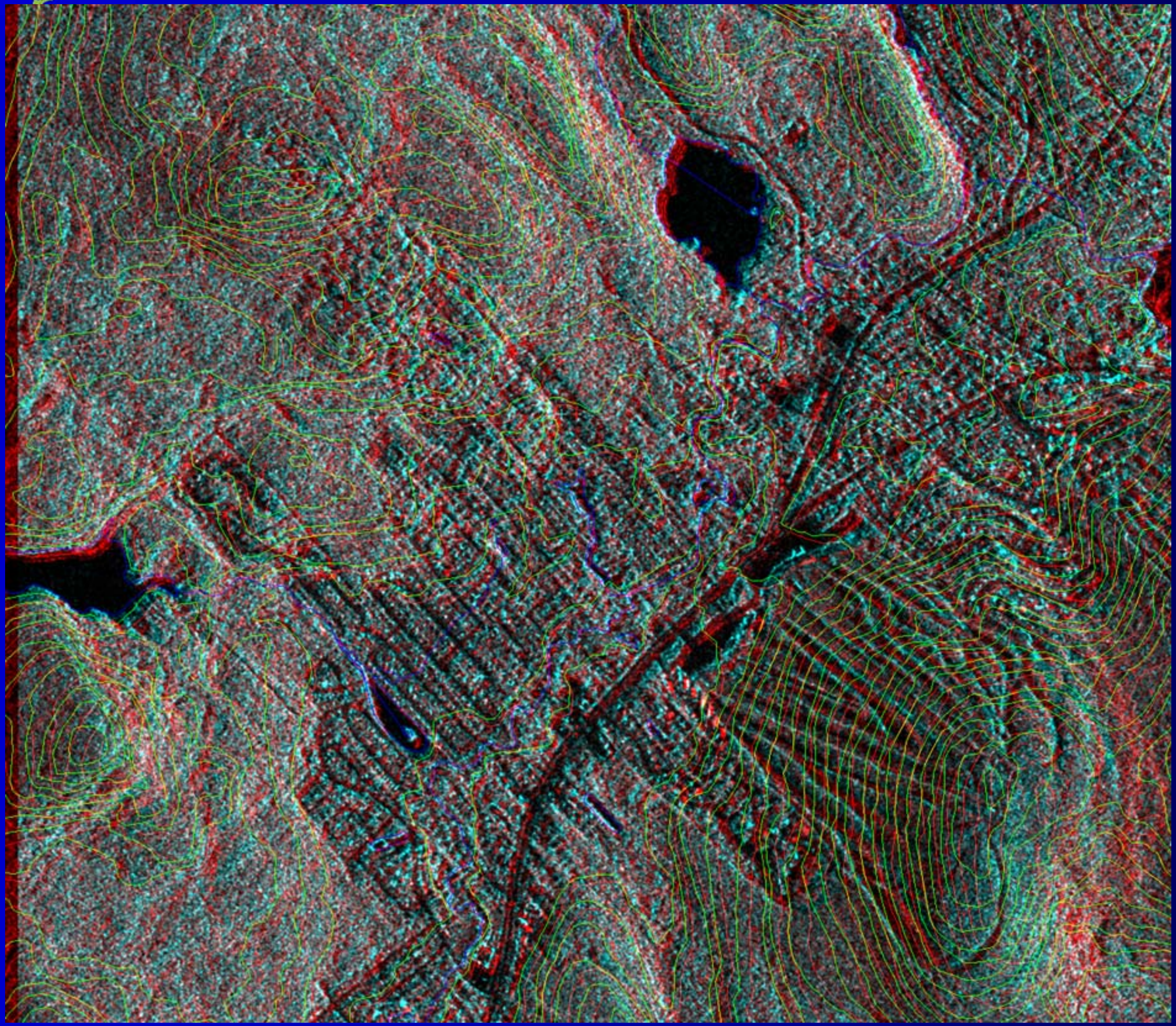


Relief backscattering is predominant

Land cover backscattering is predominant

Radarsat-2 Stereo Images

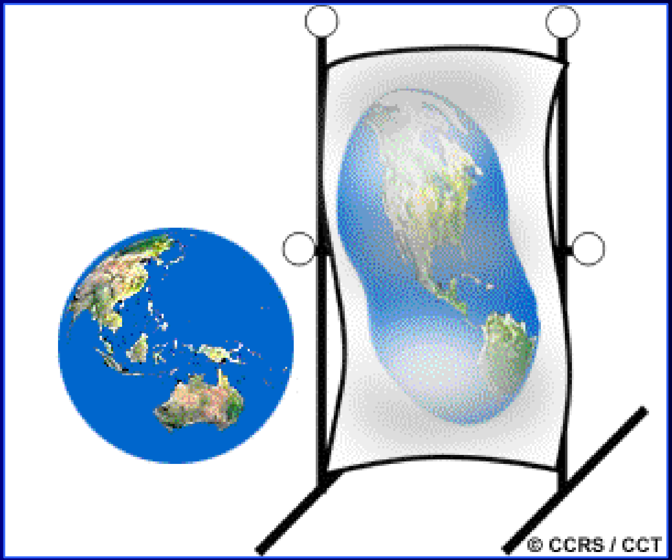
Beauport, Quebec, Canada



Radarsat-2 ultra-fine mode stereo anaglyph (1.5 m spacing) with 1:50,000 contour lines overlaid

Geometric processing

1. Characterization of geometric distortions
2. Geometric corrections: models and algorithms
3. Single image processing
4. Strip and block processing
5. Stereo processing



Characterization of geometric distortions

Remotely sensed images usually contain geometric distortions so significant that they cannot be used directly with map base products in a geographic information system (GIS).

Consequently, multi-source data integration (raster and vector) for cartographic/thematic applications requires geometric and radiometric processing adapted to the nature and characteristics of the data in order to keep the best information from each image in the composite ortho-rectified image.

Characterization of geometric distortions

Although geometric distortions have always been present in remotely sensed images, they have become a more significant problem in recent years.

In 1972, the impact of the distortions was quite negligible for the following reasons:

- The images were nadir viewing with coarse resolution (80 m)
- The products, resulting from the image processing were analogue on paper
- The interpretation of the final products was performed visually
- The fusion and integration of multi-source and multi-format data did not exist

Characterization of geometric distortions

Today, however, the distortions having the same nature are no longer negligible because:

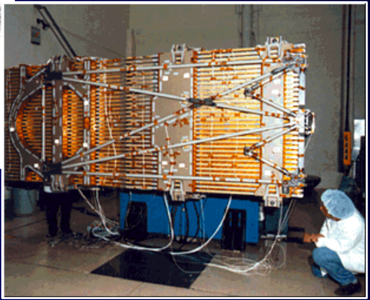
- The images are off-nadir viewing with much finer resolution (sub-meter level)
- The products resulting from image processing are fully digital
- The interpretation of the final products is realised on computer
- The fusion of multi-source images (different platforms and sensors) is in general use
- The integration of multi-format data (raster/vector) is a general tendency in geomatics

Sources of geometric distortions

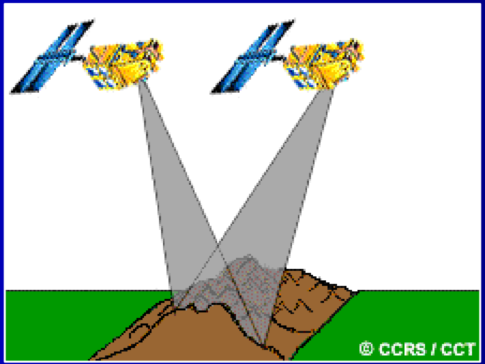
Geometric distortions vary considerably with the platform and the sensor

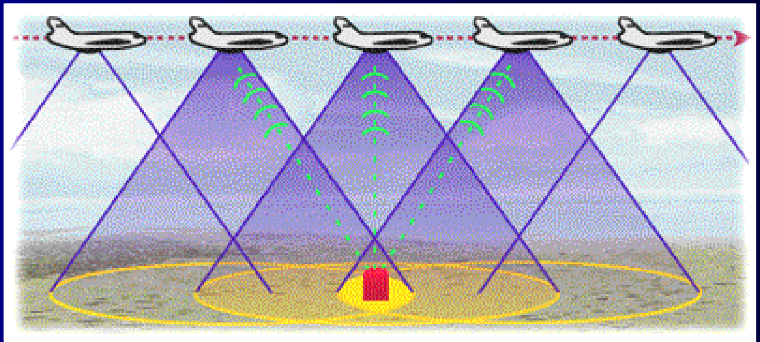
However, it is possible to make general categorizations of these distortions, which can be grouped into two broad categories:

- ***The Observer*** or the acquisition system
  - Platform (airborne or spaceborne)
  - Imaging sensor (scanning, push-broom, SAR)
  - Measuring instruments (GPS, gyro, stellar sensor)



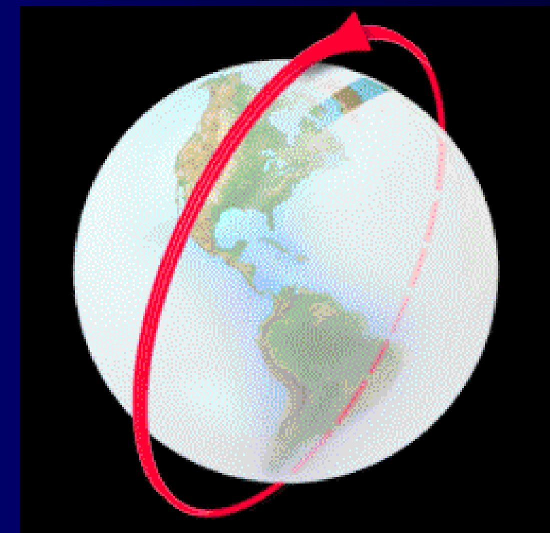
- ***The Observed***
  - Atmosphere
  - Earth
  - Map

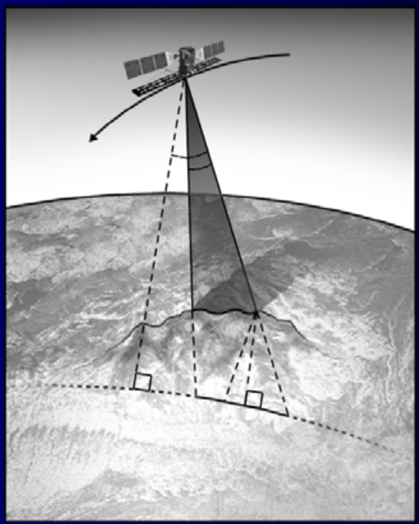




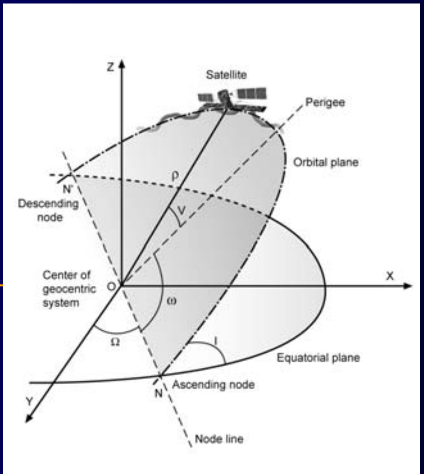
Sources of geometric distortions

CATEGORY	SUB-CATEGORY	DESCRIPTION OF ERROR SOURCES
The Observer or The Acquisition System	**Platform (spaceborne or airborne)**	Variation of the movement Variation in platform attitude (low to high frequencies)
	Sensor (VIR, SAR or HR)	Variation in sensor mechanics (scan rate, scanning velocity) Viewing/look angles Panoramic effect with FOV
	Measuring instruments	Time-variations or drift Clock synchronicity
The Observed	**Atmosphere**	Refraction and turbulence
	Earth	Curvature, rotation, topographic effect
	Map	Geoid to ellipsoid Ellipsoid to map





Characterization geometric distortions

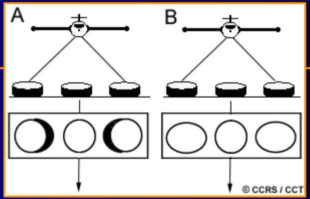


PLATFORM

- Altitude variations change the pixel spacing
- Attitude variations (roll, pitch and yaw) change the orientation and the shape of VIR images
- Velocity variations change the line spacing or create line gaps/overlaps

SENSOR

- Calibration parameter uncertainty such as lens distortions, view and IFOV for VIR sensors or the range gate delay (timing) for SAR sensors
- Panoramic distortion in combination with the oblique-viewing system changes the ground pixel sampling along the column



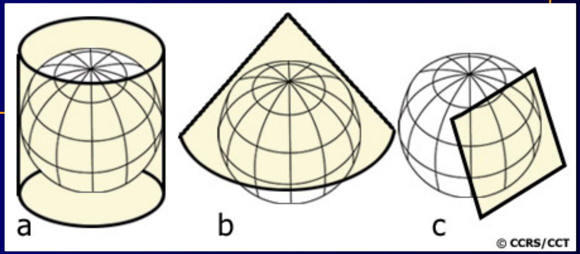
Characterization of geometric distortions

EARTH

- Rotation, which generates latitude-dependent displacements between image lines
- Curvature, which for large width image creates variation in the pixel spacing
- Topographic relief, which generates a parallax in the scanner direction

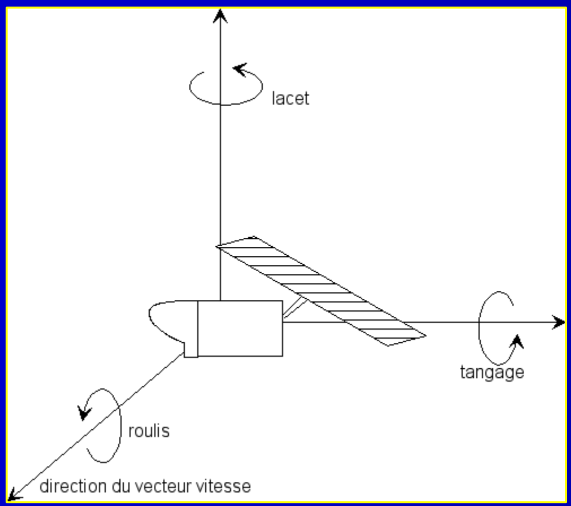
MAP PROJECTION

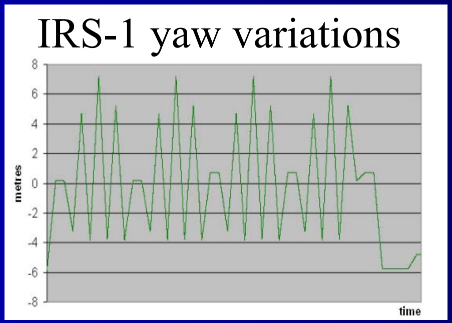
- Approximation of the geoid by a reference ellipsoid
- Projection of the reference ellipsoid on a tangent plane

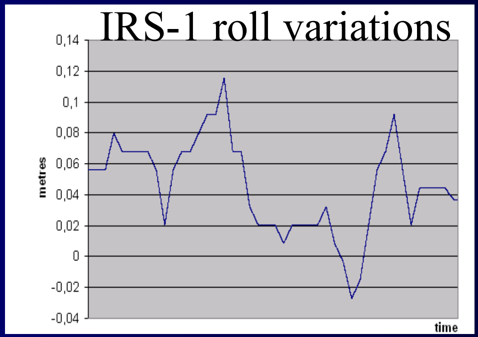


Characterization of geometric distortions

Attitude definition

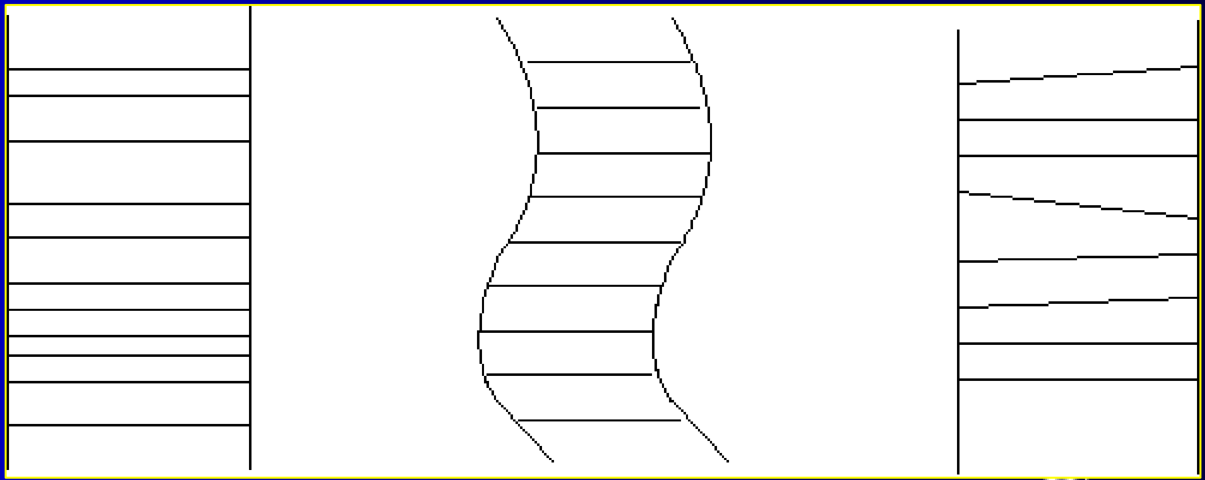






Impact on the ground

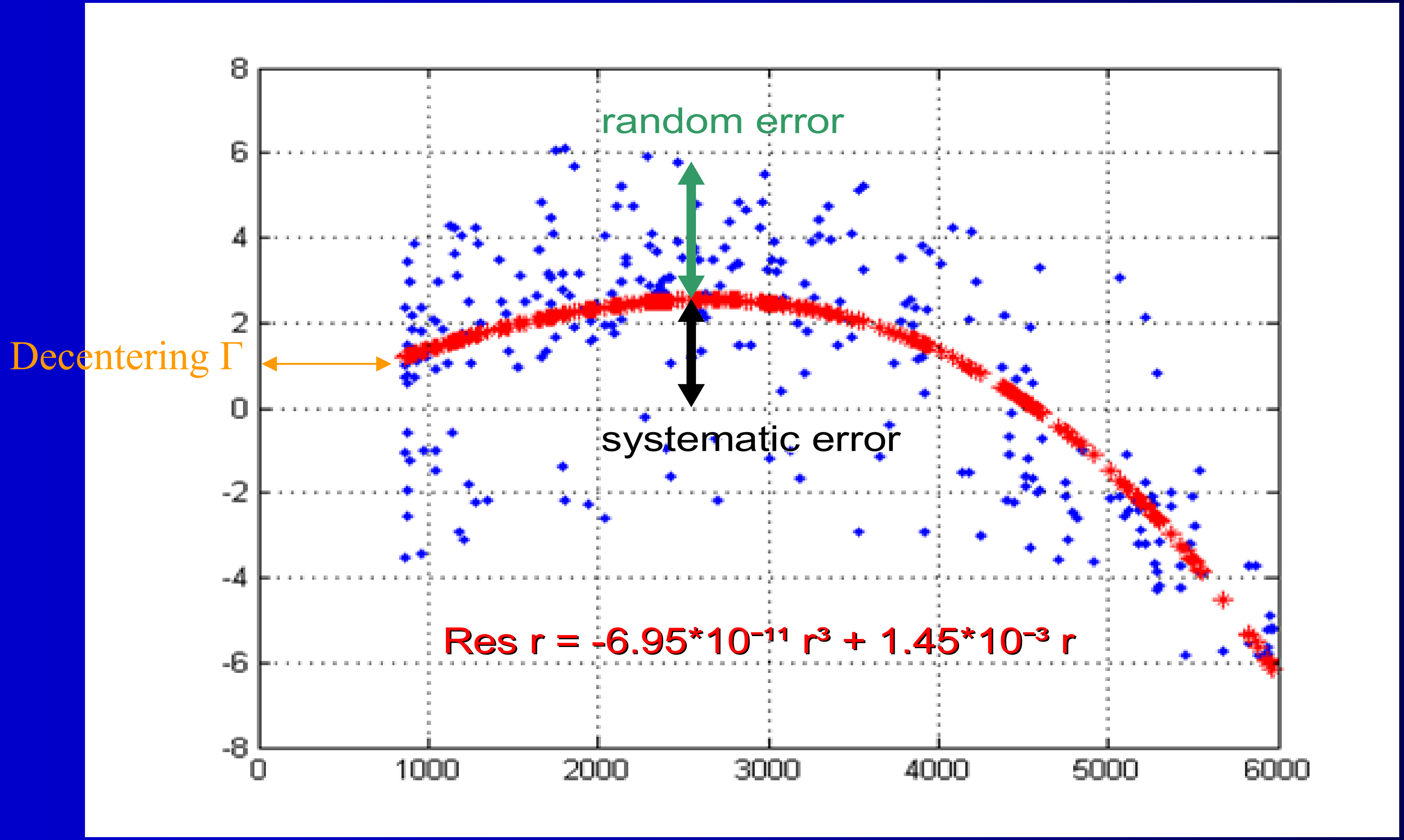
Pitch Roll Yaw



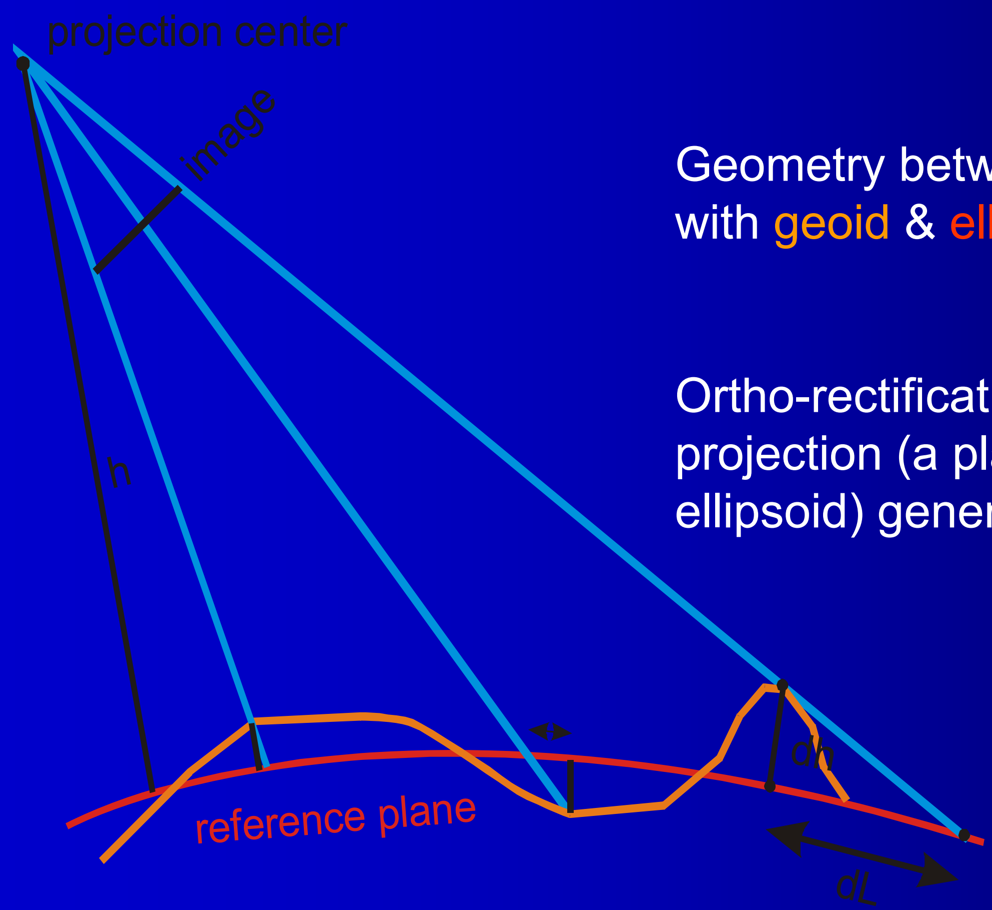
Characterization of geometric distortions

Lens distortions: decentering and symmetrical radial:

$$\Delta r = \Gamma + \Sigma a_i r_i \quad [i=1, 3, 5, 7]$$



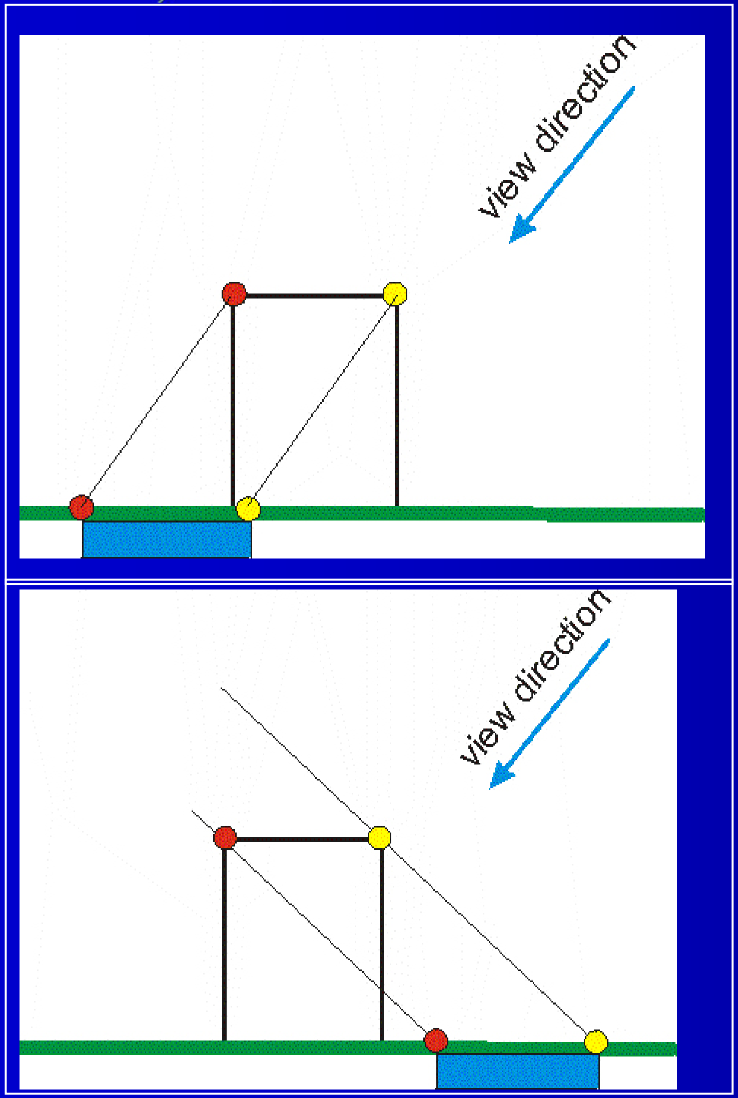
Characterization of geometric distortions



Geometry between satellite & VIR sensor with geoid & ellipsoid

Ortho-rectification in a specified map projection (a plane parallel to the earth ellipsoid) generates deformations

Characterization of geometric distortions



Elevation displacement

Optical sensor: shift in view direction

SAR sensor: shift against view direction

Characterization of geometric distortions

However, some geometric distortions are correlated:

- The *'orientation' of the image* is a combination of:
  - the **platform** heading due to orbital inclination,
  - the yaw of the **platform**,
  - the convergence of the meridian
- The *'scale factor' in along-track direction* is a combination of:
  - the velocity and the altitude of the **platform**
  - the detection signal time and the in-track viewing angle of the **sensor**
  - the component of the **Earth** curvature in the along-track direction
- The *'leveling angle' in across-track direction* is a combination of:
  - the **platform** roll,
  - the across-track viewing angle of the **sensor**,
  - the **Earth** curvature
  - the map projection

Geometric processing

1. Characterization of geometric distortions
2. Geometric corrections: **models** and algorithms
3. Single image processing
4. Strip and block processing
5. Stereo processing

Geometric corrections: models

What math model can we use to correct them?

- **2D/3D empirical models**

  Do not reflect the viewing geometry and distortions
  Based on statistical regression using GCPs
  Correct locally at GCPs
  Need generally numerous and well distributed GCPs

- **3D physical models**

  Based on math parametrization of the physic phenomenon
  Reflect the viewing geometry and distortions
  Correct globally the full image
  Need few GCPs

Geometric corrections: models

2D/3D Empirical Models can be used

Geometric Models	Mathematical Functions* P_{2D}, P_{3D} & R_{3D}	Number of unknown terms
2D Polynomial	$P_{2D}(XY) = \sum_{i=o}^{m} \sum_{j=o}^{n} a_{ij} X^i Y^j$	1^{st} order: 3 + 3 2^{nd} order: 6 + 6 3^{rd} order: 10 + 10
3D Polynomial	$P_{3D}(XYZ) = \sum_{i=o}^{m} \sum_{j=o}^{n} \sum^{p} a_{ijk} X^i Y^j Z^k$	1^{st} order: 4 + 4 2^{nd} order: 10 + 10 3^{rd} order: 20 + 20
3D Rational	$R_{3D}(XYZ) = \dfrac{\sum_{i=o}^{m} \sum_{j=o}^{n} \sum_{k=o}^{p} a_{ijk} X^i Y^j Z^k}{\sum_{i=o}^{m} \sum_{j=o}^{n} \sum_{k=o}^{p} b_{ijk} X^i Y^j Z^k}$	1^{st} order: 8 + 8 2^{nd} order: 20 + 20 3^{rd} order: 40 + 40

*X, Y, Z are the cartographic coordinates;
i, j, k are integer increments;
m, n and p are integer values, generally comprised between 1 and 3
m + n + p is the order of the polynomial functions

Geometric corrections: models

3D physical models differ depending on the sensor, the platform and its image acquisition geometry:

- The instantaneous acquisition system of digital photogrammetric cameras, such as Resurs-DK1
- The push-broom scanners, such as SPOT5-HRG/HRS or Cartosat
- The agile scanners, such as Ikonos or Quickbird
- The synthetic aperture radar (SAR), such as RADARSAT-1/2, TerraSAR-X or Cosmo-SkyMed

Geometric corrections: *models*

3D Physical Models	Mathematical Equations	Description of Parameters
VIR Images Collinearity Equations	$$x = -f \frac{m_{11}(X - X_0) + m_{12}(Y - Y_0) + m_{13}(Z - Z_0)}{m_{31}(X - X_0) + m_{32}(Y - Y_0) + m_{33}(Z - Z_0)}$$ $$y = -f \frac{m_{21}(X - X_0) + m_{22}(Y - Y_0) + m_{23}(Z - Z_0)}{m_{31}(X - X_0) + m_{32}(Y - Y_0) + m_{33}(Z - Z_0)}$$	x,y: image coordinates X,Y,Z: map coordinates X_0, Y_0, Z_0 projection centre coordinates -f: focal length of the VIR sensor m_{ij}: elements of ortho-gonal 3-rotation matrix
SAR Images Doppler-range Equations	$$f = \frac{2(\overrightarrow{V}_S - \overrightarrow{V}_P) \bullet (\overrightarrow{S} - \overrightarrow{P})}{\lambda \left| \overrightarrow{S} - \overrightarrow{P} \right|}$$ $$r = \left| \overrightarrow{S} - \overrightarrow{P} \right|$$	f: Doppler value r: range distance S and Vs: sensor position and velocity P and VP: target-point position and ground velocity λ: radar wavelength

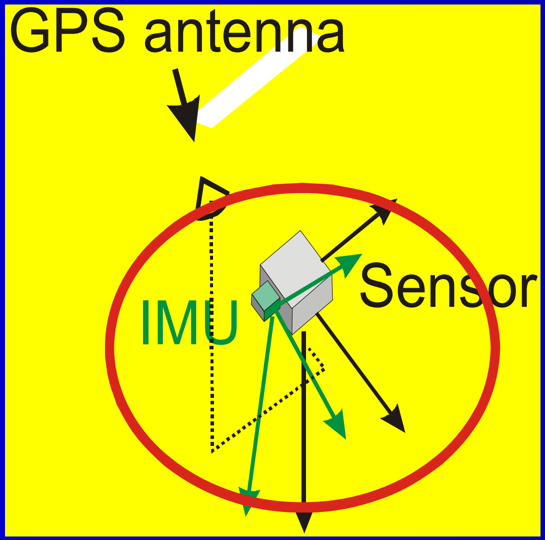
Geometric corrections: models

Different 3D Physical SAR Models developed and used

Mathematical Equations	Institutions	Advantages	Disadvantages
Doppler-Time	IGN, DLR Vexcel, ISTAR	Physically precise Few GCPs (1-2)	Mathematical approximation Non users-friendly
Radargrammetric	Graz U., Hannover U. Intermap	Photogrammetric derived Physically precise User-friendly	Mathematical approximation More GCPs (4-6)
Generalized	IGN, CCRS (Graz U.), (Hannover U.)	Mathematically precise Unified and integrated User-friendly	Physical approximation More GCPs (4-6)

Geometric corrections: models

Star sensors – for update of gyros



Direct sensor orientation

Satellites equipped with:

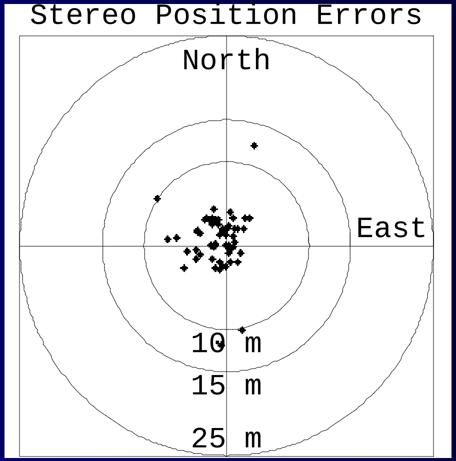
- GPS or DORIS (for positioning)
- Gyros/IMU (for attitude),
- Star sensors (for attitude variations)

→Direct sensor orientation = determination of orientation without control points.

It achieved standard deviation of one to few pixels and potential problems with national datum

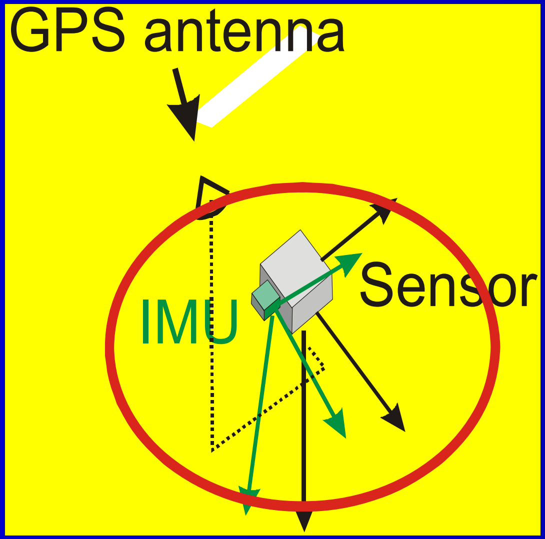
Discrepancies of direct sensor orientation of Ikonos

(from Gene Dial, GeoEye)



Geometric corrections: models

Star sensors – for update of gyros



Indirect sensor orientation

Satellites equipped with:

- GPS or DORIS (for positioning)
- Gyros/IMU (for attitude),
- Star sensors (for attitude variations)

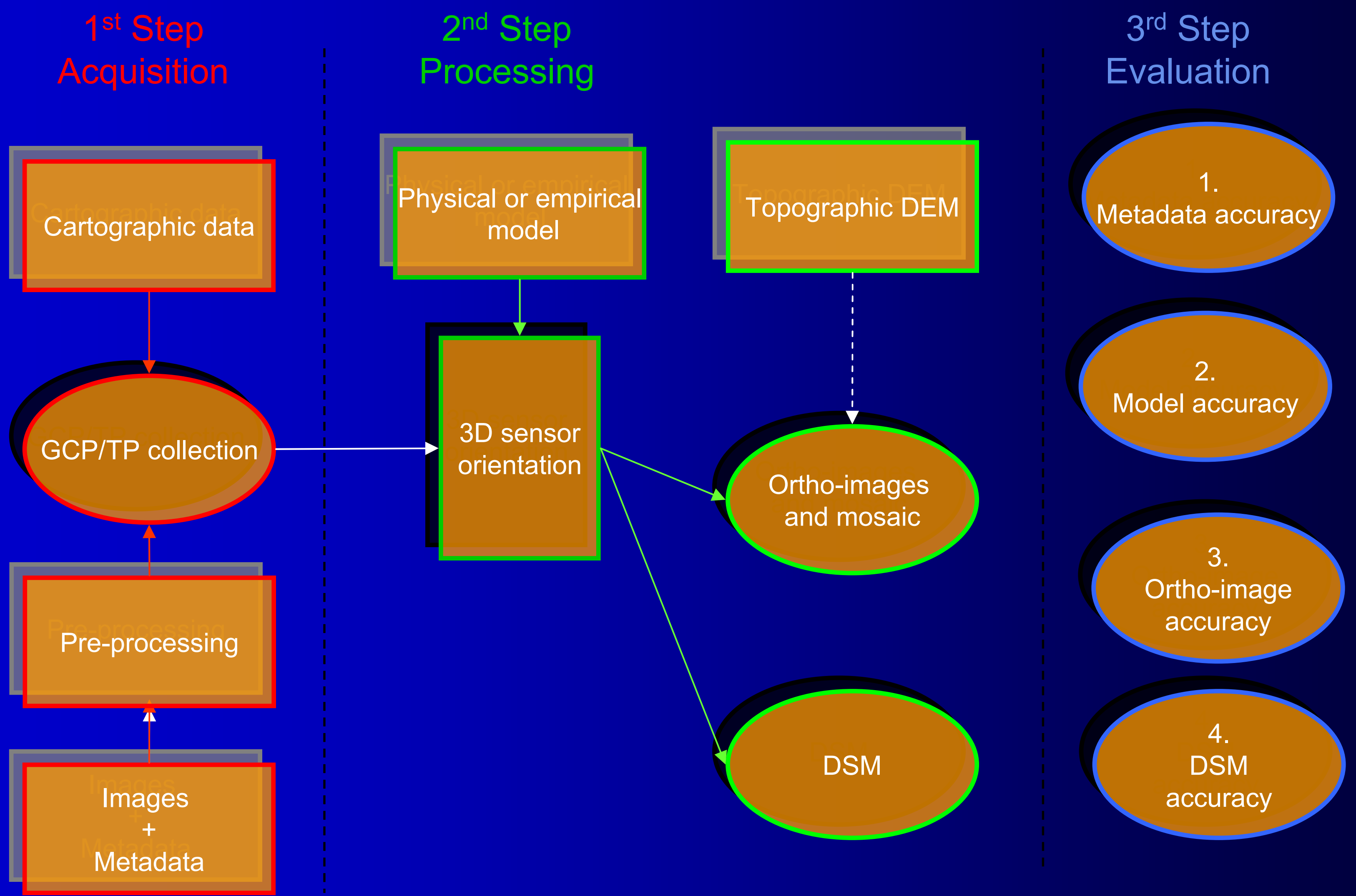
→ Indirect sensor orientation = approximation of the math model with metadata + accurate determination of orientation using control points and iterative least-squares adjustment.

It achieves modeling accuracy of one pixel or less

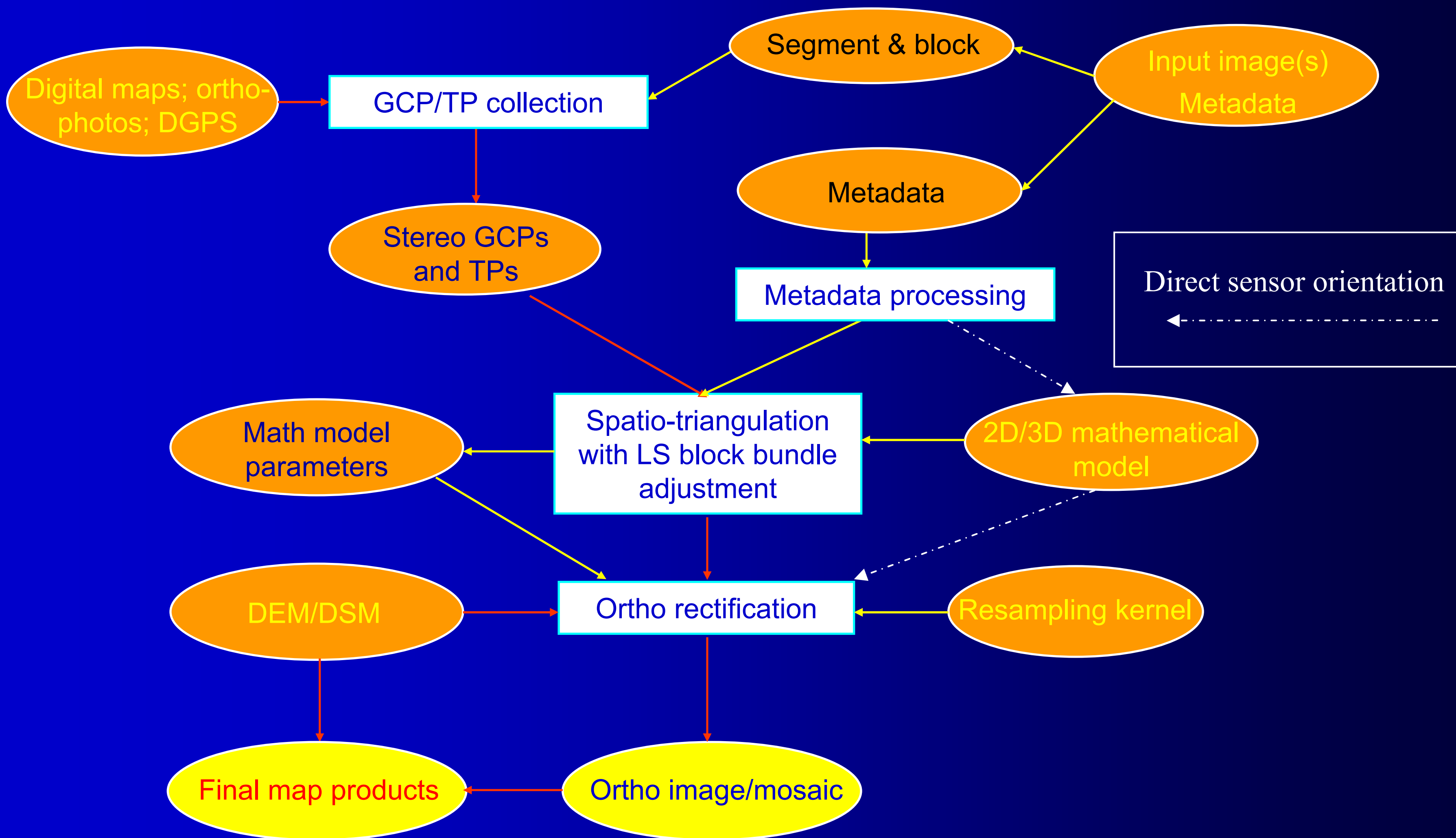
Geometric processing

1. Characterization of geometric distortions
2. Geometric corrections: models and **algorithms**
3. Single image processing
4. Strip and block processing
5. Stereo processing

Geometric processing: algorithms



Geometric Processing: algorithms



Geometric Processing: algorithms

- **Raw images** with only normalization and calibration of the detectors (e.g. level 1A for SPOT5 or 1B for QuickBird-2) without any geometric correction are **satellite-track oriented**.

  In addition, full metadata related to sensor, satellite (ephemeris and attitude) and image are provided. Generation of image segment can be performed for the spatio-triangulation.

- Geo-referenced images (e.g. level 1B for SPOT5 or Geo for Ikonos) corrected for systematic distortions due to the sensor, the platform and Earth rotation/curvature are **satellite-track oriented**.

  Generally, few metadata related to sensor and satellite are provided; some of metadata are related to the 1B processing.

- Map-oriented images, also called geocoded images, (e.g. level 2A for SPOT or Cartera Geo for Ikonos) corrected for the same distortions as geo-referenced images are **North oriented**.

  Generally, very few metadata related to sensor and satellite are provided; most of metadata are related to the 2A processing and the ellipsoid/map characteristics

Geometric Processing: algorithms

- **Slant range images** with only SAR calibration (e.g. SLC for Radarsat-1/2) without any geometric correction are **satellite-track oriented**.

In addition, full metadata related to sensor, satellite (ephemeris and attitude) and image are provided. Generation of image segment can be performed for the spatio-triangulation.

- Ground range images (e.g. SGF or SGX for Radarsat-1/2) corrected for systematic distortions due to the sensor, the platform and Earth rotation/curvature are **satellite-track oriented**.

Generally, few metadata related to sensor and satellite are provided; some of metadata are related to the ground range processing.

- Map-oriented images, also called geocoded images, (e.g. level 2A for SPOT or Cartera Geo for IKONOS) corrected for the same distortions as geo-referenced images are **North oriented**.

Generally, very few metadata related to sensor and satellite are provided; most of metadata are related to the 2A processing and the ellipsoid/map characteristics

Level of processing not available to general users

Level of processing useful for GC

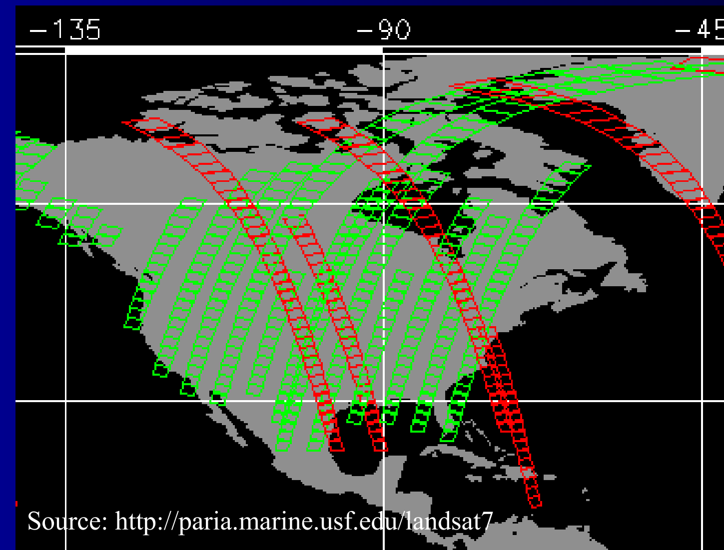
Level of processing **useless** for GC

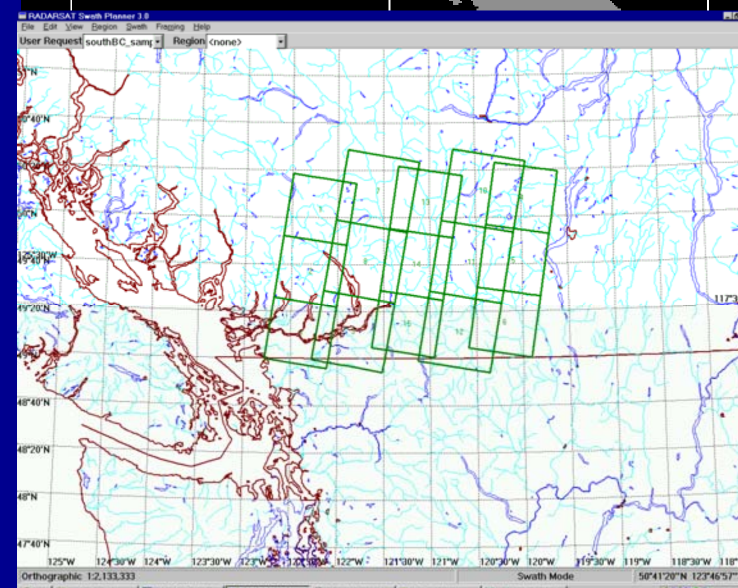
System	Raw data without any correction; orbit oriented	Radiometric correction; orbit oriented	Radiometric & geometric corrections; orbit oriented	Radiometric & geometric corrections; map oriented	Radiometric& geometric corrections with control data; map oriented	Radiometric & geometric corrections with control data & DTM; map oriented
SPOT1—5	0A	1A	1B	2A	2B	3
IRS1C/D		1A	1B	2A		3
Ikonos-2				Geo Standard	Reference Pro	Precision Precision Plus
EROS A		1A	1B			Special request
Kompsat-1	1A	1R	1GR		1GC.P	1GC.D
QuickBird-2		Basic	Standard			Ortho DG/DOQQ
OrbView-3		Basic				Ortho
Formosat-2		1A	1B			3
Cartosat-1	0A	0B	1SYS		2GCP	3A/B DEMA/B
Topsat	0	1A		2A	2B	3
ALOS	1A	1B1	1B2	1B2		
EROS B		1A	1B			Special request
Kompsat-2		1A	1B	2A		3
Cartosat-2				User request		Precision/High-Precision
WorldView-1		Basic	Standard			Ortho DG/DOQQ

Geometric processing: algorithms

Sensor acquires data in continuous paths but images are "artificially" cut in squares: segment of images has to be used

Due to cloud cover there is some restriction in the segment length with VIR images





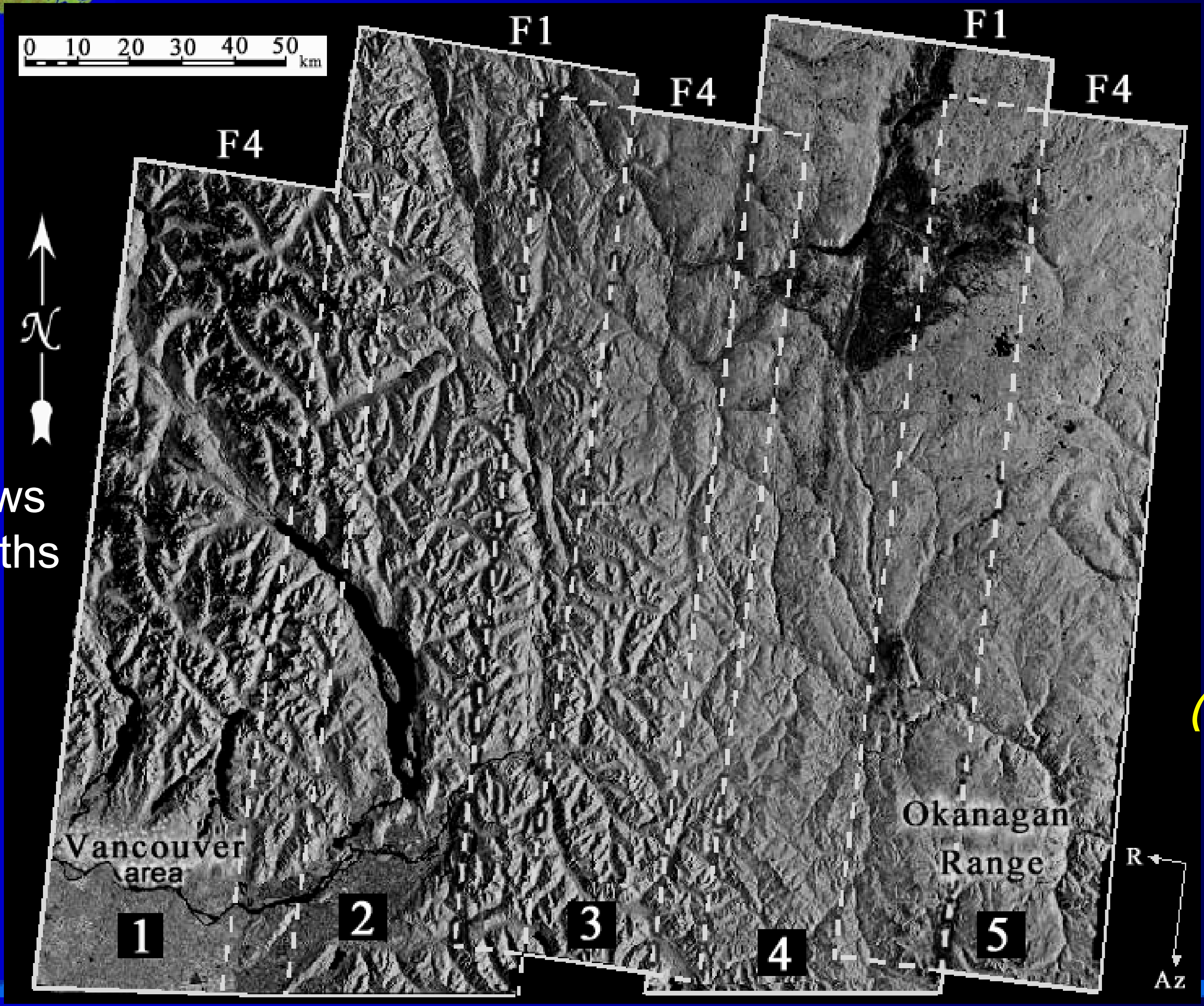
Block is thus formed with adjacent strips from different orbits in the East/West direction

GCPs are then selected in the block and tie points (TPs) link adjacent images and/or strips

Geometric processing: algorithms

Image segment and block generation

3 rows
5 paths



RADARSAT-1 (200x150km)

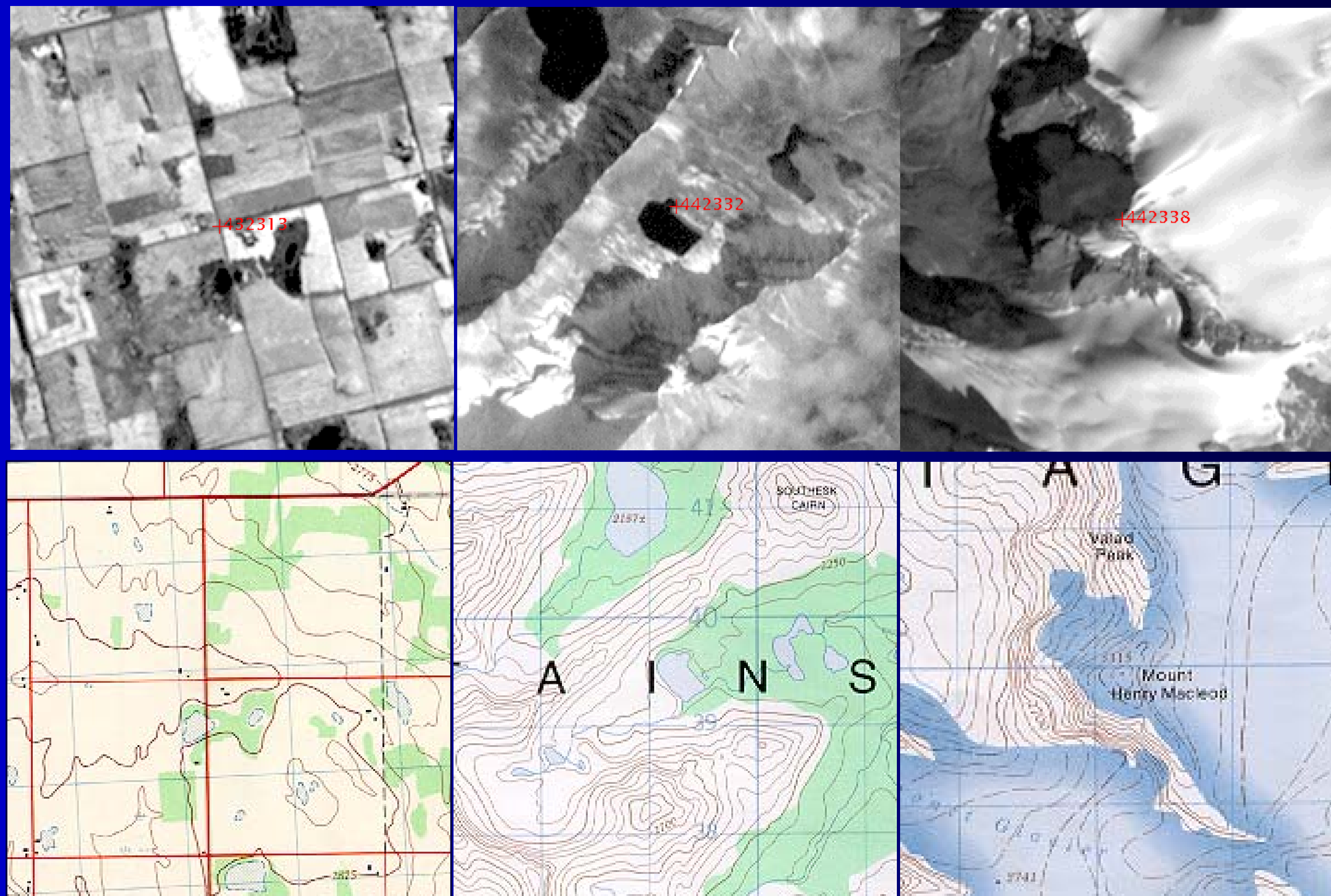
Geometric processing: algorithms

GCP collection method function of image resolution and final accuracy

SPOT5-HRS 10 m res.:

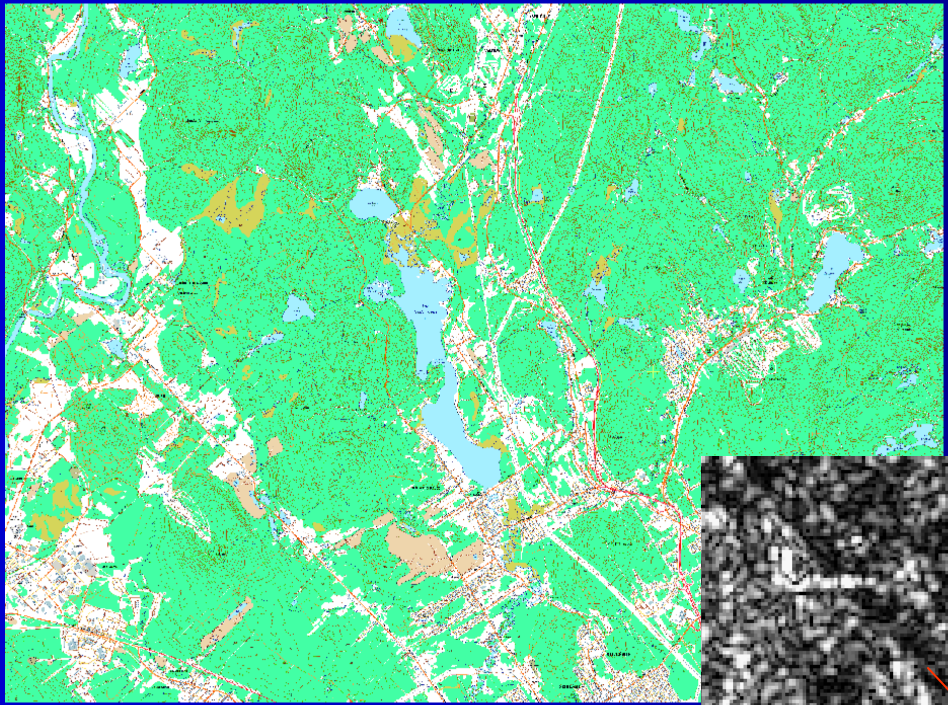
5-m accurate GCP is good;

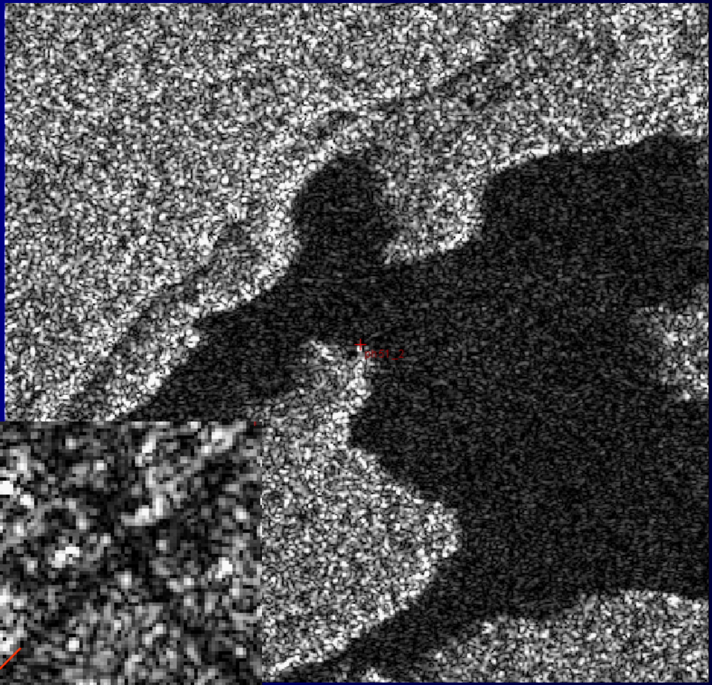
10-m in mountainous area can be acceptable

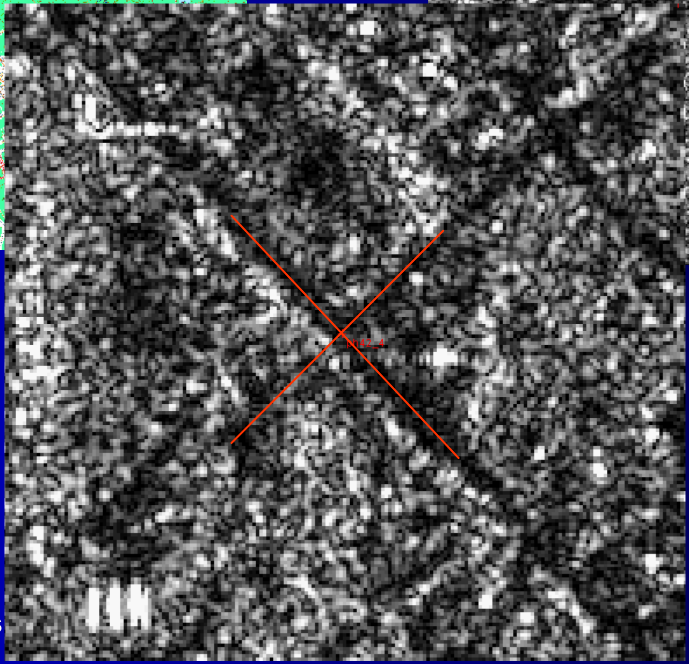


Geometric processing: algorithms

3-m Radarsat-2 fine mode: road intersection; lakes







Largest error will arise from GCP positioning in SAR image:1-2 pixel

Geometric processing: algorithms

Radarsat-2 ultra-fine mode (3 m resolution; 1.56 m spacing)

20k aerial photo (1 m spacing)

GCP with 2-m accurate positioning on ortho-photo is good enough with FQ Radarsat-2 but not for UF and SpotLight: DGPS is required

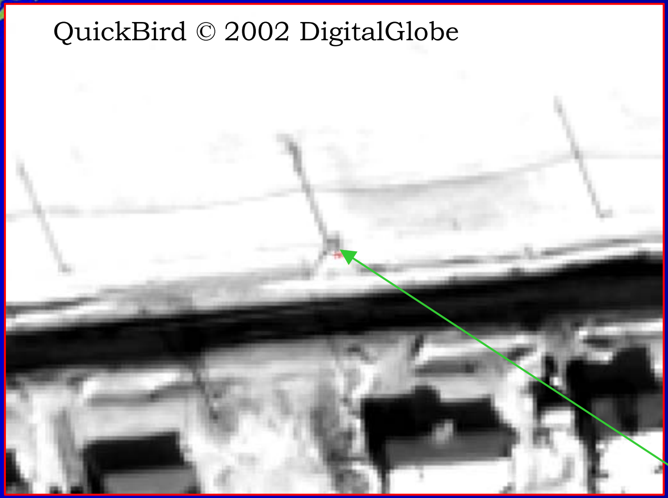
Geometric processing: algorithms

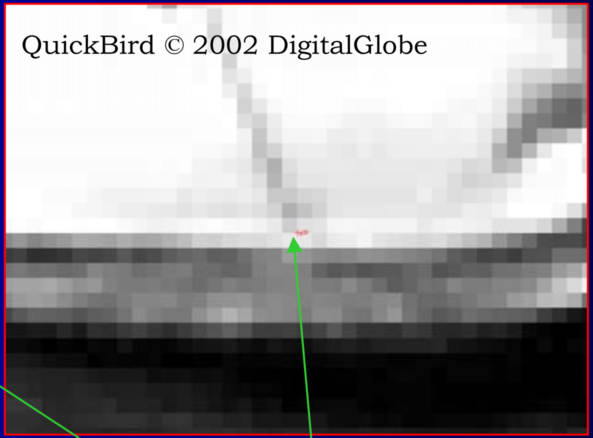
QuickBird

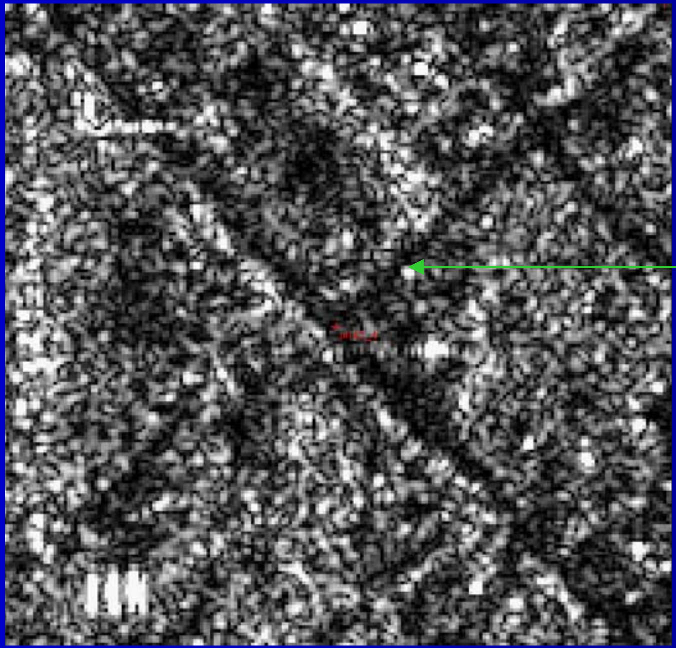
20k aerial photo

GCP with 2-m accurate positioning is not enough with VFSR QuickBirb

Geometric processing: algorithms







Pole or pole shadow used as GCP for VFSR VIR or SAR

Better than 1 pixel accuracy

Radarsat-2 ultra-fine mode (HH; 3-m resolution; 1.56-m spacing)

Geometric processing: algorithms

A posteriori collection

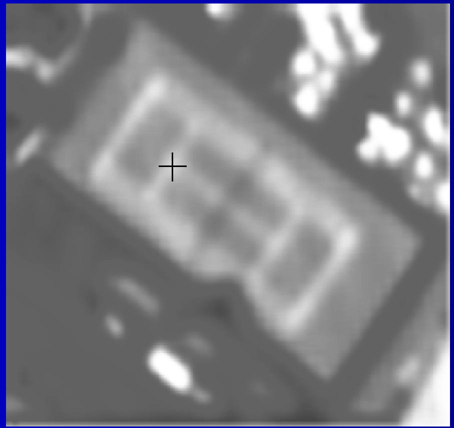
QuickBird

A priori collection

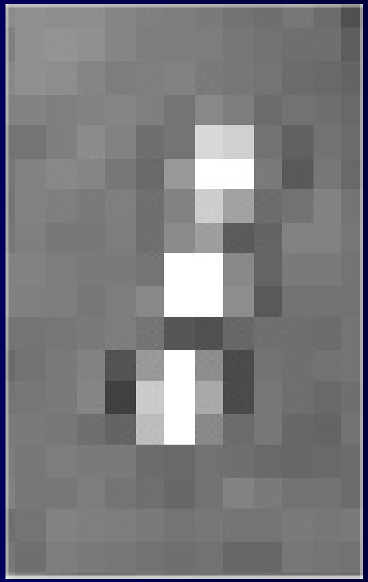
Geometric processing: algorithms

Control points should be symmetric targets using special tools for pointing

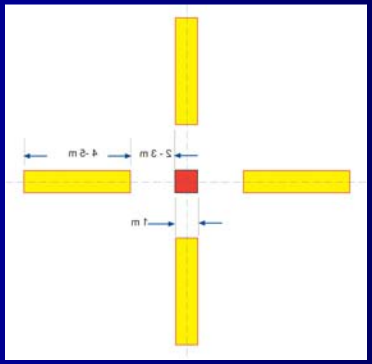
Ikonos

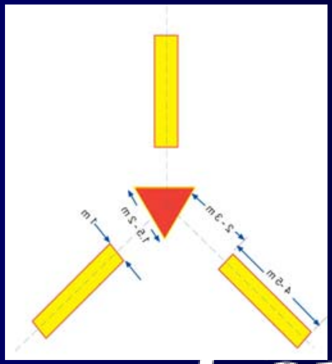


Corner positions → shift from bright to dark



Artificial targeting





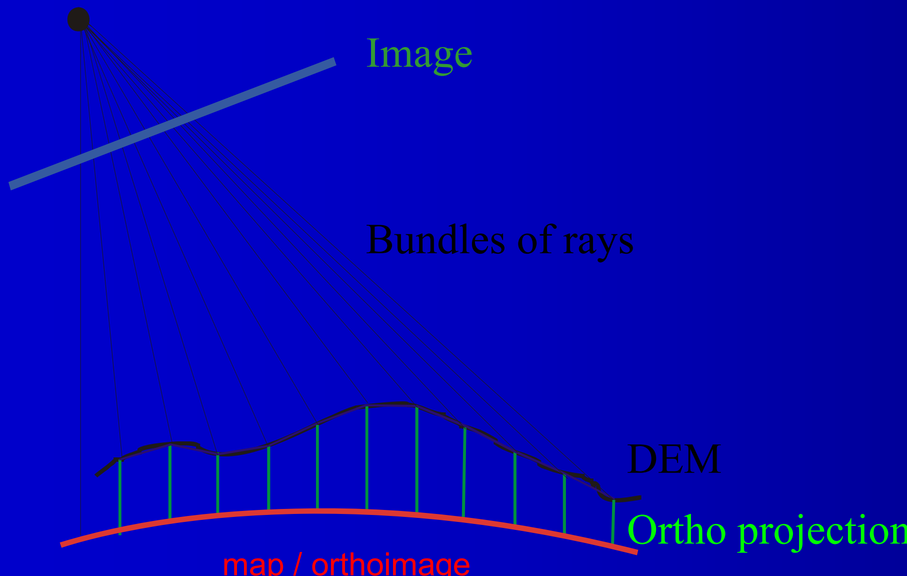
Geometric processing: algorithms

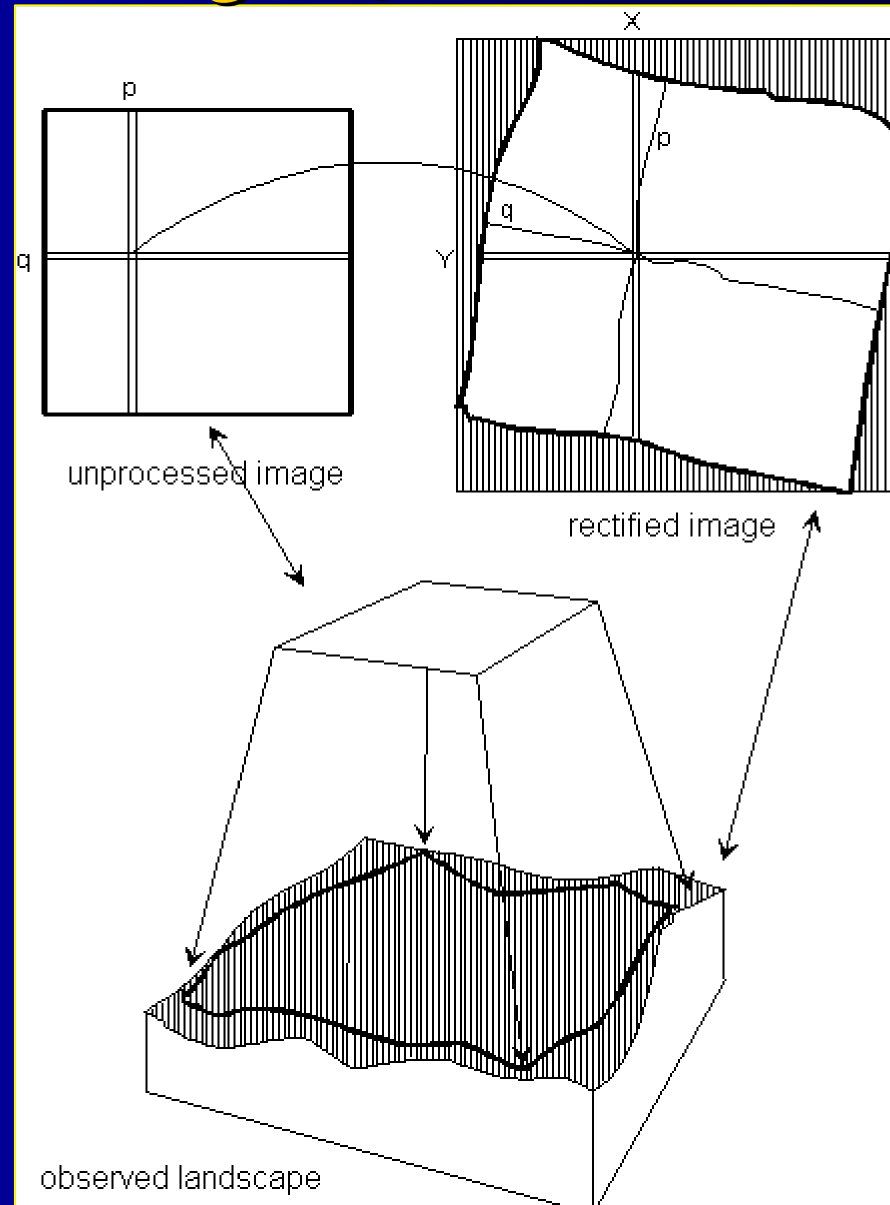
Least-square bundle adjustment is used to computed the math model. All bundles (of rays) in the image are simultaneously adjusted (relative plus absolute orientations). The basic unit is a pair of image coordinates for the bundle.

Image Type	Examples of Images	Geometric Models
Raw level	QuickBird Basic EROS-A Basic 1A SPOT-5 1A	**3D physical** 3D $2^{nd}/3^{rd}$-order rational
Georeferenced	SPOT-5 1B EROS-A 1B	**3D physical** 3D $1^{st}/2^{nd}$-order polynomial 3D $1^{st}/2^{nd}$-order rational
Map-Oriented	QuickBird Standard IKONOS Geo SPOT-5 2A	**3D physical** 3D 1^{st}-order polynomial 3D 1^{st}-order rational

Geometric processing: algorithms

Ortho rectification



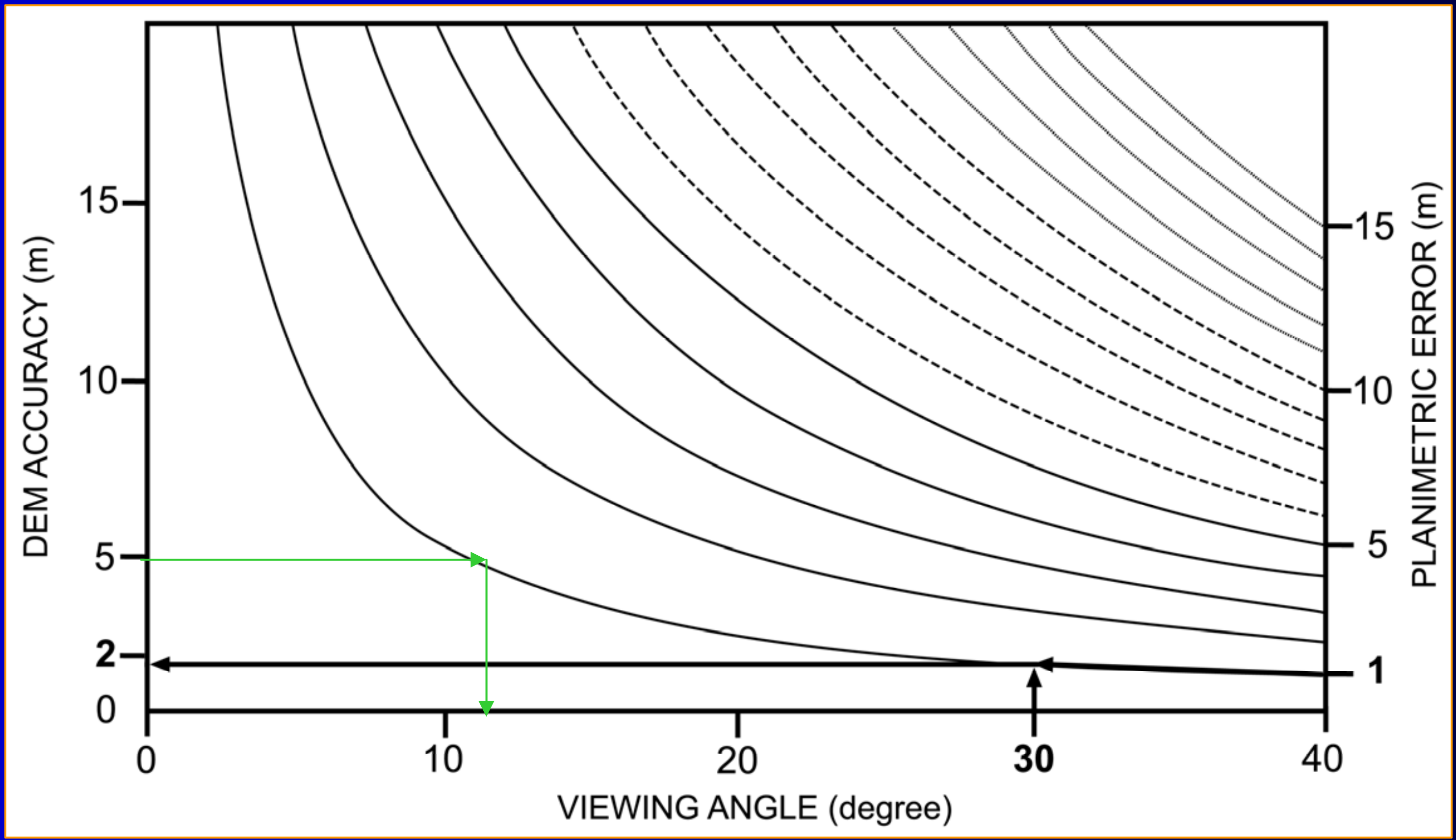


Firstly, the process "to ortho project" the image on the ground to be registered to a map needs:

- A geometric operation to project the image. A digital elevation model must be used for higher accuracy

Geometric corrections: algorithms

DEM accuracy



1-m accuracy requires 2-m accurate DSM with 30° viewing angle

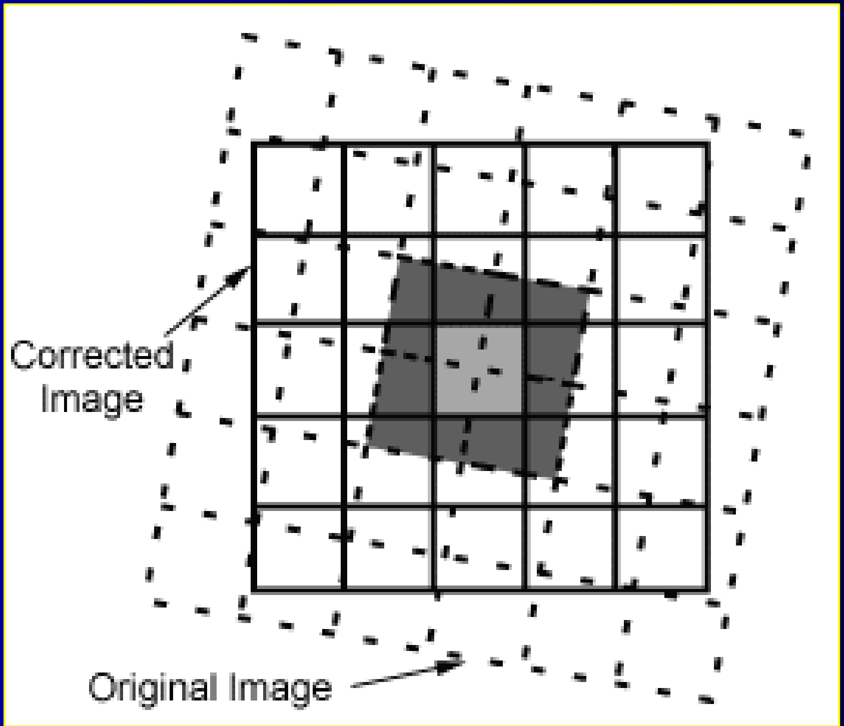
5-m accurate DSM requires 10° viewing angle for 1-m accuracy

Geometric processing: *algorithms*

Ortho-rectification (2/2)

Secondly, the process "to project" the image on the ground to be registered to a map needs:

A radiometric operation to compute the grey value in the rectified image. Different resampling kernels can be used.



GC: algorithms

Resampling

A: nearest neighbour

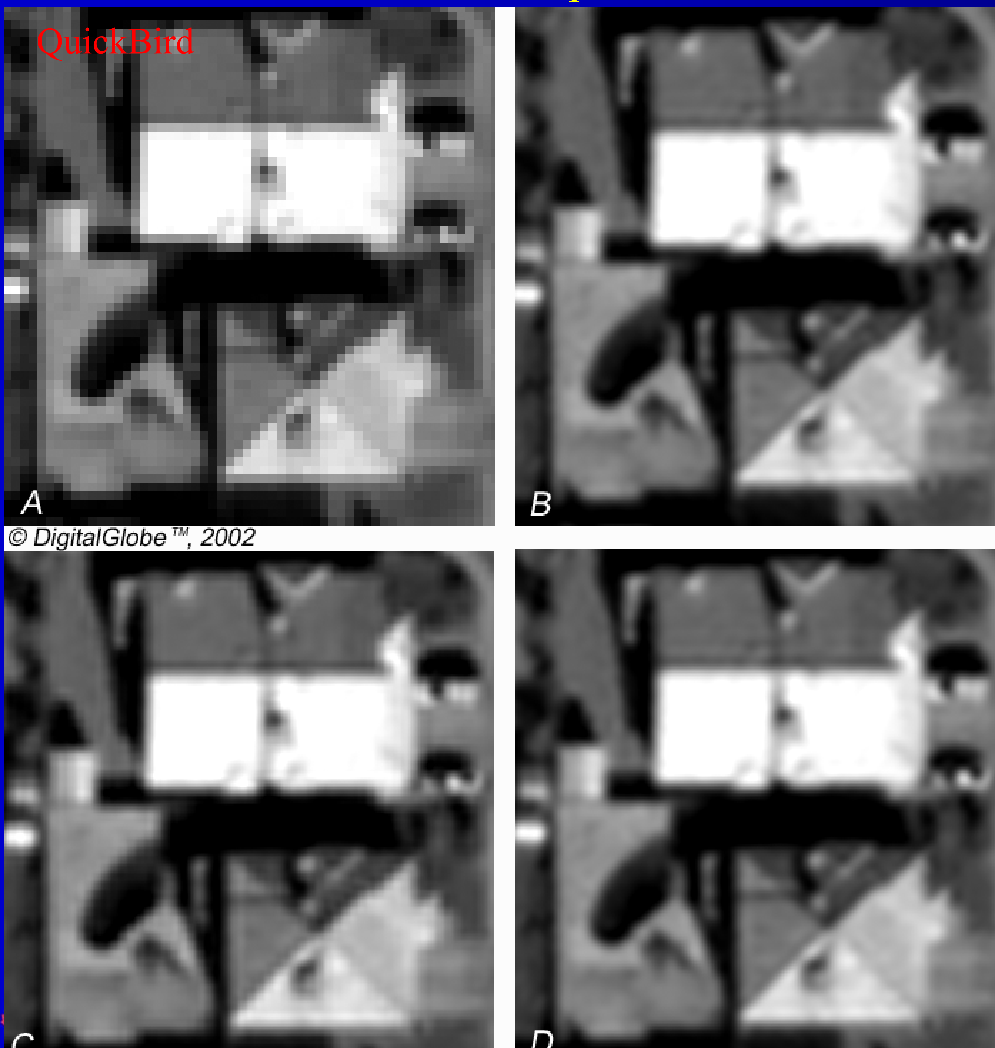
B: bilinear (2x2 window)

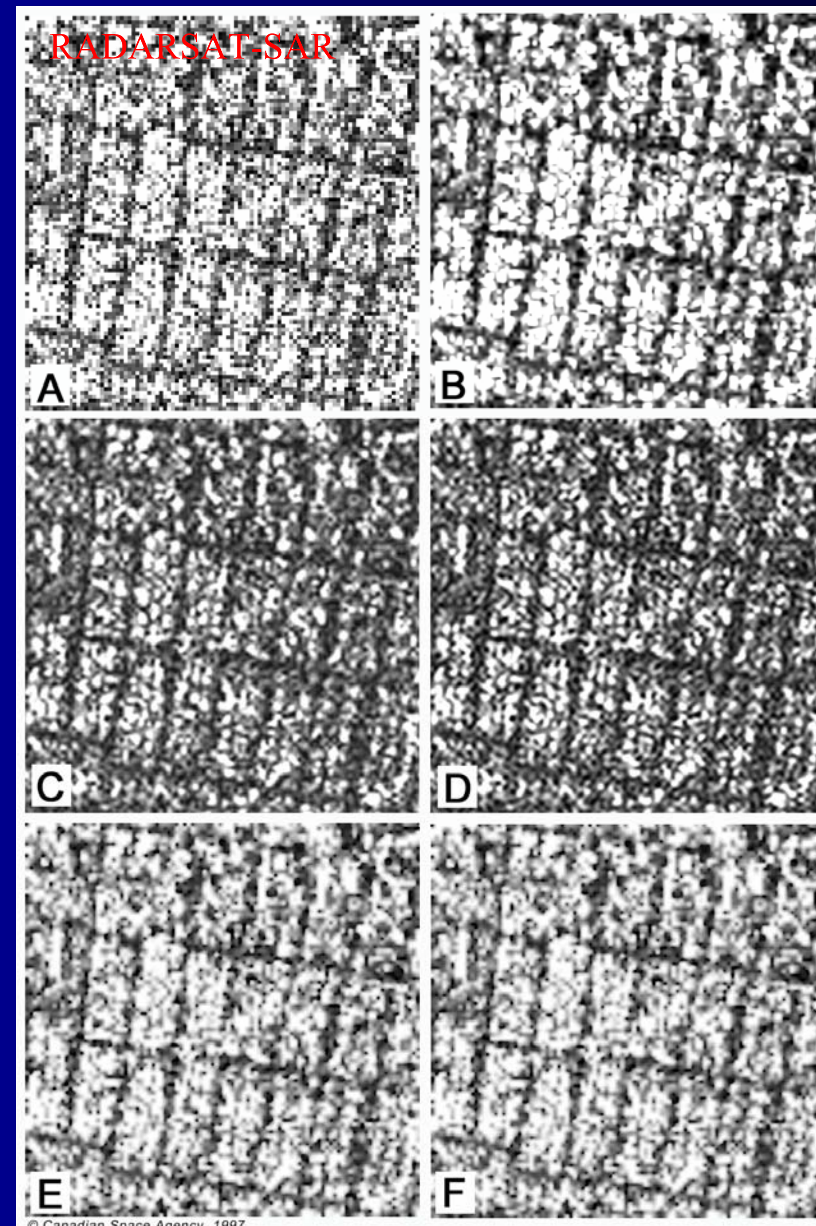
C: cubic convolution (3x3 window)

D: sinx/x (16x16 window)

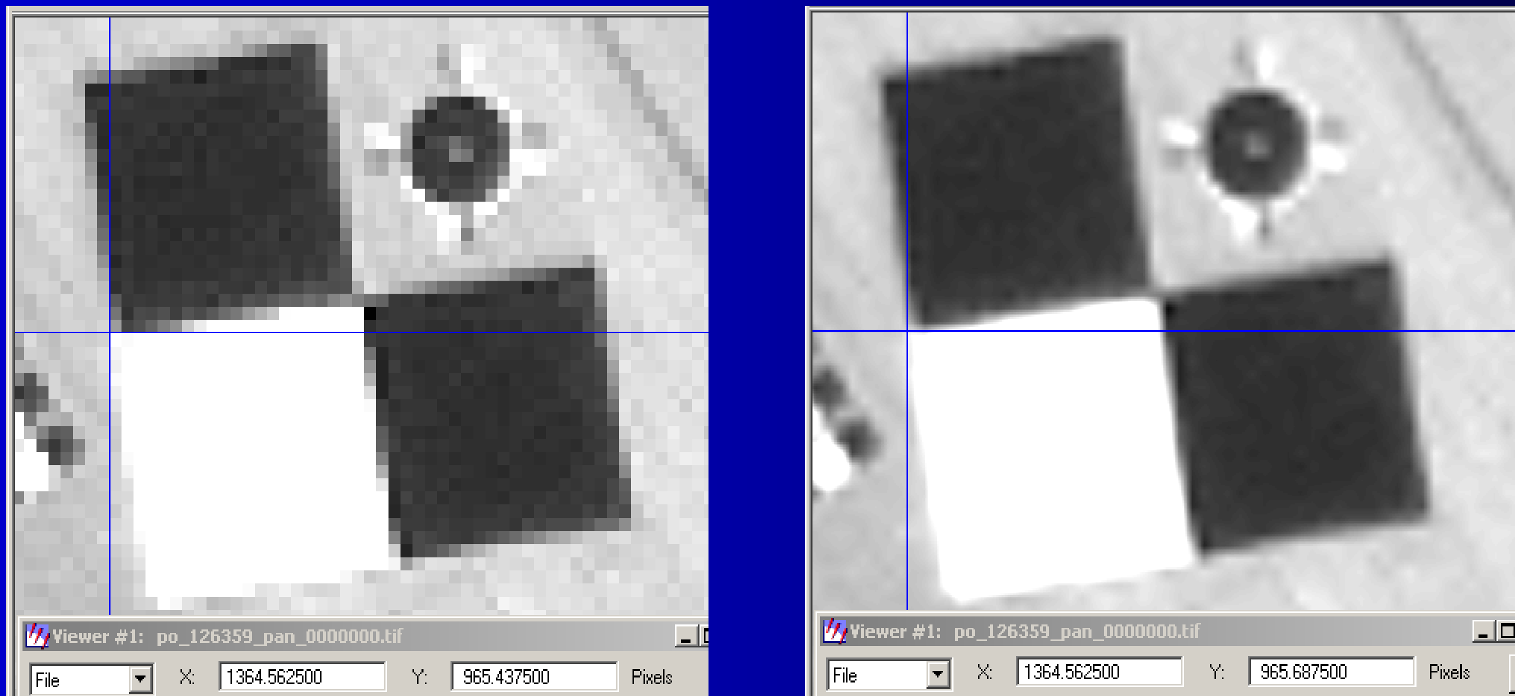
E: enhanced Lee adaptive filter

F: Gamma adaptive filter





Geometric processing: algorithms



Change from nearest neighbor to cubic convolution resampling moves apparent corner position by 0.25 pixels

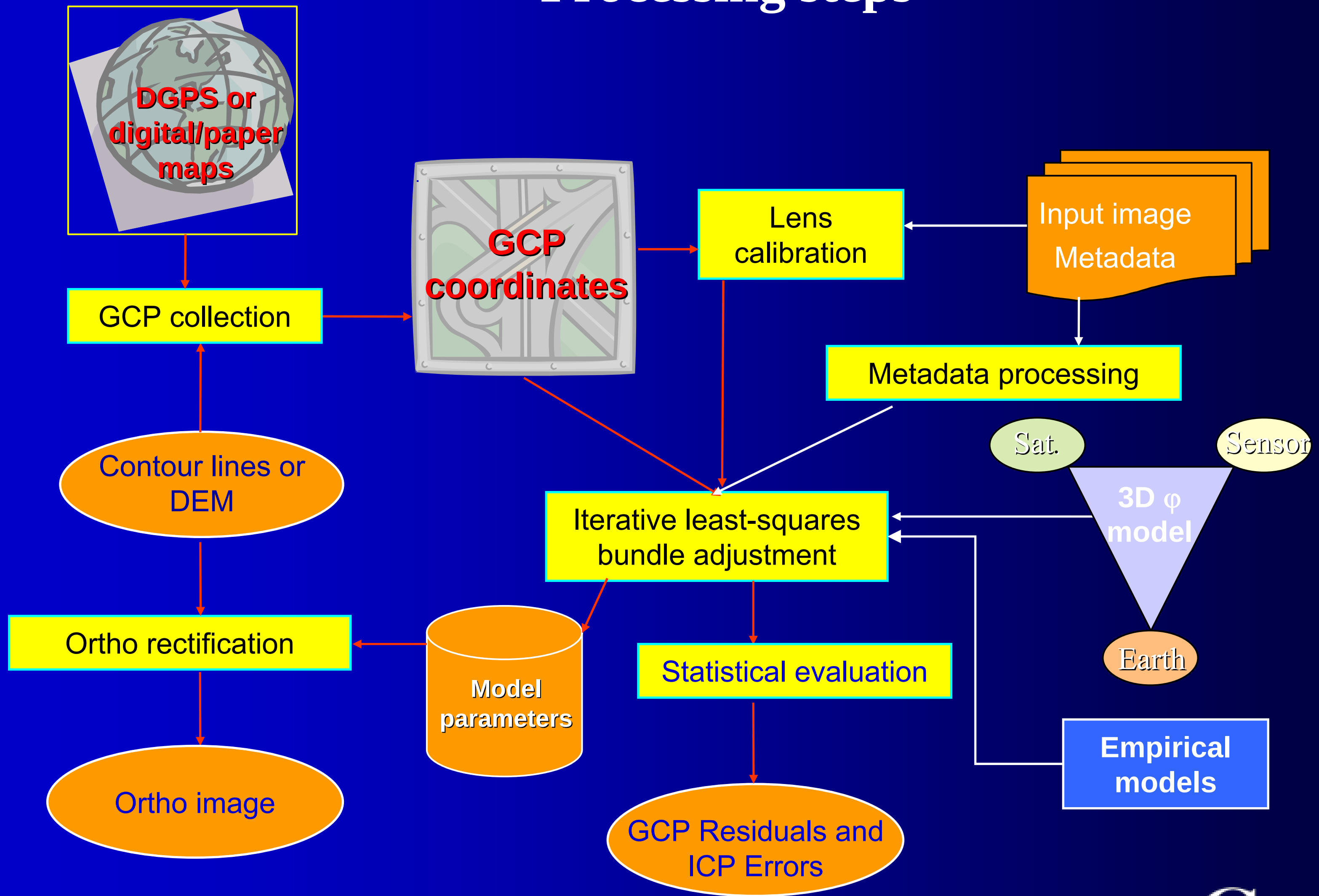
from Gene Dial (GeoEye)

Geometric processing

1. Characterization of geometric distortions
2. Geometric corrections: models and **algorithms**
3. Single image processing
4. Strip and block processing
5. Stereo processing

Geometric corrections: single image

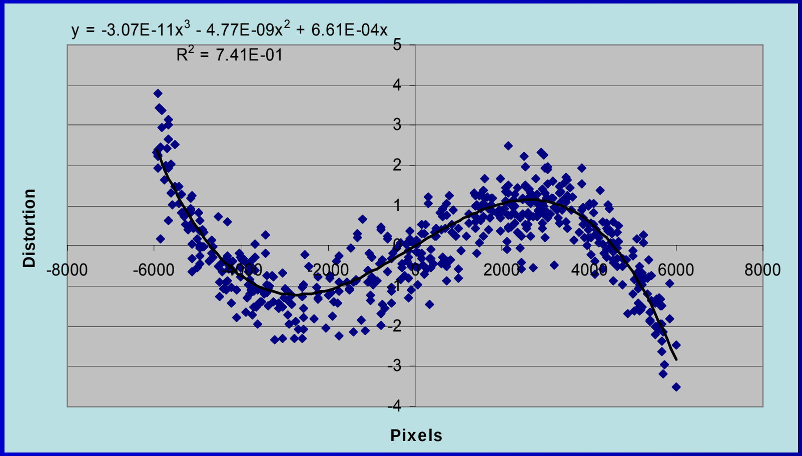
Processing steps

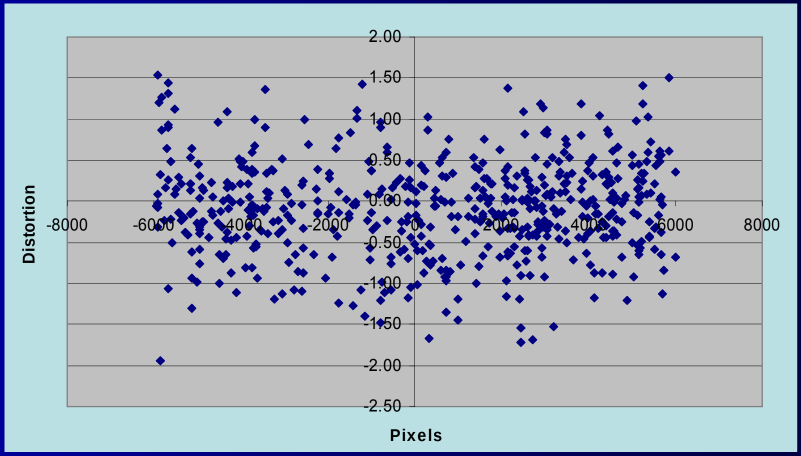


Geometric processing: single image

Lens distortions: symmetrical and asymmetrical radial

$$\Delta r = \Sigma a_i r_i \qquad [i=1, 6]$$





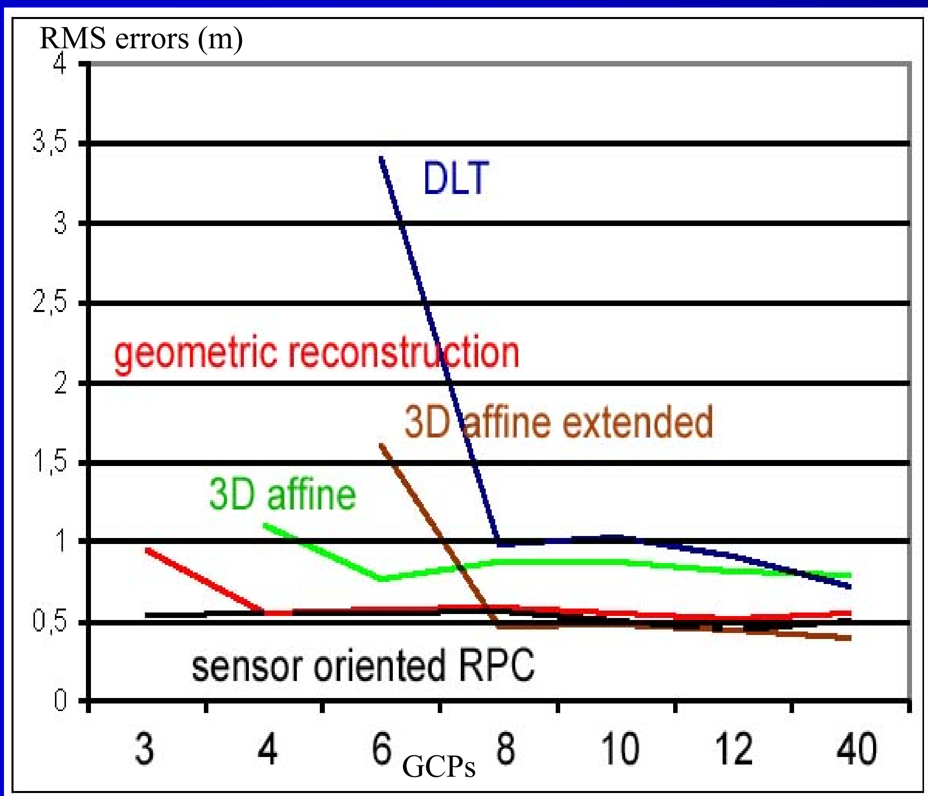
Before corrections:
a systematic and
random components

After corrections:
only a random
component

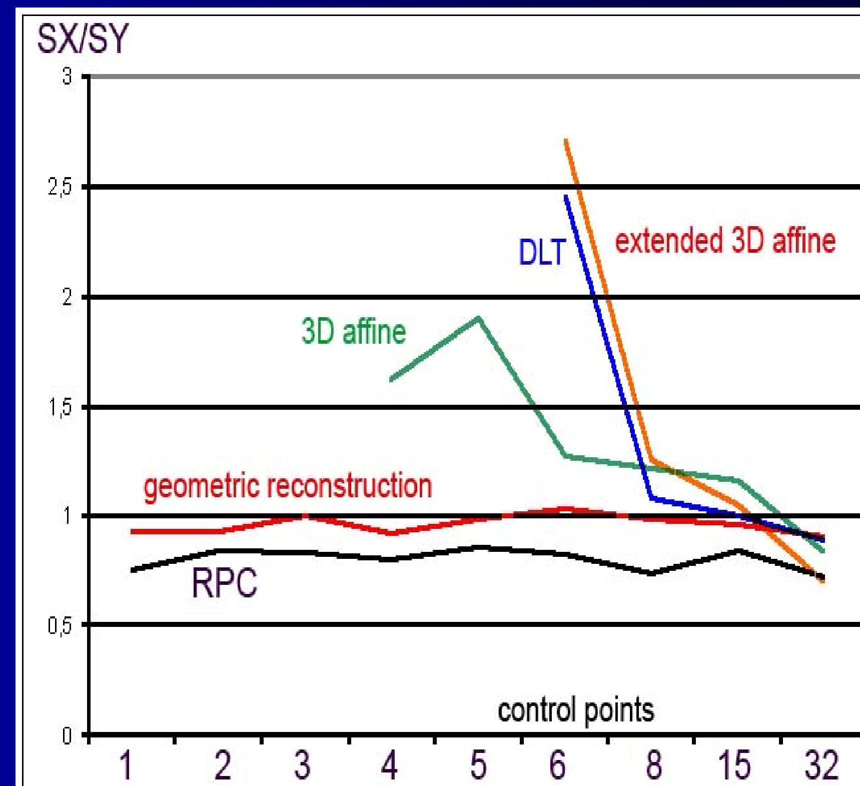
Geometric processing: single image

Bundle adjustment (Hannover Uni. Dr. Jacobsen)

Results with QuickBird



Results with Ikonos



GCPs have sub-pixel accuracy

Geometric processing: *single image*

Accuracy versus number of GCPs used in bundle adjustment

10 GCPs with 1-m accuracy
15 GCPs with 3-m accuracy
20 GCPs with 5-m accuracy
30 GCPs with 10-m accuracy

Study Site	GCP Number	ICP Number	RMS Errors X	RMS Errors Y	Min./Max Errors X	Min./Max Errors Y
Ottawa						
QuickBird	10	28	0.8	0.8	-2/2	-2/2
QuickBird	15	38	1.6	1.4	-2/2	-7/3
QuickBird	20	38	4.2	2.6	-15/1	0/9
QuickBird	30	38	3.2	4.5	-3/11	-9/11

Messages (Dr. Armin Gruen, ETH Zurich)

*(1) **Subpixel accuracy** georeferencing is a solved problem*

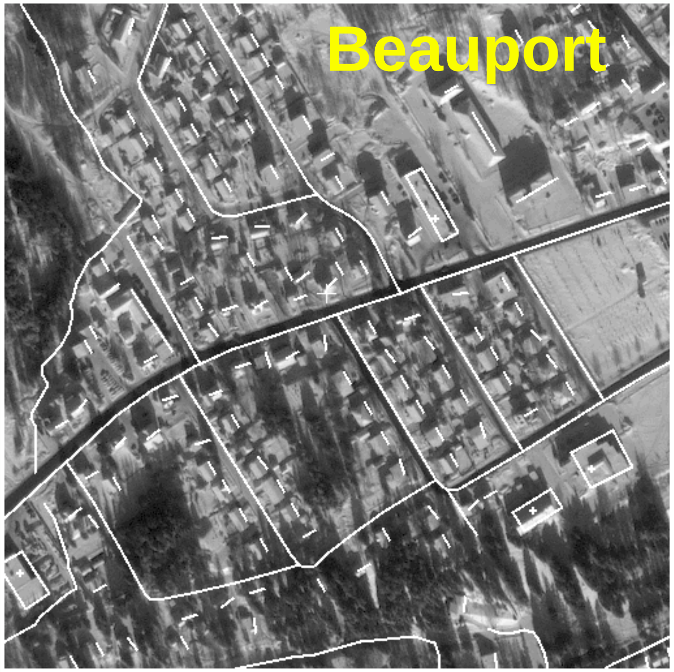
*(2) Bias-corrected **RPCs** & rigorous **collinearity-based** models **with same results***

Geometric processing:

single image

Evaluation of ortho-image with ortho-photos: checked data are not always the best !

Ortho-IKONOS with 1:20000 vector lines

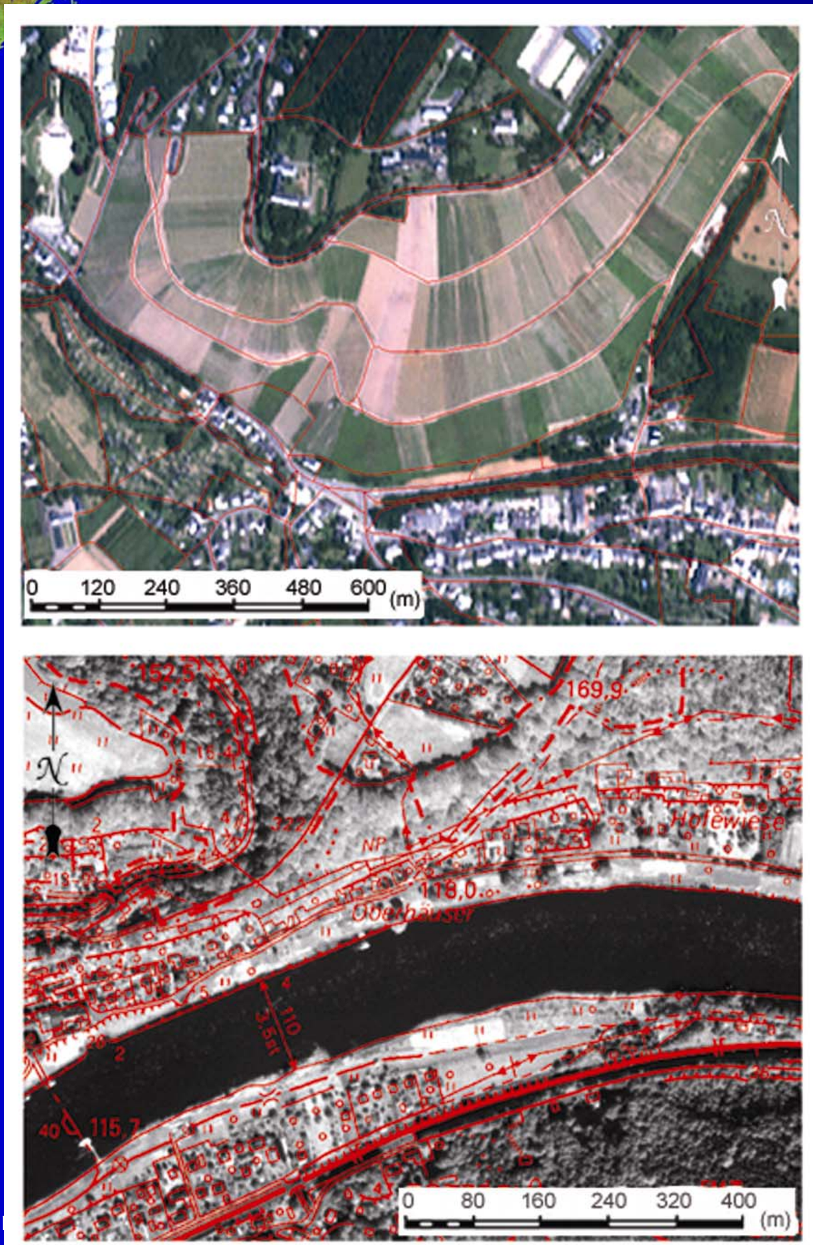


Ortho-photo with 1:20000 vector lines

Absolute accuracy:

about 1 m

Geometric processing: *single image*



Germany

Ortho-IKONOS with 1:20000 vector lines

Absolute accuracy:about 1 m

Stereo processing: bundle results

Examples with Radarsat-2 Ultra-fine/Spotlight modes

Results (in metres) over ICPs from the adjustment computed with only one GCP

Image(s)	ICP	RMSE-X	RMSE-Y	RMSE-Z	Max X	Max Y	Max Z
U2 HH	88	4.5	1.5	--	8.9	3.7	--
U25 HH	113	45.6	5.9	--	81.7	10.9	--
SLA24 HH	19	1.9	1.2	--	4.2	2.7	--

Error in U25 metadata (corrected since Fall 2008)

Results (in metres) over ICPs from the adjustment computed with 8 GCPs

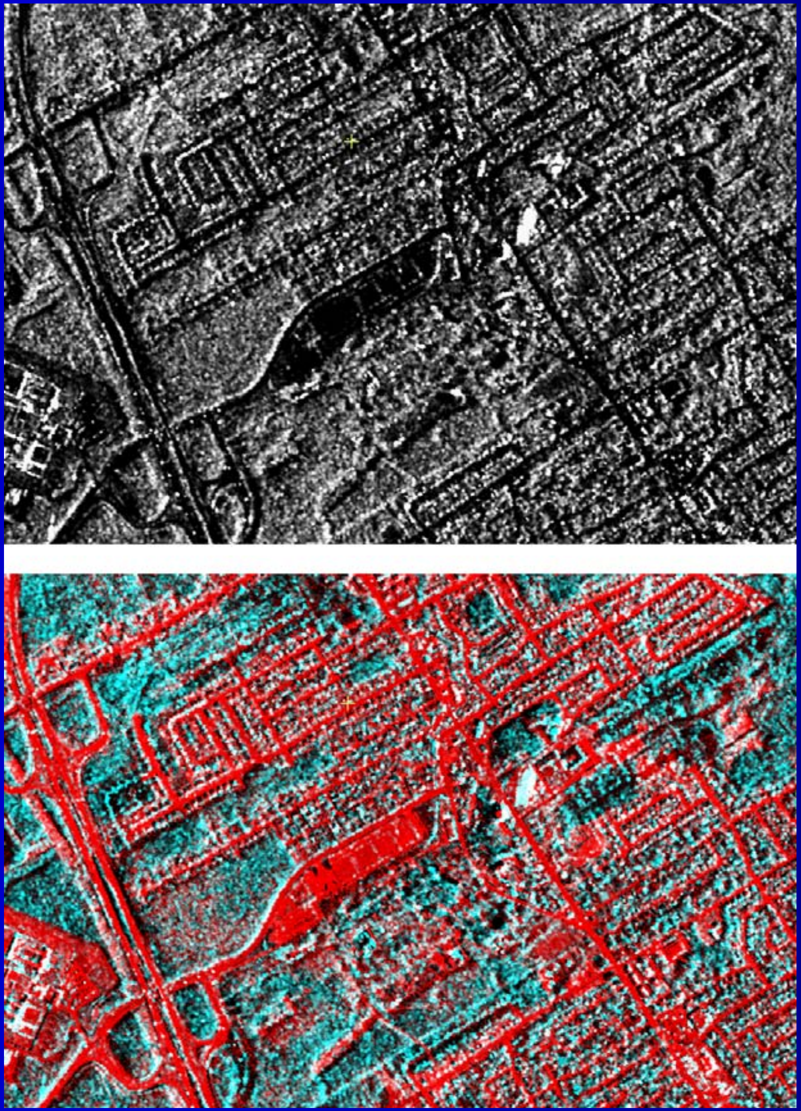
Image(s)	ICP	RMSE-X	RMSE-Y	RMSE-Z	Max X	Max Y	Max Z
U2 HH	81	1.5	1.4	--	3.9	3.4	--
U25 HH	105	1.4	1.3	--	4.2	3.2	--

Geometric processing: *single image*

Comparison of ortho Radarsat-2 UF (1-m spacing) with 20k map

No more than 1-2 pixel differences (1-2 m) between the ortho-image and map: Part of this error is **due** to the map

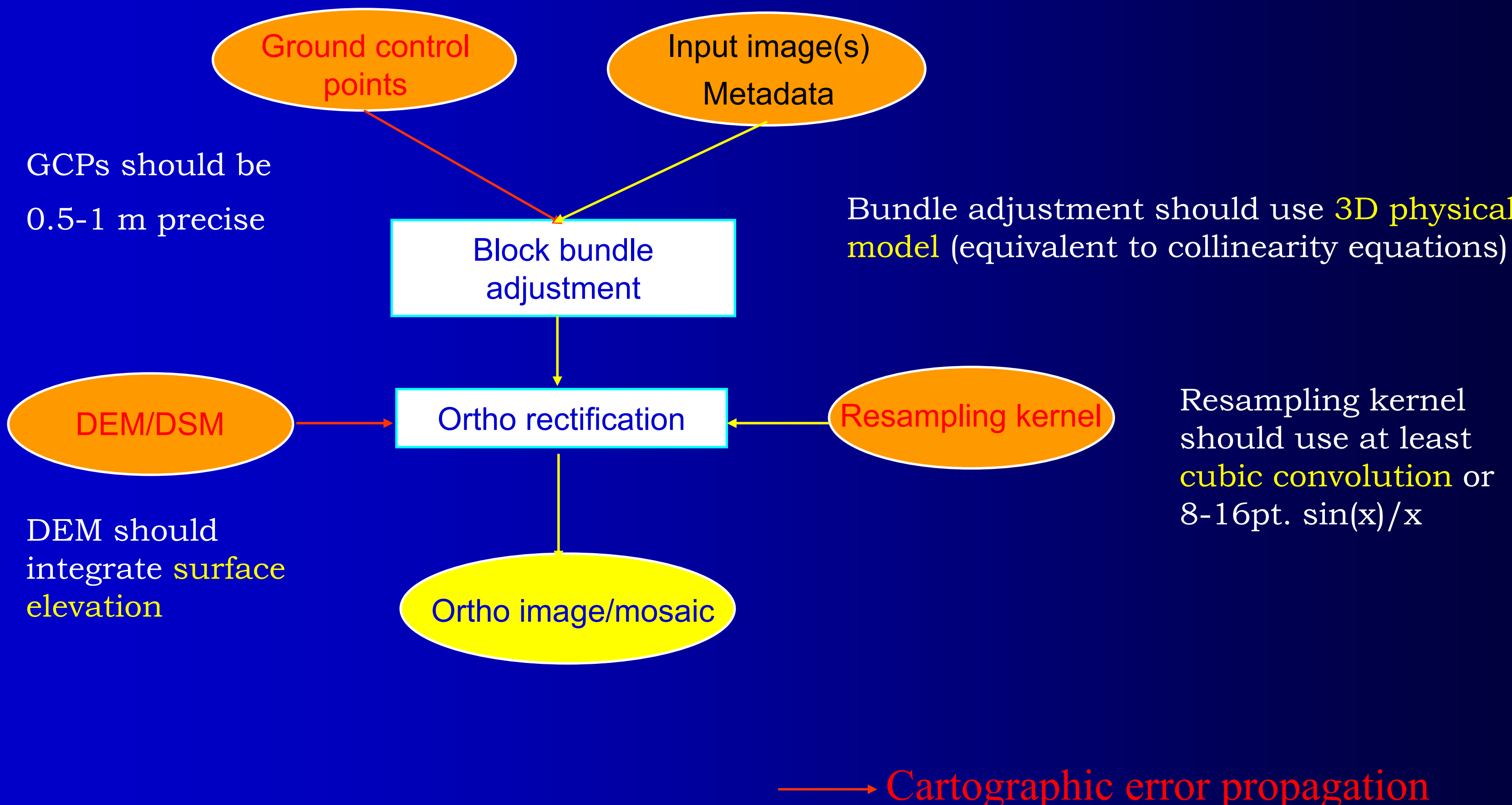
Geometric processing: *single image*



Comparison of ortho Radarsat-2 UF (1-m spacing) with 1-m accurate ortho-photo

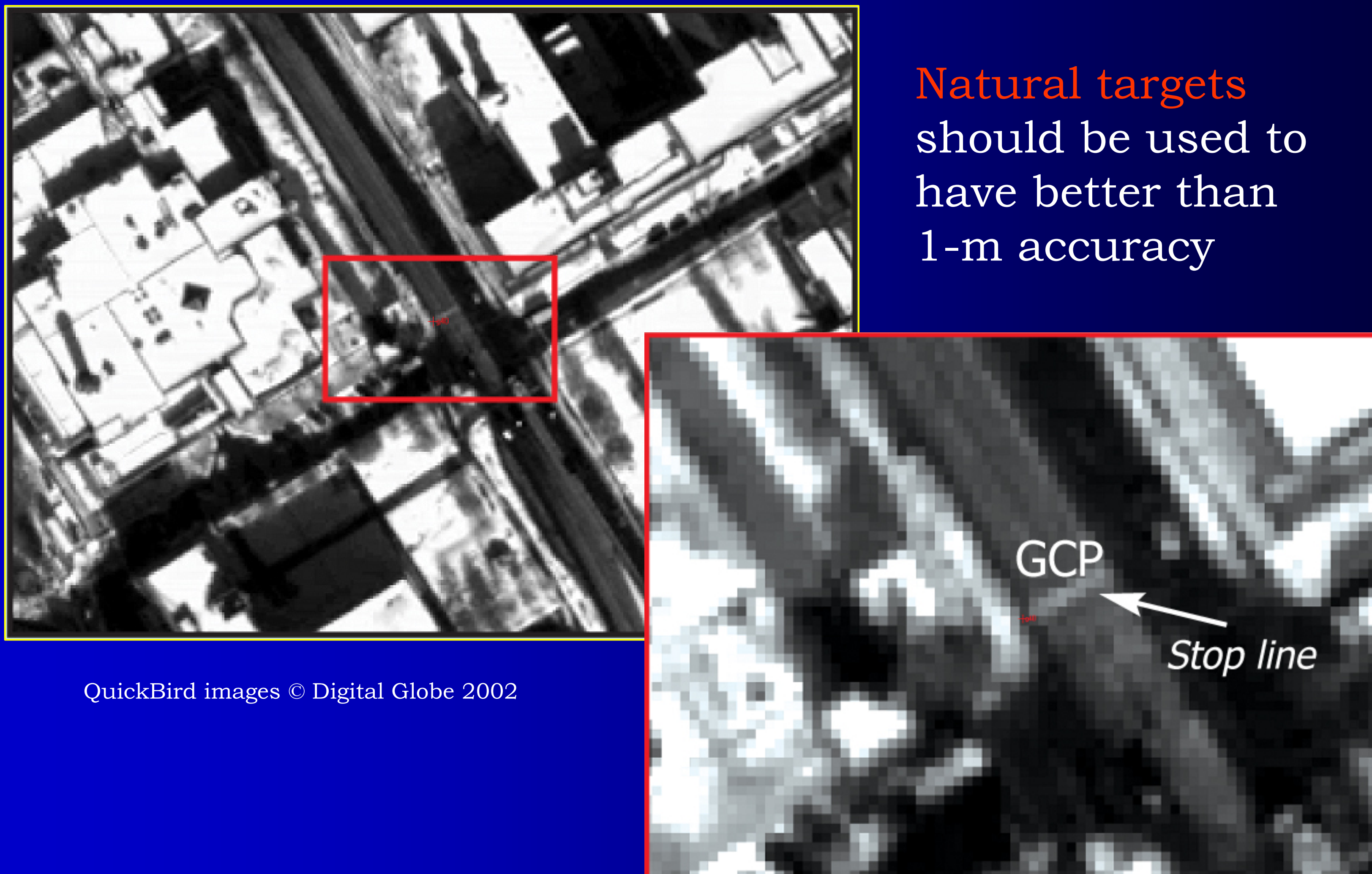
No more than 1 pixel differences between the ortho-image and ortho-photo: Part of this error is **due** to the ortho-photo

Geometric Processing: *error propagation*



Geometric Processing: *error propagation*

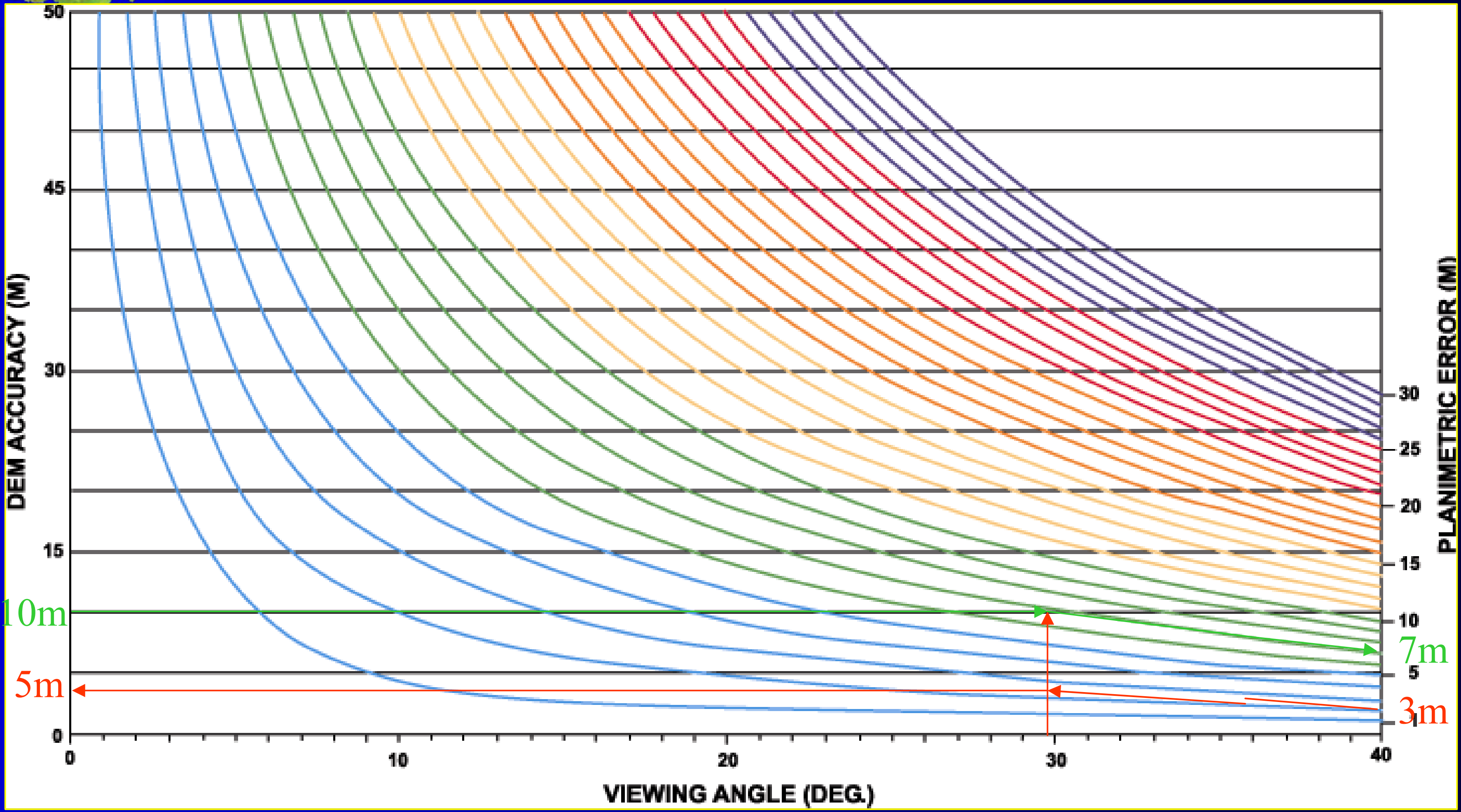
Definition and pointing with better than 1-m accuracy



Natural targets should be used to have better than 1-m accuracy

QuickBird images © Digital Globe 2002

Geometric Processing: *error propagation*

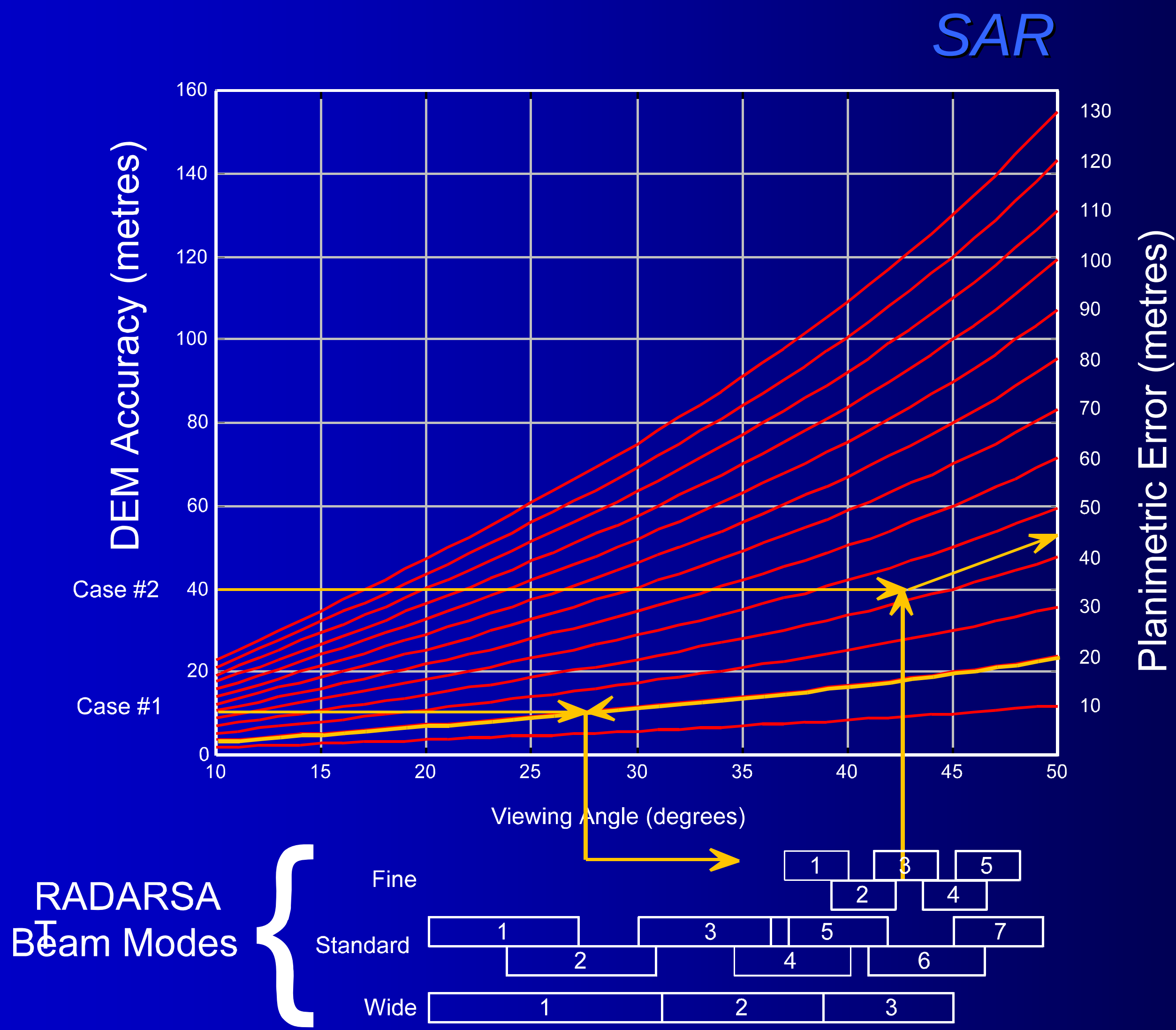


With 30° viewing angle,

3-m accuracy requires 5-m accurate DEM

10-m elevation error generates 7-m error

Geometric Processing: error propagation



Geometric Processing: *error propagation*

- **Geometric modelling**
  - Mathematical modelling (~0.1 m)
  - Definition of GCPs (0.5-2 m)
  - Pointing of GCPs (0.5-2 m)
  - Cartographic co-ordinates (X, Y and Z) of GCPs (0.1-1 m)

- **Ortho-rectification**
  - DEM (2-5 m)
  - Surface height (5-10 m)
  - Resampling kernel (~0.5 m)

Geometric processing

1. Characterization of geometric distortions
2. Geometric corrections: models and **algorithms**
3. Single image processing
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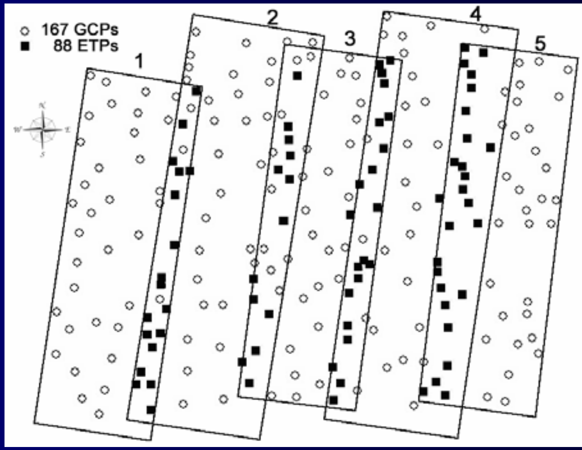
5. Stereo processing

Geometric processing: strip & block

Spatio-triangulation is a procedure for the extension of horizontal/vertical control whereby the measurements of angles and/or distances on overlapping images are related into a combined spatial solution using the geometric principles of the images



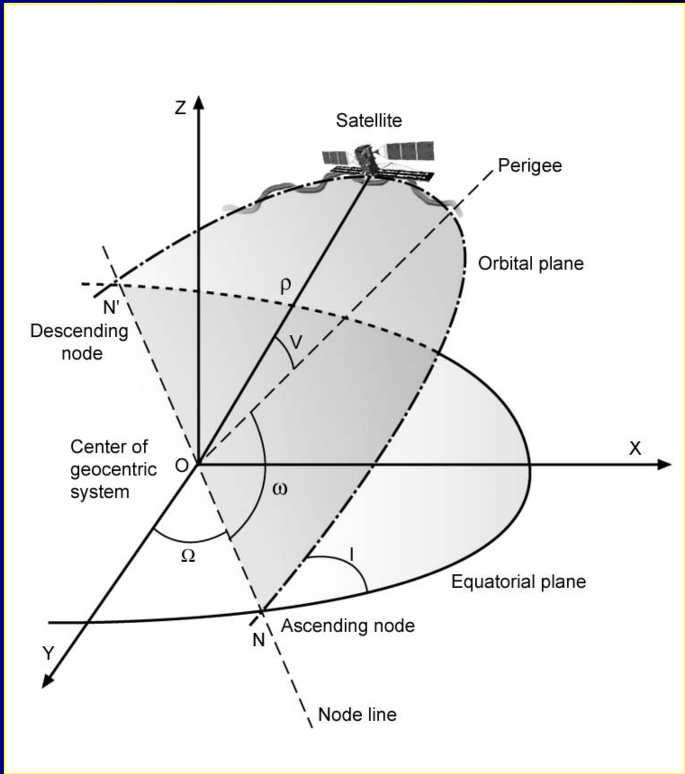
There are different advantages to simultaneously compute all geometric models:

- To reduce the number of GCPs using tie points
- To obtain a better relative accuracy between the images
- To obtain a more precise and homogeneous mosaic over large areas
- To generate homogeneous GCP network for future geometric processing

Geometric processing: strip & block

For modelling the satellite motion, different math models can be used:

- A tangent line
- A circular orbit
- An elliptic orbit
- **An osculatory orbit**



An osculatory orbit model with Gauss' and Lagrange's equations related to celestial mechanics should be preferred for image segment and block

Geometric processing: strip

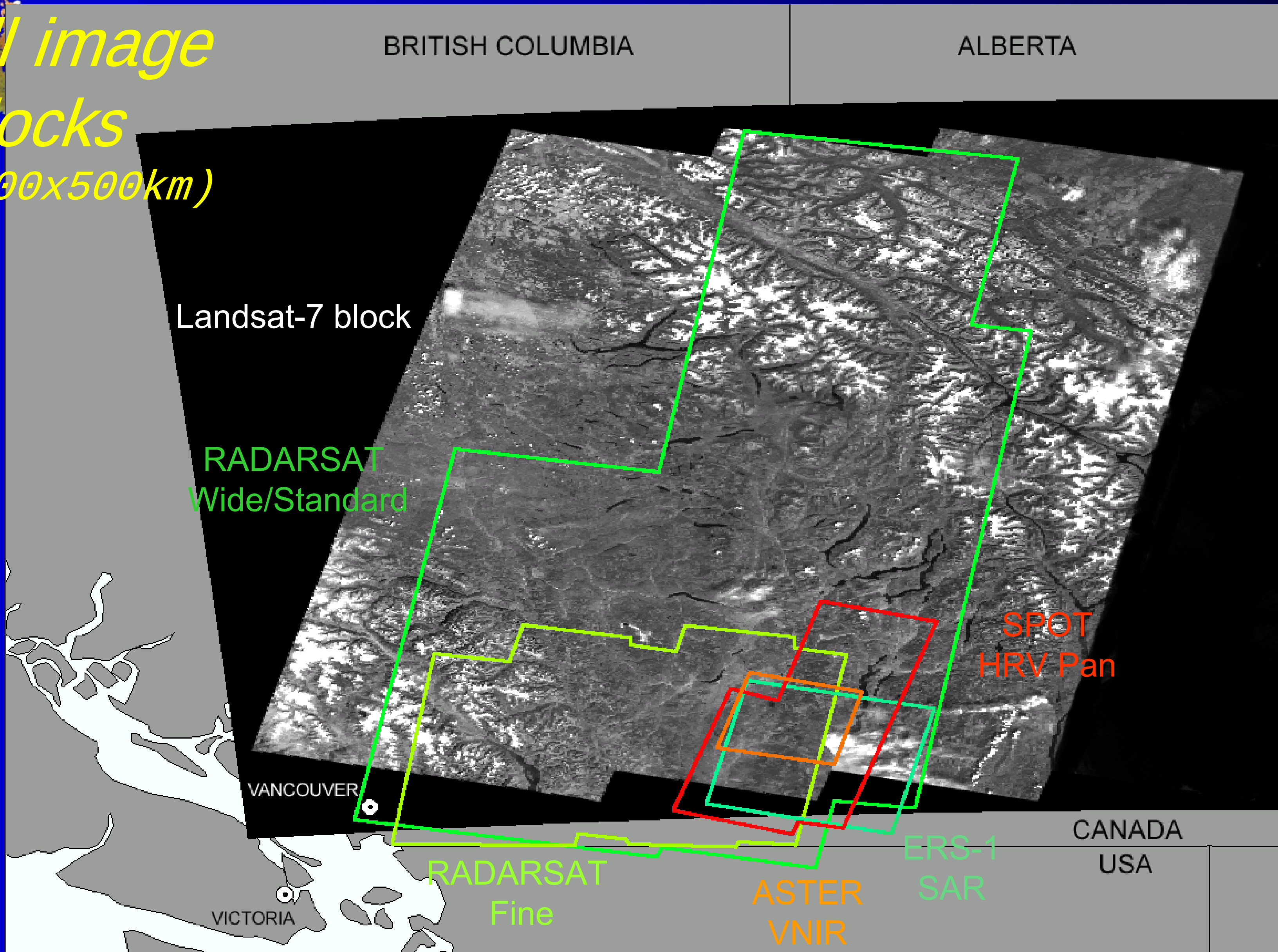
Segment can be ordered from image providers or can be stitched by users

- Theoretically, the same number of 3-6 accurate GCPs is required for a long segment than for an image
- Practically, the GCP number will depend on cartographic accuracy: less accurate more GCPs you need
- Avoid extrapolation in planimetry and elevation
- For spatio-triangulation, tie points in the overlap areas for linking images and/or segments, but elevation must be added when stereo geometry is weak

Segment of 5 SPOT images: 60 by 295 km acquired over Kazakhstan © CNES 2000

All image blocks

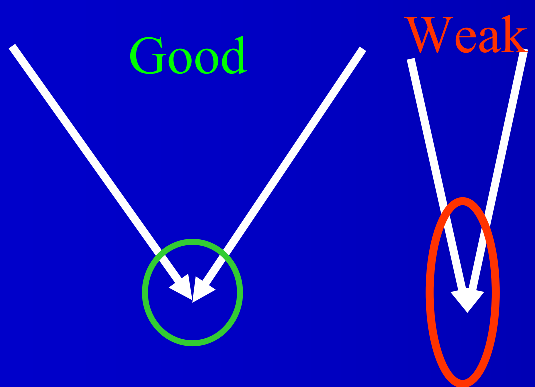
(400x500km)

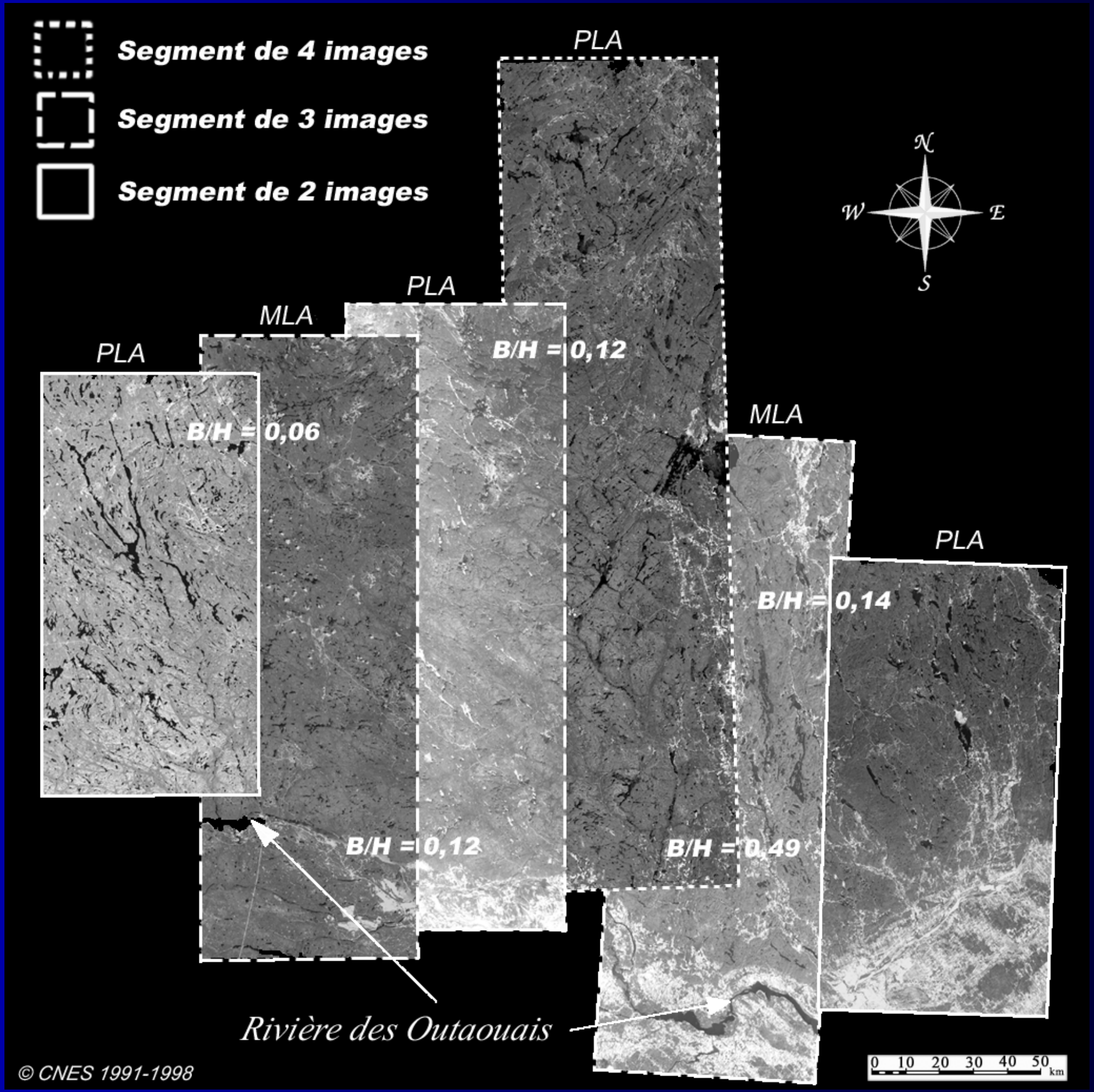


Geometric processing: *SPOT block*

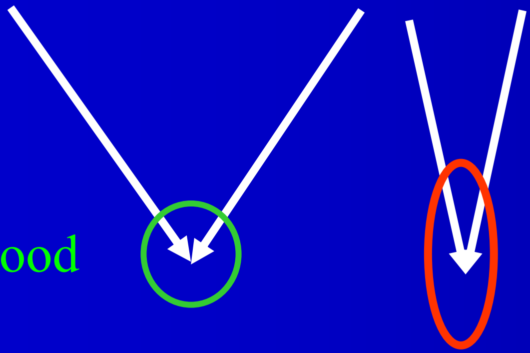
Block should carefully be ordered from image providers using appropriate viewing angles between segments

With spatio-triangulation:
tie points in the overlap areas for linking images segments, but elevation must be added when stereo geometry is weak





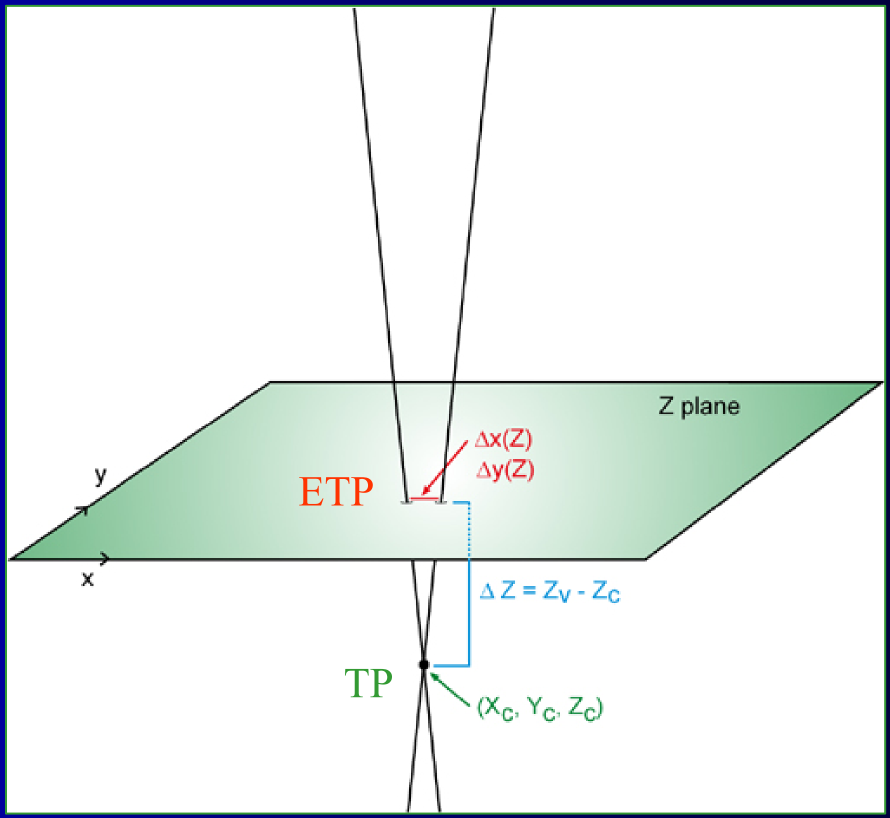
Geometric processing: block



When stereo geometry is weak, adding an elevation value to tie points forces the computation of the stereo-intersection in the Z-plane Δx(Z) & Δy(Z) instead of computing X_C Y_C Z_C

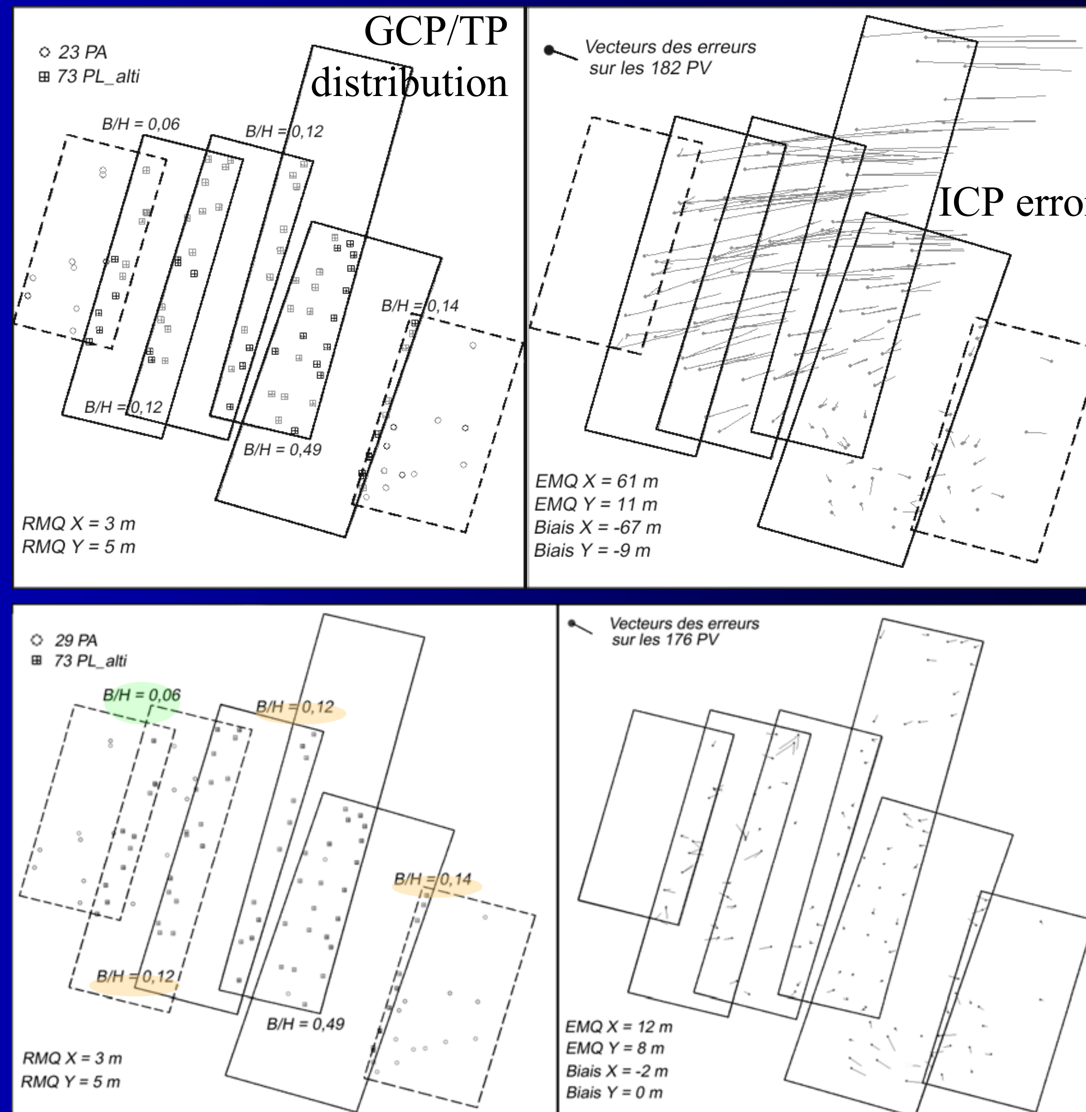
It is still more important for the planimetry with same-side off-nadir stereo-intersection.

Necessity of elevation tie points



Geometric processing: block

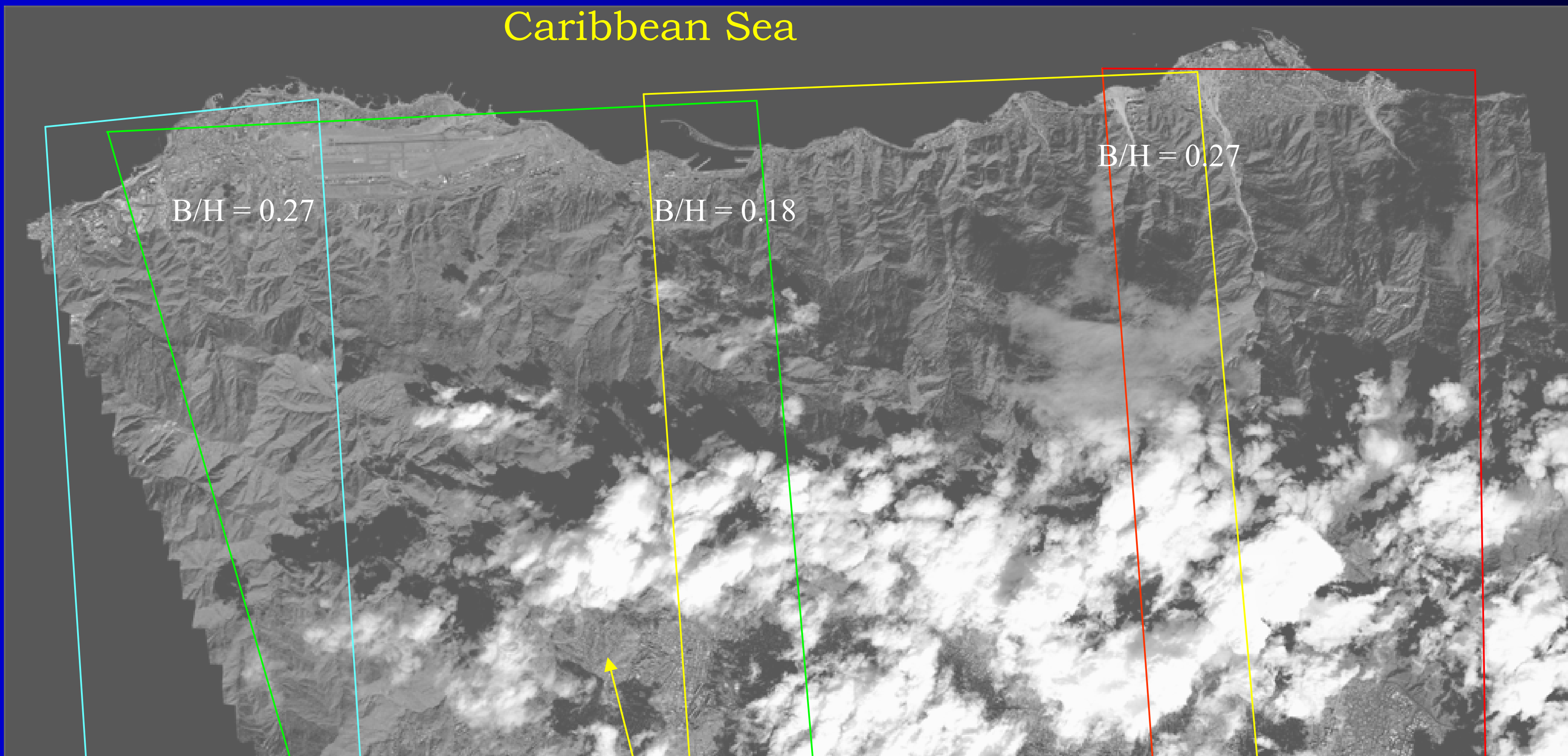
Due to weak stereo-intersection geometry (B/H < 0.5) between all segments, GCPs in the outer segments are not enough: error propagates through the centred segments



GCPs are needed in Segment 2 (B/H=0.06) and elevation tie points for the others (0.10 < B/H < 0.5)

Geometric processing: Ikonos block

Weak stereo-intersection geometry between the 4 segments: B/H < 0.3



(40 x 20 km)

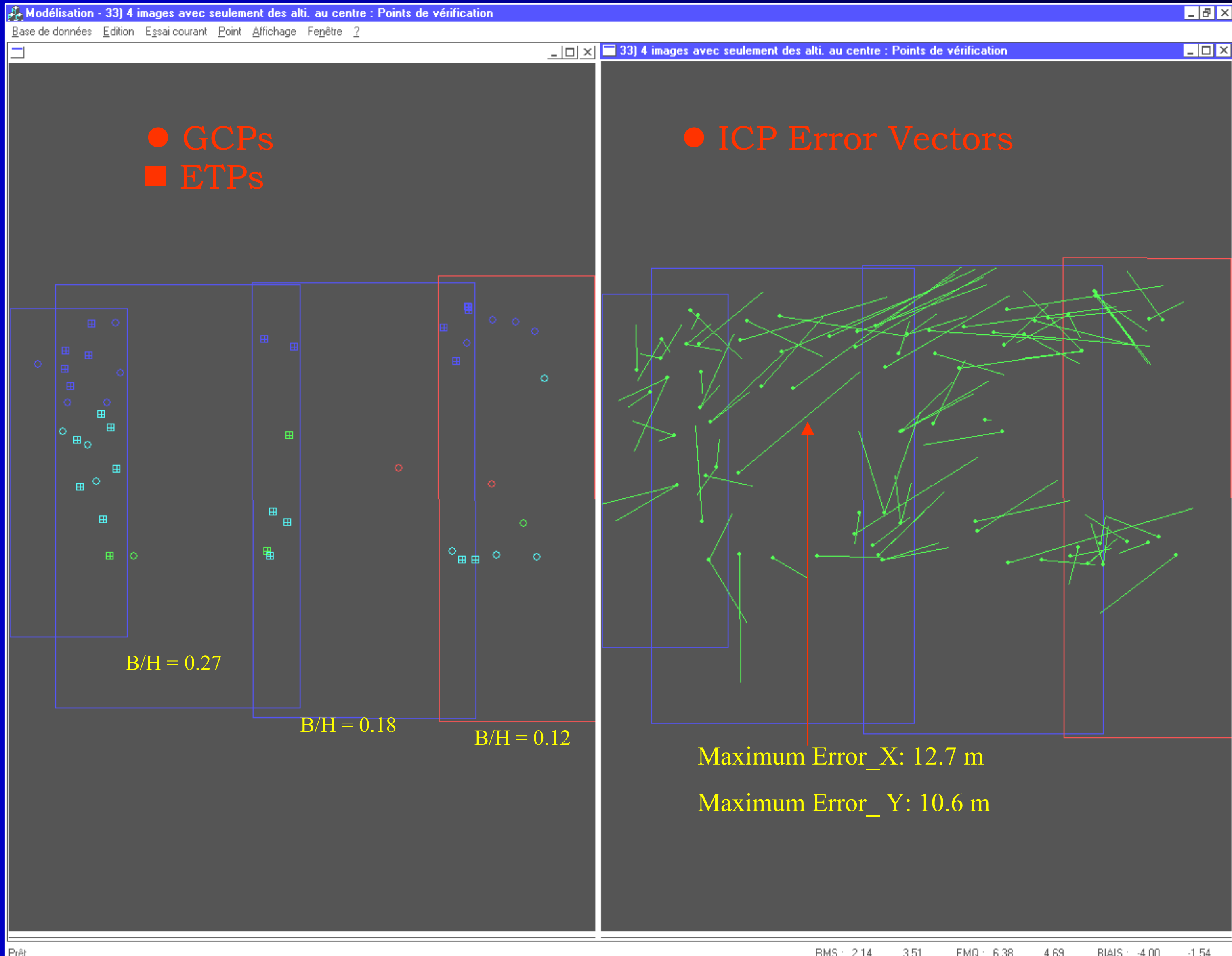
Caracas

IKONOS Images © 1999 Space Imaging LLC

Geometric processing: *Ikonos block*

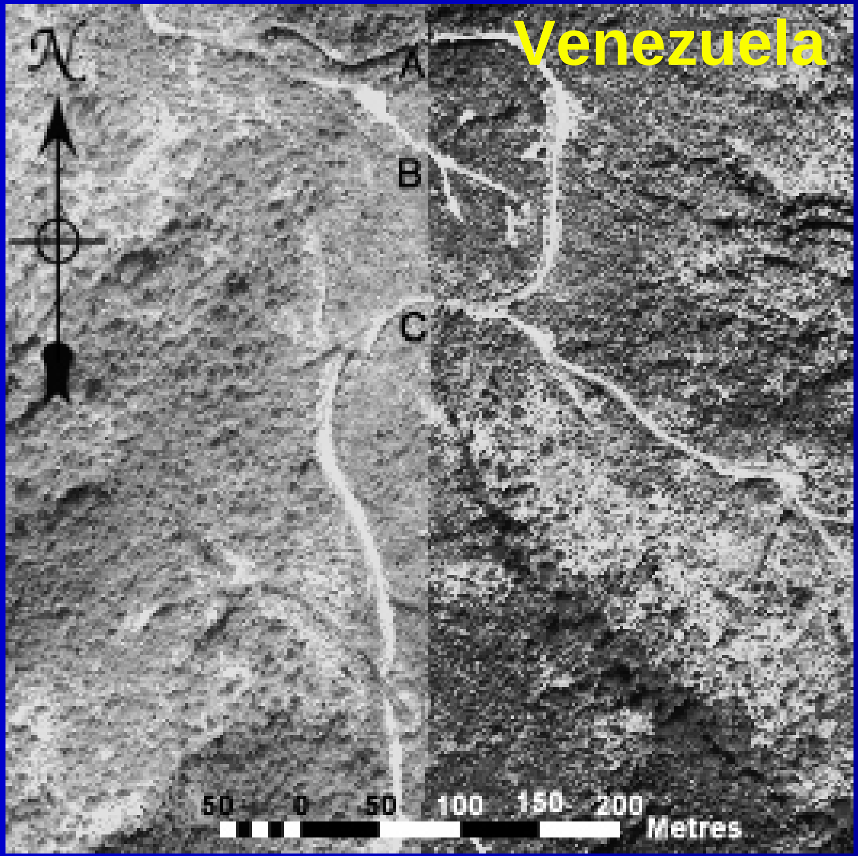
12 GCPs on outer images and 6-10 ETPs on inner images

The RMS errors are around 5m, which reflects the input map error



Relative evaluation of ortho-mosaic

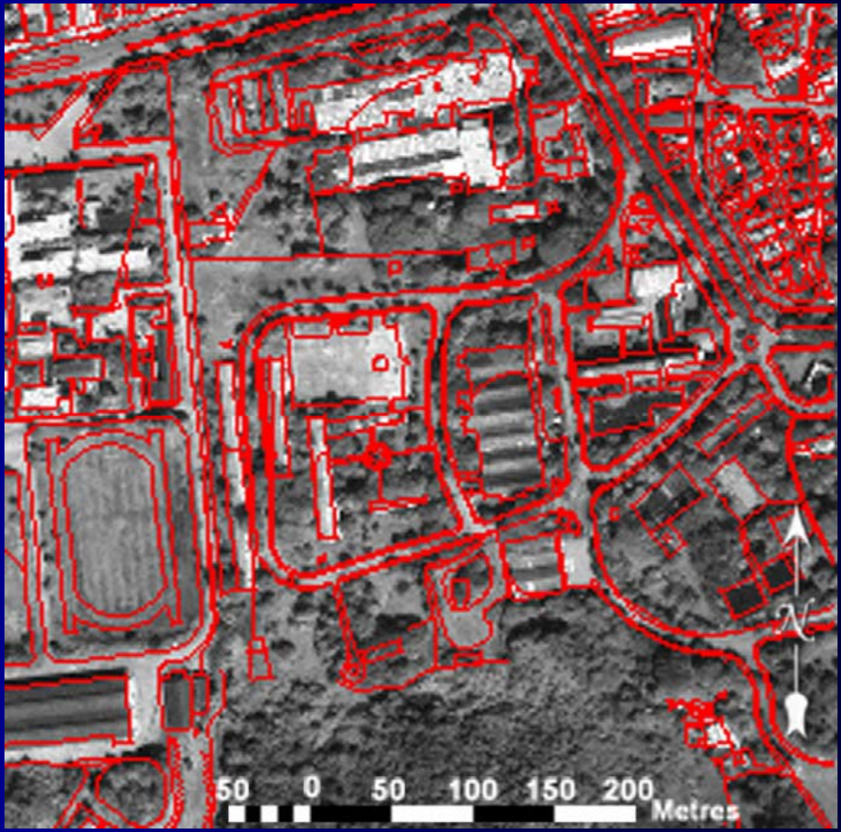
Two ortho-IKONOS



Relative accuracy: about 1 pixel

Evaluation with vector lines

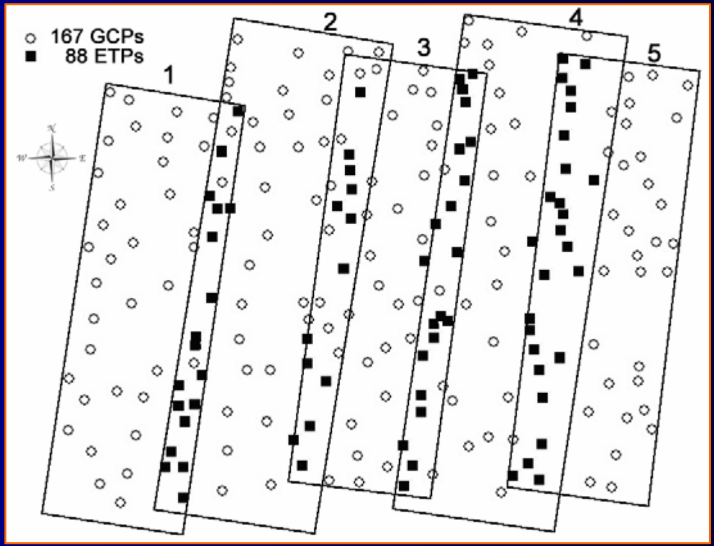
Ortho-IKONOS with 1:1000 vector lines

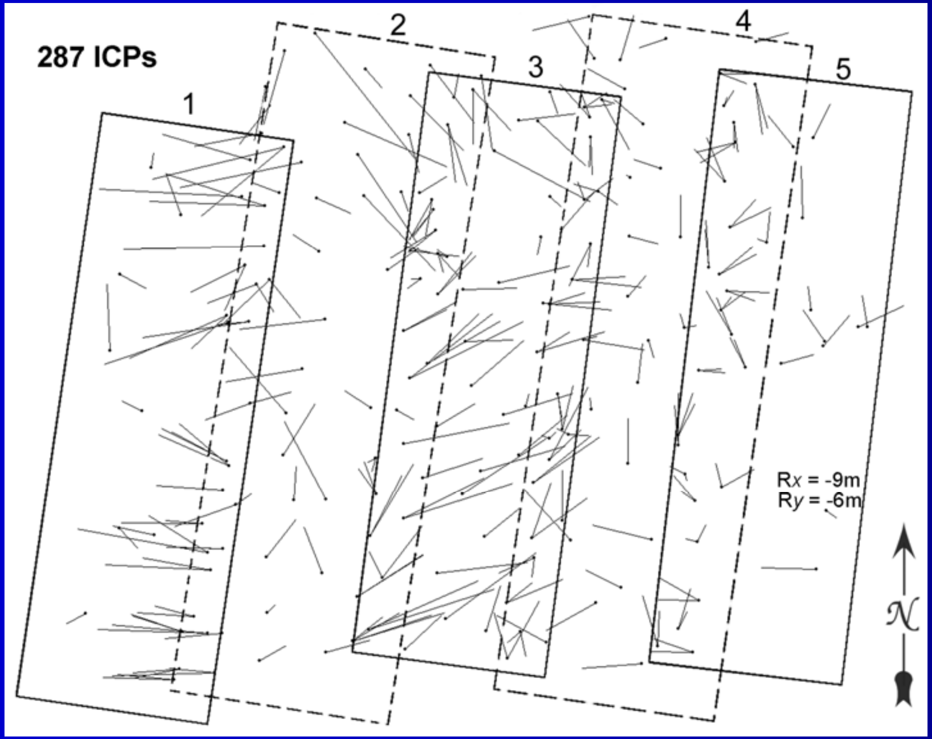


Absolute accuracy: about 1 m

Geometric processing: SAR block

GCPs and elevation TPs distribution within RADARSAT-1 fine mode image block

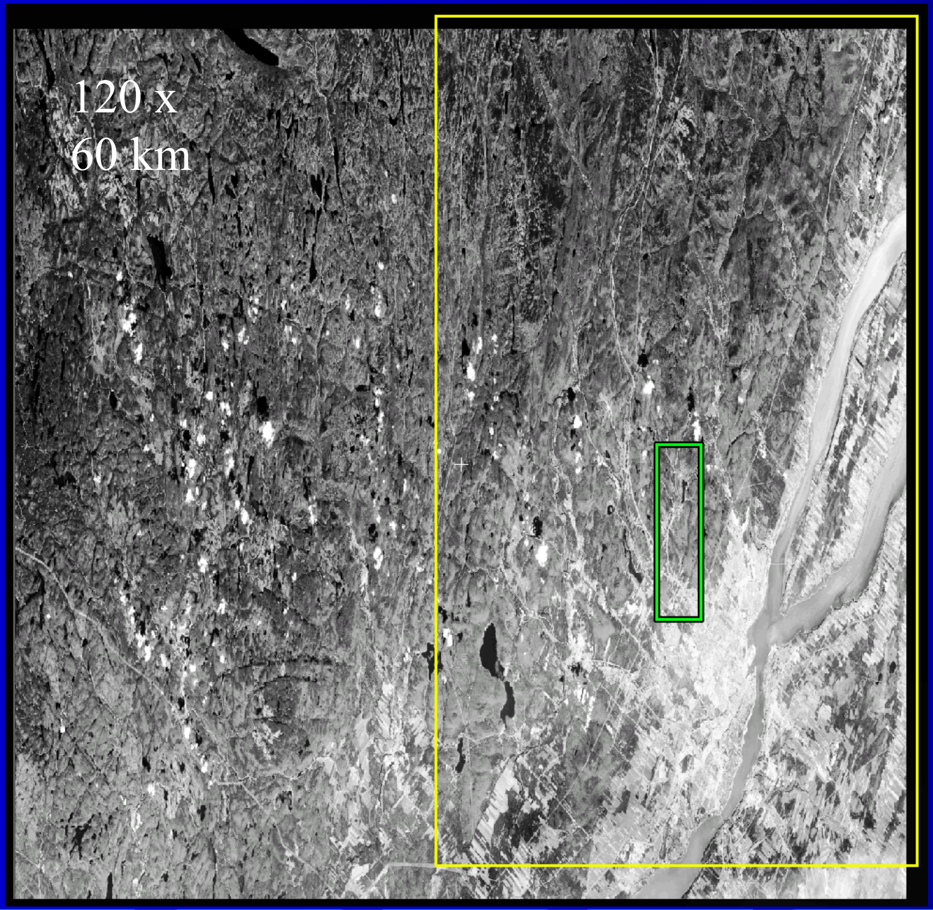




Due to weak stereo-intersection geometry bewtween F2-F4 (4°) GCPs were used every two segments

Geometric processing: *VFSR block*

Stereo block of SPOT5 HRS/SPOT5 HRG/Ikonos/QuickBird



The experiment used one of the SPOT5 stereo-pair (either HRS or HRG) as master, where only 12 GCPs are collected.

The other stereo pairs (HRG, Ikonos, QuickBird) are slave, where only TPs common with the master are collected.

The results are evaluated on ICPs belonging only to the slave stereo-airs.

Geometric processing: VFSR block

Processing of SPOT5 *master block* using **12 stereo GCPs** combined with all *slave blocks* using **few stereo ETPs**

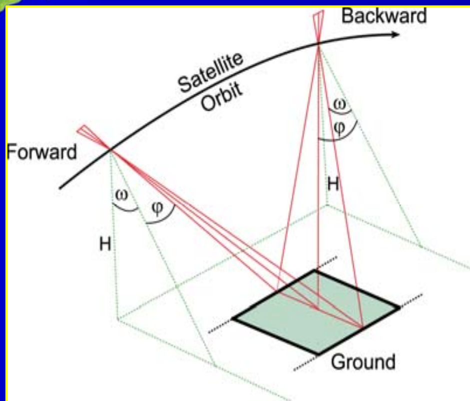
Master	Stereo Block Adjustment	ETP/ICP	RMS Error X	Y	Z
HRS	All *slave* blocks	82/84	2.4	2.9	3.1
HRG	All *slave* blocks	61/90	1.8	1.8	2.1

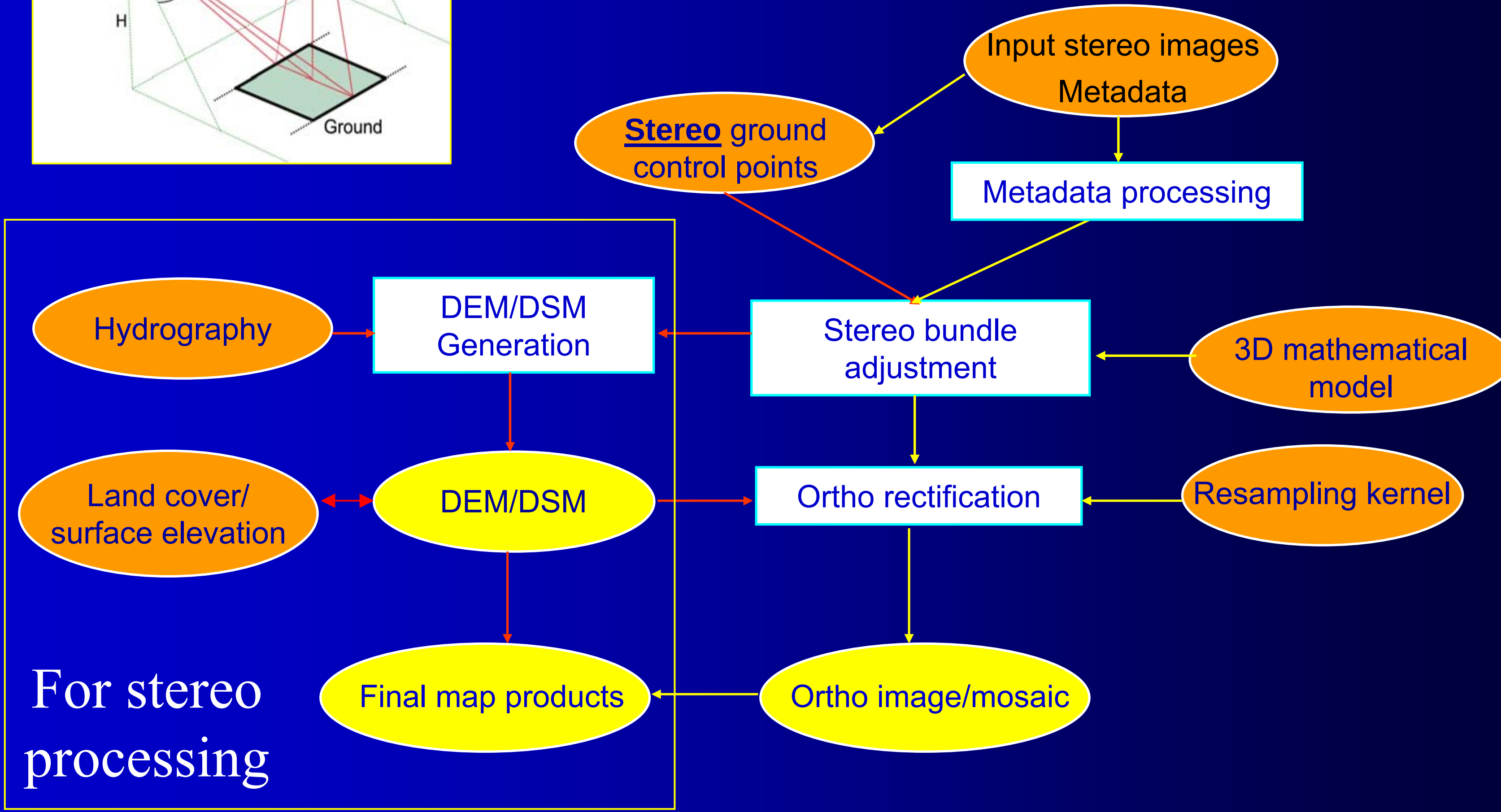
ICPs, belonging only to slave block(s), give errors for the slave block(s)

Geometric processing

1. Characterization of geometric distortions
2. Geometric corrections: models and **algorithms**
3. Single image processing
4. Strip and block processing
5. Stereo processing

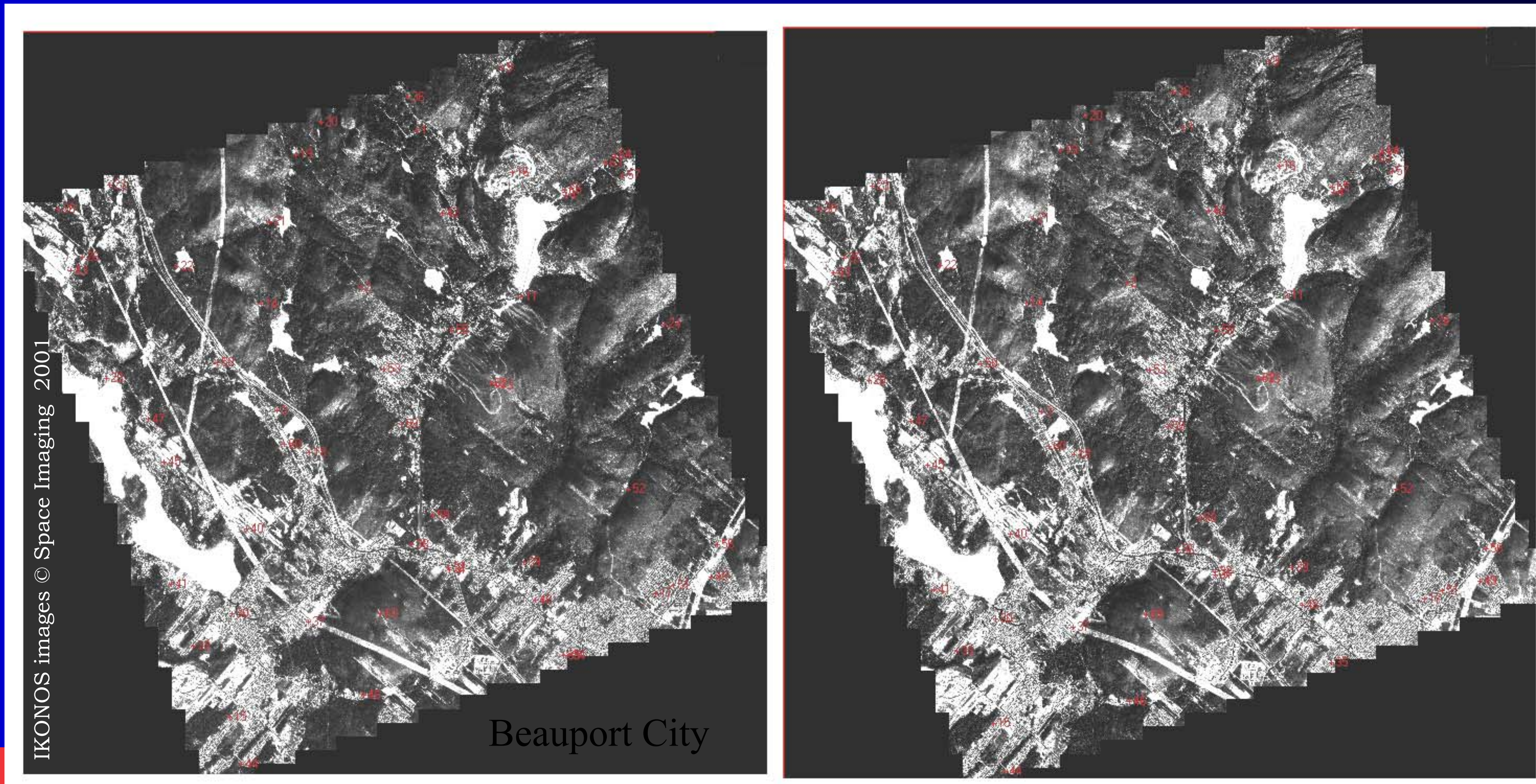
Stereoscopic processing





Stereo processing: GCPs

It is important to acquire GCPs in true stereoscopy with an apparatus instead of double monoscopy: stereo viewing cancels Y-parallaxes and improves the quality of the stereo modeling.



Stereo processing: GCPs

RADARSAT-SAR: field corner in stereo

Stereo collection enables

1. A better point definition
2. a link between the two images
3. A better relative/absolute accuracy

Stereo processing: bundle results

Stereo Bundle Test		RMS GCPs Residuals			RMS ICP Errors		
		X	Y	Z	X	Y	Z
SPOT-HRS	10 GCPs/88 ICPs	7.1	6.4	3.1	13.9	8.7	4.7
SPOT-HRG	10 GCPs/23 ICPs	1.5	1.4	1.3	2.6	2.2	2.9
EROS	18 GCPs/112 ICPs	2.4	2.8	3.8	4.2	4.2	5.9
I KONOS	10 GCPs/45 ICPs	1.5	1.4	1.3	2.6	2.2	2.9
Quickbird	10 GCPs/38 ICPs	0.6	0.7	0.4	1.5	1.6	1.4

RMS residuals/errors reflect the GCP/ICP errors: their definition and pointing (1-2 pixels) and map (2-3 m)

…but the 3D modeling precision is better than the pixel

Stereo processing: stereo bundle results

Examples with Radarsat-2 Ultra-fine (U)/Spotlight (SL) modes

Results (in metres) over ICPs from the adjustment computed with only one GCP

Image(s)	ICP	RMSE-X	RMSE-Y	RMSE-Z	Max X	Max Y	Max Z
U2-U25 HH	88	24.8	3.3	42.9	42.1	5.5	74
U2-U25 VV	60	2.1	3.6	3.6	4.8	5.8	8.0
SLA1-SLA24 HH	16	2.5	3.6	4.3	6	5	5

Error in U25 HH metadata (corrected since Fall 2008)

Accuracy on independent check points (ICP) around than 1-2 resolutions

Results (in metres) over ICPs from the adjustment computed with 8 GCPs

Image(s)	ICP	RMSE-X	RMSE-Y	RMSE-Z	Max X	Max Y	Max Z
U2-U25 HH	81	1.4	1.3	1.6	3.2	2.4	3.4
U2-U25 VV	52	1.7	1.9	2.5	4.7	3.7	6.1
SLA1-SLA24 HH	9	0.9	1.1	1.2	1.3	1.8	2.8

Accuracy on independent check points (ICP) better than one pixel

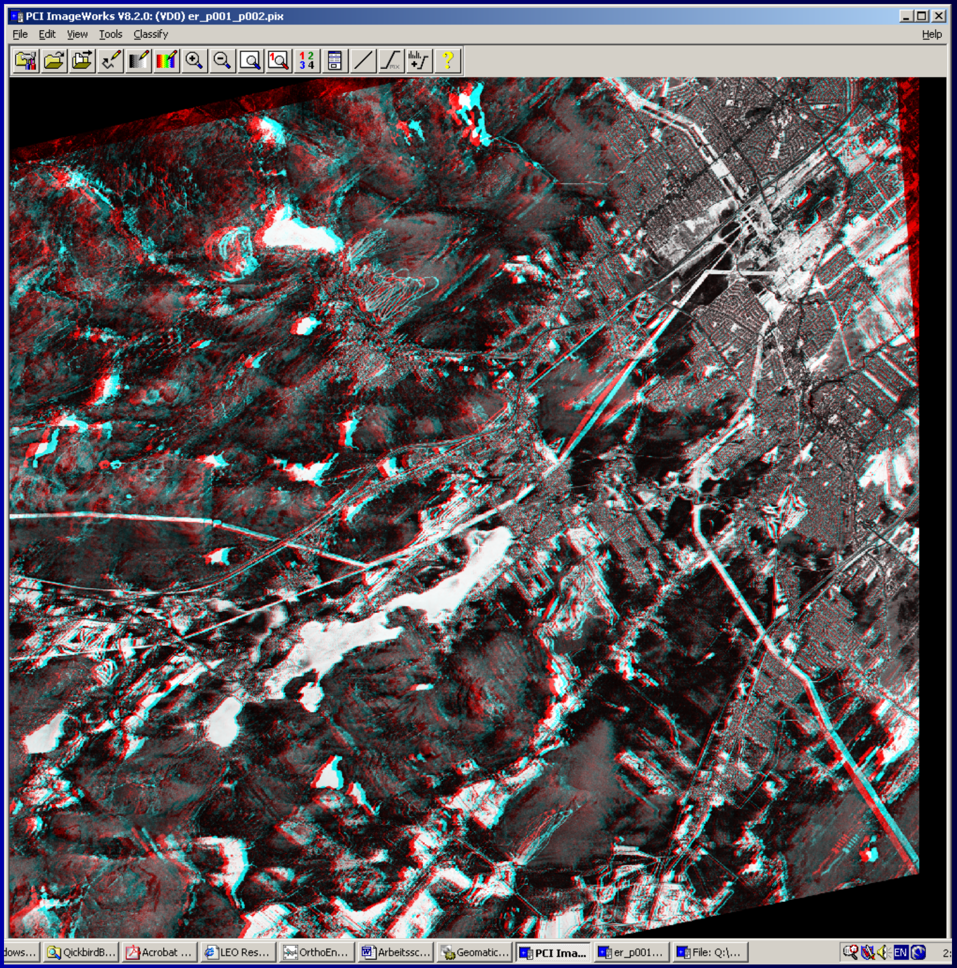
Stereo processing: *epipolar*

Epipolar images are stereo pairs that are reprojected so that the left and right images have a common orientation, and matching features between the images appear along a common x axis.

- Corrected for systematic distortion (satellite, sensor, earth rotation)

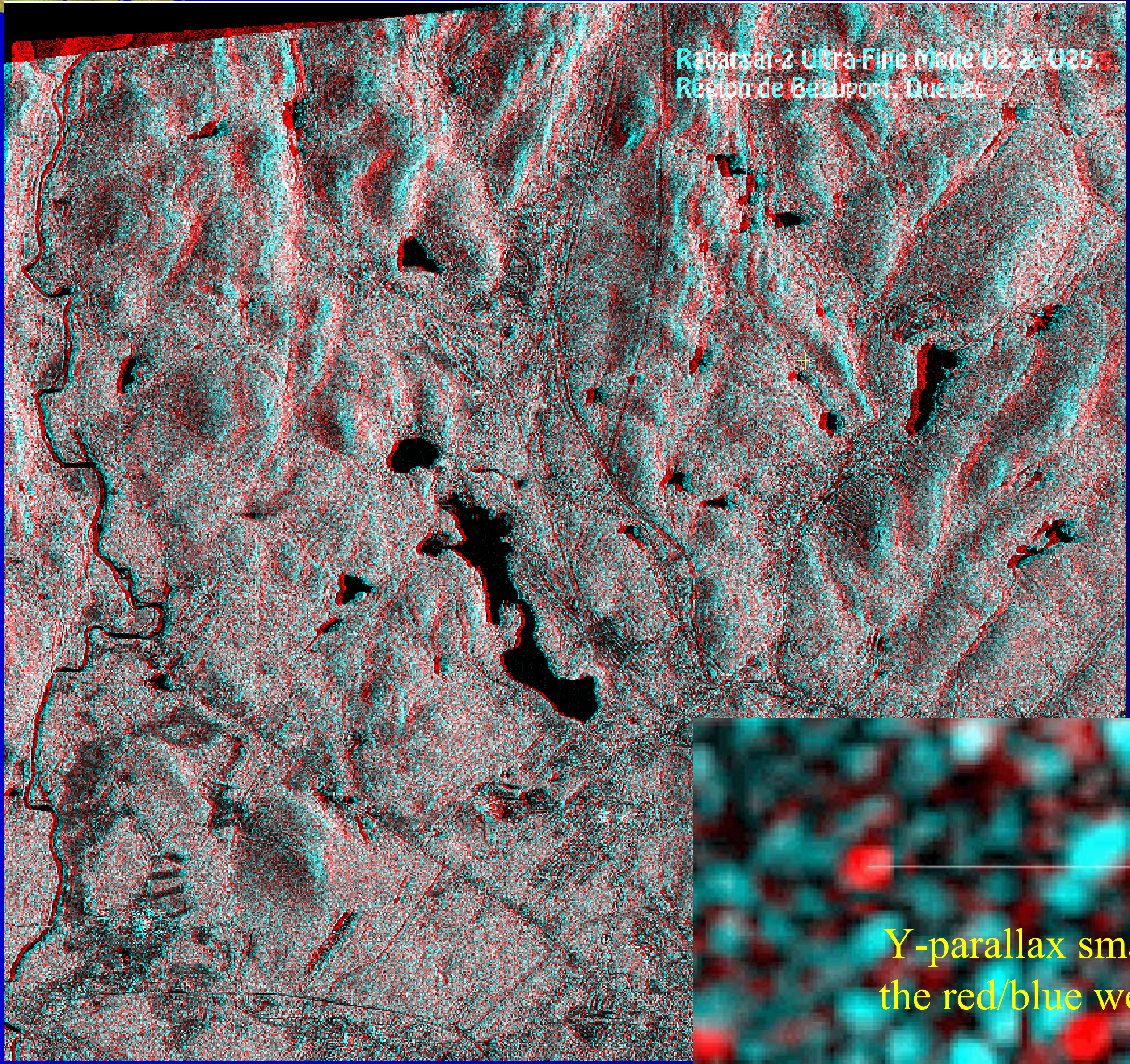
- Corrected stereoscopic parallax (is caused by a shift in the position of observation)

- Correlation (looking for the same point in the two images)

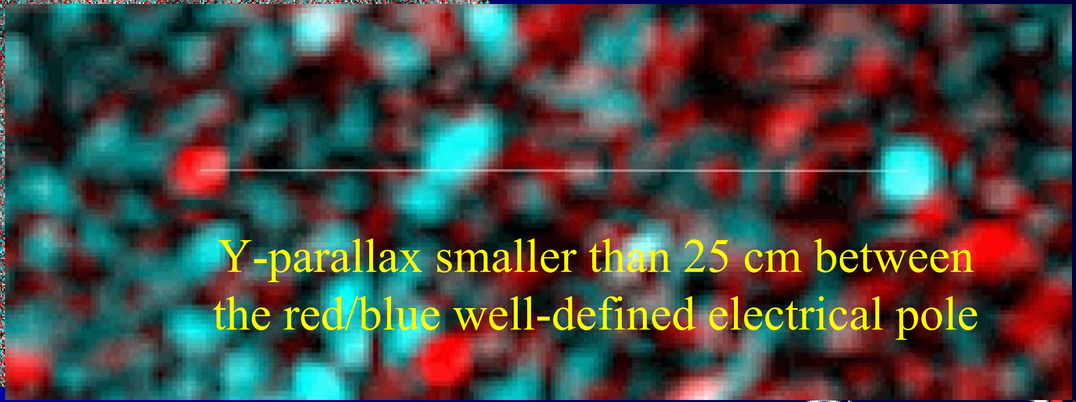


Formosat-2 anaglyph

Stereo processing: epipolar



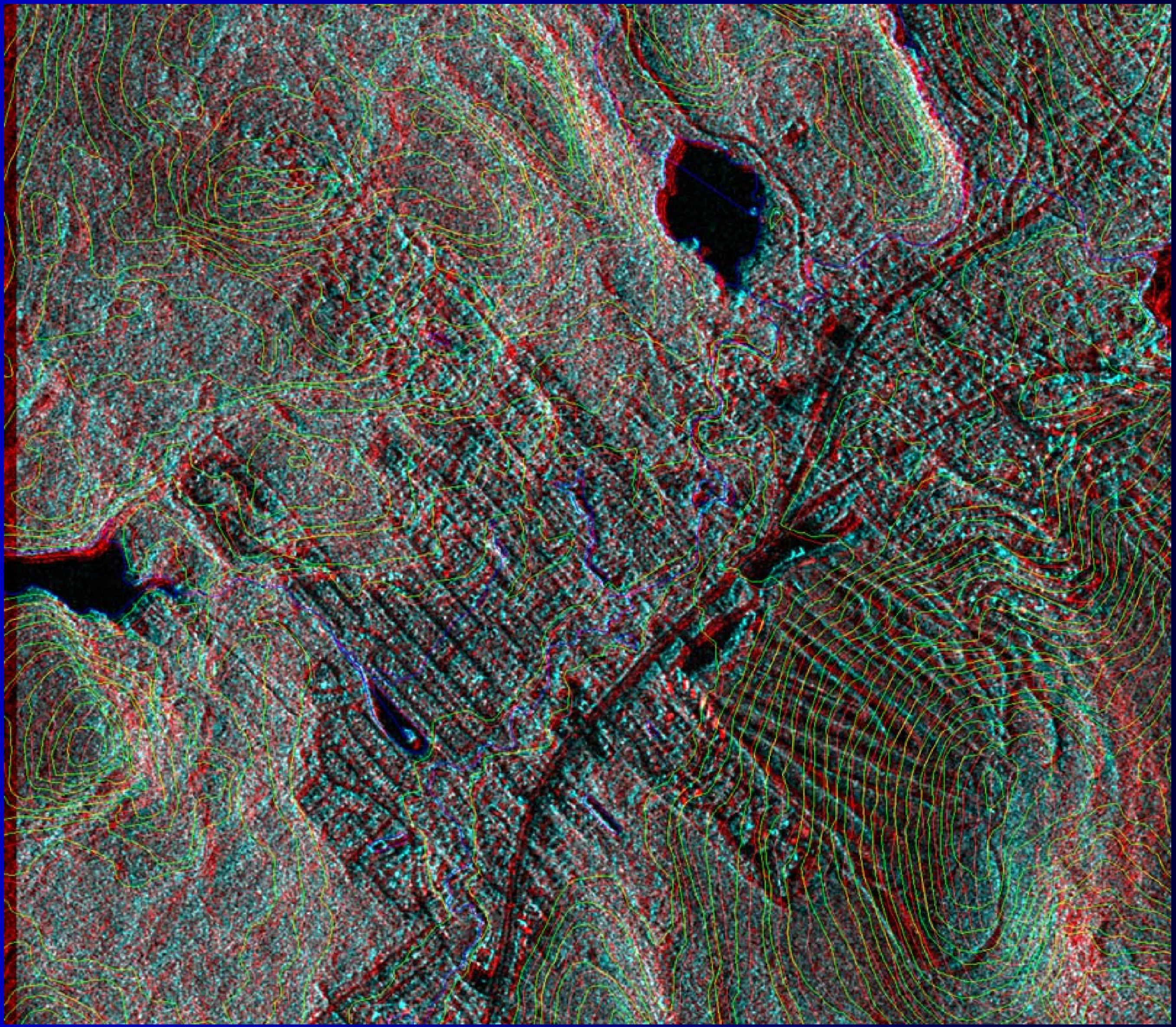
Good stereo-vision implies no Y-parallax and thus good geometric modeling (<1 pixel)



Stereo processing: *epipolar*

Radarsat-2 ultra fine mode (3-m resolution)

Epipolar ovelaid with 20k contour lines



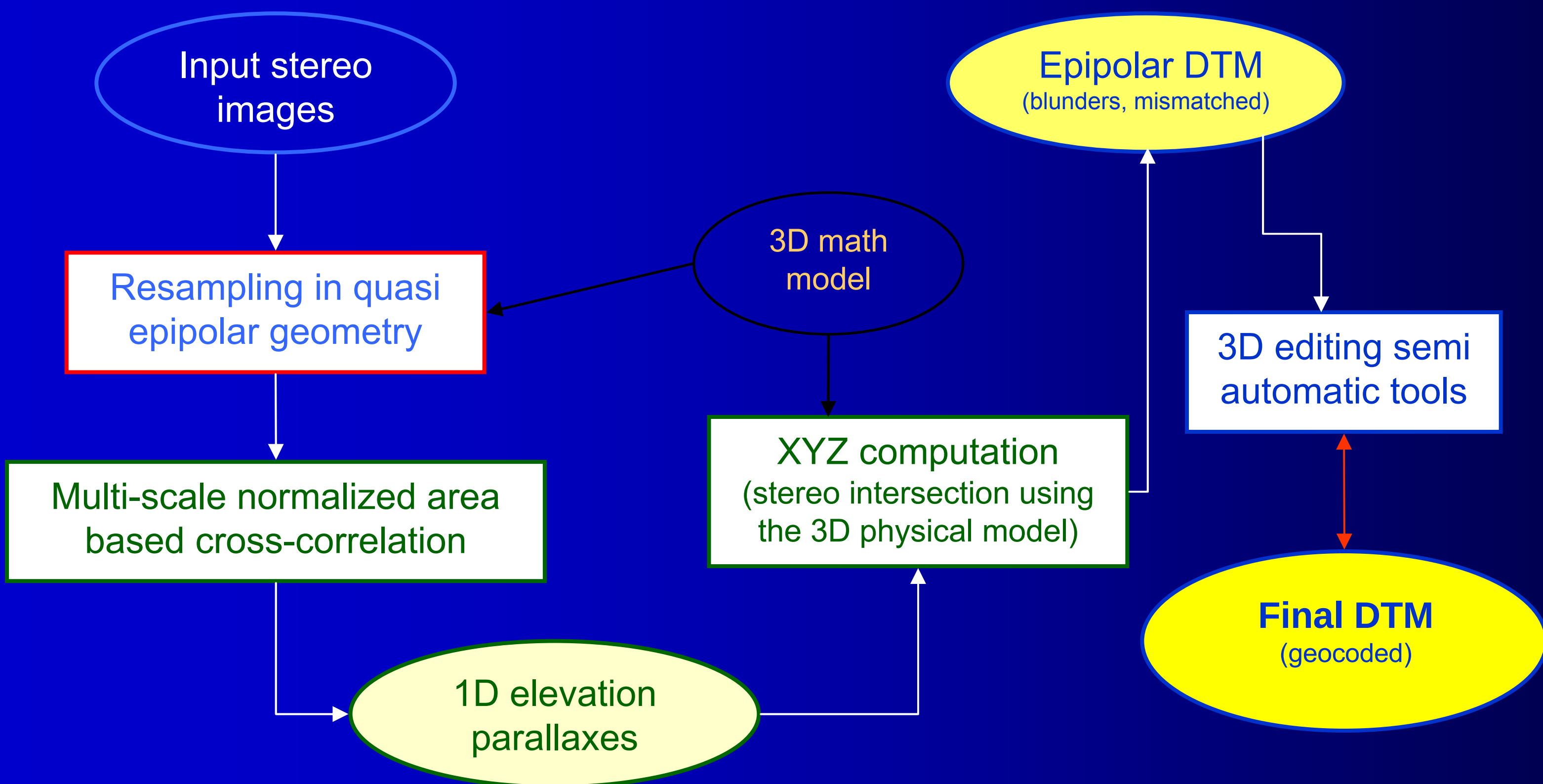
Stereo processing: matching

There are different tools to extract elevation parallaxes between the stereo images (Marr, 1982)

- Grey level image matching (Mar and Poggio, 1977)
  - Performed on area in the image domain *with normalized cross-correlation*
  - Widely used in remote sensing
- Least-square matching (Förstner, 1982)
  - Performed on area in the object domain
  - Least square approach *minimizing the squares of image grey level differences*
  - Widely used with digital air photos due to multiple overlaps
- Feature based image matching (Mar and Hildreth, 1980)
  - Performed with common feature in image domain
  - Widely used in computer vision, not very popular in remote sensing

Stereo processing: matching

DSM Generation steps



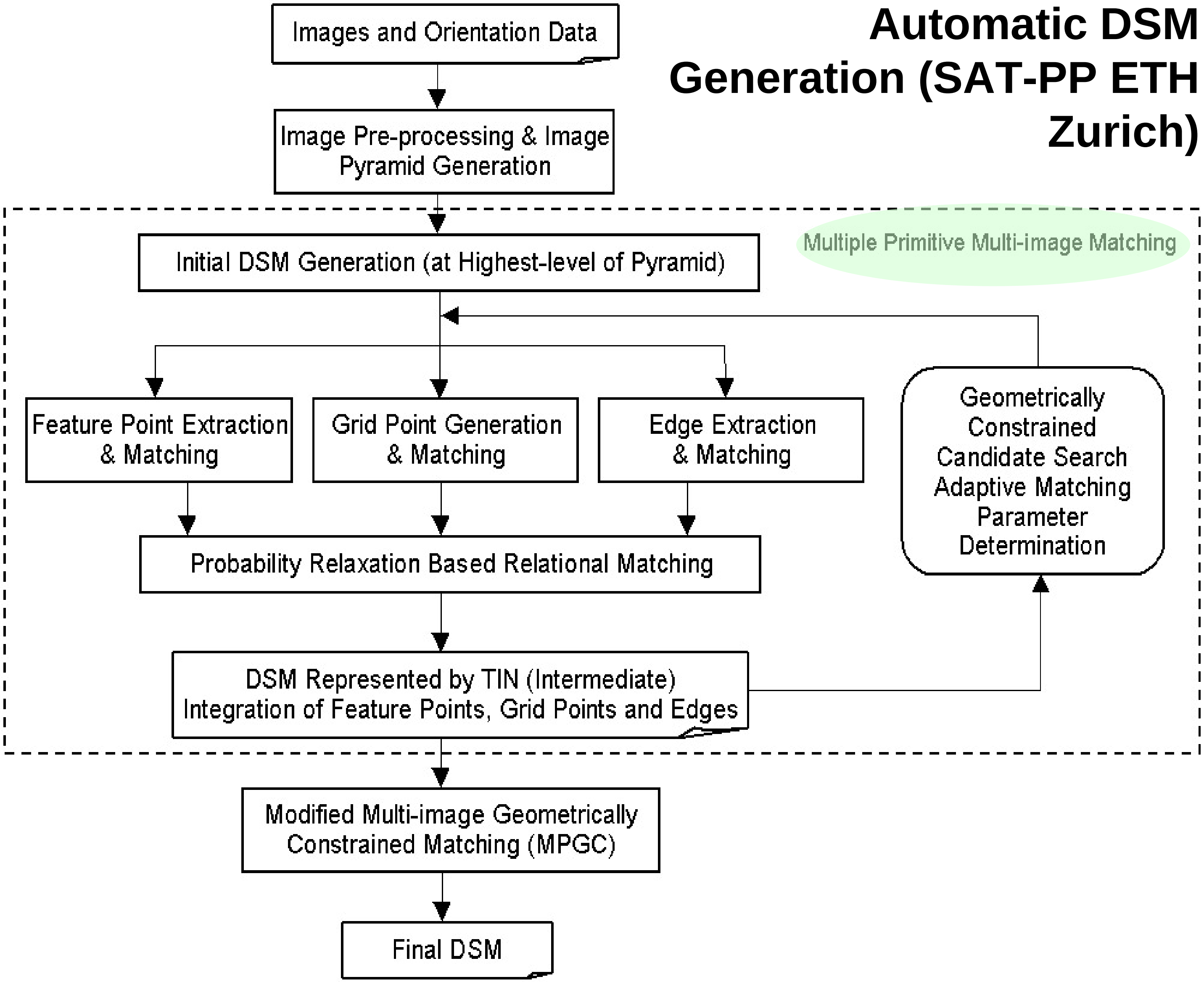
Stereo processing: matching

Automatic DSM Generation

- Matching modules exist in various commercial RS and photogrammetric systems. Methods used are often based on cross-correlation and match at a regular object or image grid.
- Much better methods exist in research labs.
- For good quality the breaklines must be well modeled, which can be achieved by using edge-based matching, in combination with other matching methods.
- In urban and mountainous areas, if possible, it is essential to use more than 2 images, for better reliability, accuracy and reduction of occlusions (but currently a maximum of only 3 along-track images can be acquired with ALOS-PRISM)

Stereo processing: matching

Automatic DSM Generation (SAT-PP ETH Zurich)



Stereo processing: DSM accuracy

System (resolution)	Count	LE68	LE90	Bias	Min./Max.
SPOT HRS (10x5 m)	5.4 M	6.5 m	10 m	2 m	-80/72 m
SPOT HRG (5 m)	5.3 M	6.5 m	10 m	2 m	-80/72 m
EROS (1.8 m)	5.4 M	20.0 m	31 m	3 m	-52/115 m
IKONOS (0.8 m)	5.5 M	4.0 m	7.5 m	2 m	-28/30 m
QuickBird (0.6 m)	5.3 M	6.7 m	9.0 m	6 m	-21/29 m

The largest errors (over ± 20 m) with SPOT represent only 1%, due to radiometric differences (melting snow) between the images

The worse results are obtained with the asynchronous EROS system.

The biases are related to images in winter versus lidar DEM in summer.

DEMs are in fact DSMs, which integrate surface heights

Stereo processing: DSM

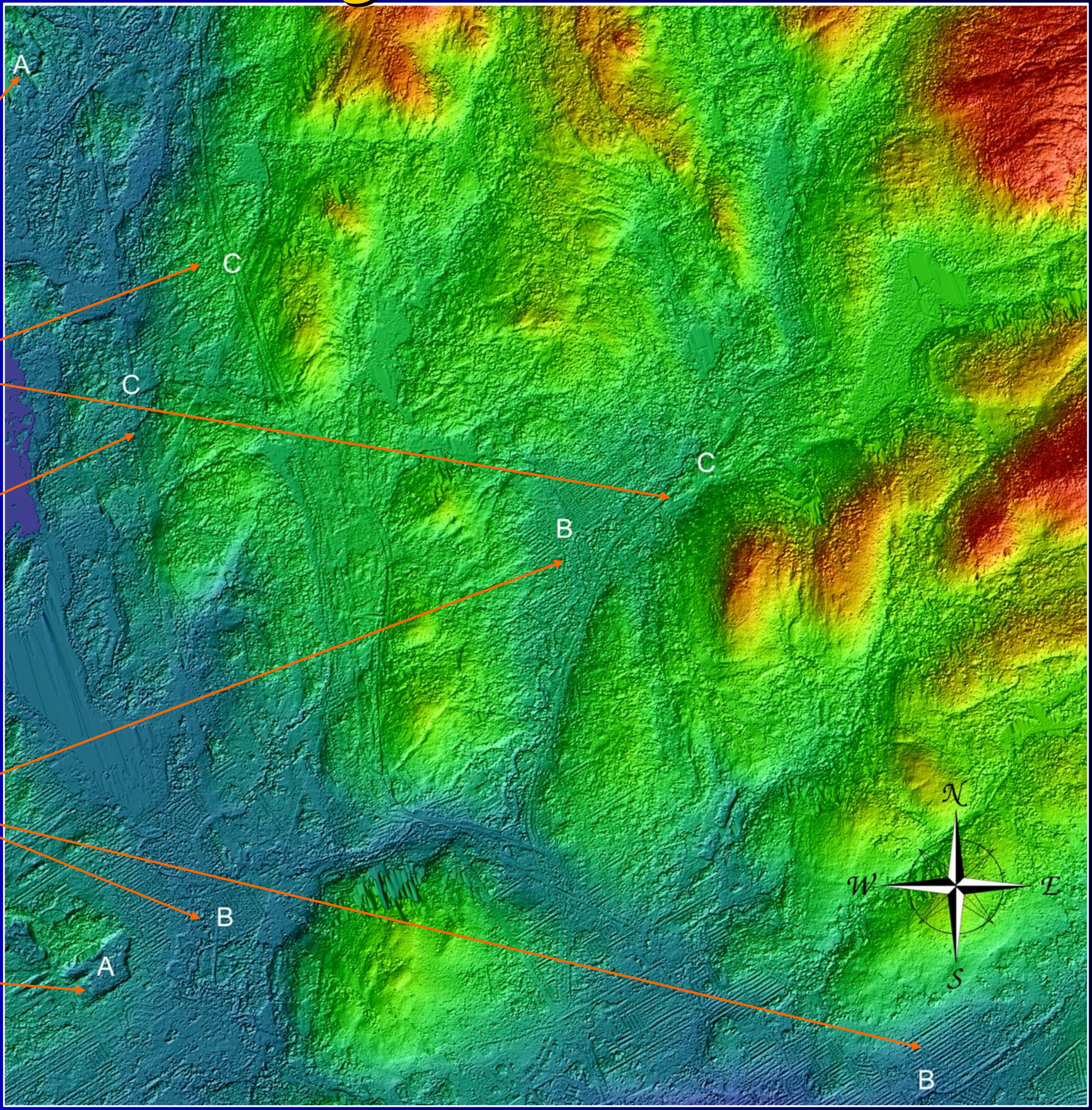
A Sand pits

C Roads

C Power lines

B Residential areas

A Sand pits



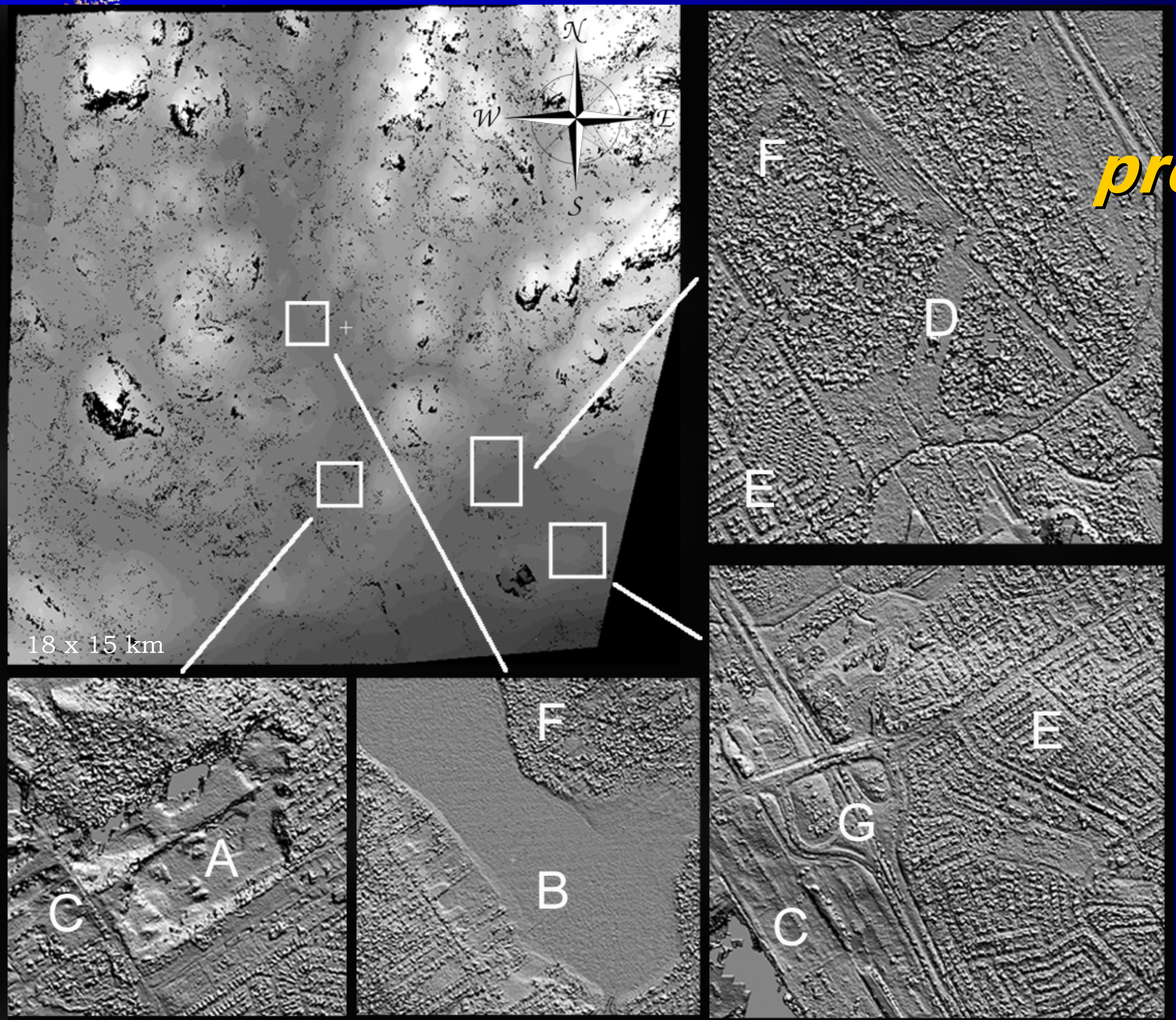
10 km x 10 km

Stereo processing: DSM

1 km x 1 km

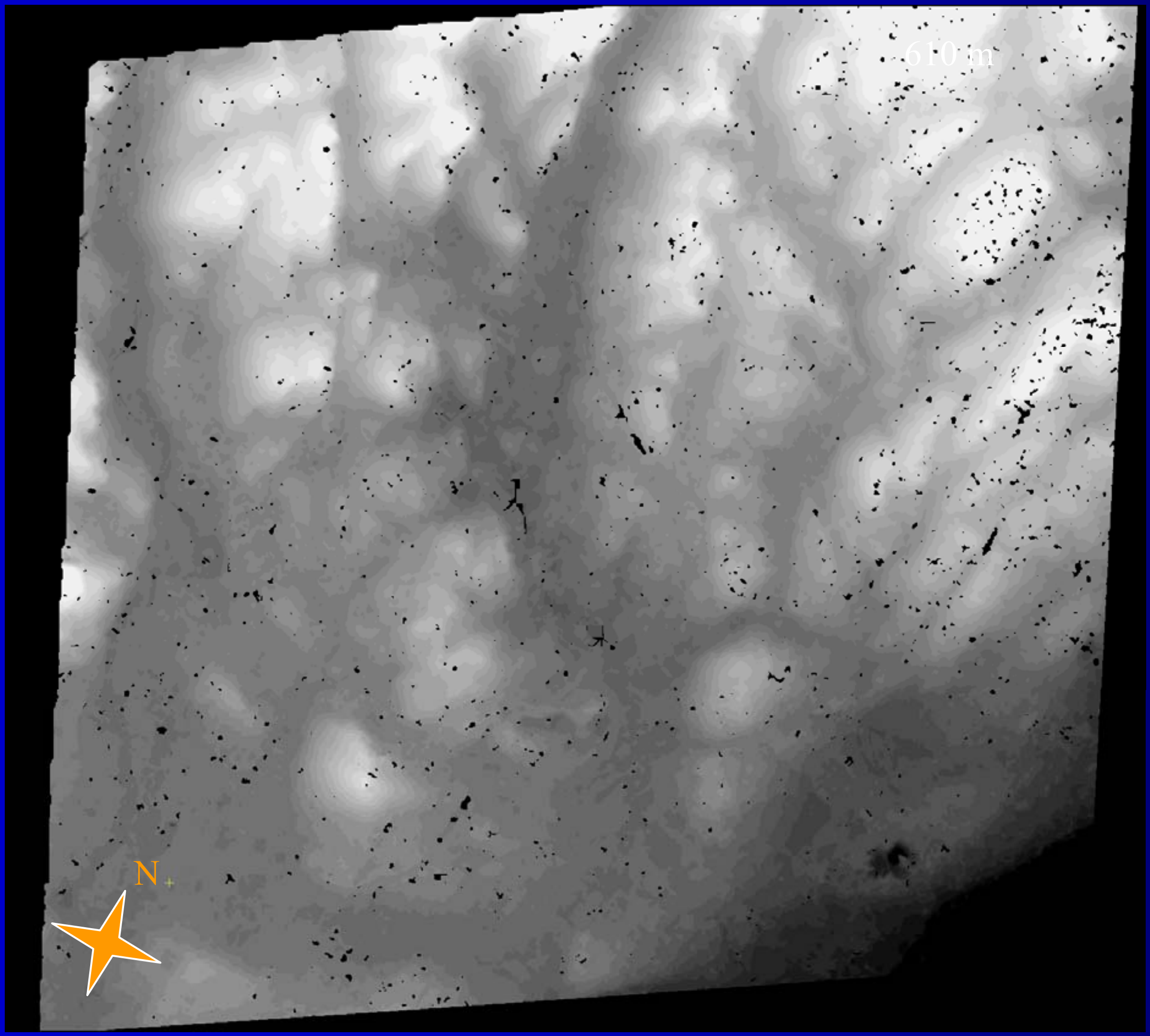
Stereo processing: DSM

Stereo processing: DSM



A Sand pits
B Lakes
C Bare soils
D Power corridors
E Residential
F Trees no leaves
G Highways

Stereo processing: SAR DSM



Raw DSM U2-U25

3 m posting

More than 98% matching

-2 m bias

2.9 m RMS errors on 89 ICPs

Lidar – DSM

-4 m bias; 4-6 m LE68

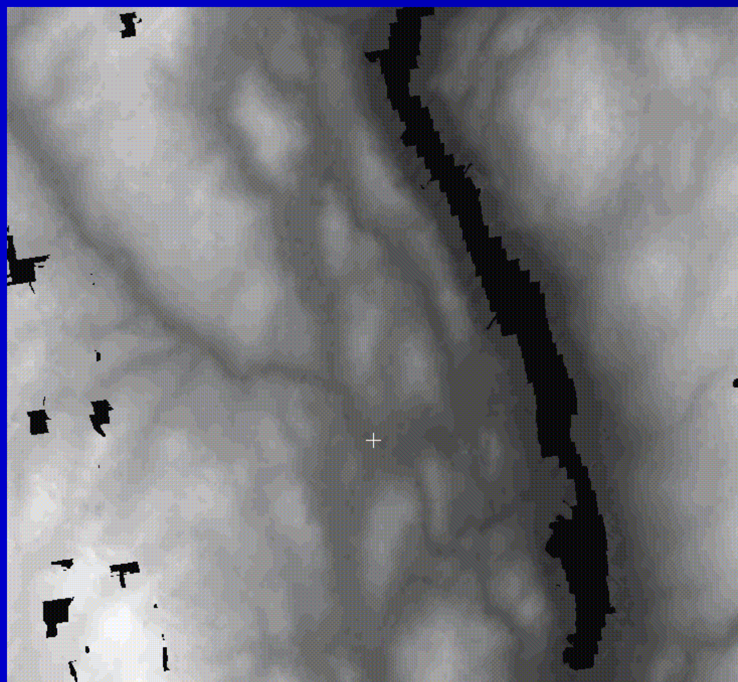
Min/Max -48/88 m due to blunders

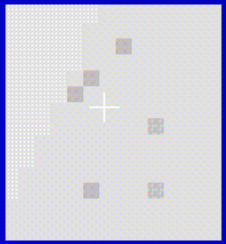
The raw DSM needs some post-processing:

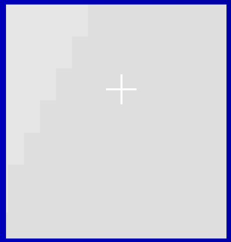
- blunders removals
- water bodies
- interpolation
- smoothing

Stereo processing: DSM post-processing

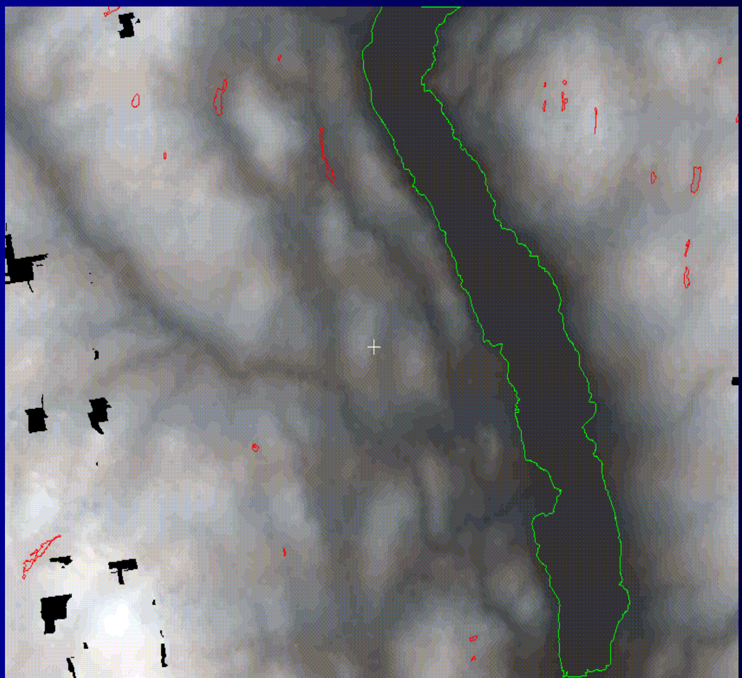
Blunders removed

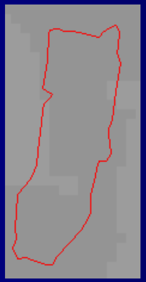


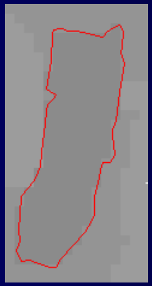




Lakes corrected

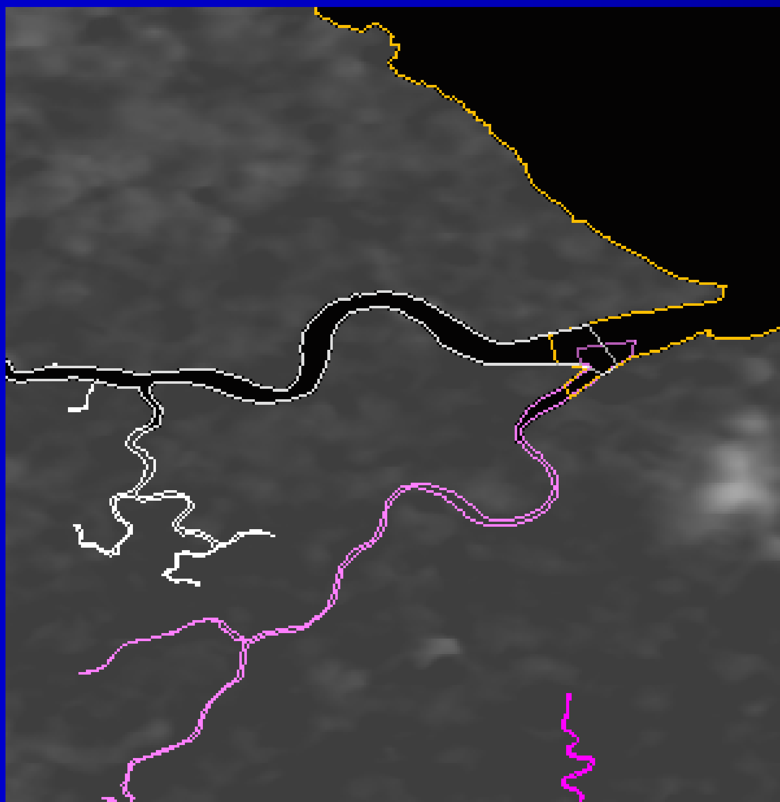






Stereo processing: DSM post-processing

Water courses & shorelines

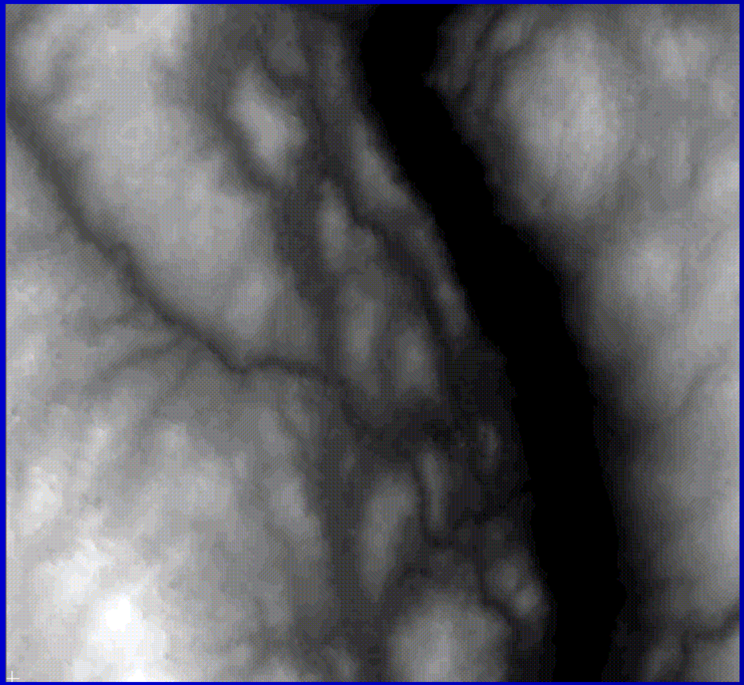


Large mismatched areas corrected

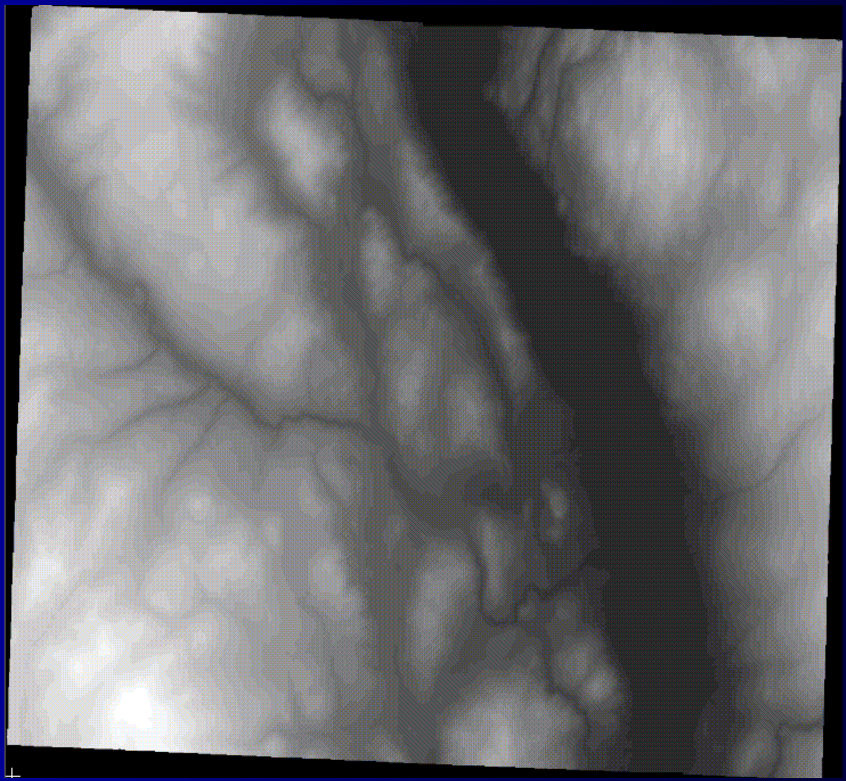
3D stereo restitution is used for this post-processing: the shorelines (left) and the contour lines (right)

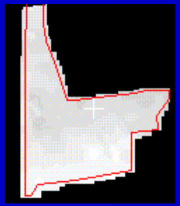
Stereo processing: DSM post-processing

Small mismatched areas interpolated



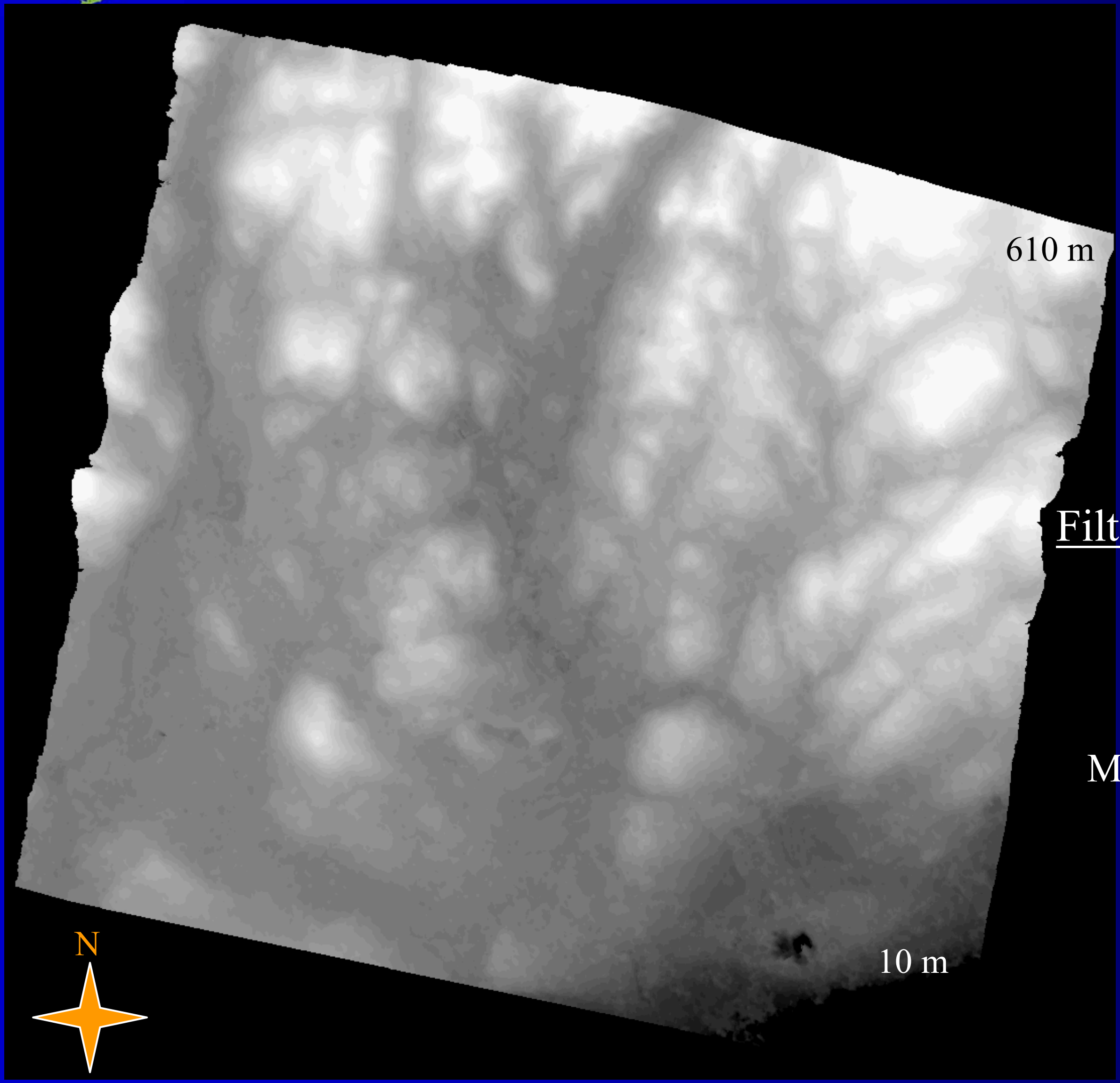
Final DEM





- Vector around mismatched area
- Elevation points using stereo plotter

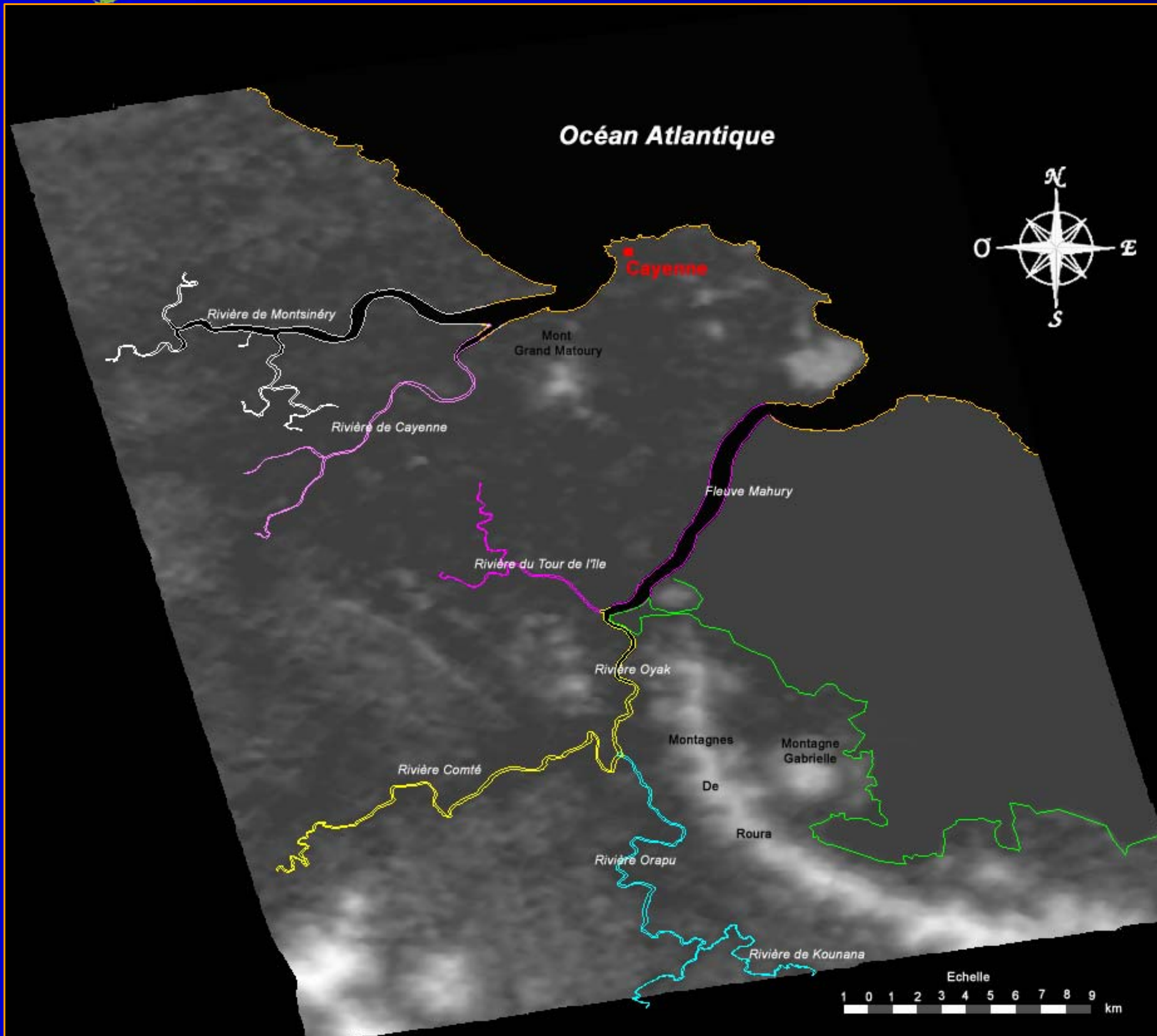
Stereo processing: SAR DSM



Filtered/Interpolated/Smoothed DSM U2-U25

Blunders were removed;
Mismatched areas were interpolated;
Smoothing was performed

Stereo processing: DSM post-processing

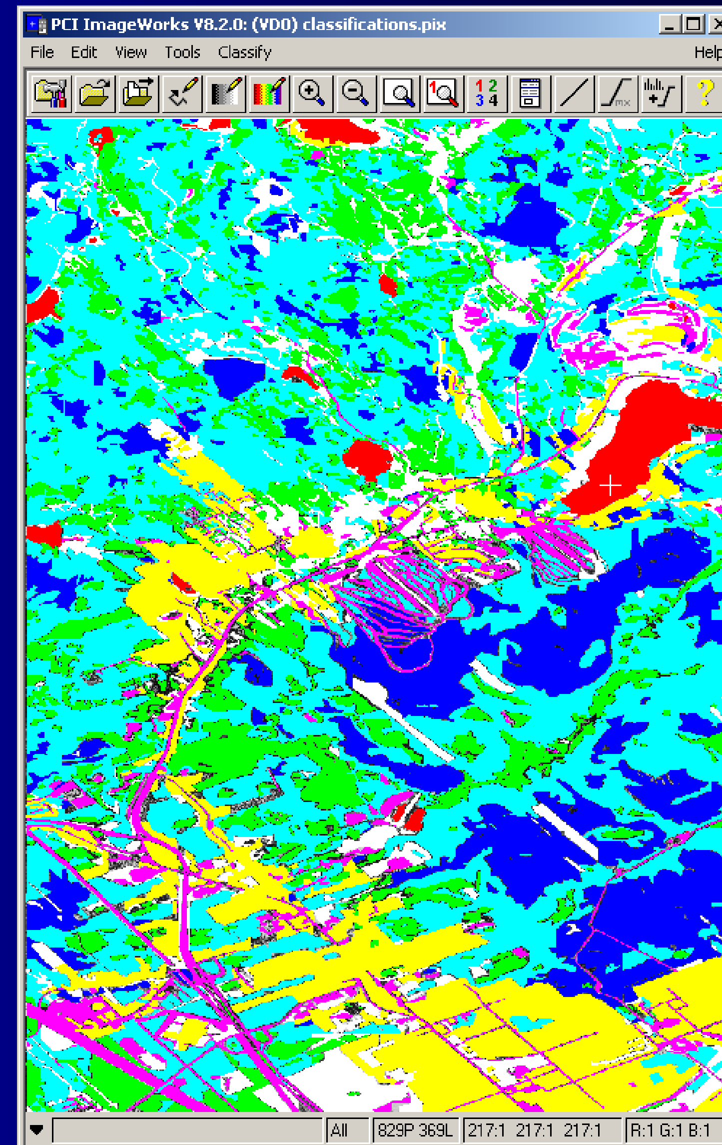


DSM should be topographically coherent with water bodies:

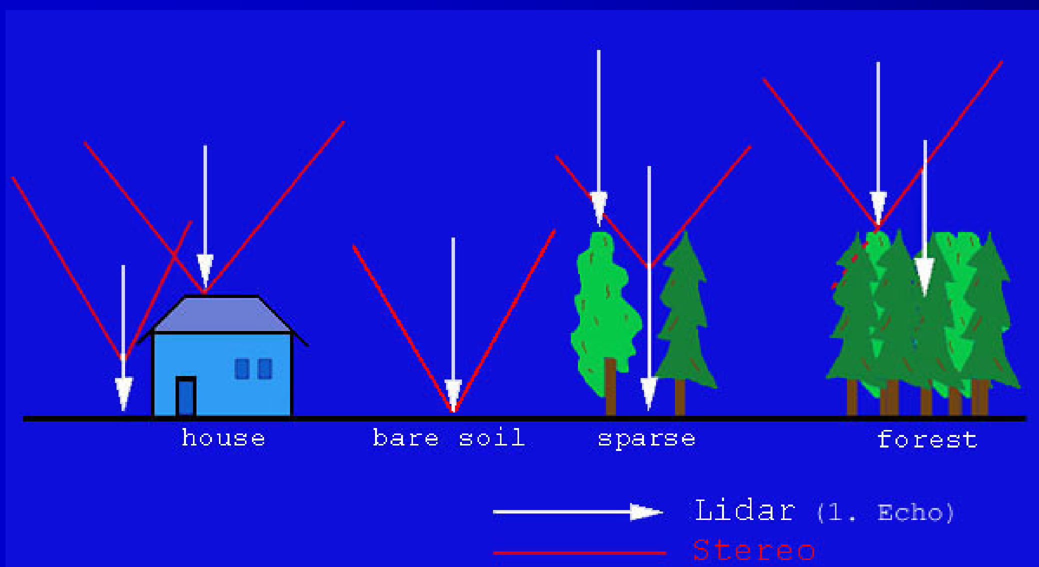
- Rivers
- Flat lakes/oceans
- Shorelines

Stereo processing: land cover

(red)	lakes
(magenta)	bare soil
(yellow)	city
(white)	sparse
(blue)	deciduous
(green)	coniferous
(cyan)	mixed



Why making different land cover classes?



Stereo processing: Land Cover

Land cover	Percentage	LE68	LE90	Bias	Min./Max.
Entire	100%	6.4 m	10 m	6.0 m	-36/64 m
Deciduous forests	31%	6.0 m	9 m	12 m	-19/37 m
Conifer forests	12%	4.0 m	7.5 m	2 m	-28/30 m
Mixed forests	36%	6.6 m	10 m	7 m	-26/65 m
Sparse forests	6%	4.0 m	8.5 m	4 m	-19/29 m
Urban/Residential	7%	2.5 m	6 m	4 m	-13/35 m
Bare soils	8%	1.5 m	3.5 m	1.5 m	-23/32 m

The entire DSM is mainly influenced by the mixed forest (36%)

The results are mainly dependent of the land cover, and the worse results (LE90 10m) are obtained in the mixed forests

The bias is related to IKONOS DSM (winter) vs lidar DSM (summer)

The best results (LE90 3.5 m) are obtained on bare soils

Stereo processing: bare surfaces

System (Resolution)	*B/H*	*LE68*	*LE90*	*Bias*	*Over 3 LE68*
SPOT-HRS (10x5 m)	0.85	2.7 m	5.6 m	0.2 m	4.0%
SPOT-HRG (5 m)	0.77	2.2 m	5.0 m	-2 m	3.0%
IKONOS (0.8 m)	1.0	1.5 m	3.5 m	1 m	5.0%
QuickBird (0.6 m)	1.1	1.3 m	3 m	0 m	4.5%

Best absolute accuracy is with the highest resolution sensor and B/H

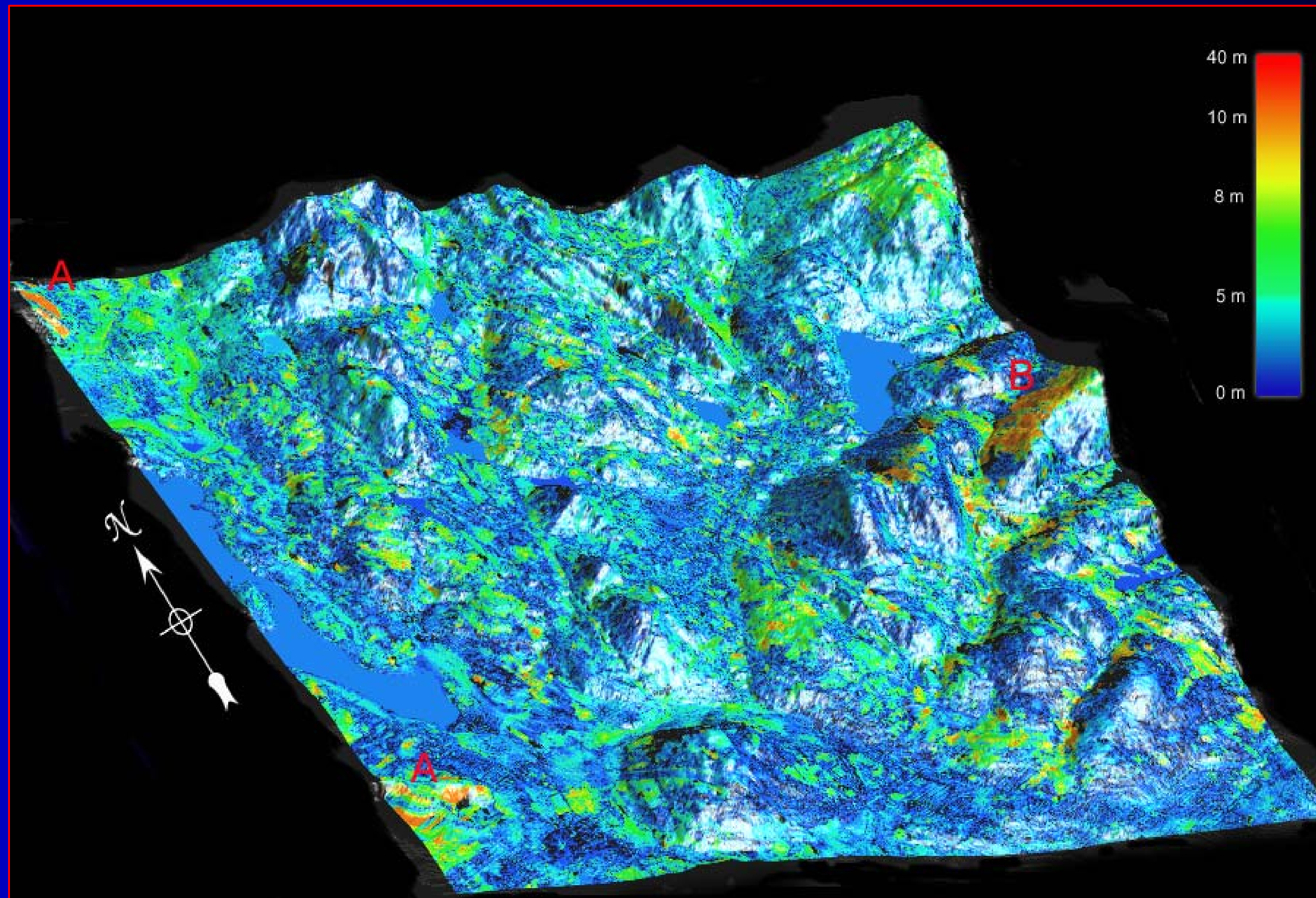
Best relative accuracy is with the lowest resolution sensor and B/H.

WHY???

1. SPOT are raw images: original radiometry and geometry
2. SPOT is at higher altitude: less orbital perturbations

Stereo processing: *slopes*

Ikonos **DSM errors** draped on topographic DEM shows correlation with slopes



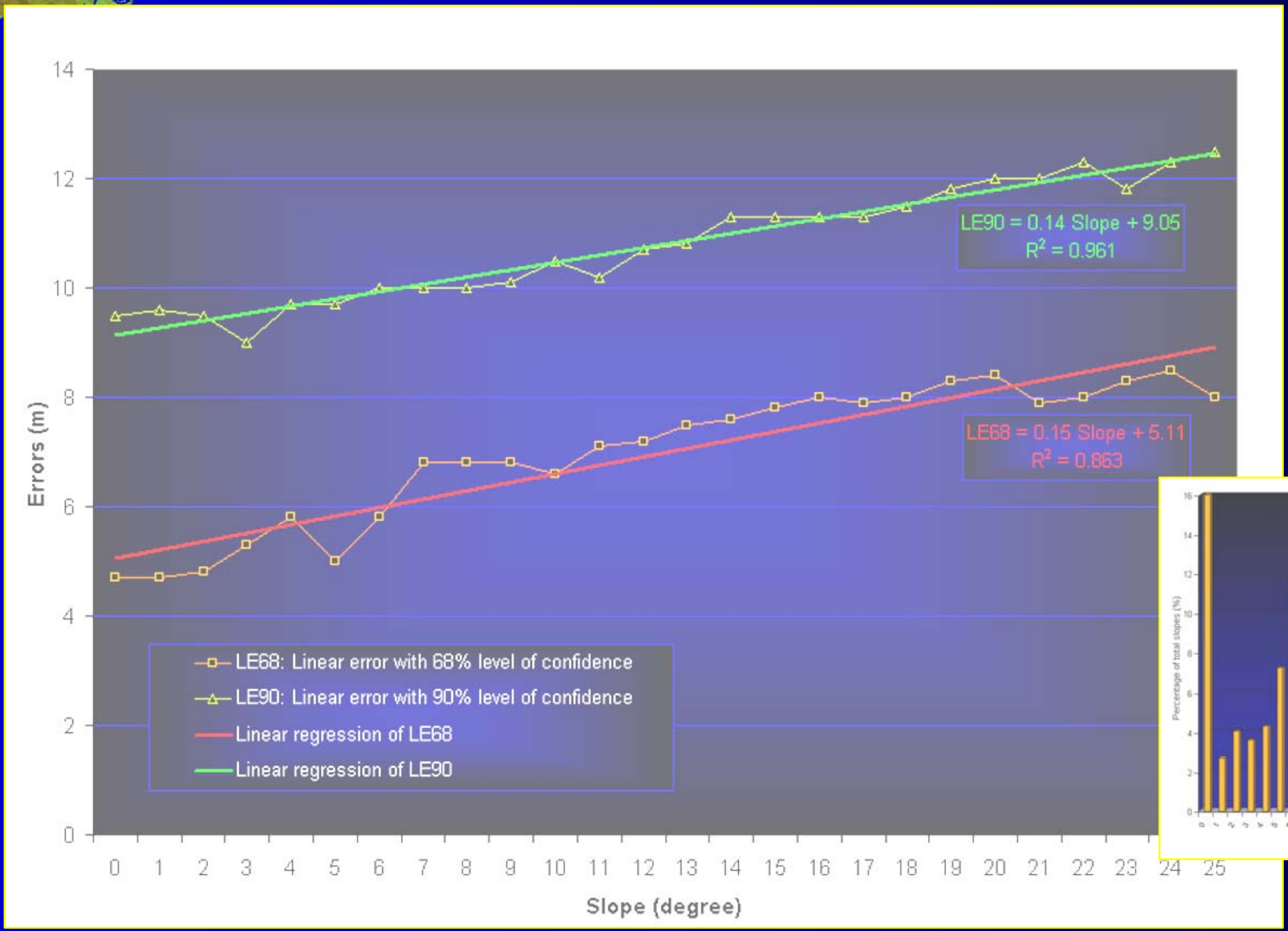
10 km x 10 km

Larger errors (>9 m)

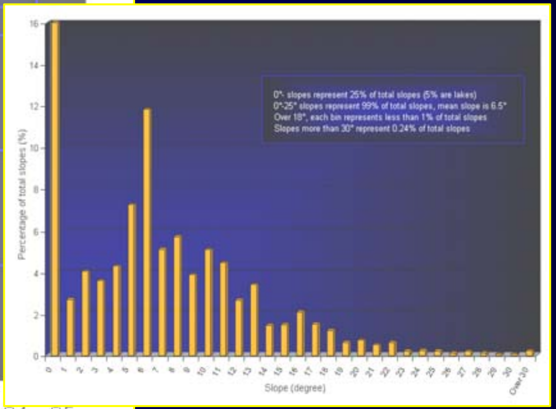
A Sand pits

B Shadow areas

Stereo processing: slopes



Slope distribution



An error evaluation function of the aspects shows that LE68 errors in the sun-facing slopes (azimuths from 76º to 256º) is 1-m (20%) smaller than LE68 errors in the slopes away from the sun (azimuths from 256º to 76º).

Stereo processing: slopes

Dr. Jacobsen
(Hannover Uni.)

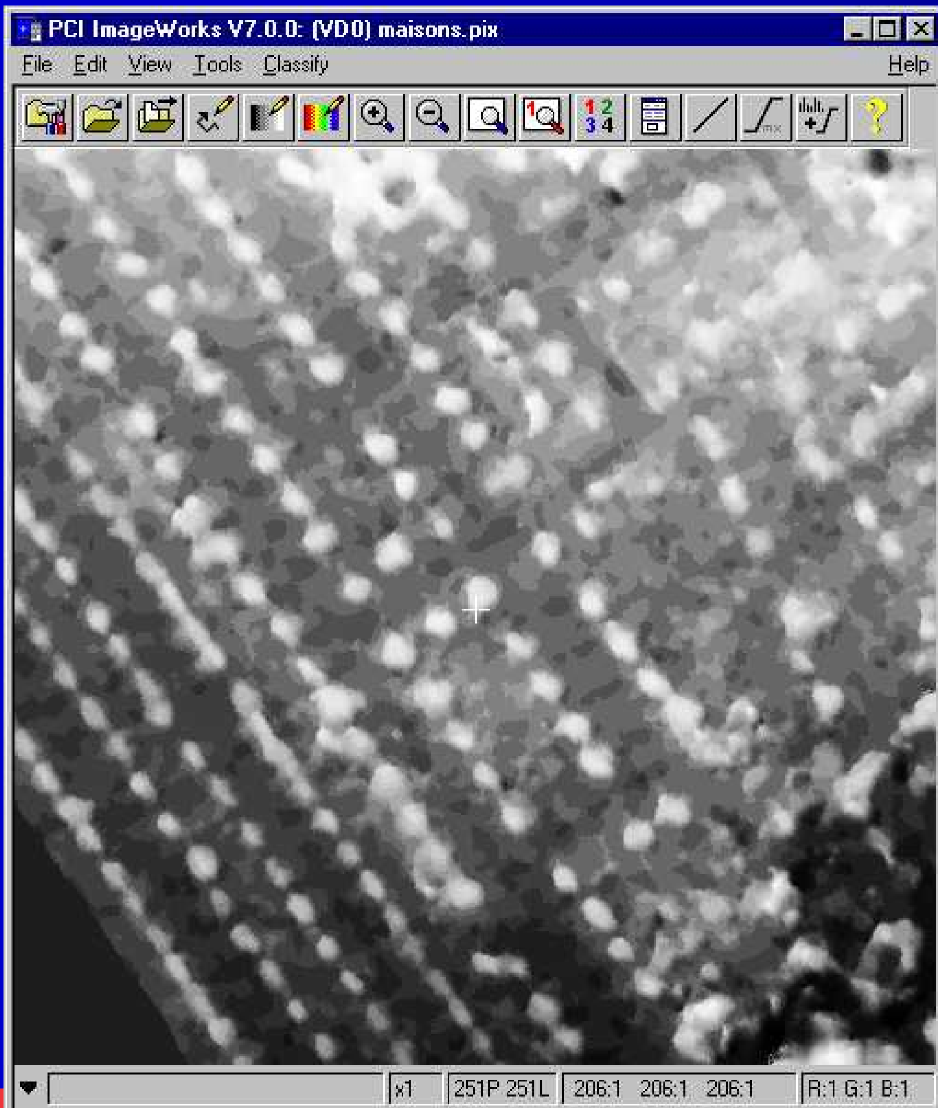
Sensor	area	RMSZ [m]	RMSZ F(slope) [m]	Spx flat areas [GSD]
ASTER Zonguldak, mountainous	open areas	25.0	$21.7+14.5*\tan\alpha$	0.7
	forest	31.2	$27.9+18.5*\tan\alpha$	0.9
	check points	12.7		0.4
KOMPSAT-1 Zonguldak, mountainous	open areas	13.6	$11.3+11.5\tan\alpha$	0.8
	forest	14.7	$14.1+12.1\tan\alpha$	1.0
SPOT 5 Zonguldak, mountainous	open areas	11.9	$5.3 + 5.9*\tan\alpha$	0.6
	forest	15.0	$6.6 + 6.3*\tan\alpha$	0.7
	check points	3.8	$3.5 + 0.9*\tan\alpha$	0.4
SPOT 5 HRS, Gars, rolling	open areas	4.7	$4.3 + 1.0*\tan\alpha$	0.7
	forest	13.0	$11.0 + 6.2*\tan\alpha$	1.8
OrbView-3, Zonguldak, mountainous	open areas	8,54	$4,37 + 15.7\tan\alpha$	3.1
	forest	12,35	$7,10 + 15.8\tan\alpha$	5,0
IKONOS, Zonguldak	open areas	5.8		1.5
IKONOS, Maras, flat	city	1.4		0.22
Cartosat-1, Warszawa, flat	open areas	2.5	$2.4 + 8*\tan\alpha$	0.6

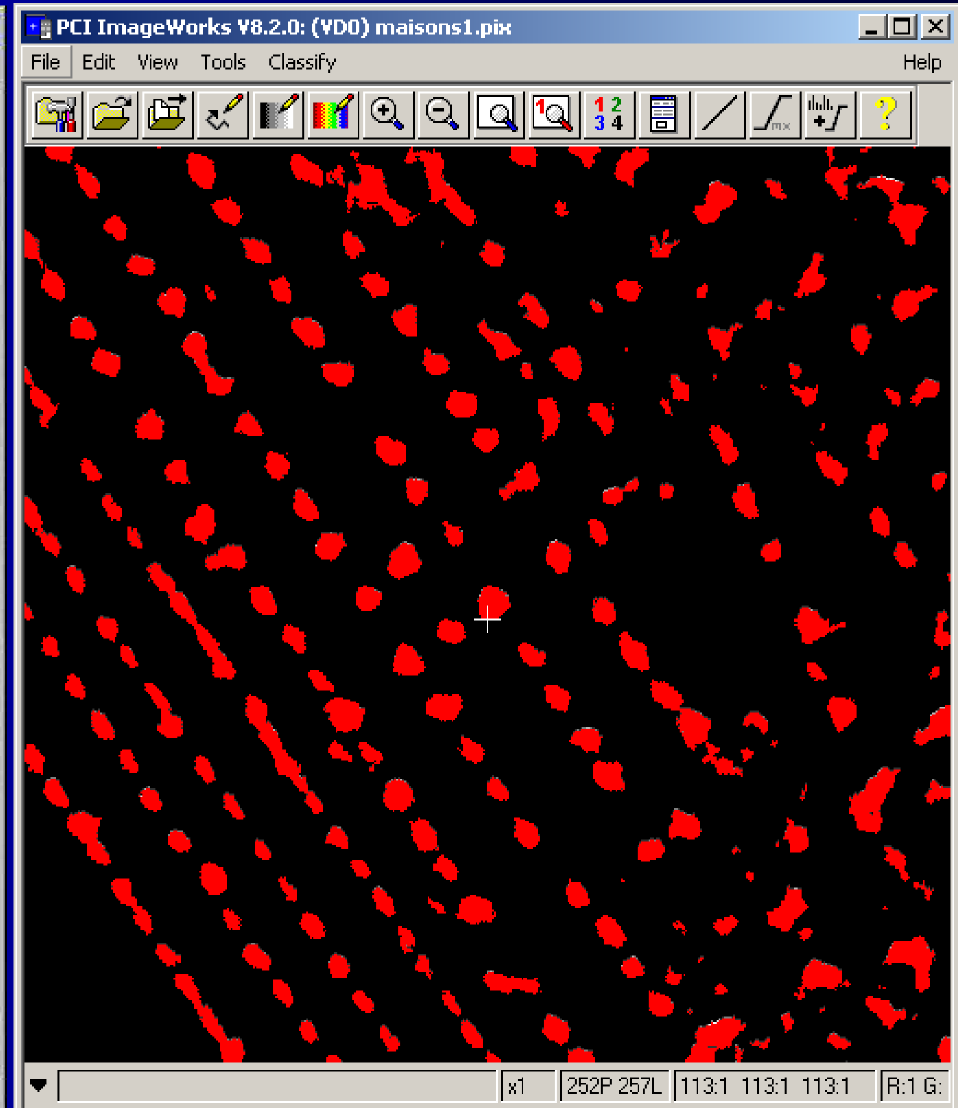
Without special problems, DSM error of 1 GSD can be reached in bare soils and low-to-medium relief

Building extraction from Ikonos DSM

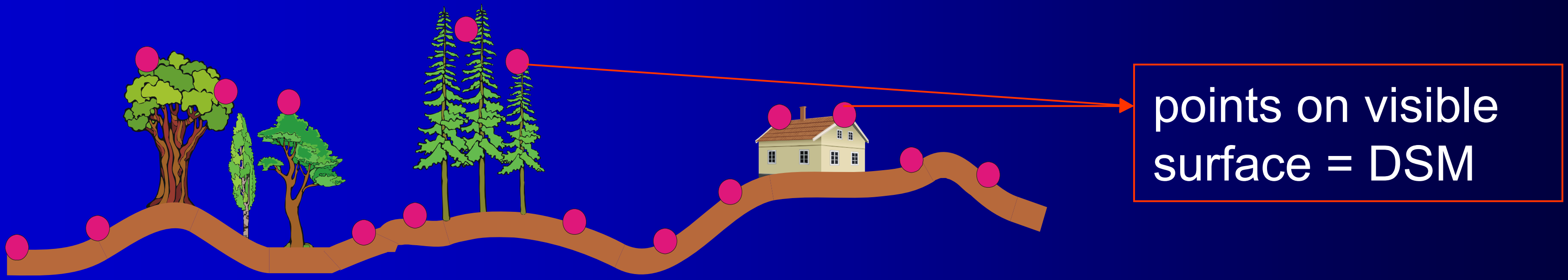
Ikonos DSM in residential area

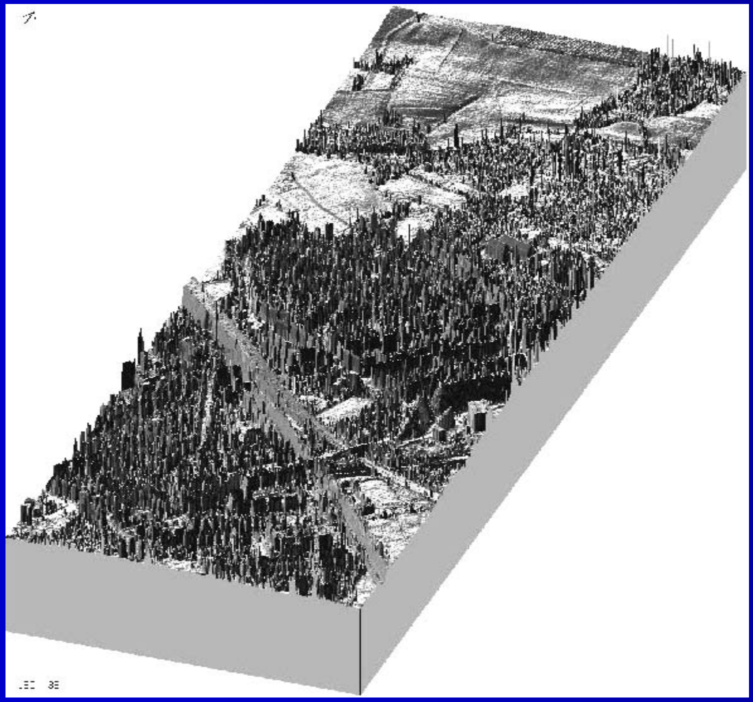
Building extracted from Ikonos DSM with their heights



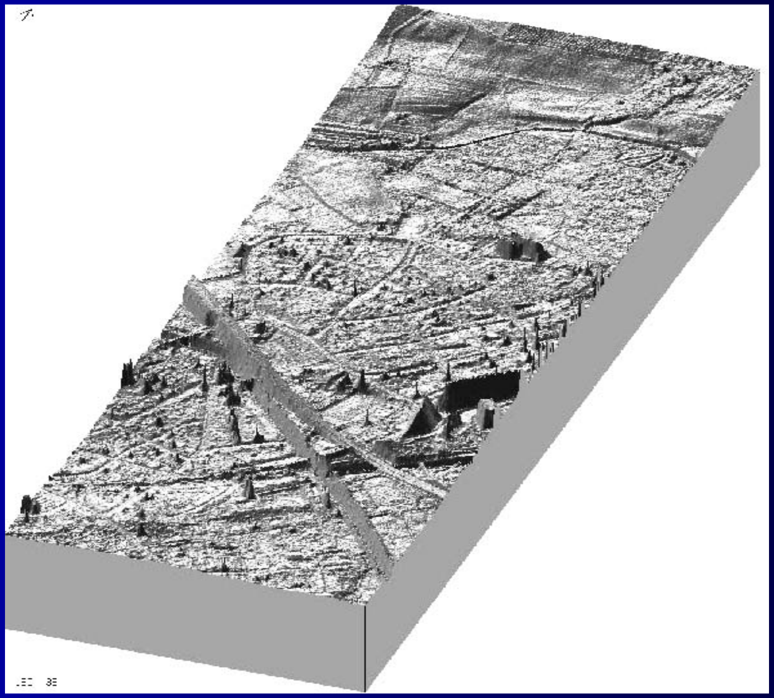


Stereo processing: features elevation





DSM



DEM after feature elevation filtering

Dr. Jacobsen Hannover Uni.

Stereo processing: TLM

The dream of Grün et *al.*, ETH Zurich

Stereo processing: conclusions

DSM generation

- Accuracy: 1-5 pixels depending on terrain slope, land cover (along track) and temporal change (accross track)
- Limiting factor for matching: Low image quality + time decorrelation
- But still many large blunders → Not ready for mapping 1: 50 000 !
- DSM ⇒ DTM reduction not solved yet

Radiometric processing

1. Information contents vs. radiometric/geometric parameters
2. Mosaicking
3. Pan-sharpening

Geometry: FSR

Better radiometry

SPOT-5

2.5 m pixel

EROS

1.8 m pixel

Fuzzy aspect due satellite movement

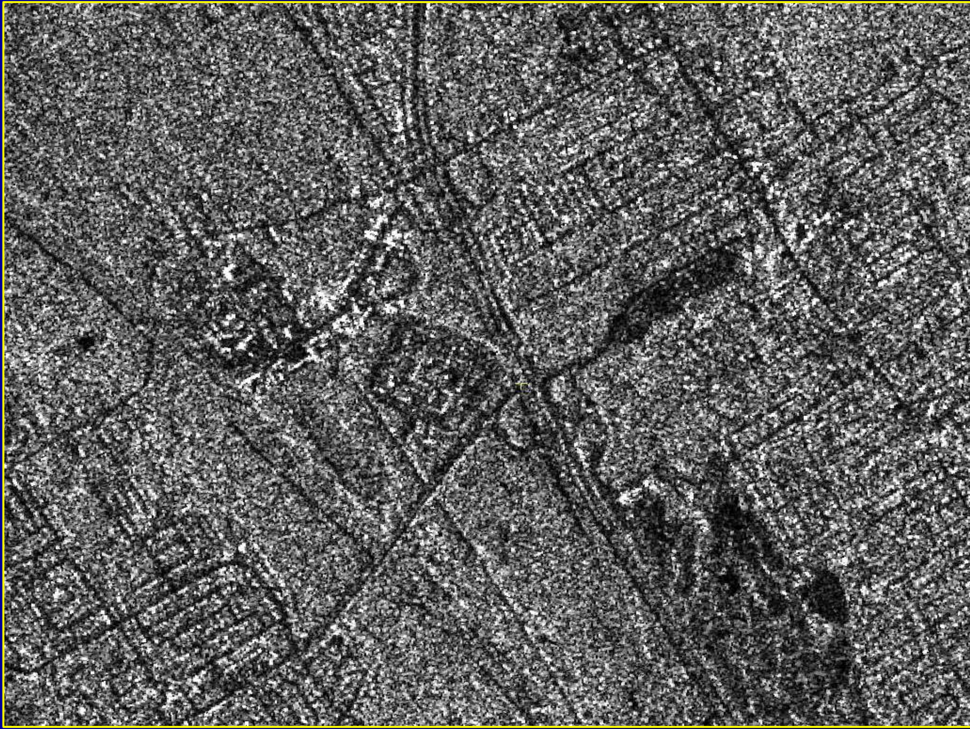
SPOT © 2002 CNES 2002

EROS © 2001 ImageSat 2001

Geometry: *Fine quad versus Ultra fine*

Radarsat-2 UF25 HH
3-m resolution

Radarsat-2 FQ18 HH
5-8-m resolution

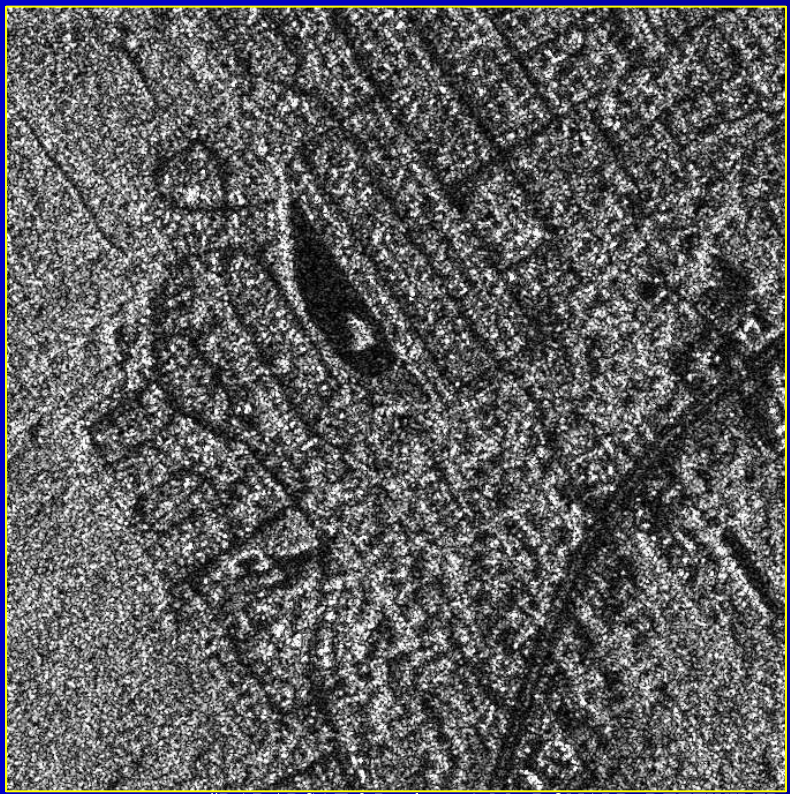


Same coverage, same geometry, same polarization, single look

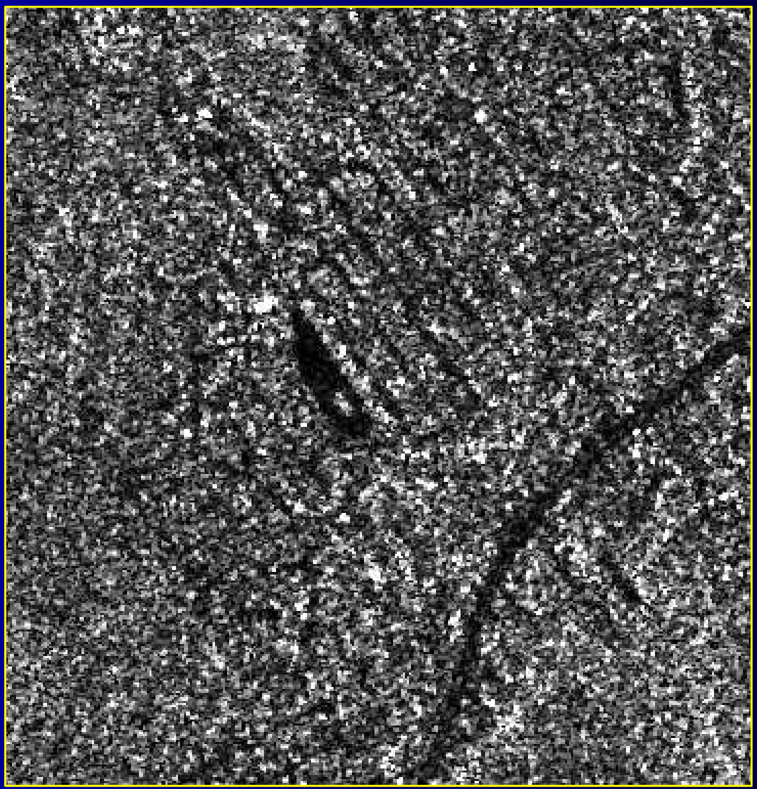
different geometric resolution and cartographic features

Geometry: Fine quad versus Ultra fine

Radarsat-2 UF25 HH
3-m resolution



Radarsat-2 FQ18 HH
5-8-m resolution

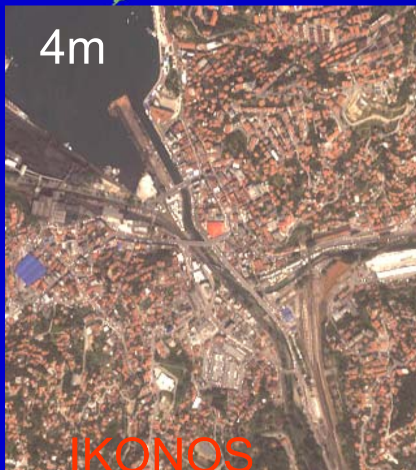


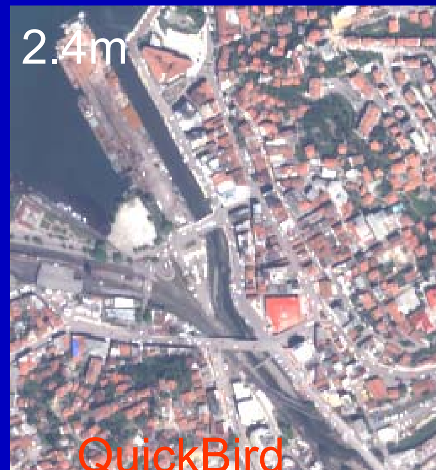
Same coverage, same geometry, same polarization, single look

different geometric resolution but more cartographic features

Geometry: VFSR XS & Pan

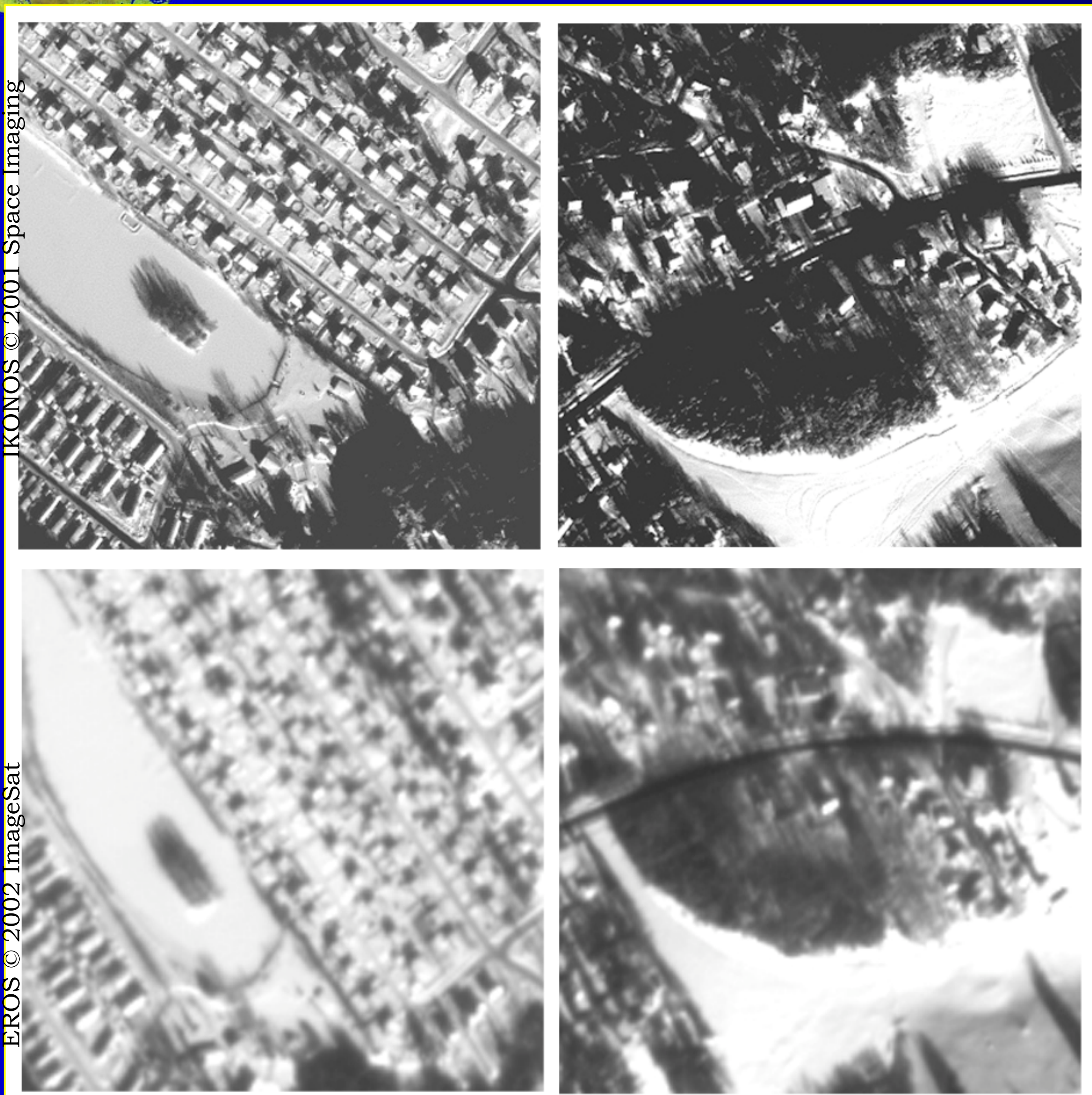
Rule of thumb: 0.1mm GSD in mapping scale required e.g. 1m GSD → 1 : 10 000





VFSR data acquired over the test field Zonguldak (*Jacobsen et al.*)

Geometry + Radiometry



IKONOS

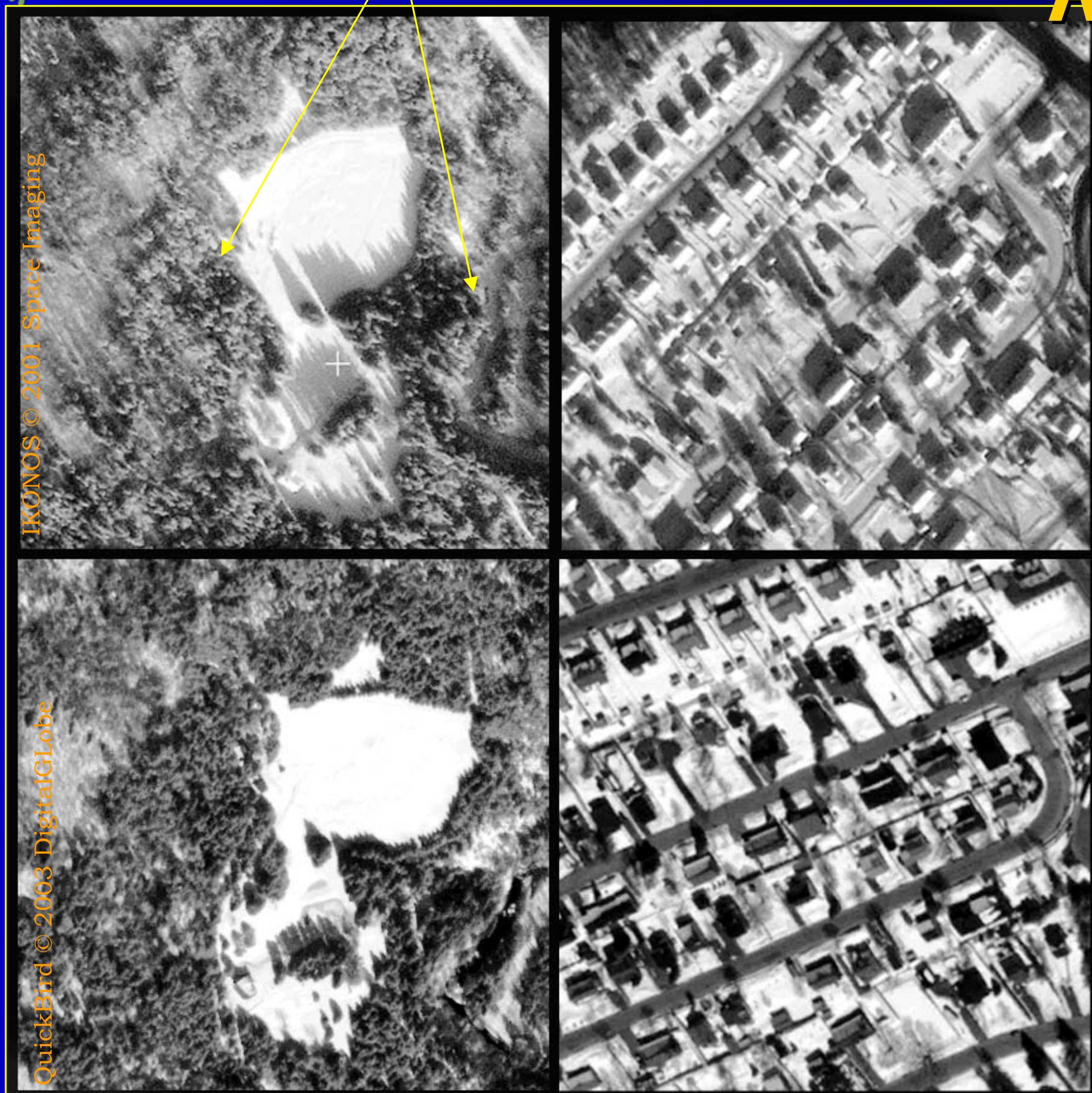
1 m pixel

EROS

1.8 m pixel

Equivalent viewing and sun illumination angles in winter time

Geometry + Radiometry



IKONOS

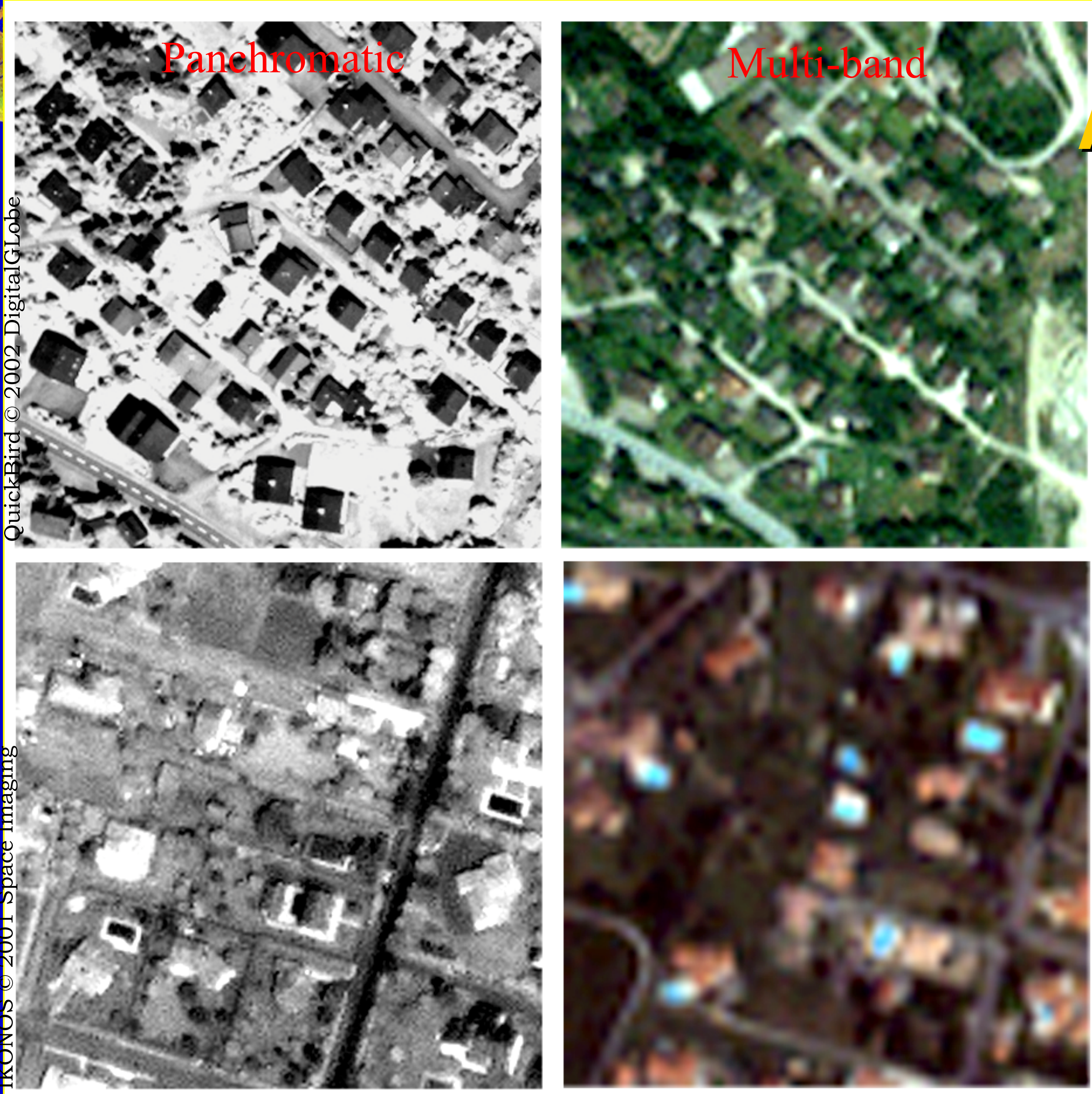
1 m pixel

QuickBird

0.6 m pixel

Equivalent viewing and sun illumination angles in winter time

Geometry & Radiometry:
Pan vs XS



QuickBird

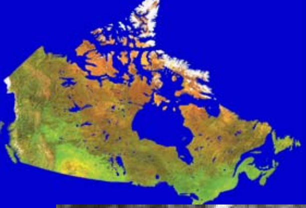
P: 0.6 m pixel

XS: 2.4 m pixel

IKONOS

P: 1 m pixel

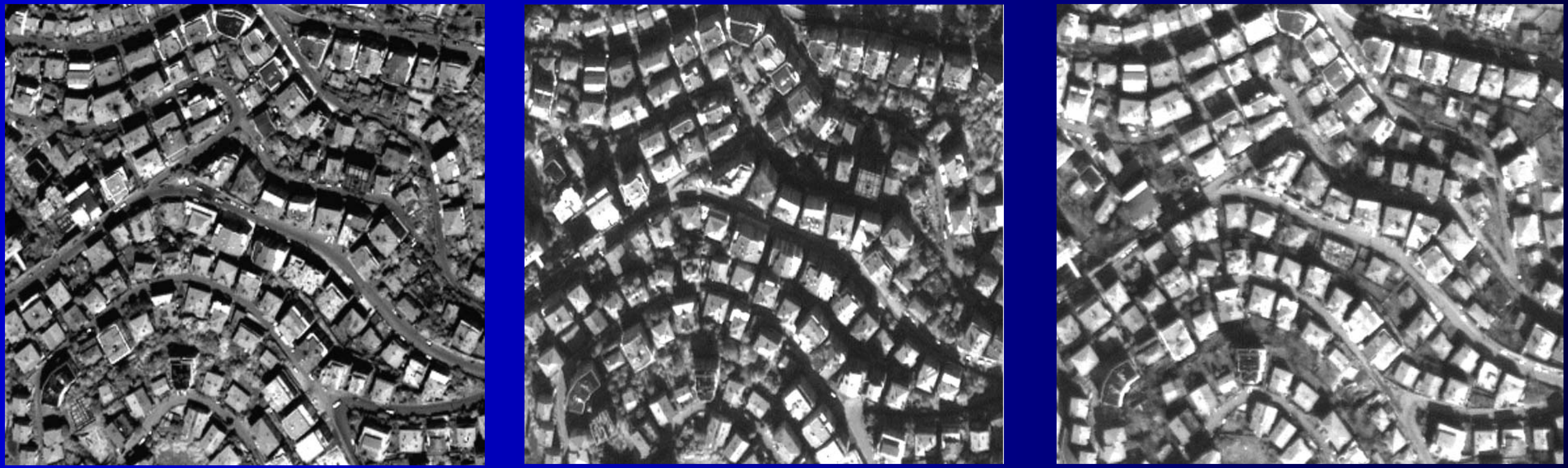
XS: 4 m pixel



Radiometry: *sun elevation*

IKONOS 1m panchromatic and 1m pan-sharpened

Identification of objects more simple, but finally identification of nearly same number of objects



IKONOS with sun elevation: 46°, 41° & 61° and slightly different azimuths

Radiometry: *multi-date*

June

August

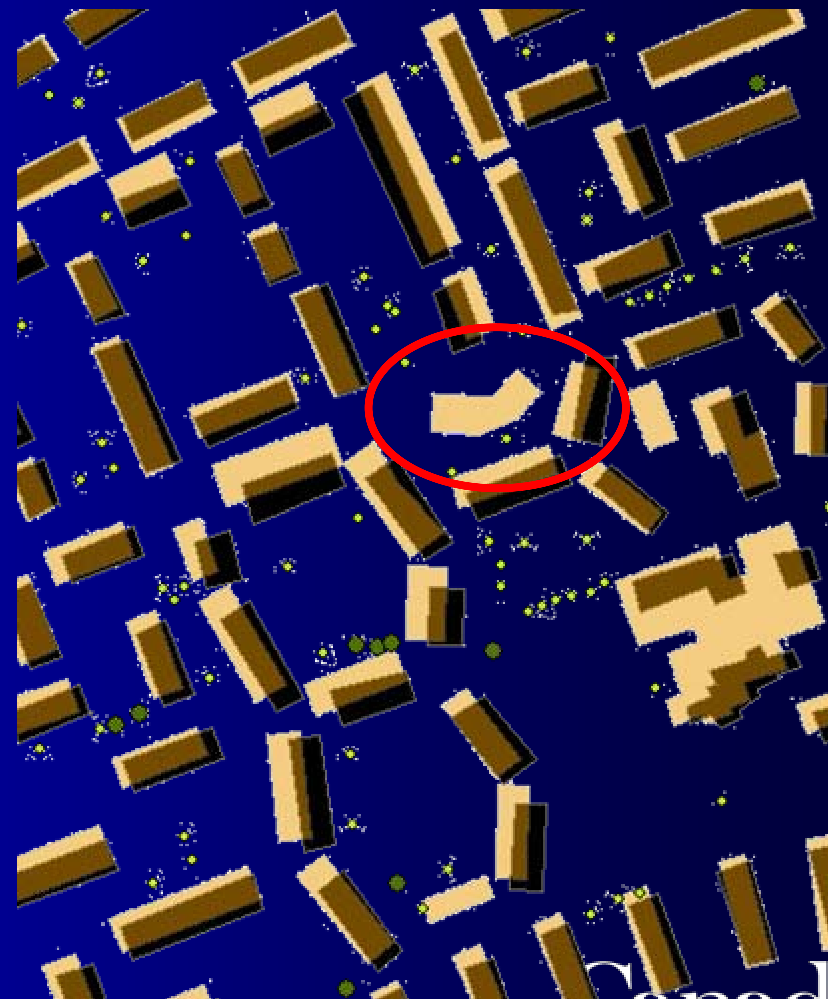
Seasonal change in Pan SPOT images due to multi-date acquisition ⇒ decorrelation

Radiometry: shadow + view angle

First results mapping - buildings and single trees

Dr. Armin Grün

- Reference Vector 25, 1:25 000
- Measurements IKONOS



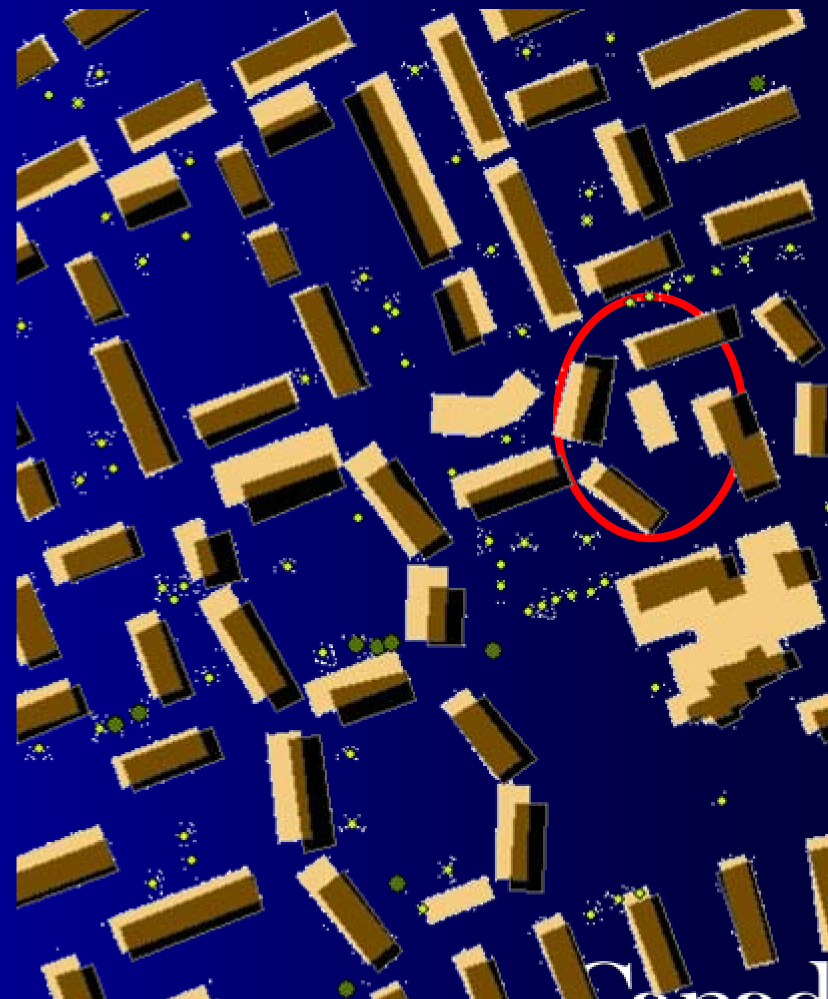
Radiometry: contrast + view angle

First results 3D mapping - buildings and single trees

Dr. Armin Grün

Reference Vector 25, 1:25 000

Measurements IKONOS



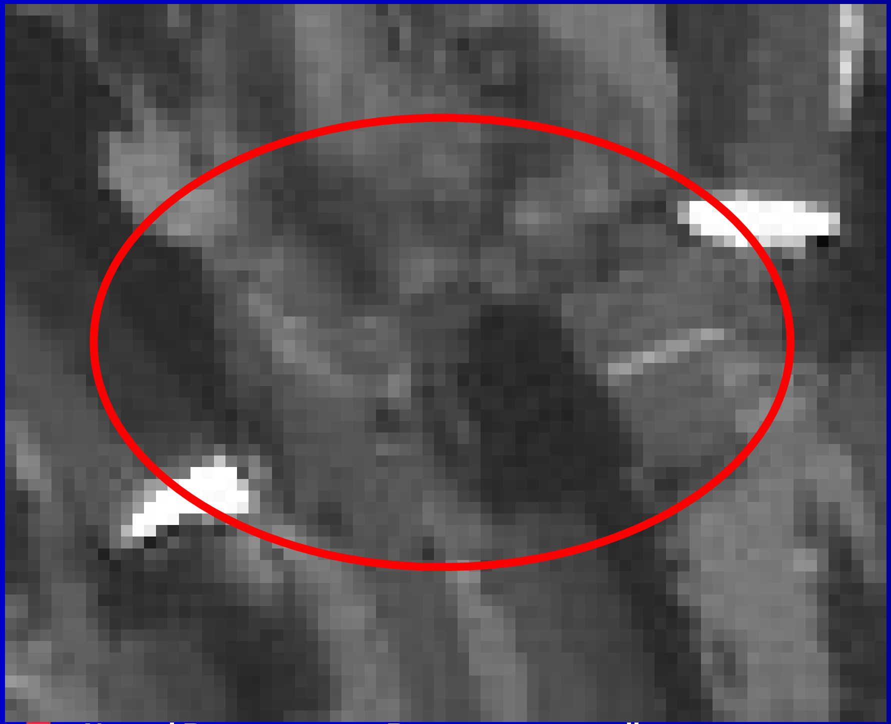
Radiometry: contrast

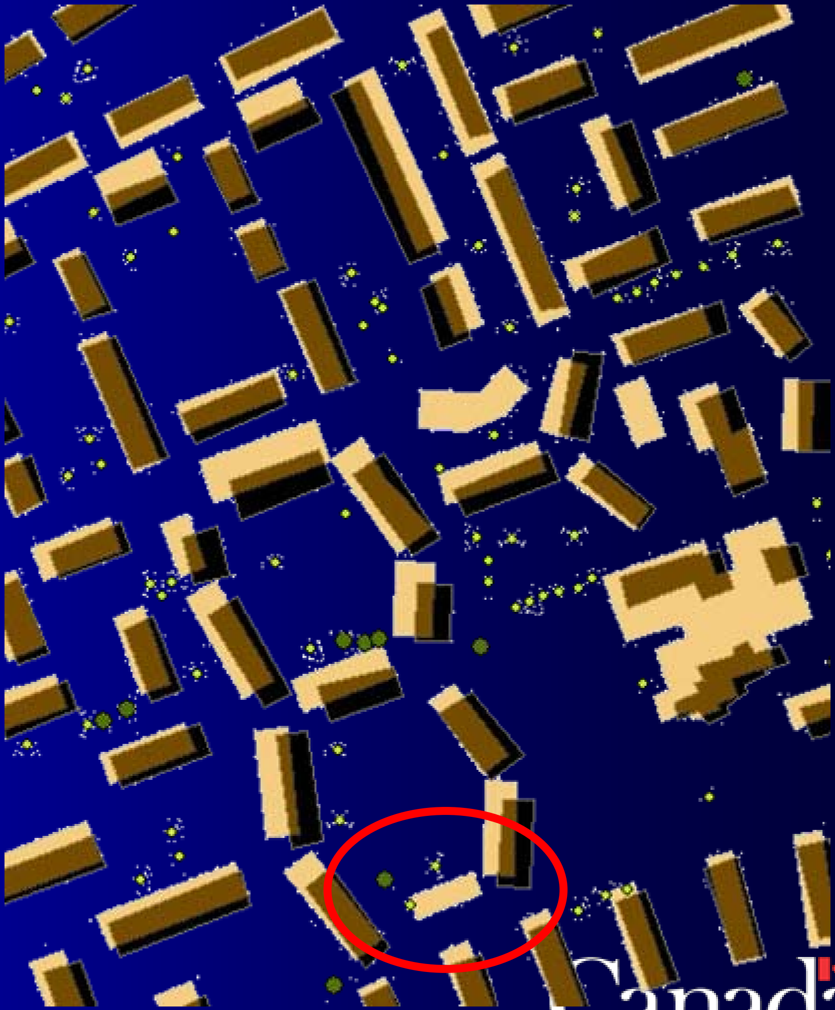
First results 3D mapping - buildings and single trees

Dr. Armin Grün

Reference Vector 25, 1:25 000

Measurements IKONOS





Radiometry: SAR antenna pattern

A radar antenna transmits more power in the mid-range portion of the illuminated swath than at the near and far ranges. This effect is known as **antenna pattern** and results in stronger returns from the center portion of the swath than at the edges.

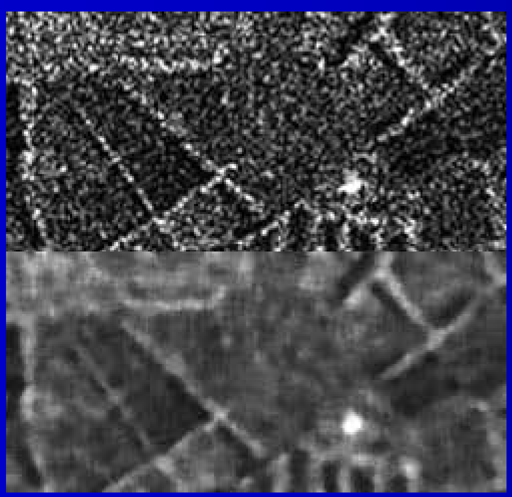
Combined with this antenna pattern effect is the fact that the energy returned to the radar decreases dramatically as the range distance increases.

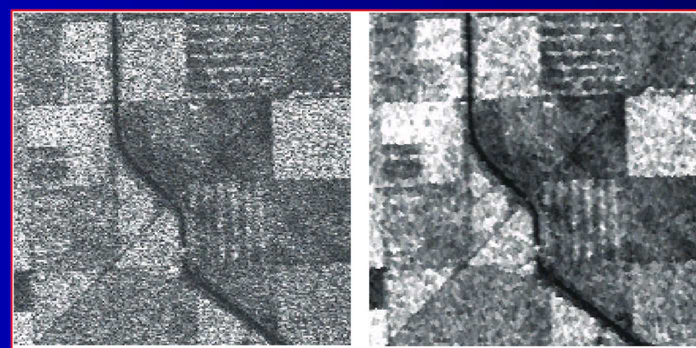
Radiometry: *SAR speckle*

Speckle reduction can be achieved with:

(1) multi-look processing with the SAR processor. It reduces the resolution.

(2) spatial filtering

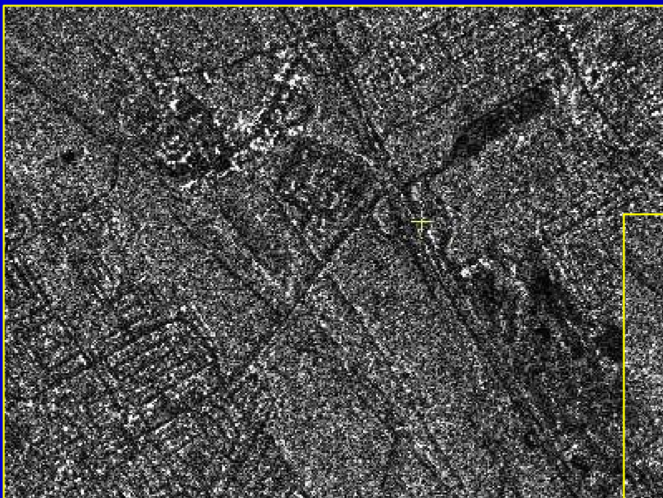




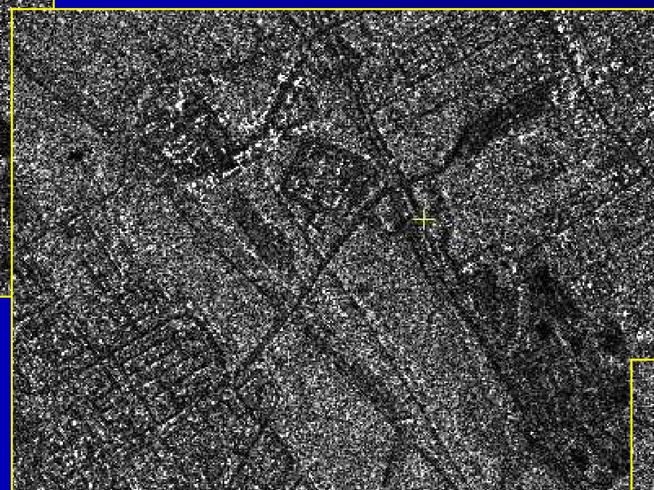
RADARSAT single look with specle noise   despeckled scene

Radiometry: HH versus VV versus HV

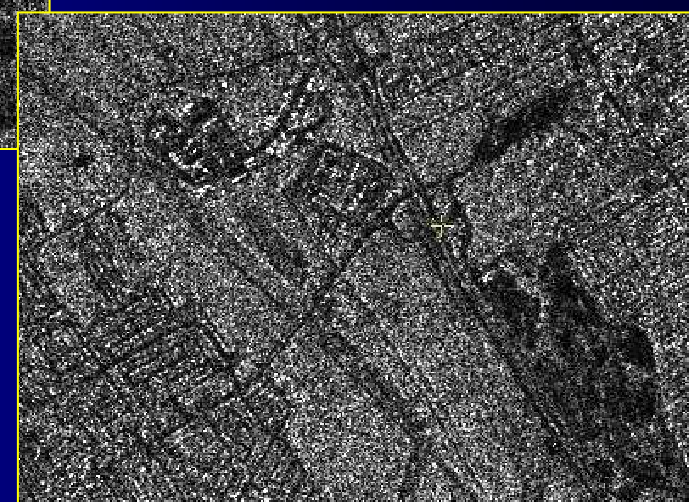
Radarsat-2 FQ18 HH
5-8-m resolution



Radarsat-2 FQ18 VV
5-8-m resolution



Radarsat-2 FQ18 HV
5-8-m resolution



Same coverage, same geometric and single look
but different radiometric resolution

Radiometry

Aerial color photo with 1.5m

SAR X-band 1.5m

EuroSDR-test area:

Trudering

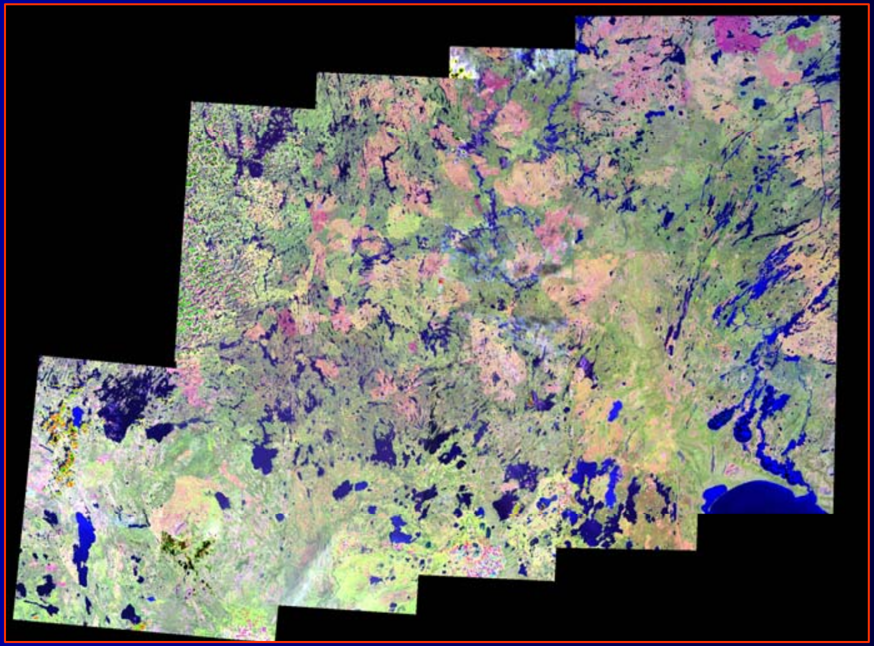
Optical image based on chemical characteristics, radar images based on physical characteristics (cf. *Jacobsen*)

In **rural areas** information contents at similar level, but partially different details.

In city, less information content with SAR intensity image. More can be obtained the SAR phase

Radiometric processing

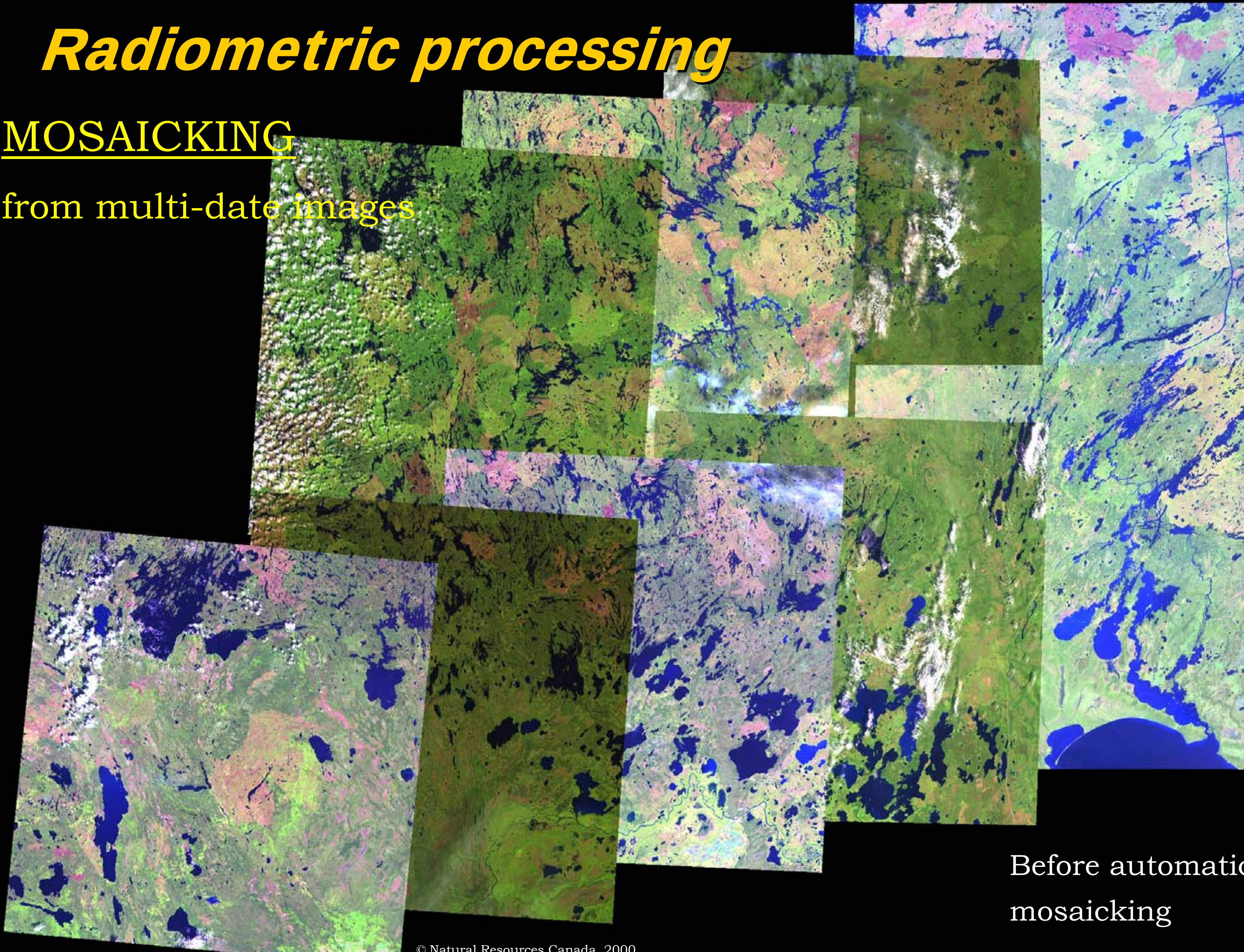
1. Information contents vs. radiometric/geometric parameters
2. Mosaicking
3. Pan-sharpening



Radiometric processing

MOSAICKING

from multi-date images

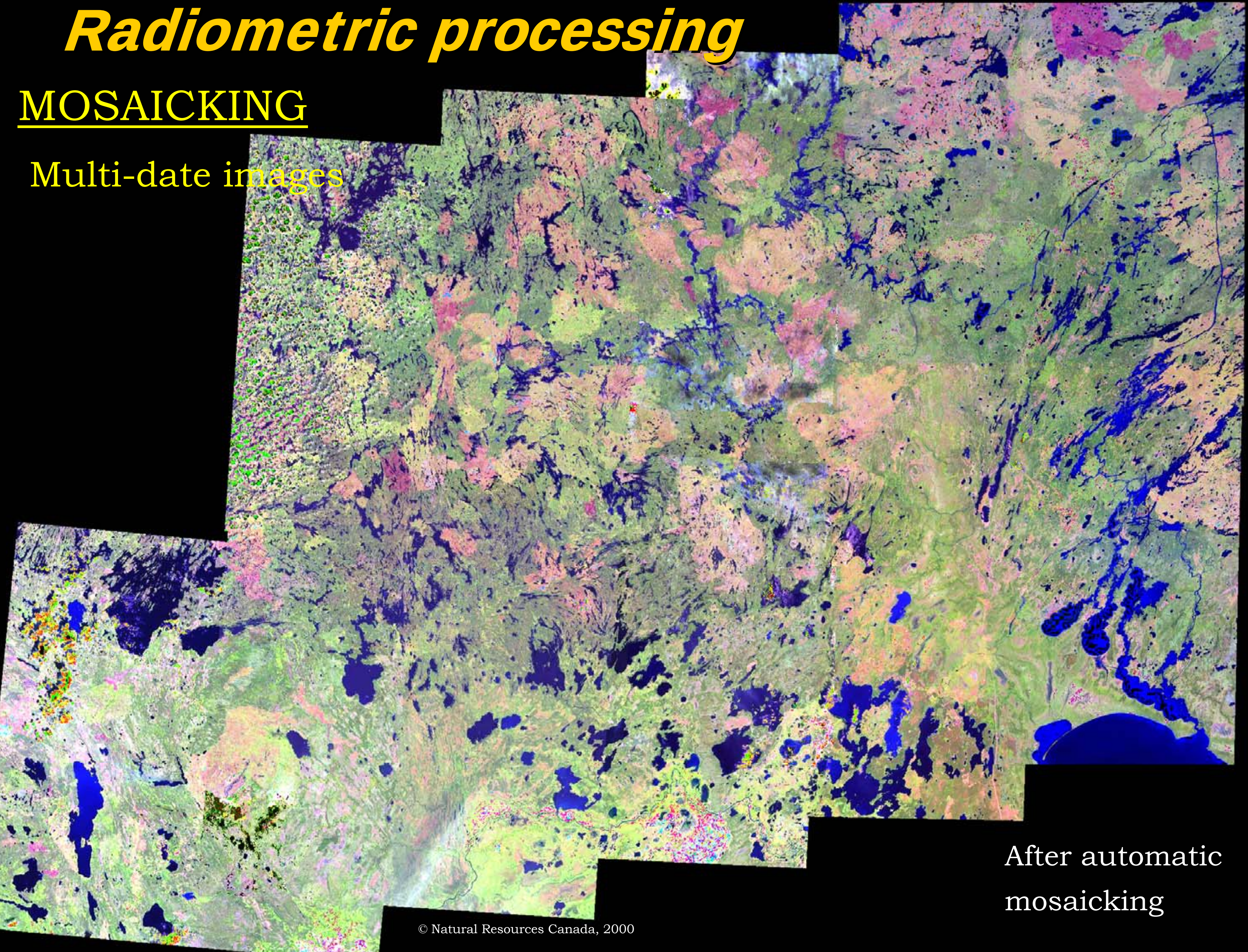


Before automatic mosaicking

Radiometric processing

MOSAICKING

Multi-date images



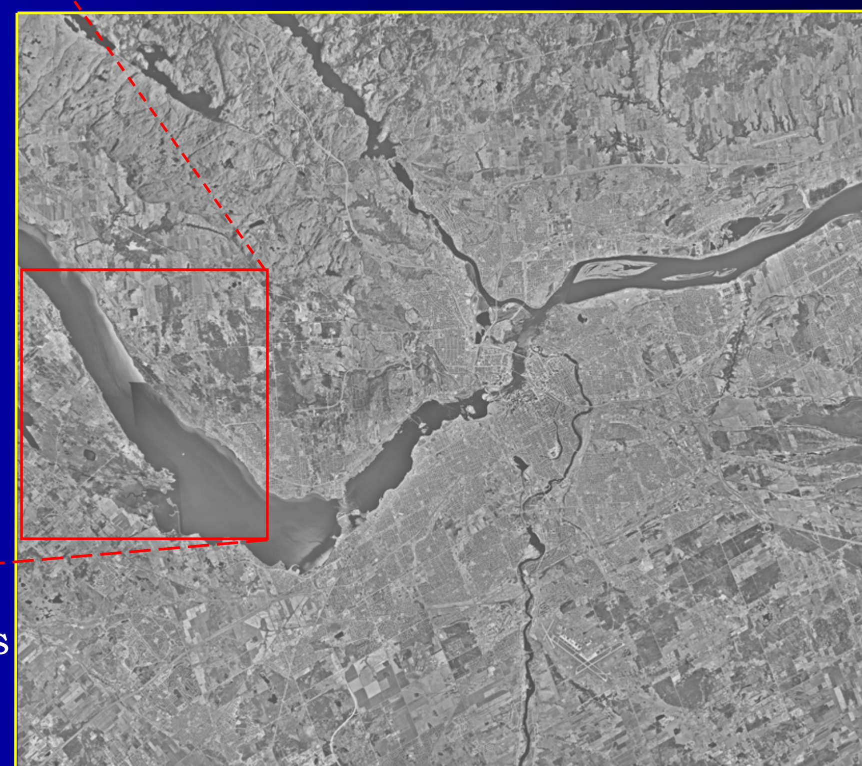
After automatic mosaicking

Radiometric processing

MOSAICKING

VFSR

Illumination variation between two images

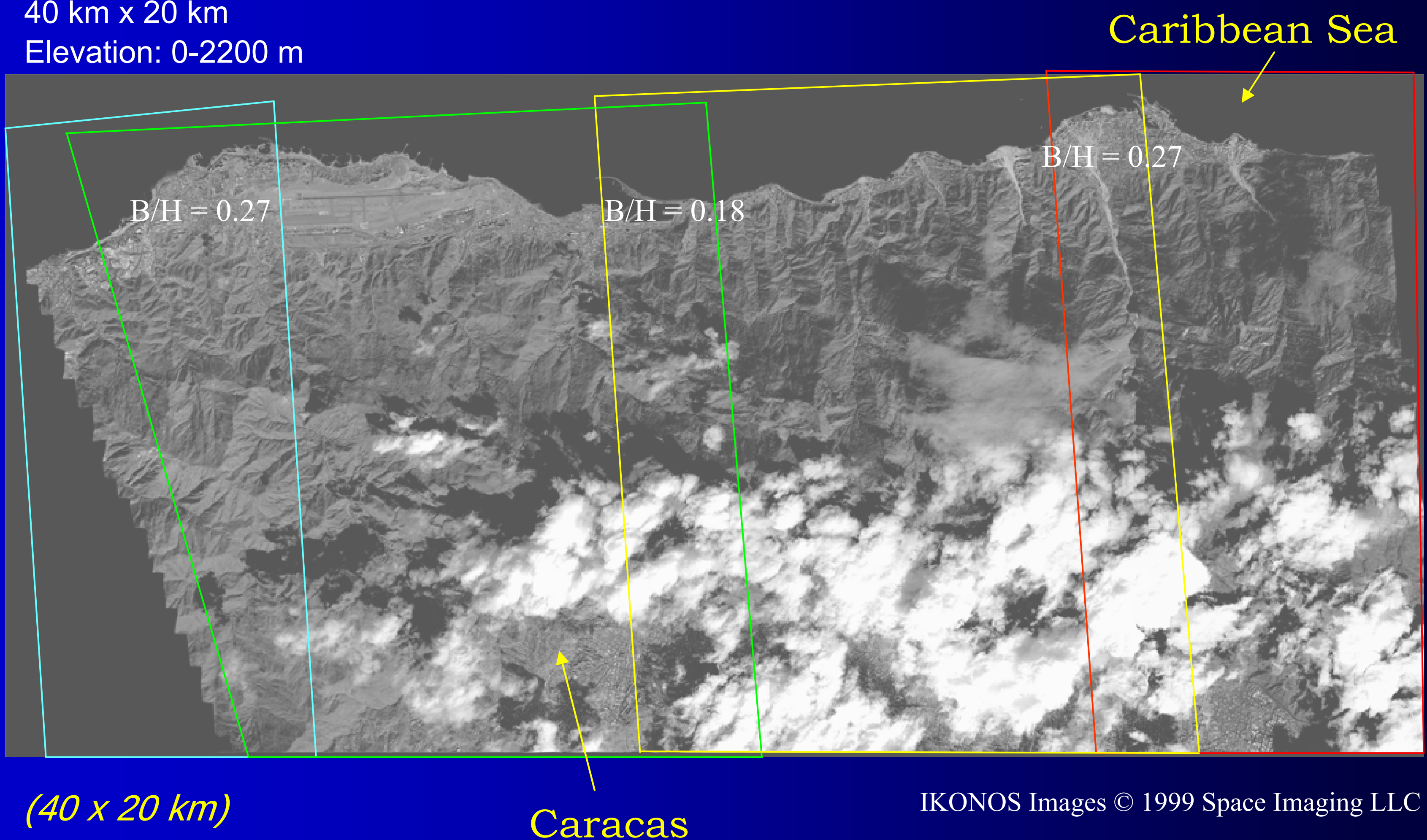


Radiometric processing: *Ikonos*

Venezuela, Vargas State, Avila Mountain Range

40 km x 20 km

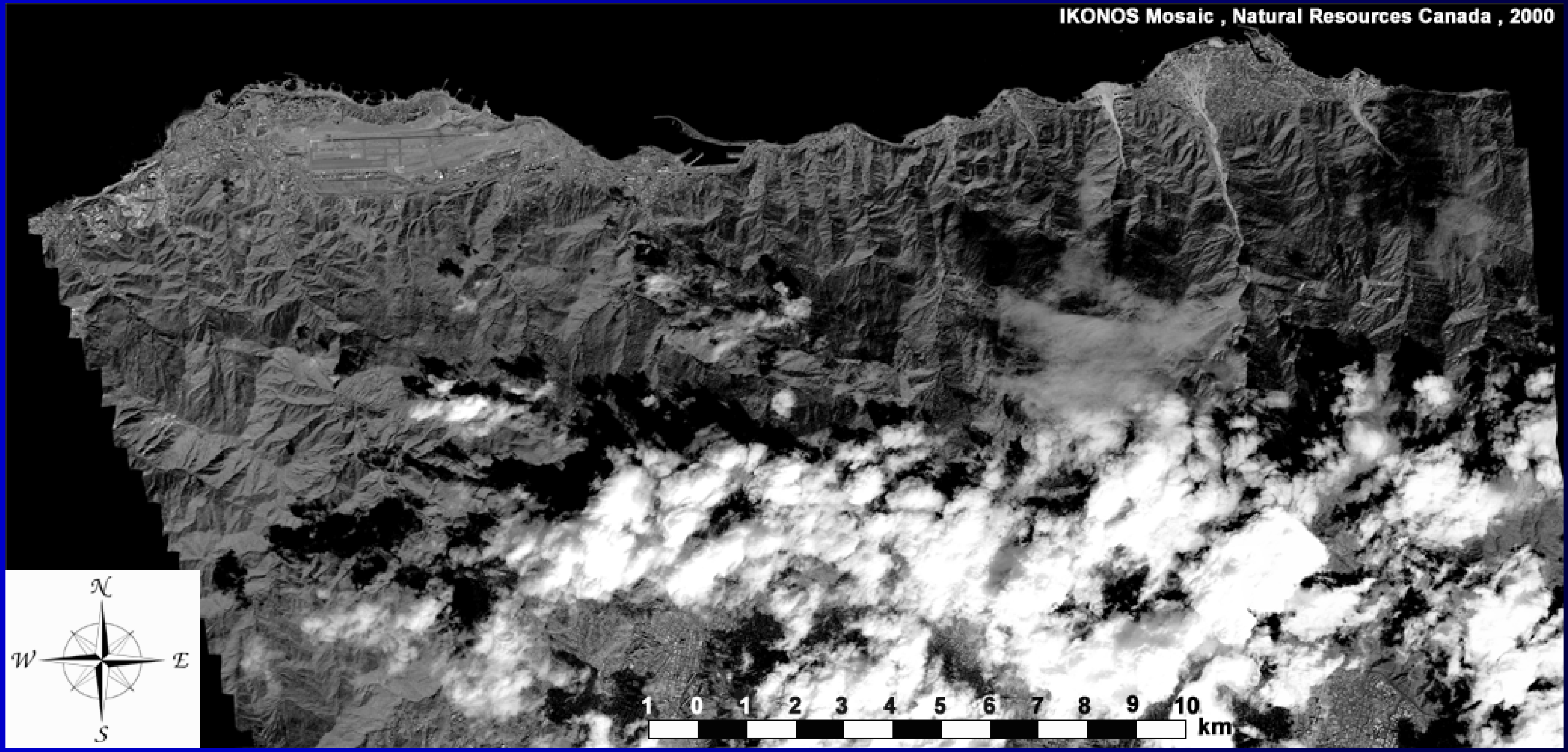
Elevation: 0-2200 m



(40 x 20 km)

Radiometric processing: *Ikonos*

Venezuela, Vargas State, Avila Mountain Range
40 km x 20 km
Elevation: 0-2200 m

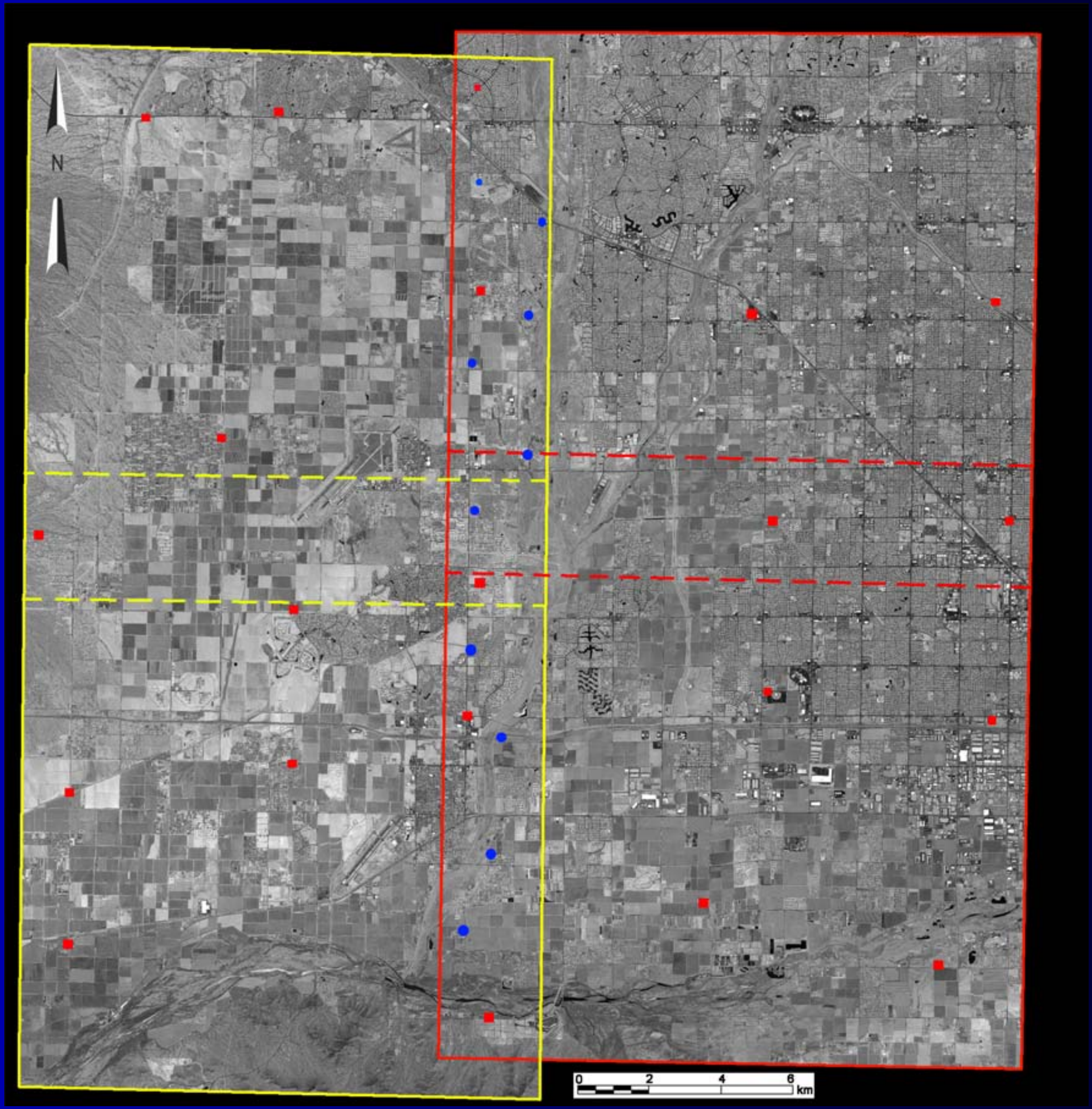


Four in-track same-date IKONOS Pan images

Radiometric processing: QuickBird

Castle Rock, Colorado, USA
30 km x 30 km
Elevation: 1800-2100 m

1. Path generation using meta data
2. Block adjustment with reduced GCPs and tie points
3. Radiometrically balanced



Canada

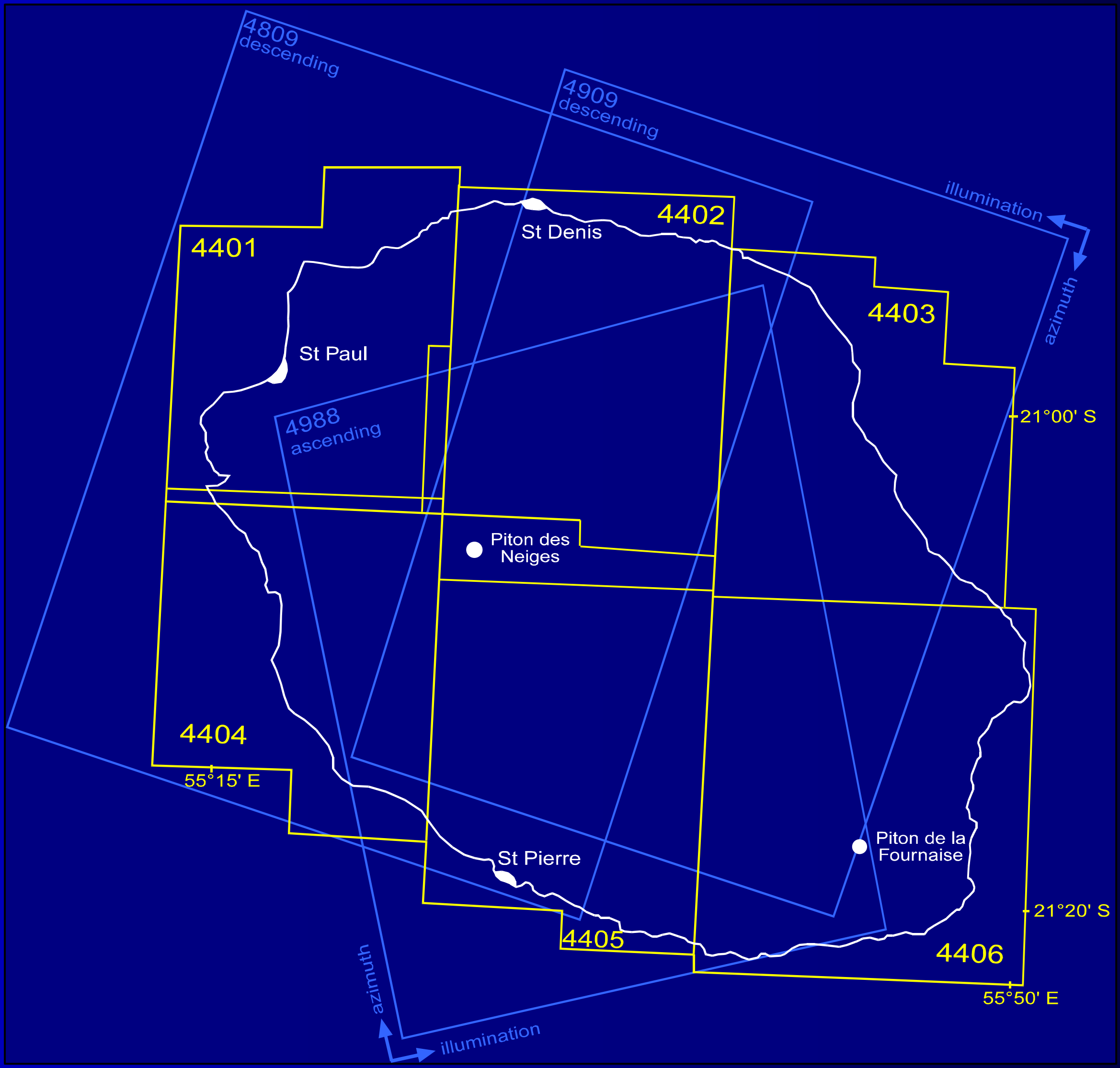
Geometric processing: algorithms

Reunion Island

Volcanic relief
3100m elevation
up to 90° slopes

3 fine mode Radarsat-1:
1 ascending and
2 descending

6 20k topo maps



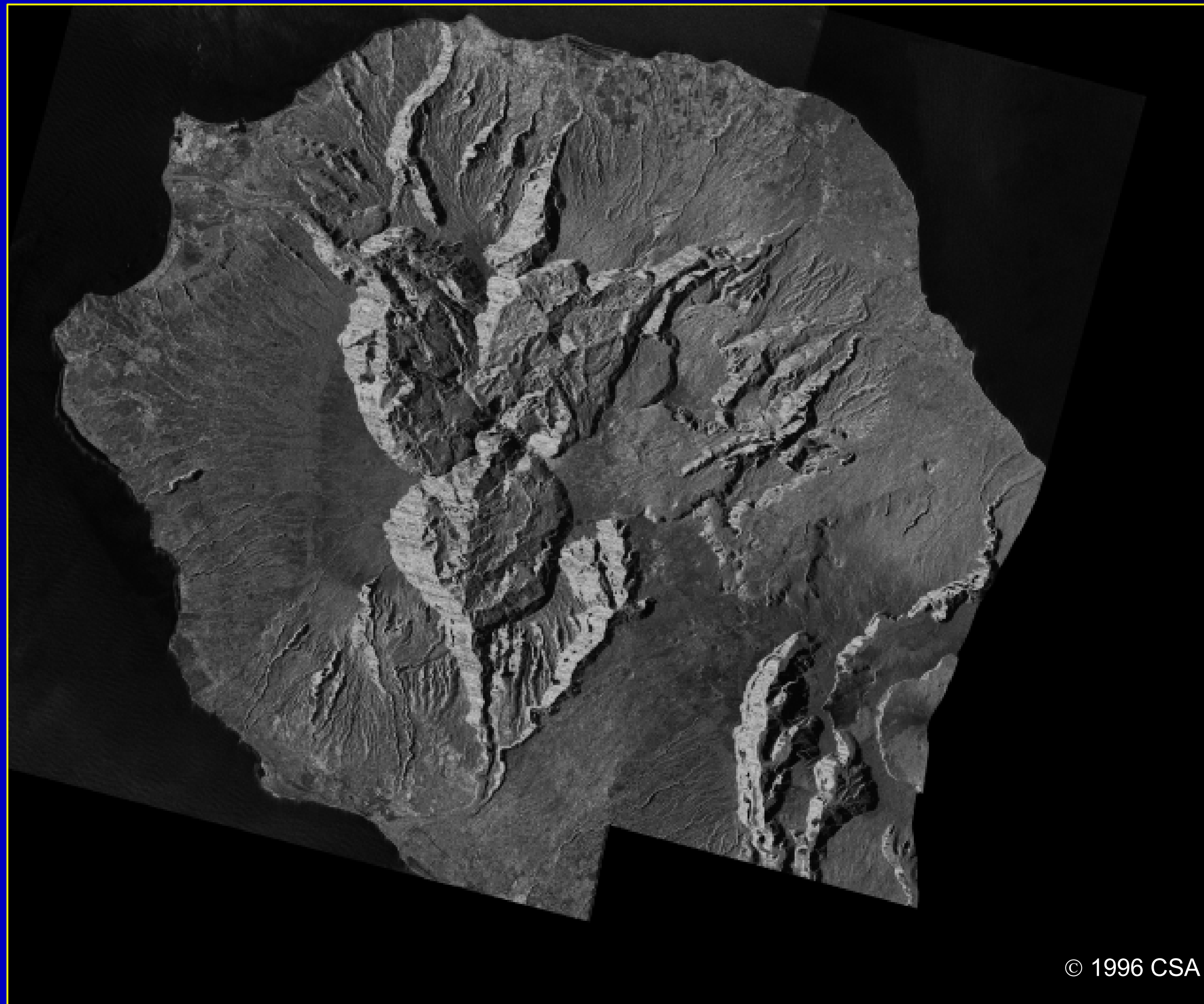
Geometric processing: algorithms

Ortho-rectify
R-1 mosaic

Reunion Island

Radiometrically corrected:

- antenna pattern
- normalization
- balancing



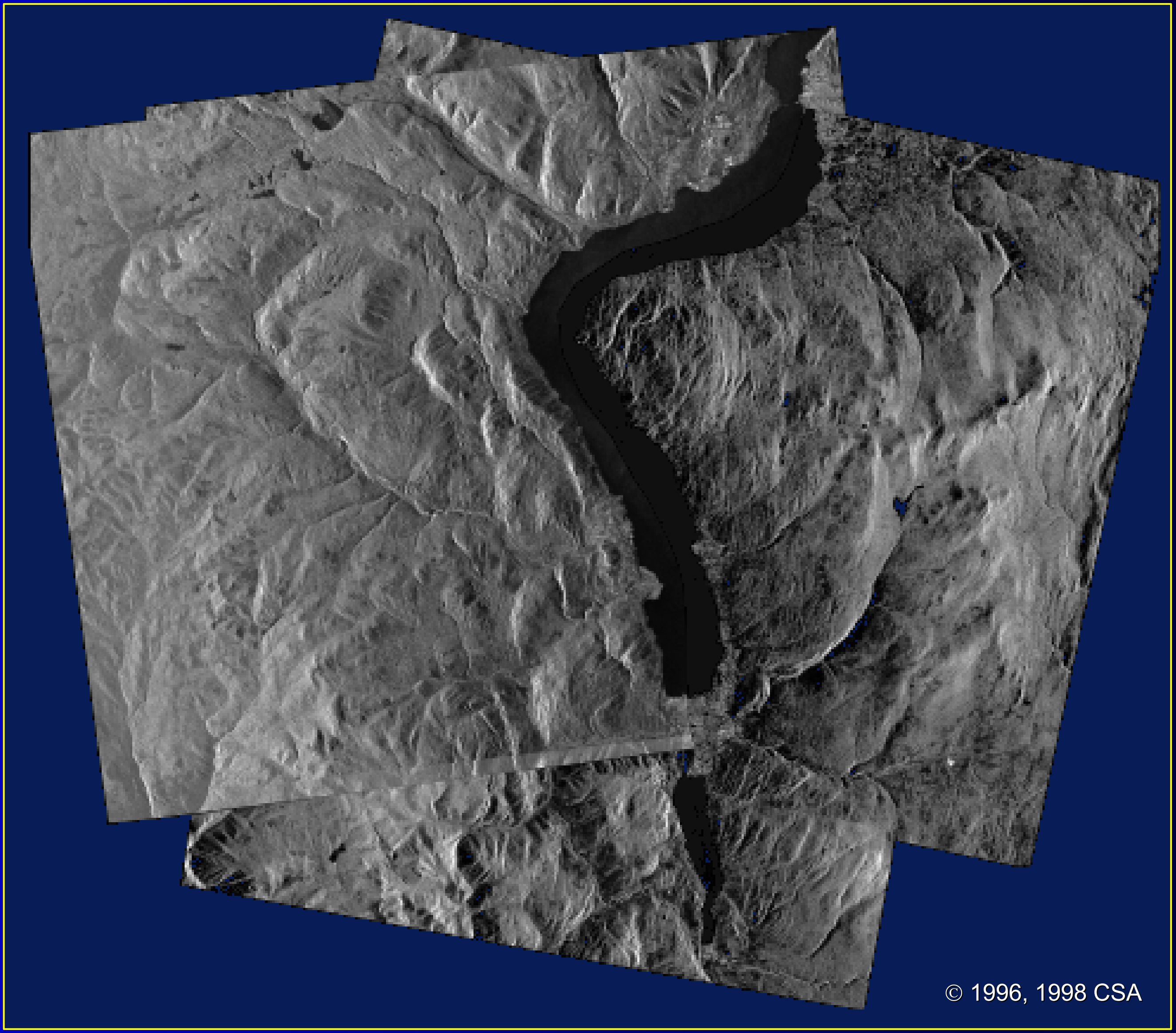
Geometric processing: algorithms

Ortho-rectify
R-1 mosaic

Okanagan, B.C.

Radiometrically corrected:

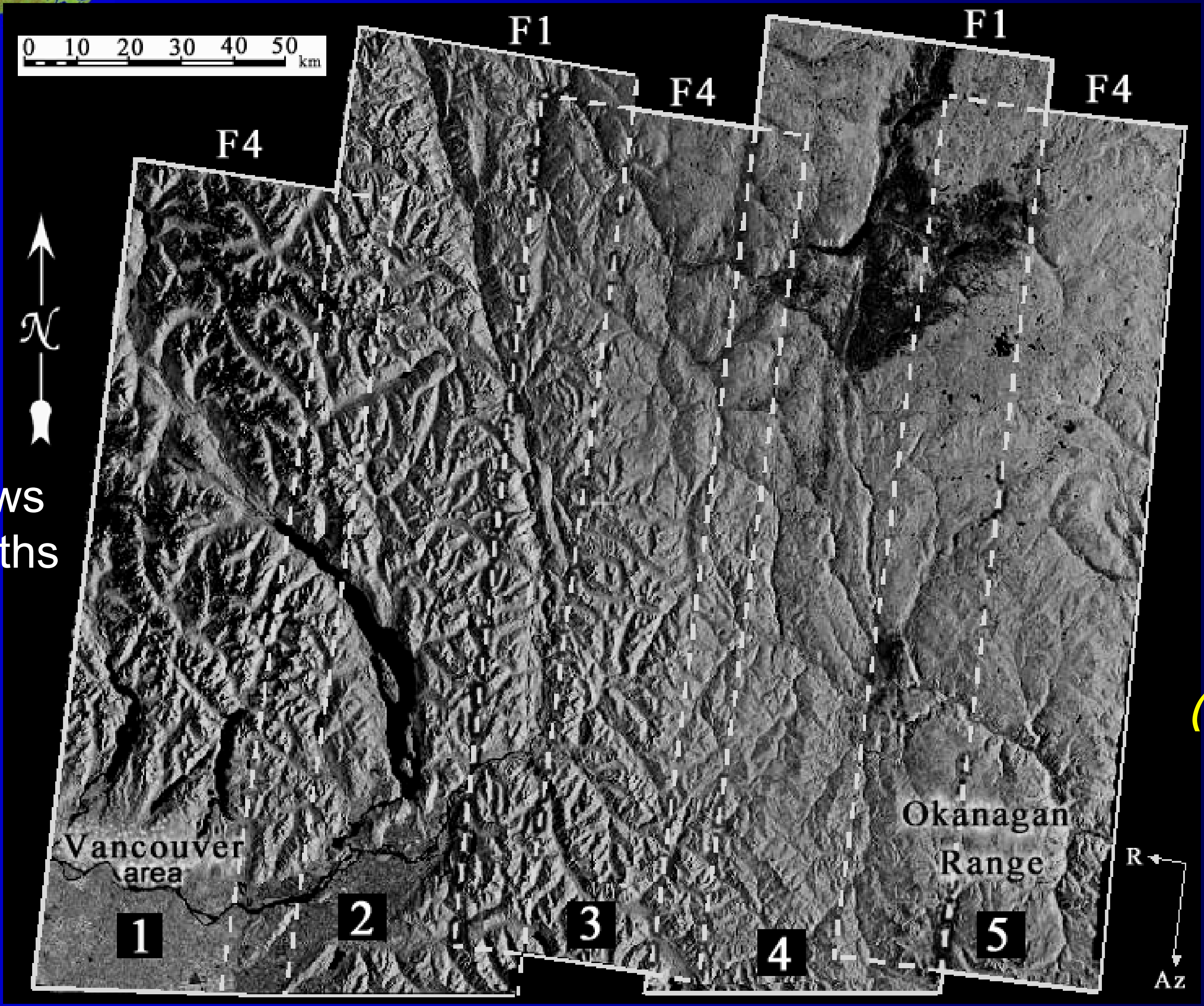
- antenna pattern
- normalization
- balancing



Geometric processing: algorithms

Image segment and block generation

3 rows
5 paths



RADARSAT-1 (200x150km)

Radiometric processing

MOSAICKING

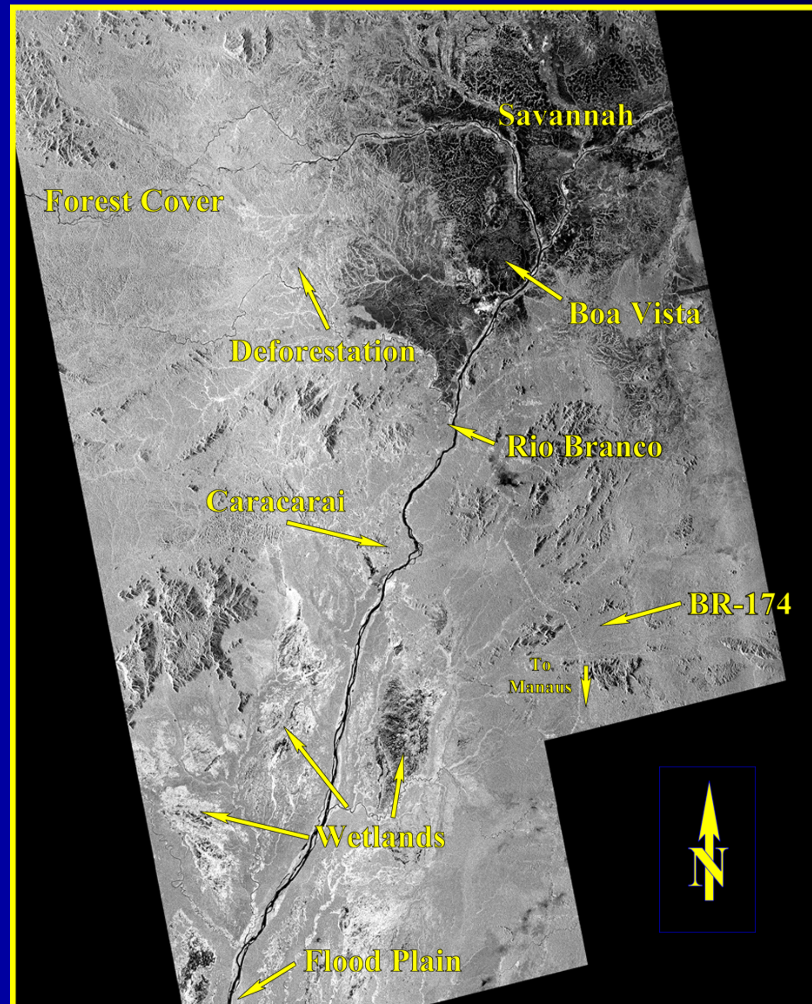
RADARSAT-1

Natural Resource Management Project Roraima State, Brazil

RADARSAT-1 Mosaic

5 frames of Beam Wide 1, Ascending Path

June 9 & 16, 1998



Radiometric processing

1. Information contents vs. radiometric/geometric parameters
2. Mosaicking
3. Pan-sharpening

Radiometric processing

- Pan-Sharpening
- Transformation RGB $\Rightarrow$ IHS
- Principal component analysis
- Wavelet transformation
- SAR- XS data fusion

Radiometric processing: pan sharpening

Fusion of high resolution black & white panchromatic with color (multispectral) imagery creating a high resolution colour image

Based on least squares, developed to best approximate the grey value relationship between the original multispectral, panchromatic and the fused images to achieve a best colour representation.

Statistical approaches were developed to realize a standardized and automated fusion process. The mean, standard deviation and histogram shape for each channel are approximately preserved.

by Dr. Yun Zhang from the University of New Brunswick.

+

=

Radiometric processing: IHS

Intensity is the lightness (or darkness) of a colour

Hue refers to the actual colour

Saturation (grayscale) is the amount of colour present

PROCESS

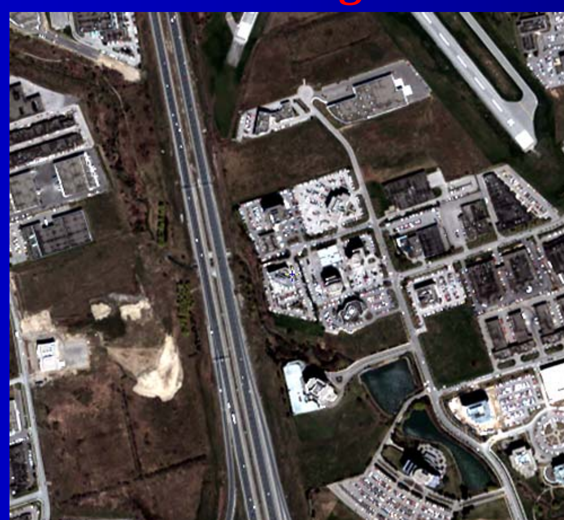
1. RGB to HIS
2. Replace I by Pan
3. HIS to RGB

Intensity

Hue

Saturation

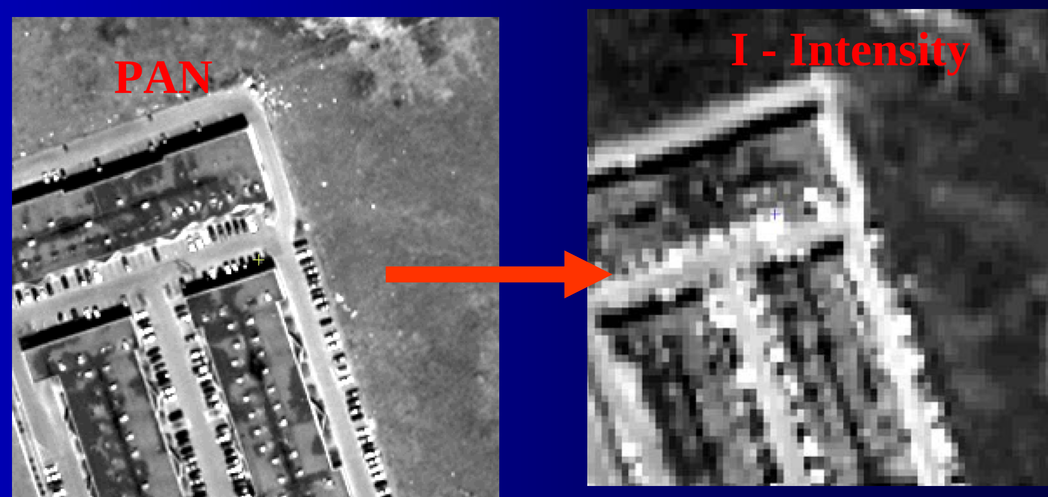
Original RGB



Radiometric Processing: *IHS*

PROCESS

1. RGB to HIS
2. Replace I by Pan
3. HIS to RGB



Radiometric Processing: *IHS*

PROCESS

1. RGB to HIS
2. Replace I by Pan
3. HIS to RGB

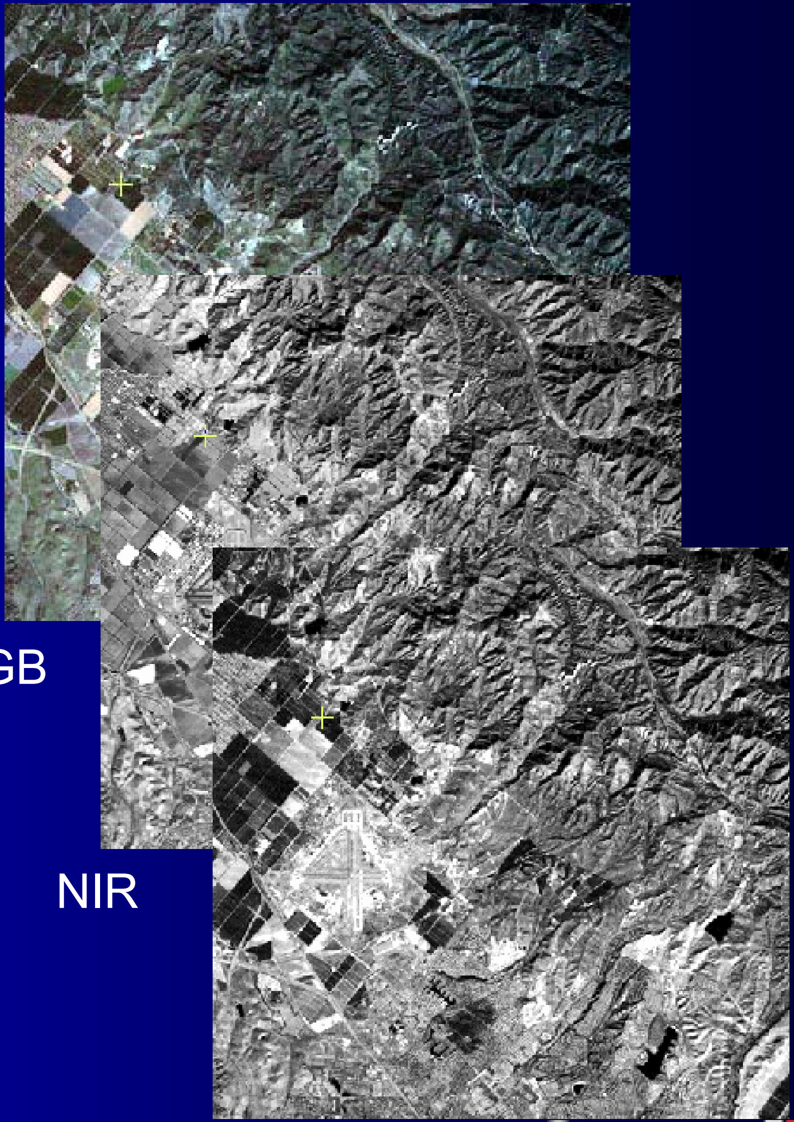
Some spectral distortions are part of the limitation of the process

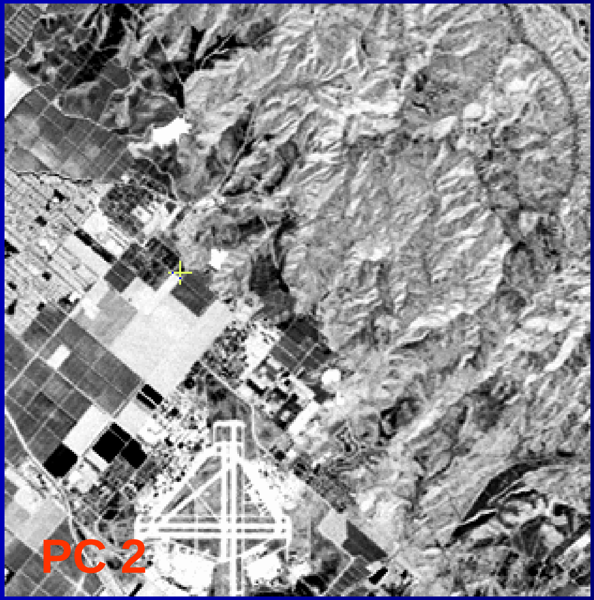
Radiometric processing: PCA

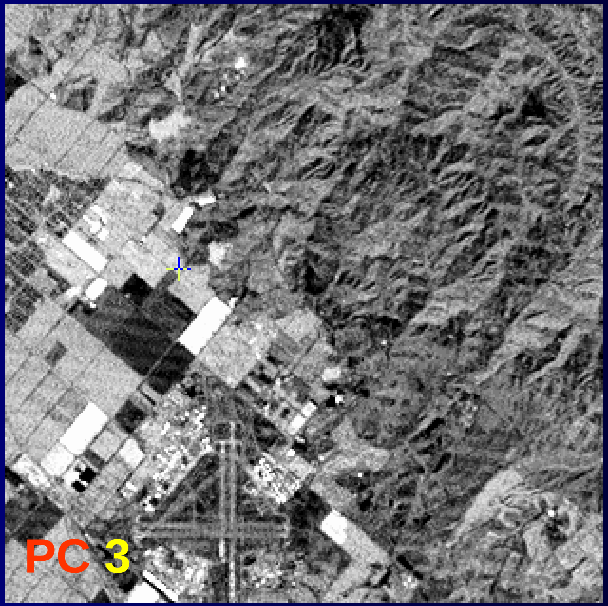
Principal Component Analysis (PCA)

Linear transformation which rotates the axes of image space along lines of maximum variance

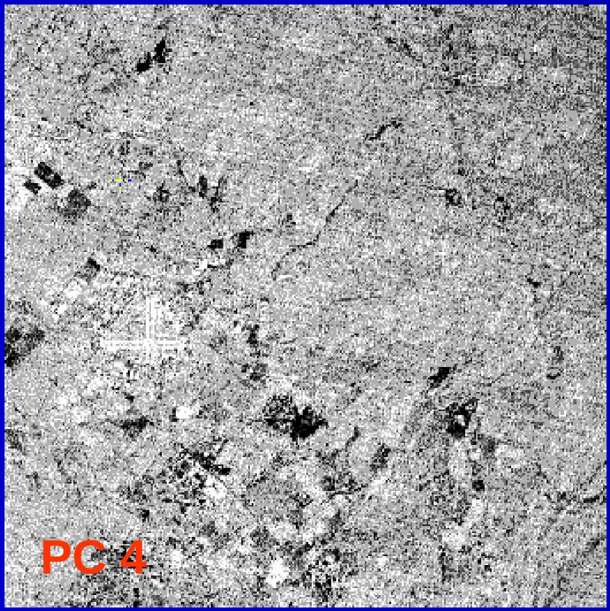
To ‘pack' the information from two or more channels to a smaller number of image channels (eigenchannels) to reduce information redundancy.

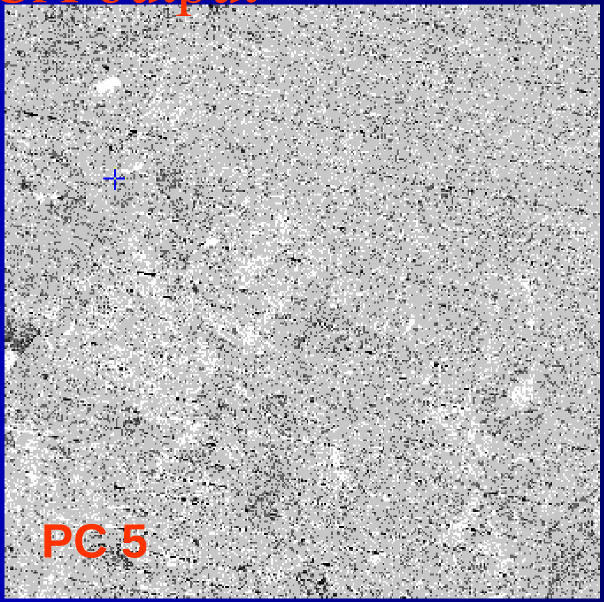






PCA output





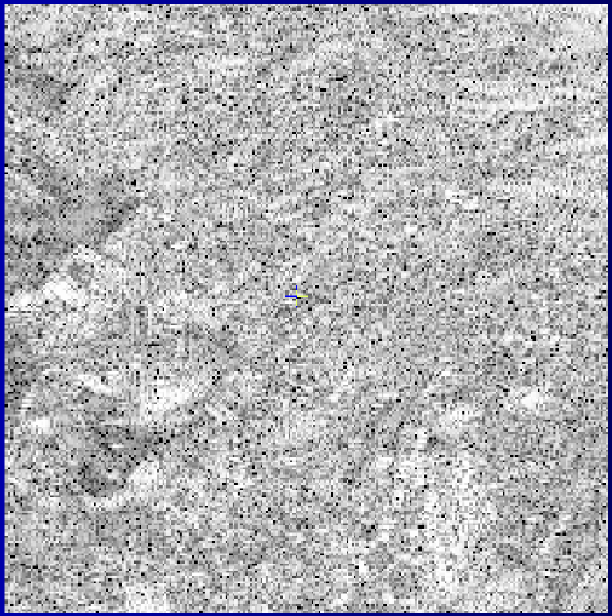

```
Time of execution : 06-Feb-2009  11:58:22:448

Run PCA

1
PCA     Principal Component Analysis            V10.1 EASI/PACE 11:58 06Fe
                                              [S    8FIC     512P     512L] 06Fe

 Input  Channels:   1   2   3   4   5
 Output Channels:   6   7   8
 Eigenchannels  :   1   2   3

 Sampling window:      0      0    512    512
 Sample size    :  32768

   Channel            Mean       Deviation

   1                64.4771       10.0178
   2                25.4875        5.9492
   3                29.1240        9.5824
   4                39.7752       11.2962
   5                25.9260       11.1319

 Covariance matrix for input channels:

            1         2         3         4         5
   +------------------------------------------------
  1|  100.356
  2|   57.234    35.392
  3|   91.265    55.315    91.822
  4|   51.623    35.933    53.626   127.605
  5|   76.609    49.949    86.124    61.284   123.920


 Eigenchannel     Eigenvalue       Deviation      %Variance

      1            353.9080         18.8124         73.87%
      2             81.4424          9.0245         17.00%
      3             39.5849          6.2917          8.26%
      4              3.0105          1.7351          0.63%
      5              1.1499          1.0723          0.24%

 Eigenvectors of covariance matrix (arranged by rows):

       0.48355  0.29935  0.48655  0.41354  0.51848
       0.28297  0.11530  0.24680 -0.90557  0.16021
       0.49801  0.19743  0.18398  0.08589 -0.81962
       0.63968 -0.19006 -0.72212  0.01107  0.18196
      -0.16999  0.90664 -0.38347 -0.03776  0.02507

Note: for the covariance matrix (above), image bands appear as
 columns and principal components appear as rows.


 Scaling Information:

 Eigen  Output  -----Unscaled-----    Deviation     Midpoint        Scale
 Channl Channl     Min         Max        Range                     Factor

     1      6    -51.607     239.398        all        0.000         1.000
     2      7    -70.693      30.709        all        0.000         1.000
     3      8    -52.428     103.298        all        0.000         1.000
Execution Successful.
```

Radiometric Processing: *Wavelet*

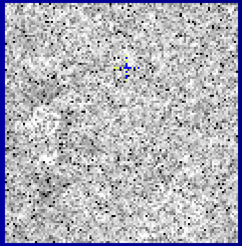
Wavelet Transformation

Decomposes input image into a set of detail mutually orthogonal images at different scales. These images contain horizontal, vertical, or diagonal details in the image within a spatial frequency band.

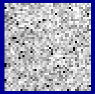
Input Ch4: Near infra-red



H_Freq_Ch4256X256



V_Freq_Ch4128X128



D_Freq_Ch464X64

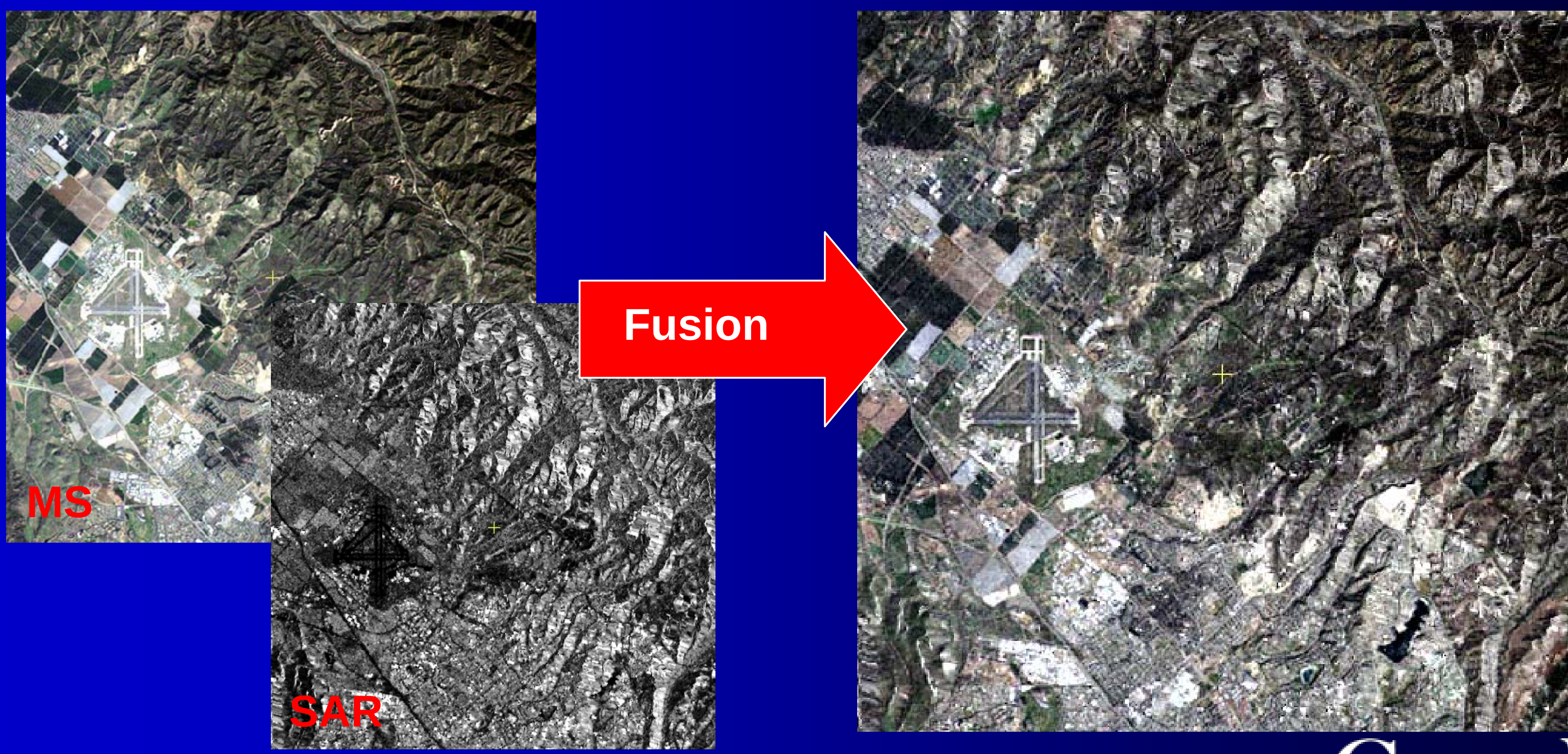
Radiometric Processing: SAR & MS Fusion

Synthetic Aperture Radar (SAR) and multispectral (MS) channel Fusion

- Algorithm in PCI developed by Dr. Yun Zhang, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada.

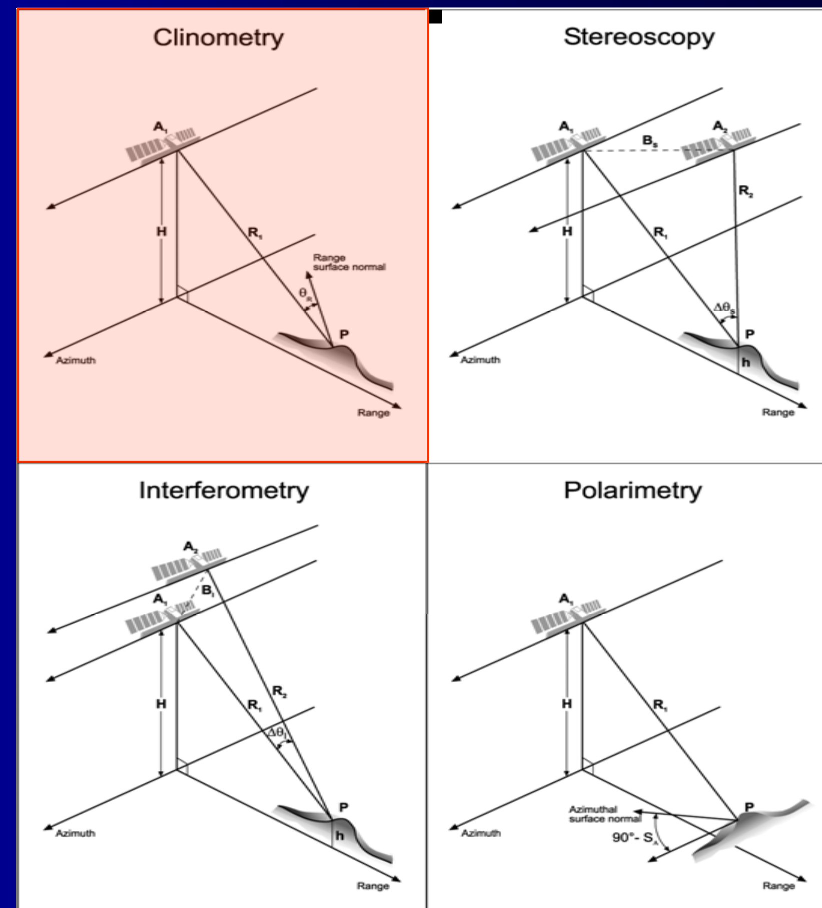
- The SAR and MS grey value ranges are calculated and then fused with linear algorithms:

Fusion = SARvalue/SCALE1 + MSstretch/SCALE2



3D topographic mapping

1. Clinometry
2. Stereoscopy
3. Interferometry
4. Polarimetry
5. Altimetry: satellite radar and Lidar



3D topographic mapping: clinometry

Three familiar phenomena:

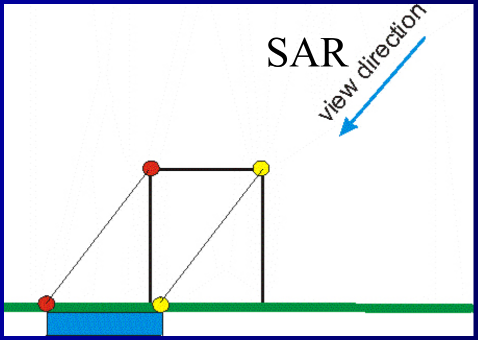
(1) Shadow when ground surface is not illuminated

(2) Occluded areas when ground surface is not visible

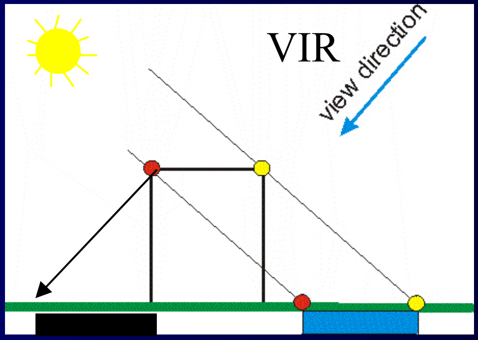
The shadow/occluded areas (and layover for SAR) lengths can then be consistently measured only from vertical structures (buildings, towers, trees) to measure relative heights

(3) Shade is the variation of brightness depending of the local incidence angle. The inversion of the mathematical expression of VIR reflectance/SAR bakscatter in terms of albedo and local incidence angle.

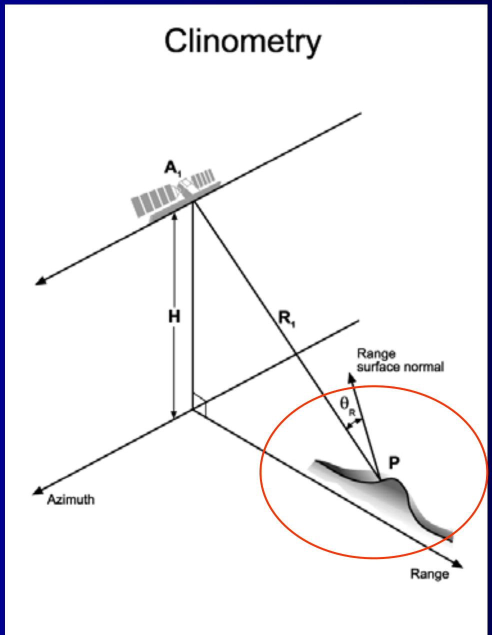
It works better with uniform reflecting surfaces (Amazon, Antarctica) using Lambertian model.



Shadow = occluded areas

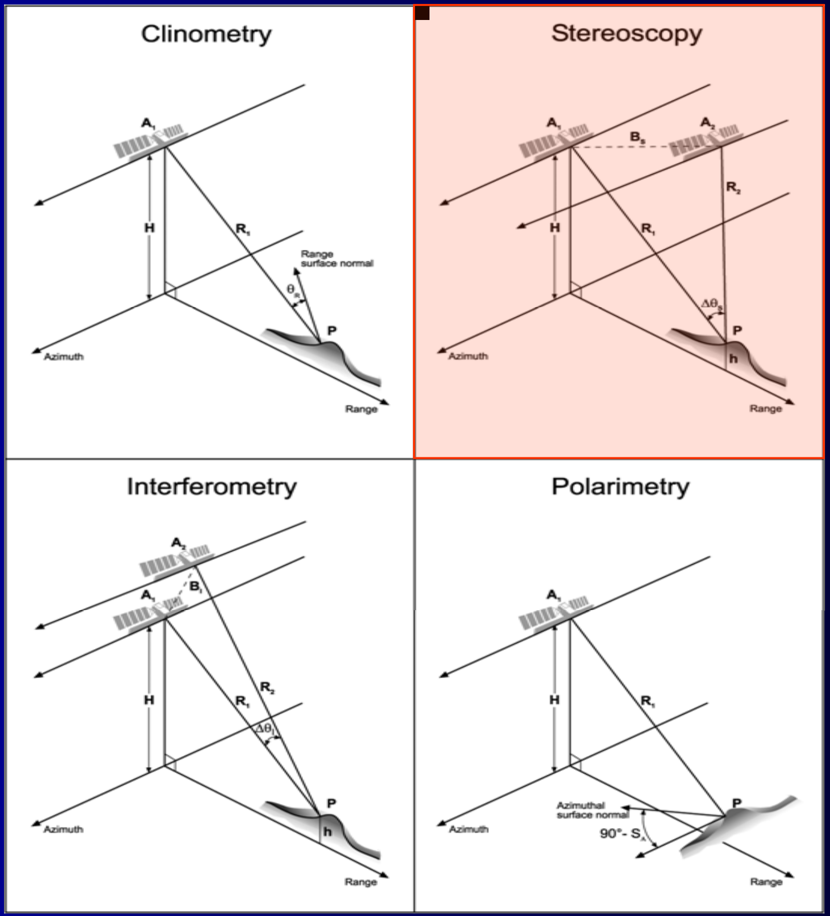


Occluded areas ≠ Shadow



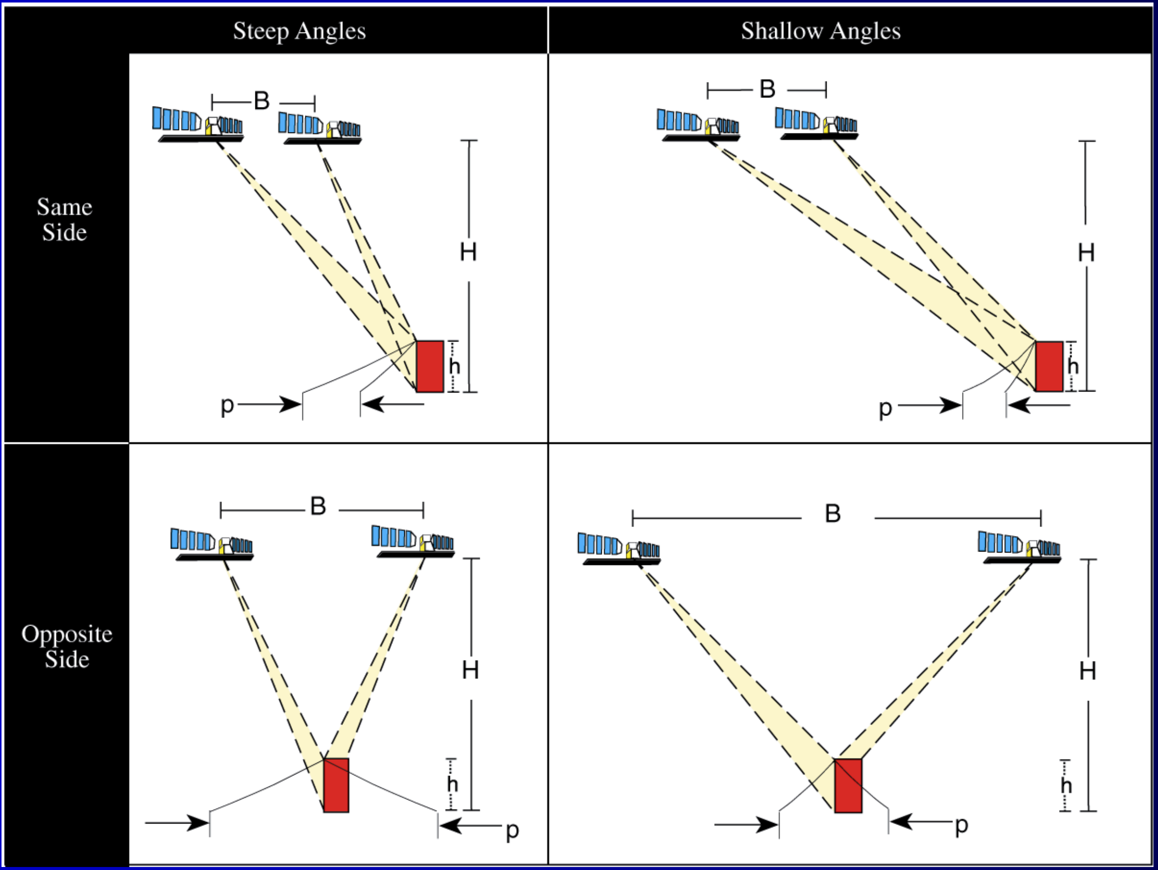
3D topographic mapping

1. Clinometry
2. Stereoscopy
3. Interferometry
4. Polarimetry
5. Altimetry: satellite radar and Lidar

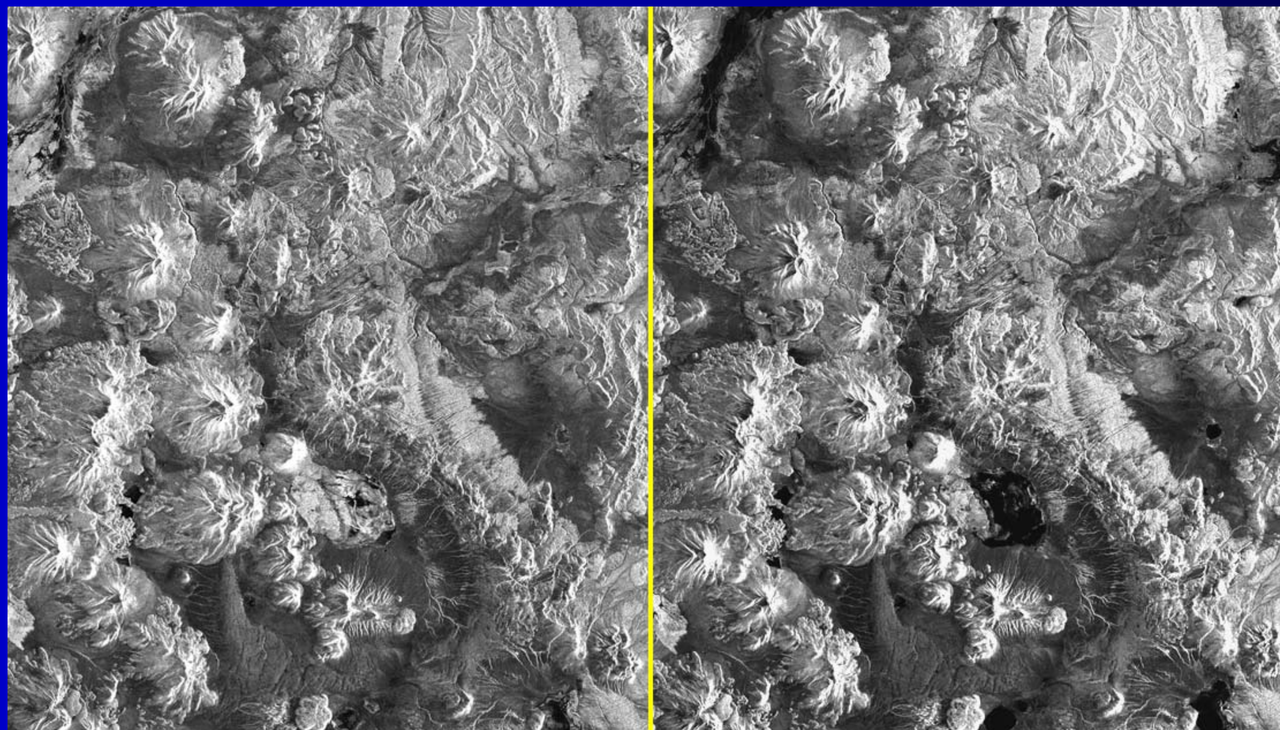


3D topographic mapping: stereo

Trade-off for stereo SAR between viewing, intersection angles and relief



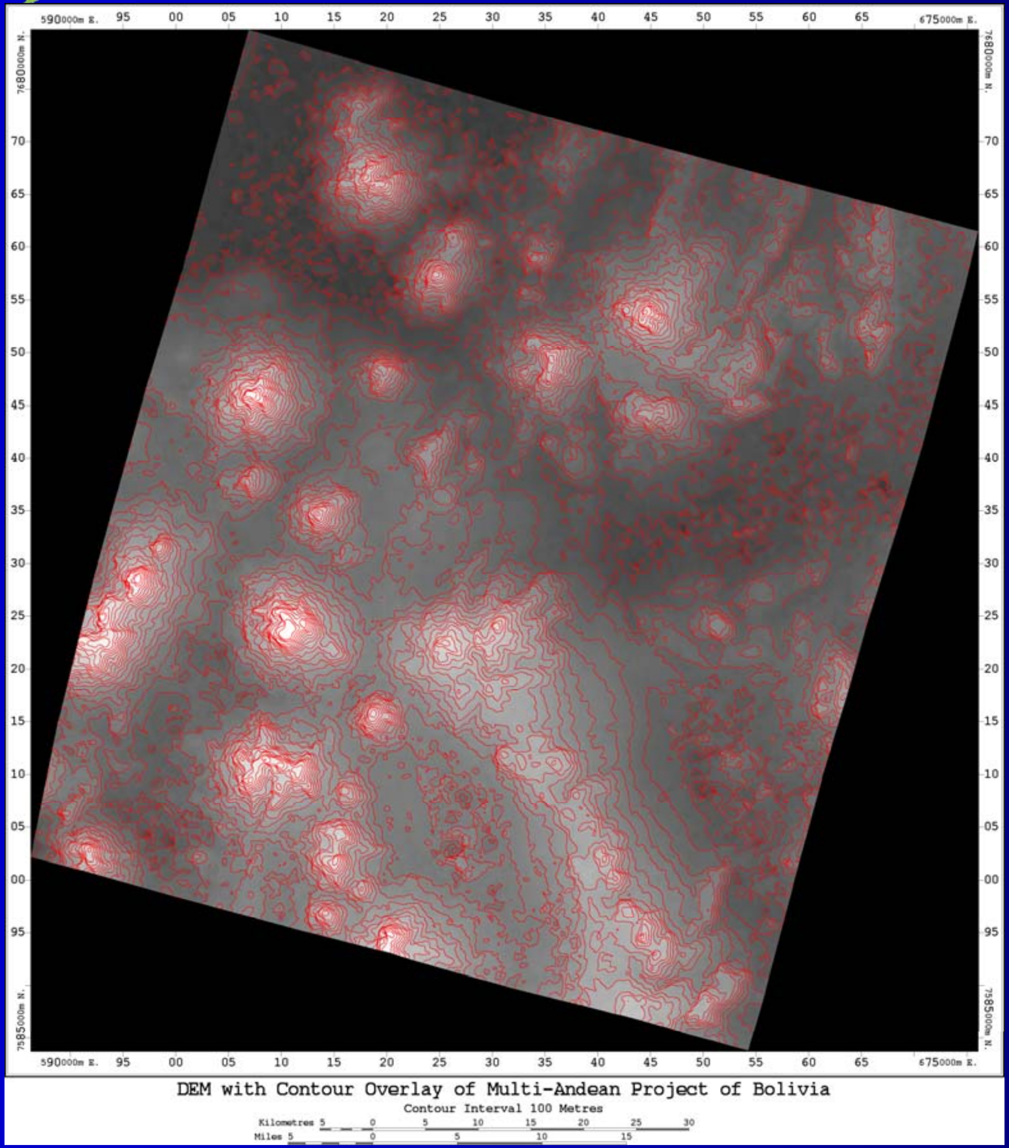
3D topographic mapping: *stereoscopy*



Par estéreo en modo estándar (S3-S6; órbita descendente; alcance terrestre; espaciado de 12,5-m pixel) utilizado en el Proyecto Multiandino de Bolivia (Lizeca *et al.*, 1999).

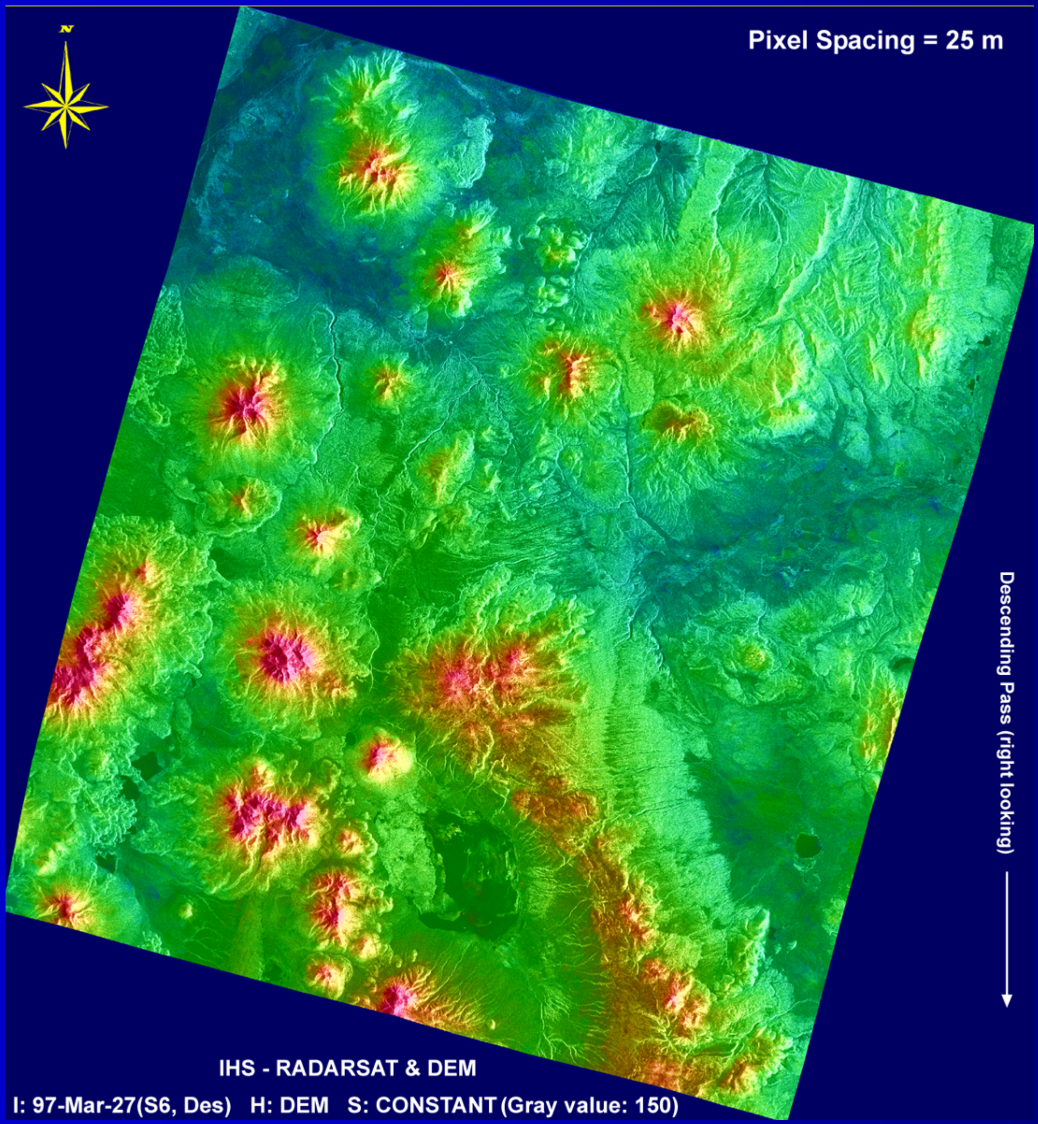
Imágenes RADARSAT: © CSA 1997, 1998; recibido por CCRS; procesado y distribuido por RADARSAT International.

3D topographic mapping: stereoscopy



DEM de extracción estéreo de 8-m resolución Radarsat-1 SAR imágenes con las líneas de nivel a 100-m superpuestas generadas a partir del par estéreo del Proyecto Multiandino de Bolivia utilizando soporte lógico PCI OrthoEngineSE.

3D topographic mapping: stereoscopy



3D imagen cromo-estereoscópica (espaciado de 25-m pixel) generada a partir de la imagen ortorectificada Radarsat-1 SAR S6 y del DEM extraído en estéreo de Radarsat-1 SAR del Proyecto Multiandino de Bolivia.

3D topographic mapping: stereoscopy

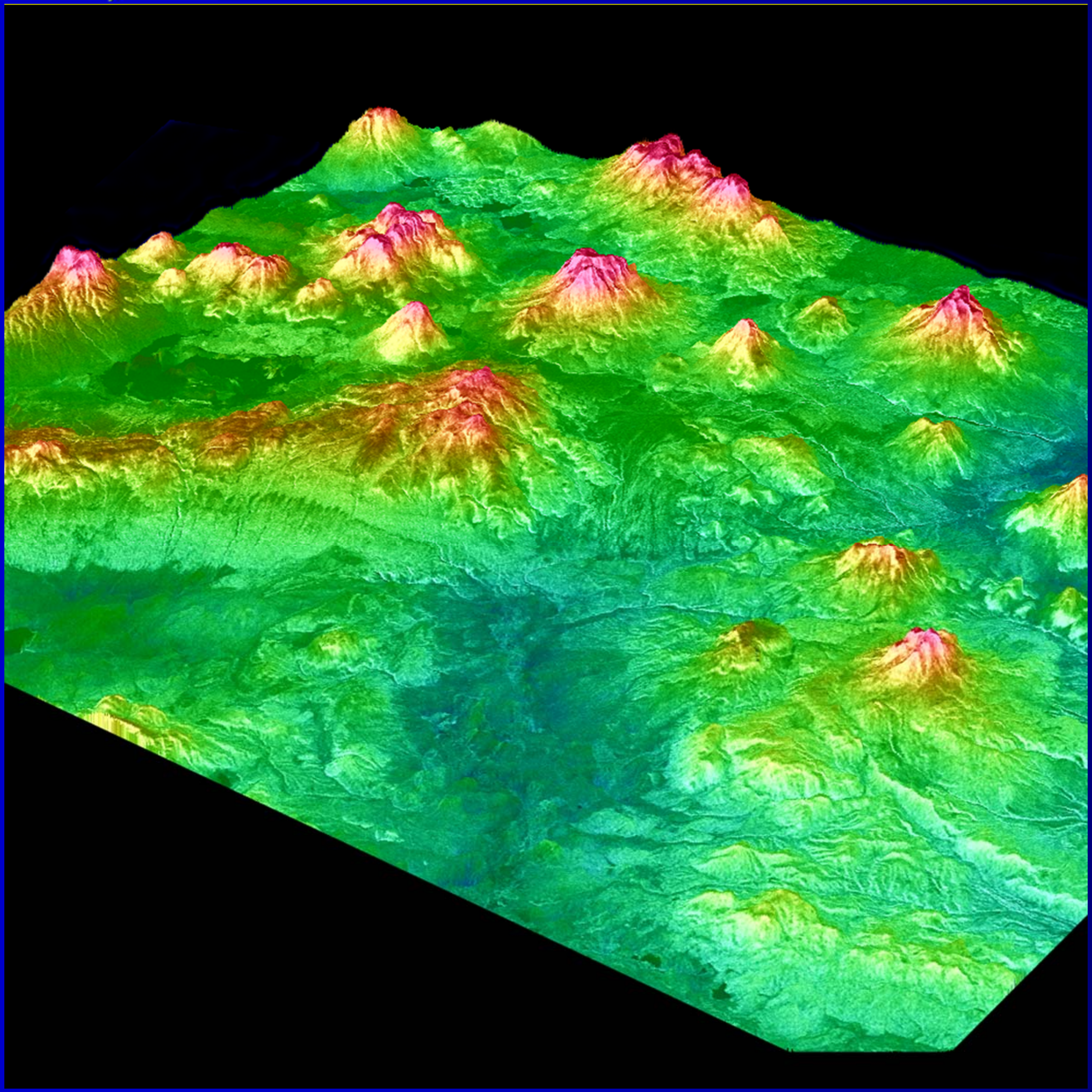
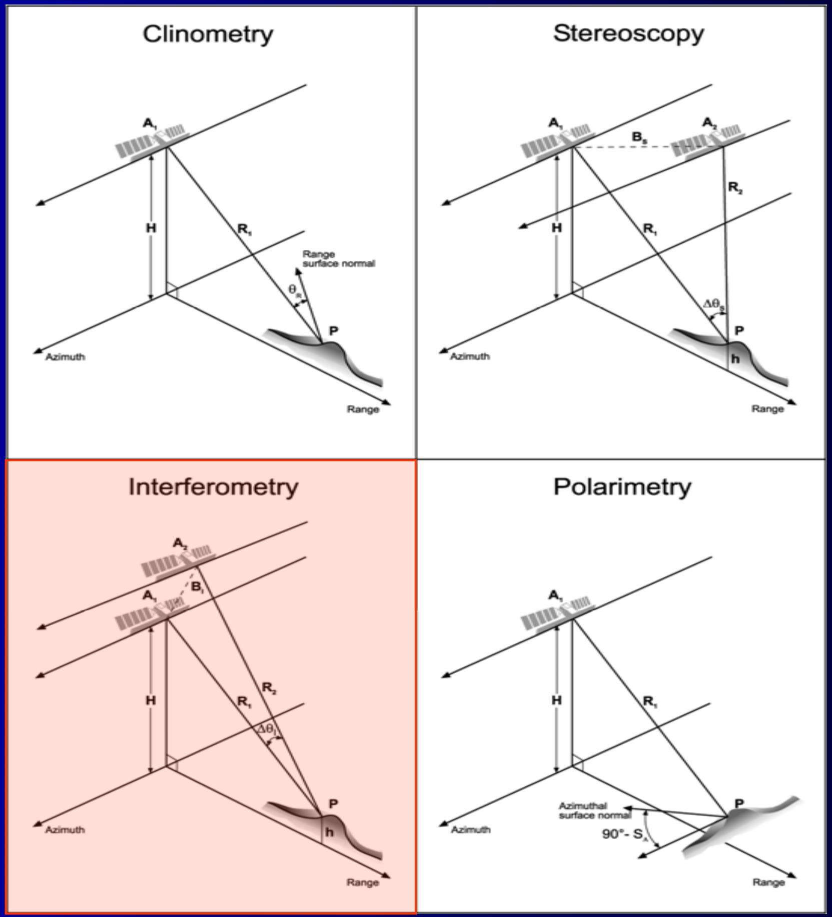


Imagen en perspectiva (espaciado de 25-m pixel) generada a partir de la imagen Radarsat-1 SAR S6 cromo-esteroscópica 3D del Proyecto Multiandino de Bolivia superpuesta al DEM extraído en estéreo de Radarsat-1 SAR imagenes.

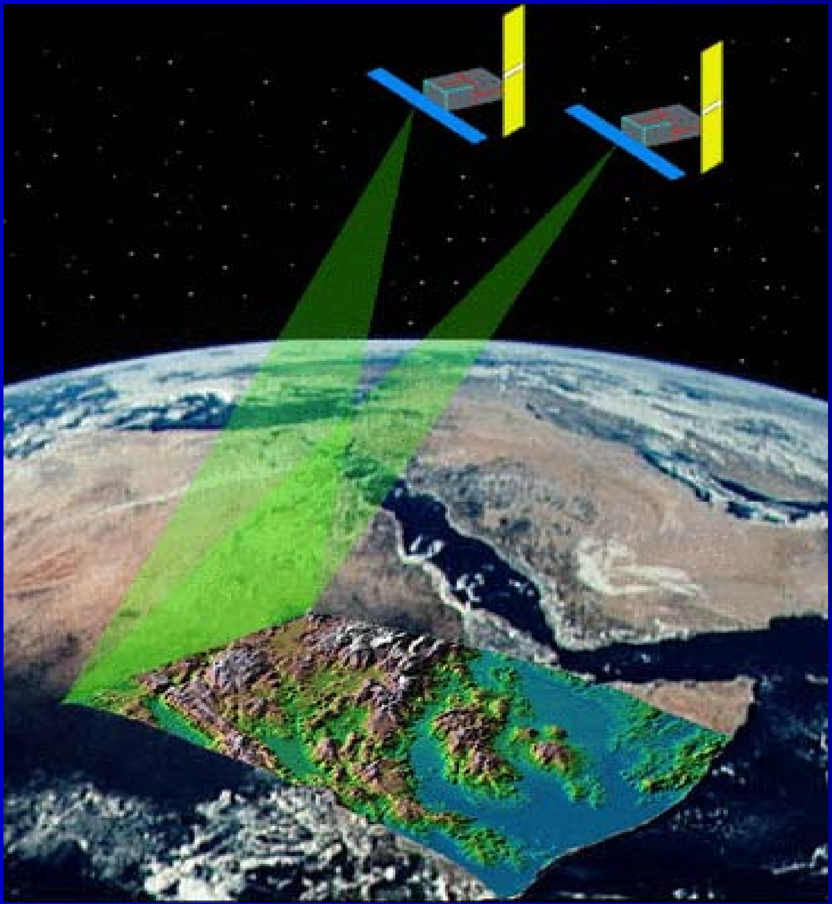
3D topographic mapping

1. Clinometry
2. Stereoscopy
3. Interferometry
4. Polarimetry
5. Altimetry: satellite radar and Lidar



3D topographic mapping: interferometry

Dr. Pierre-Jean Alasset



Drawing courtesy of Prof. Howard Zebker, Stanford University

- Two satellites image the Earth's surface
- Or one satellite takes two images a few days apart
- Data are processed into complex SAR images
- The phase difference of the two images is processed to obtain height and/or motion information of the Earth's surface

3D topographic mapping: *interferometry*

- Takes advantage of phase difference between two scenes, taken at different times (similar to time lapse photography)
- The phase difference between corresponding pixels in two radar images produce an interference pattern (interferogram)
- In principle if two sequential satellite images are taken from exactly the same position, there should be no phase difference for any pair of corresponding pixels
- If the scene on the ground changes slightly between two scans, the phases of some pixels in the 2nd image will shift.
- Large baseline (300-500 m) for DEM extraction and small baseline (50-200 m) for surface displacement
- If we want to *remove the topographic component* of phase:
  - the baseline must be small enough that the topography component can be neglected,

    or
  - an accurate DEM must be used to remove the topography component

3D topographic mapping: *interferometry*

Dr. Pierre-Jean Alasset

Difference between 2 radar images radar with topographic phase component removed.

$$\Phi_{MS} = \Phi_{orbit} + \Phi_{atm} + \Phi_{topo} + \Phi_{defo} + \Phi_{noise}$$

Φ_{MS}	Measured phase difference
Φ_{orbit}	Inaccurate orbit information
Φ_{atm}	Atmospheric effects
Φ_{topo}	Topography
Φ_{defo}	Surface displacement
Φ_{noise}	Others factors

3D topographic mapping: InSAR

Dr. Pierre-Jean Alasset

$$\Phi_{MS} = \Phi_{orbit} + \Phi_{atm} + \Phi_{topo} + \Phi_{defo} + \Phi_{noise}$$

Master

SLC Image

Slave

SLC Image

Interferometric processing for DEM generation

Precise coregistration of Master and Slave → SAR Master image

Generation and enhancement of interferogram
- Interferogram generation
- Removal of flat Earth
- Coherence image generation
- Interferogram filtering

→ Coherence image

→ Interferogram

Correction of orbital errors ($B_{\perp}$ et Yaw angle) => residual flat Earth change

Phase unwrapping

Conversion of unwrapped differential phase in slant range direction to DEM → DEM

Geocoding of all image products

3D topographic mapping: DInSAR

$$\Phi_{MS} = \Phi_{orbit} + \Phi_{atm} + \Phi_{topo} + \Phi_{defo} + \Phi_{noise}$$

Master
SLC Image

Slave
SLC Image

High Res DEM

Interferometric processing - 2-pass differential

Precise coregistration of Master and Slave → SAR Master image

Precise coregistration of DEM to Master

Generation and enhancement of differential interferogram
- Interferogram generation
- Removal of flat Earth and topographic phase
- Coherence image generation
- Interferogram filtering

→ Coherence image
→ Differential interferogram

Correction of orbital errors ($B_{\perp}$ et Yaw angle) => residual flat Earth and topographic phase change

Phase unwrapping

Conversion of unwrapped differential phase to slant range direction change → Deformation map

Geocoding of all image products

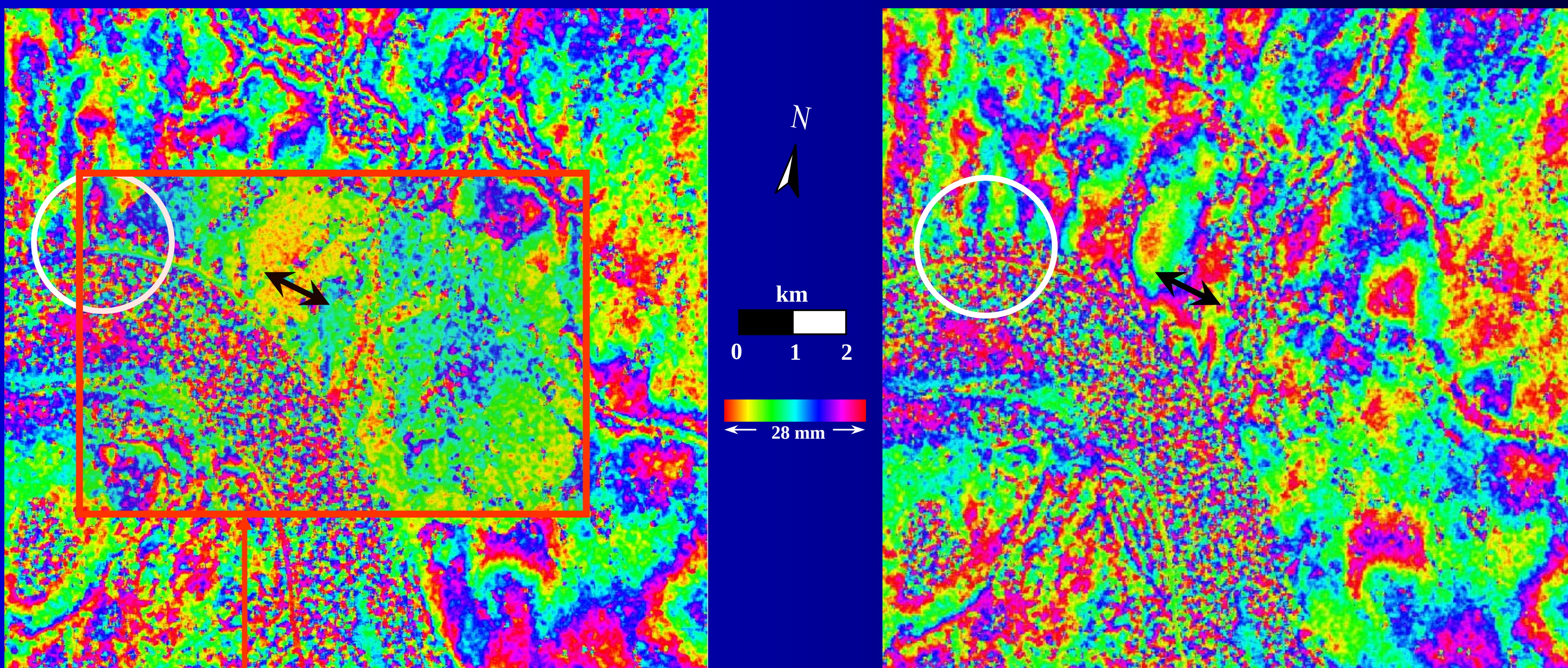
3D topographic mapping: DInSAR

Dr. Pierre-Jean Alasset

DEM resolution – influence on processing

Mackenzie River, NWT, Canada

- 23-Aug-06 / 19-Sep-06 interferogram, orth. baseline: 527 metres



WITH High Res. DEM in the ROI

WITHOUT High Res. DEM in the ROI

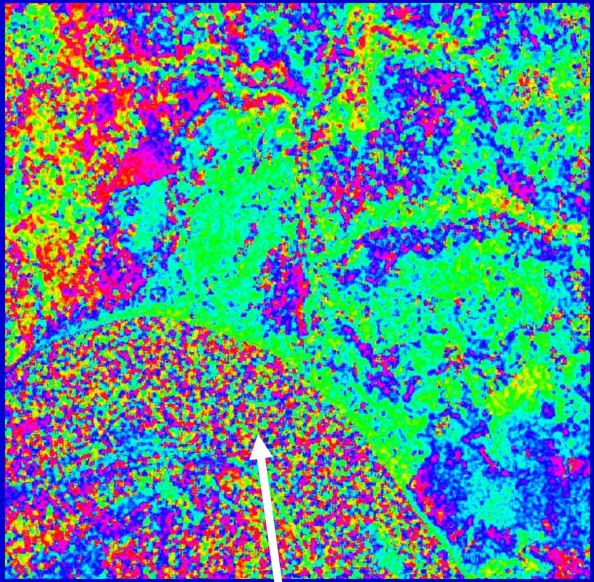
3D topographic mapping: DInSAR

Dr. Pierre-Jean Alasset

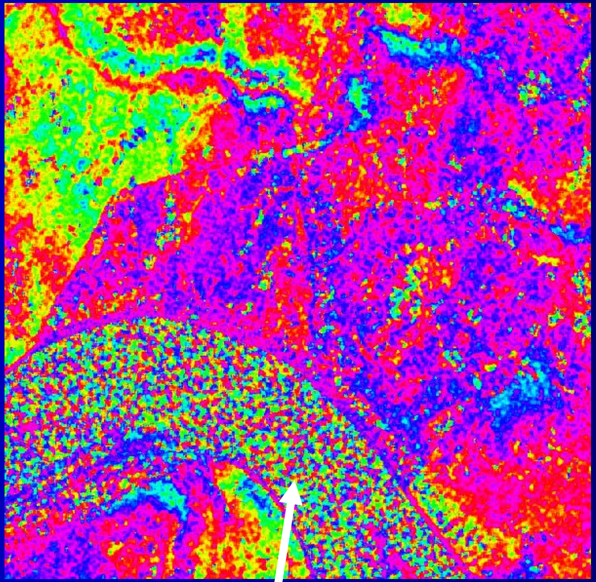
Time spanned between 3 acquisitions

Interferograms corrected of DTM phase from summer 2006 example

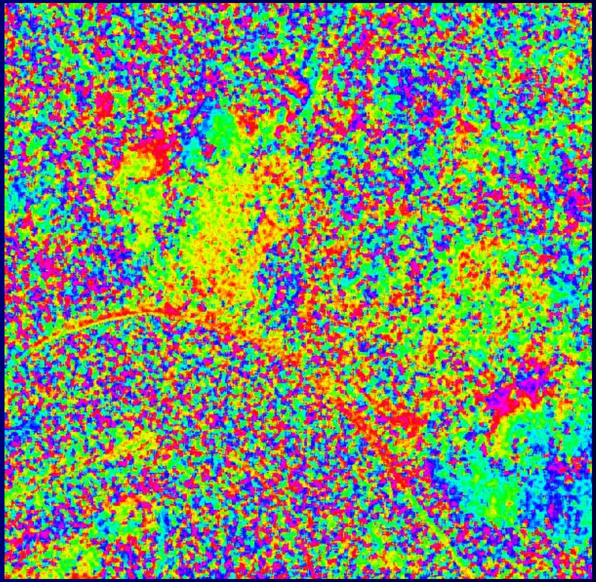
24 days RSAT-1
04-Aug-06 / 28-Aug-06



24 days RSAT-1
28-Aug-06 / 21-Sep-06



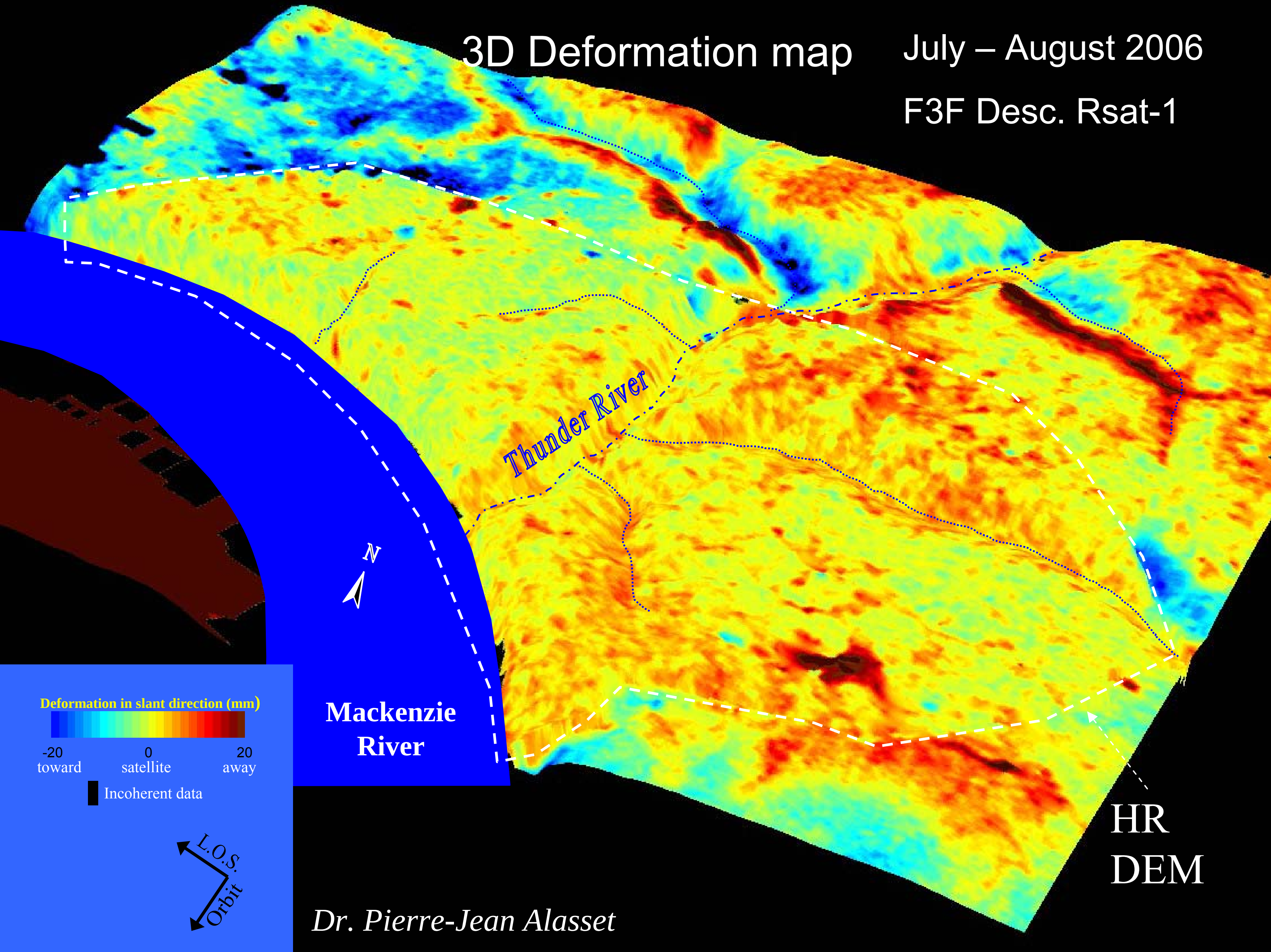
48 days RSAT-1
04-Aug-06 / 21-Sep-06



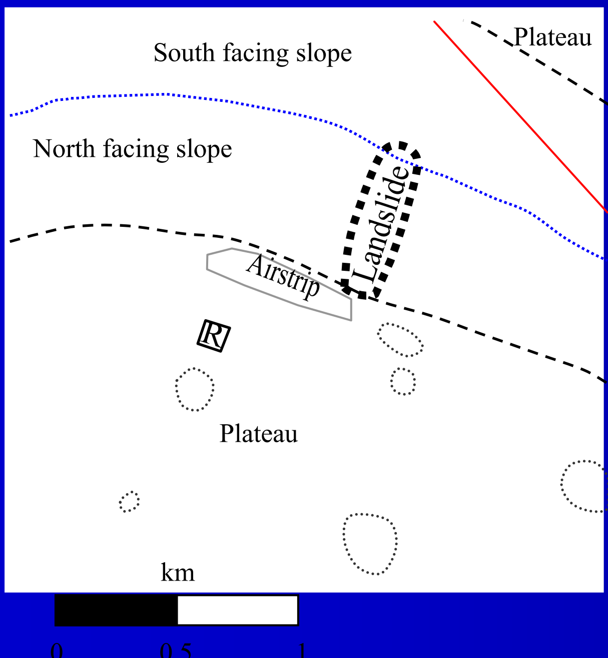
River: loss of coherence

N

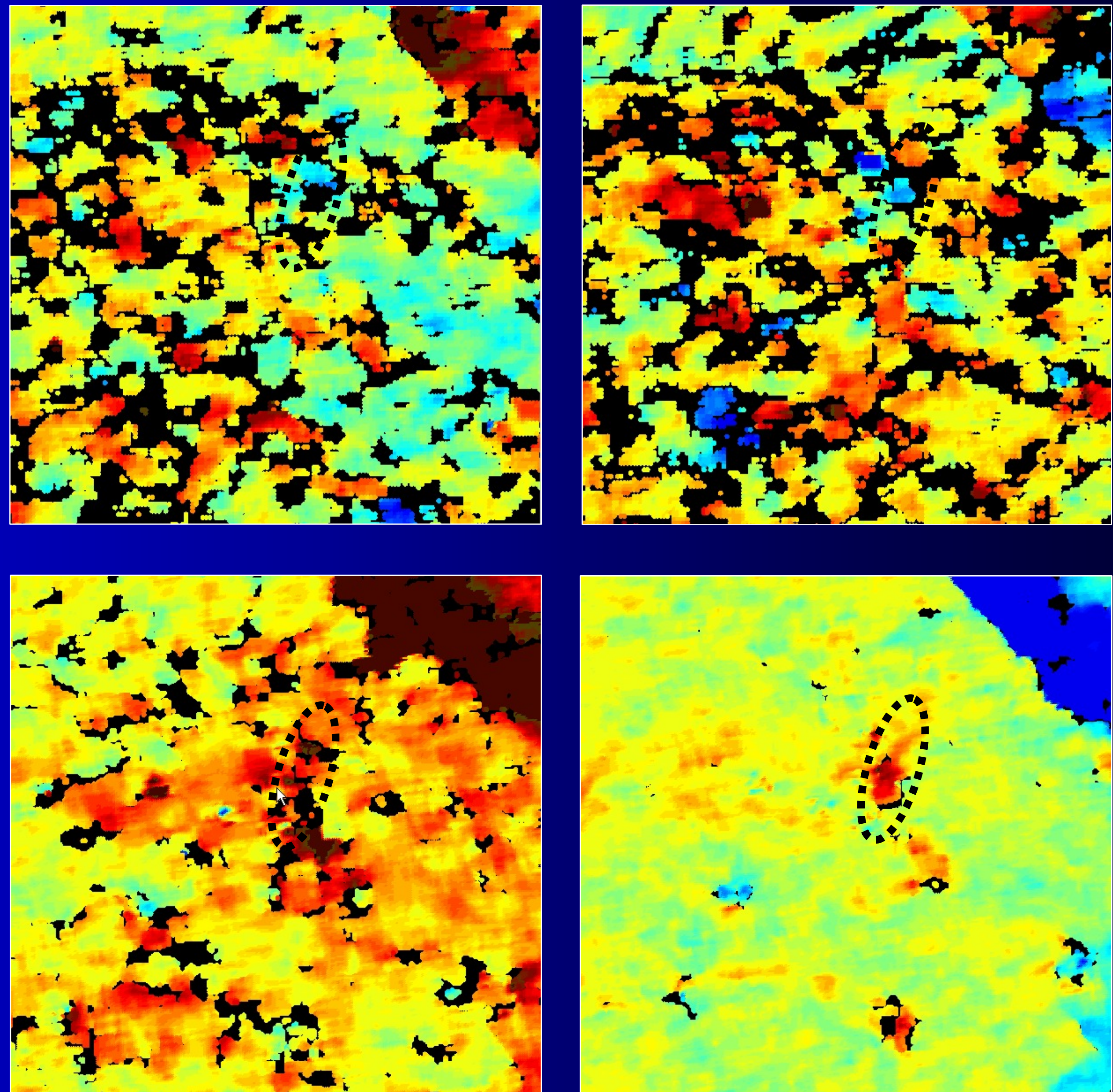
Temporal decorrelation


3D Deformation map
July – August 2006
F3F Desc. Rsat-1
Thunder River
N
Mackenzie River
Deformation in slant direction (mm)
-20 toward
0 satellite
20 away
Incoherent data
L.O.S.
Orbit
HR DEM
Dr. Pierre-Jean Alasset

Permafrost activity

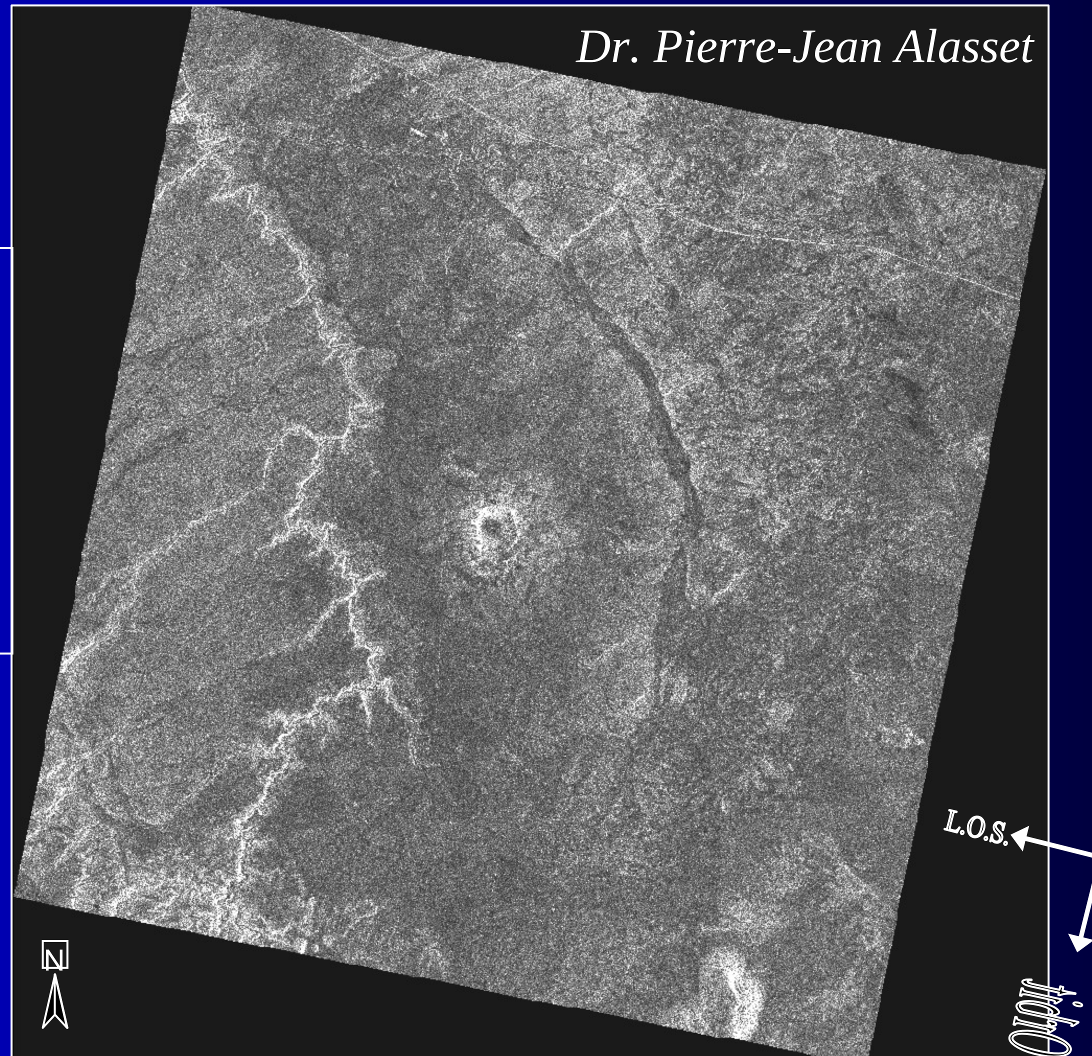


5 Rsat-1F3F images
Ascending orbit
24 days time interval



3D topographic mapping: interferometry

Radarsat-2 ultra fine mode
3-m resolution
Slant range
Descending orbit
Incidence angle ~ 30°
Acquired on 2008-Oct-23



Barringer Meteor Crater Arizona

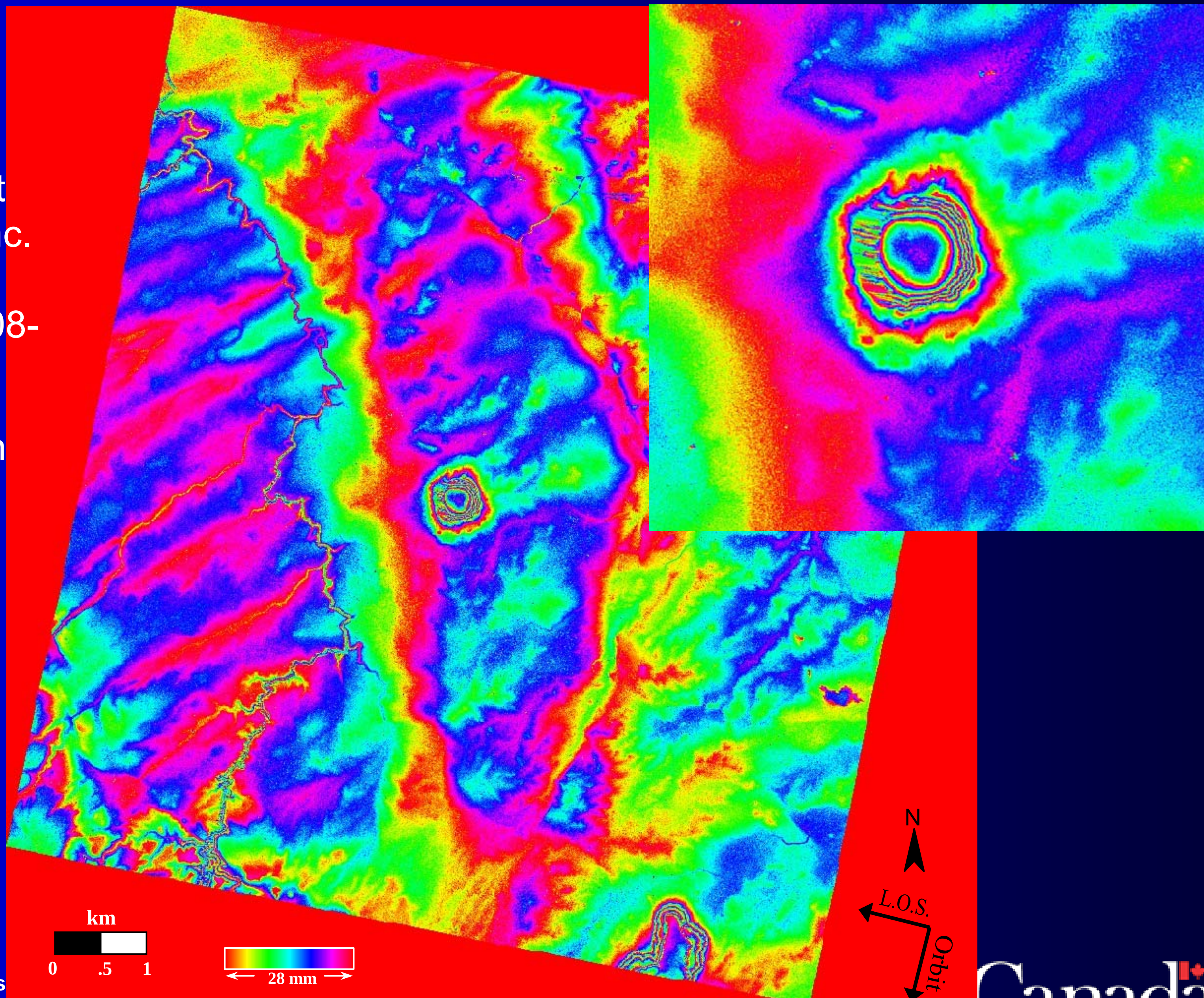
Barringer Meteor Crater Arizona

Ultra Fine UF1
Descending orbit
Interferogram (Inc. Angle ~ 30deg)
2008-Oct-23/2008-Nov-16

1 fringe = 28 mm in Line-Of-Sight

Orthogonal baseline: 418m

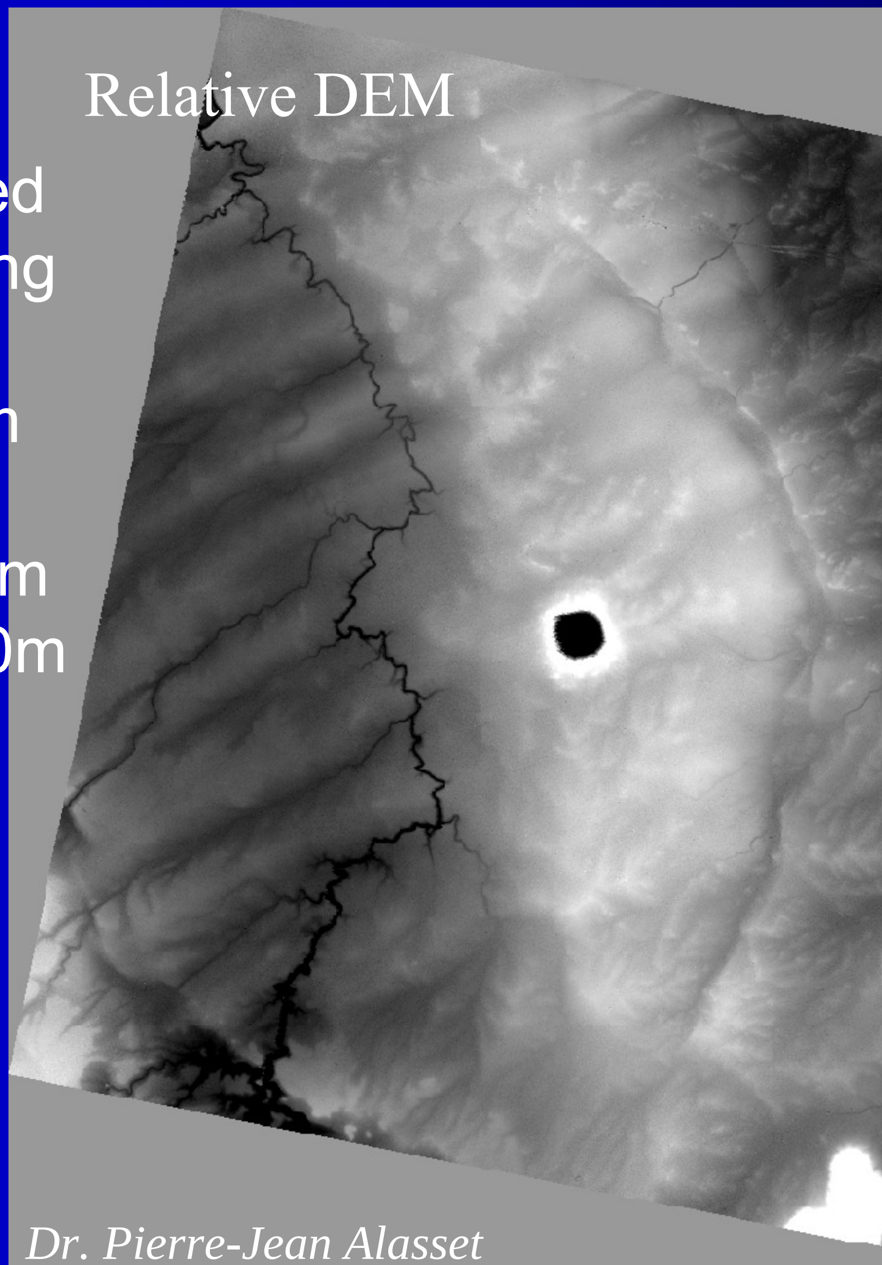
Crater elevation: 180 m

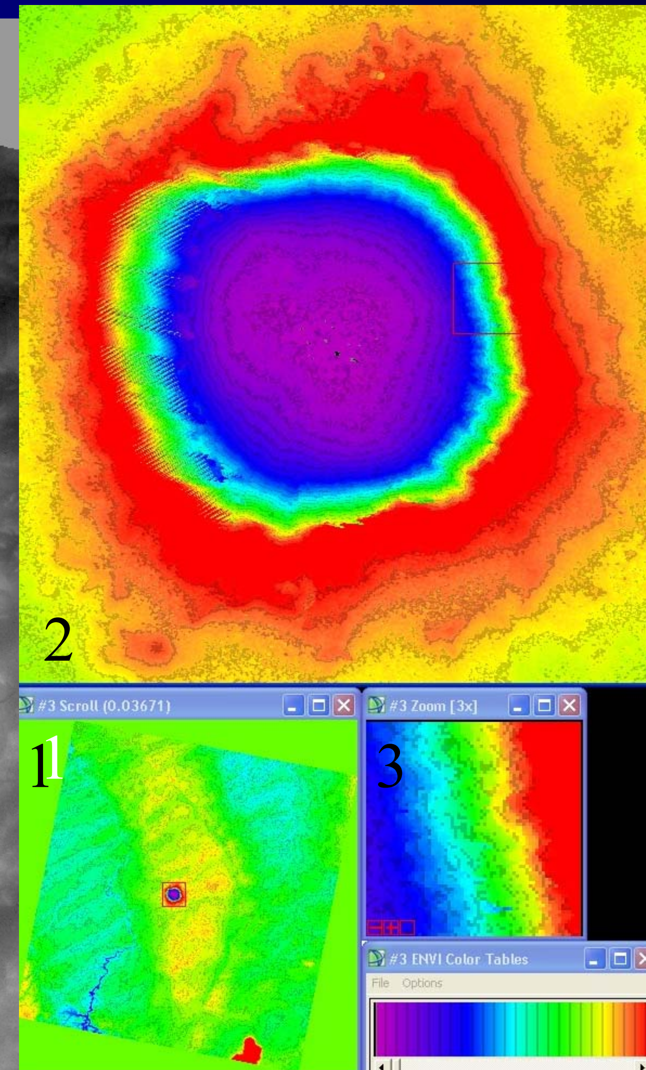


Barringer Meteor Crater Arizona

DEM obtained by unwrapping the interferogram

Elevation from 1550 to 1750m





Dr. Pierre-Jean Alasset

3D topographic mapping: ***interferometry***

General results of interferometric-DEM accuracy. As with stereo SAR, results from low relief terrain (lowest values) will be better than those from areas with significant relief (highest values), although no quantitative evaluation has been done on this topic. Quantitative tests of the accuracy of Radarsat-2 ultra-fine mode InSAR are presently limited but should achieve better results than with Radarsat-1 fine mode.

Satellite	Resolution (m)	Accuracy (m)	Notes
ERS 1/2	24	3-20	For most areas, except tropical forest or regions with significant vegetation or moisture variability. The ERS 1/2 tandem data archive is extensive.
JERS	18	10-20	L-band shows better coherence (for more terrain types and for longer time periods) than C-band.
RADARSAT (standard mode)	20-29	10-20	Dry terrain is preferred due to the 24-day orbit repeat cycle and potential loss of coherence.
RADARSAT (fine mode)	7-9	3-10	Dry terrain preferred. Larger baselines are possible, increasing accuracy and reducing sensitivity to propagation effects.

3D topographic mapping

1. Clinometry
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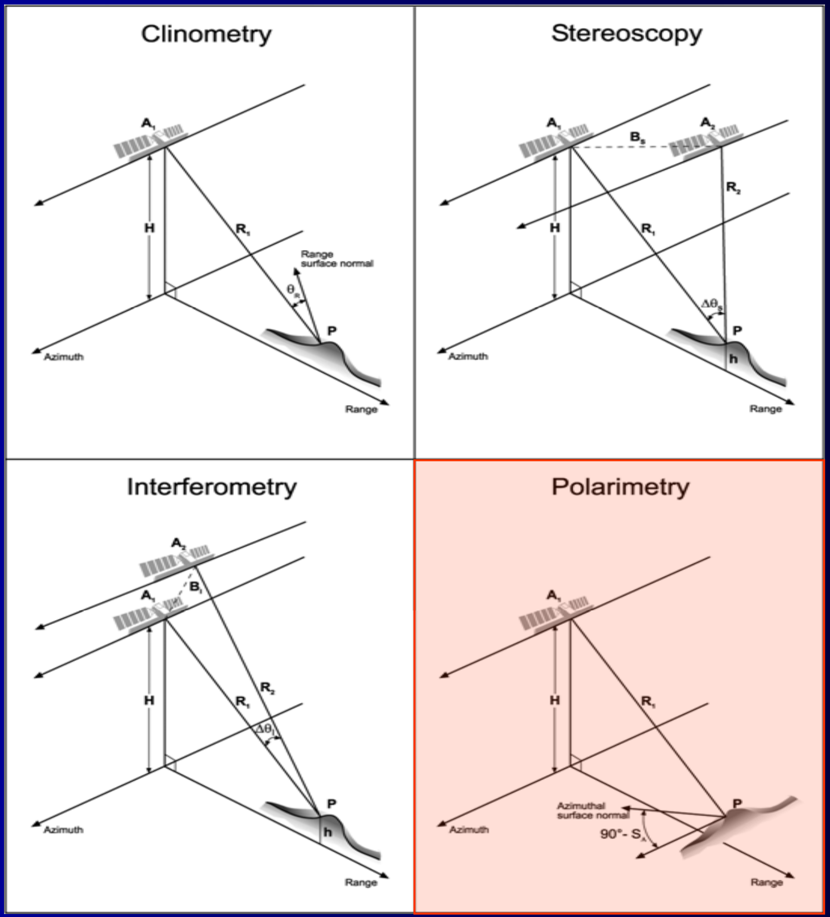


3D topographic mapping: *polarimetry*

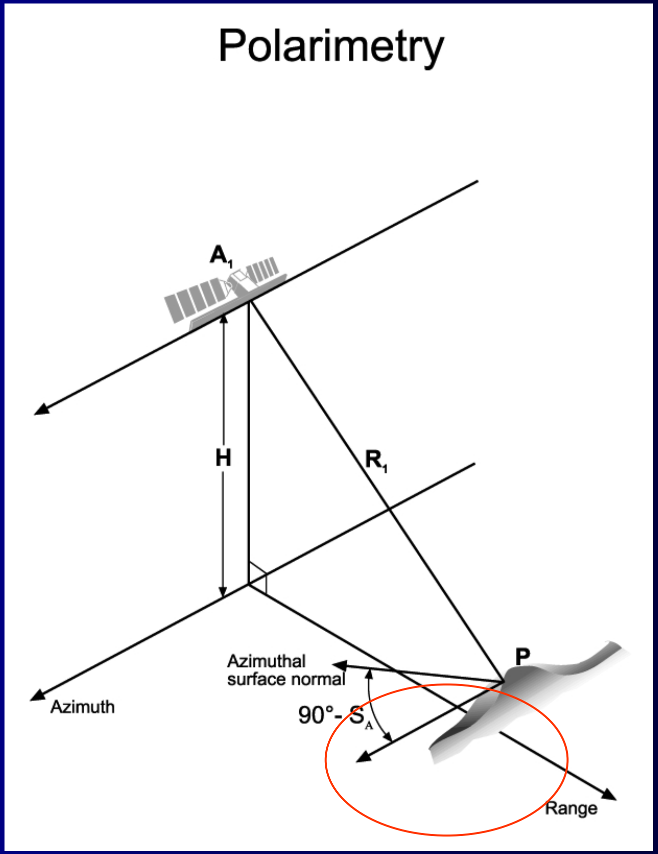
Polarimetric SAR measures the amplitude and phase terms of the complex scattering matrix.

Based on a theoretical scattering model for tilted, slightly-rough dielectric surfaces (Valenzuela, 1968), azimuthal surface slope angles and signature-peak orientation displacements produced by such slopes are proportional over a range of azimuthal slopes.

An azimuthal angle of an open-field terrain causes a proportional shift of the co-polarised polarimetric signature maximum from its flat position by an angle almost equal to the terrain slope.

Azimuthal direction slopes can then be computed from the polarimetric SAR data without any prior knowledge of the terrain.

By integrating the slope profiles in the azimuthal direction relative terrain elevation can be derived. To obtain absolute elevation, one elevation point must be known along each slope profile.



But scientists are now not too confident about this relationship

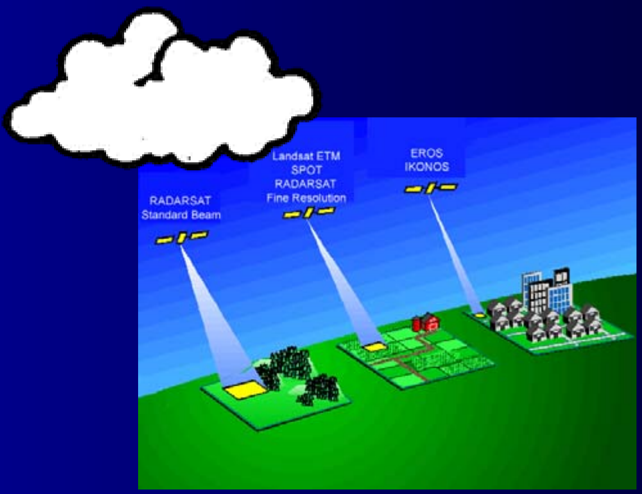
3D topographic mapping

1. Clinometry
2. Stereoscopy
3. Interferometry
4. Polarimetry
5. Altimetry: satellite radar and Lidar

Geosat (2 km), Cryosat (250 m), ICESat (70 m), do not provide high resolution data for 3D topo mapping !

Map updating

1. Techniques and processes
2. Examples of 2D/3D products for map updating
3. Applications with VIR data
4. Applications with SAR data



Map updating: *Techniques & processes*

GENERALITIES

Map older than 10-15 years → New map generation

New ellipsoid or datum → New map generation

Large area to be mapped → Block adjustment

DEM too coarse or not precise → Stereoscopic method

Map updating

Advantages of satellite imagery over aerial photography

- The satellite is operational 365 days of the year,
- Frequent re-visit times (e.g. every 4 days),
- Imagery is post-processed relatively quickly,
- No Air Traffic Control restrictions apply,
- Large area footprint (e.g. 16.5 x 16.5 km2) cuts down the need for block adjustment and creation of image mosaics,
- The satellite can easily access remote or restricted areas,
- No aircraft, cameras or expensive equipment are required (by the end user).

Map updating

And the disadvantages ...

- The typical off-nadir viewing angle of up to 25° is not acceptable
- The production processes required for high resolution satellite imagery may be different to those of traditional photogrammetric data capture
- The reliability of capture and delivery of imagery is unknown,
- Image resolution is low compared to most aerial photography.
- There is a strong possibility of cloud cover

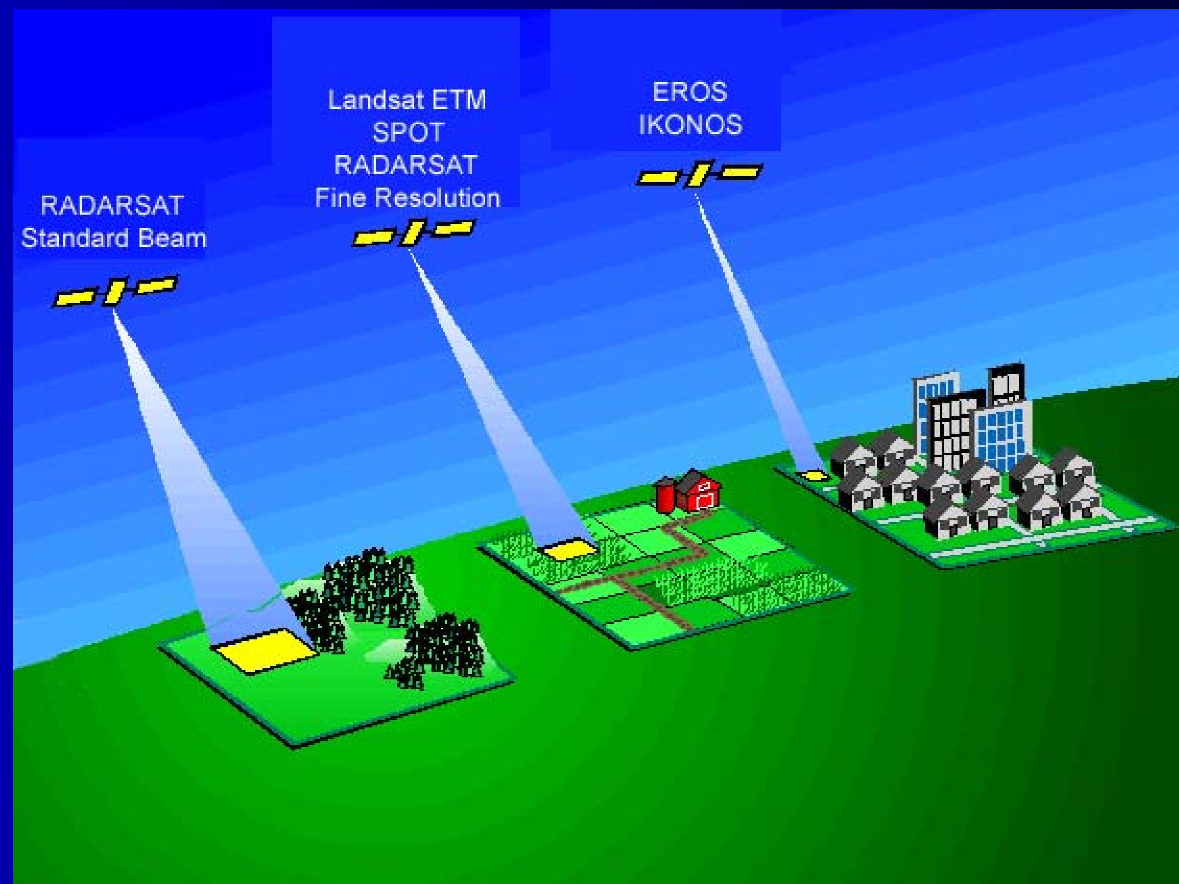
Map updating: Techniques & process

- Resolution: VFSR: QuickBird, Ikonos, WorldView, GeoEye, DK1
  FSR: SPOT5, Cartosat, Formosat,…
  SAR: Radarsat-2, TerraSAR, Cosmo-SkyMed

Rule of thumb for sufficient map contents (cf. Jacobsen):
0.05 - 0.1mm of map per pixel
e.g. for map 50k 2.5m – 5m pixel size

VFSR for 1:10000 & 1:25000

FSR for 1:50000



Map updating: Techniques & process

IMAGES: Satellite

- Resolution
- Data search/programming

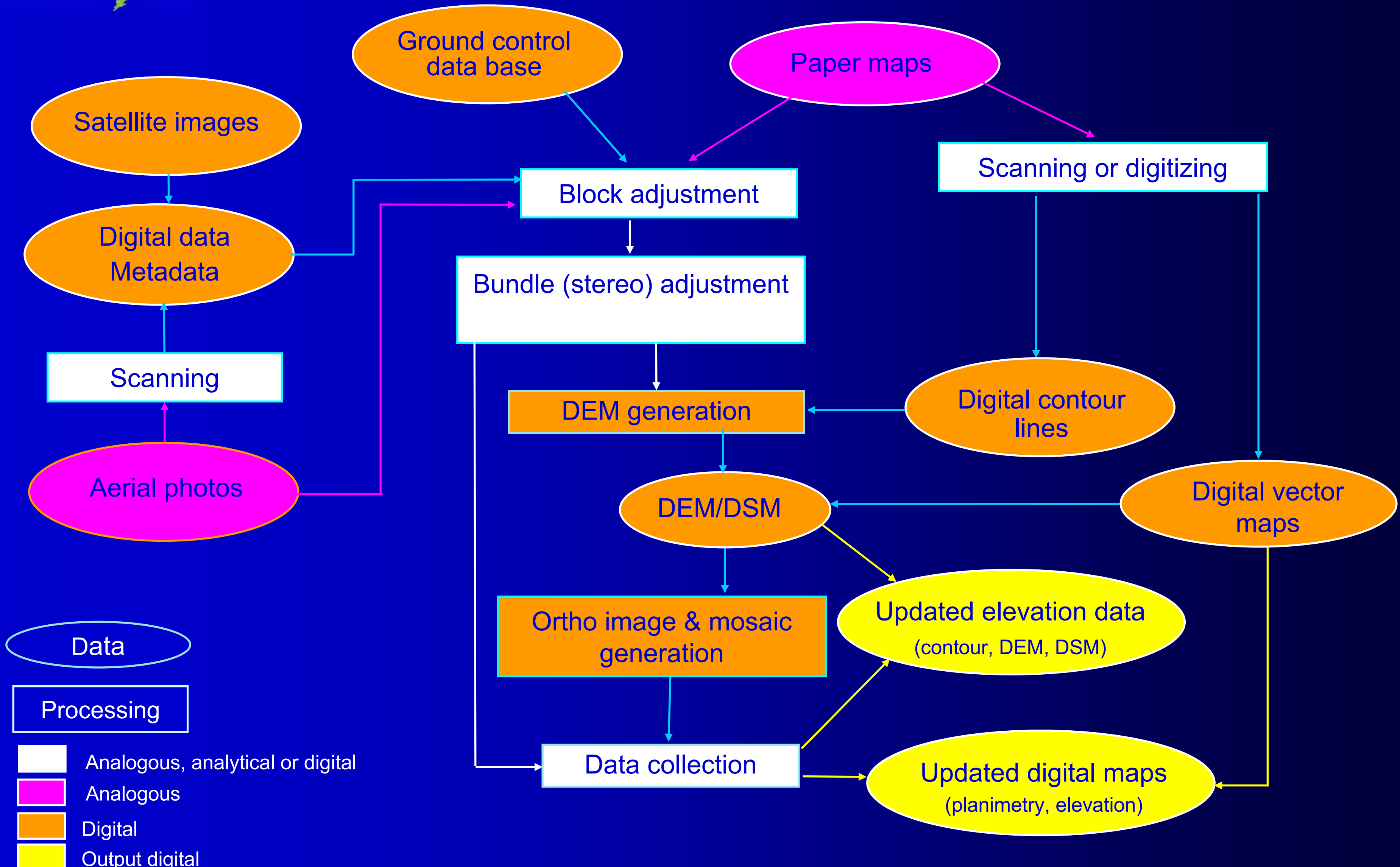
Data search should favour strip acquisition in N/S and same-season acquisition in E/W
http://edcsns17.cr.usgs.gov/EarthExplorer

Data programming is only possible for off-nadir sensors: SPOT5 http://sirius.spotimage.fr/anglais/Welcome.htm and RADARSAT-2

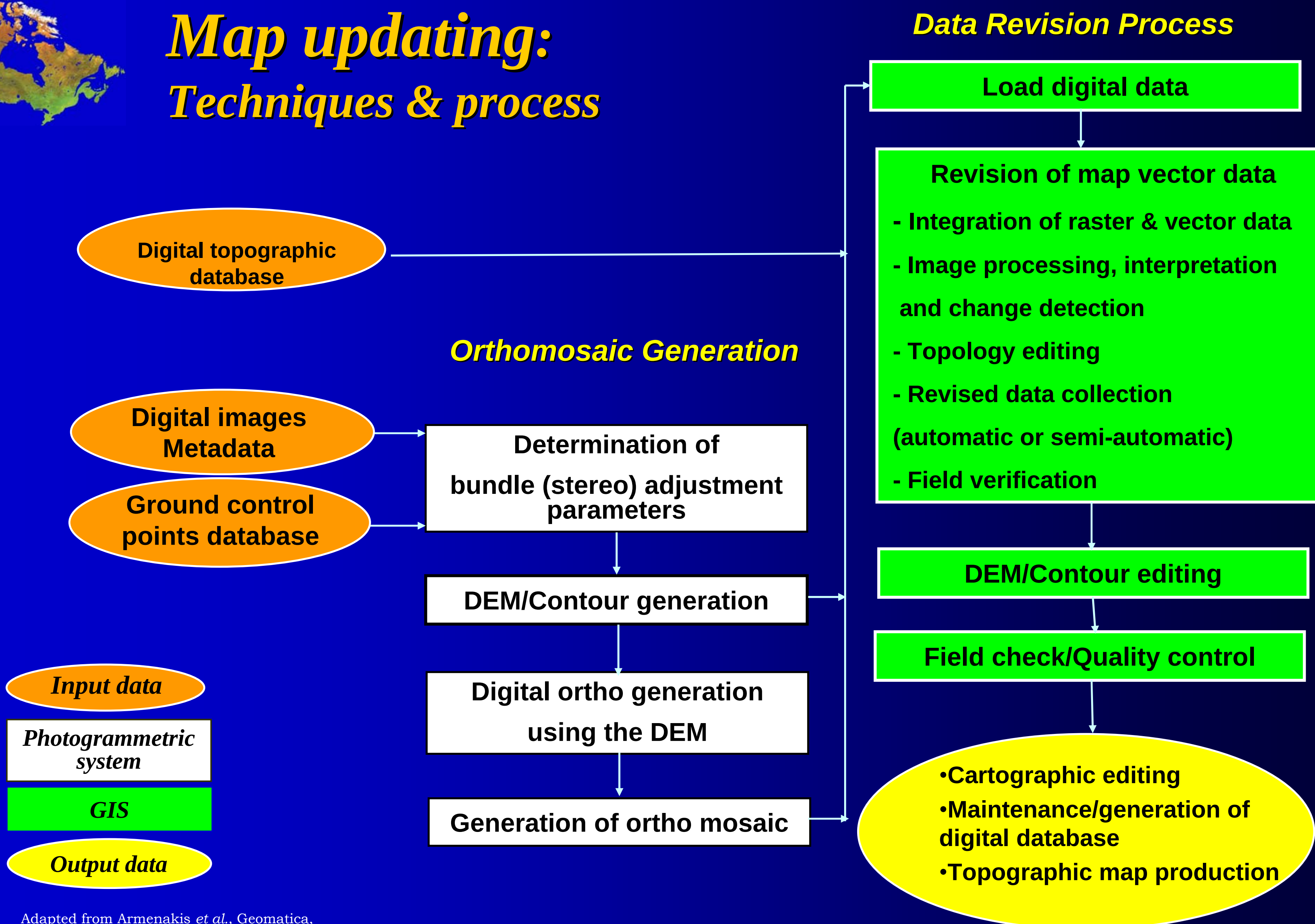
Almost no control for programming HR data, except SPOT5

Cloud cover, temporal change, solar illumination are the major problems in search/programming of image block

Map updating: Techniques & process

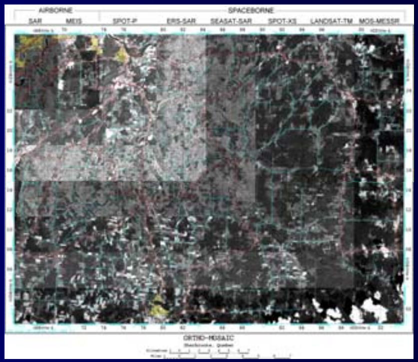


Map updating:
Techniques & process



Adapted from Armenakis *et al.*, Geomatica, 1995, 49(4):433-443

Map updating



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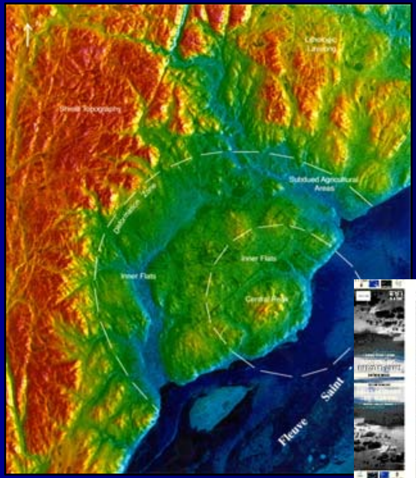
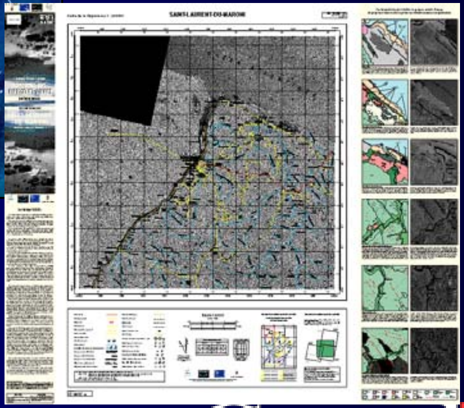
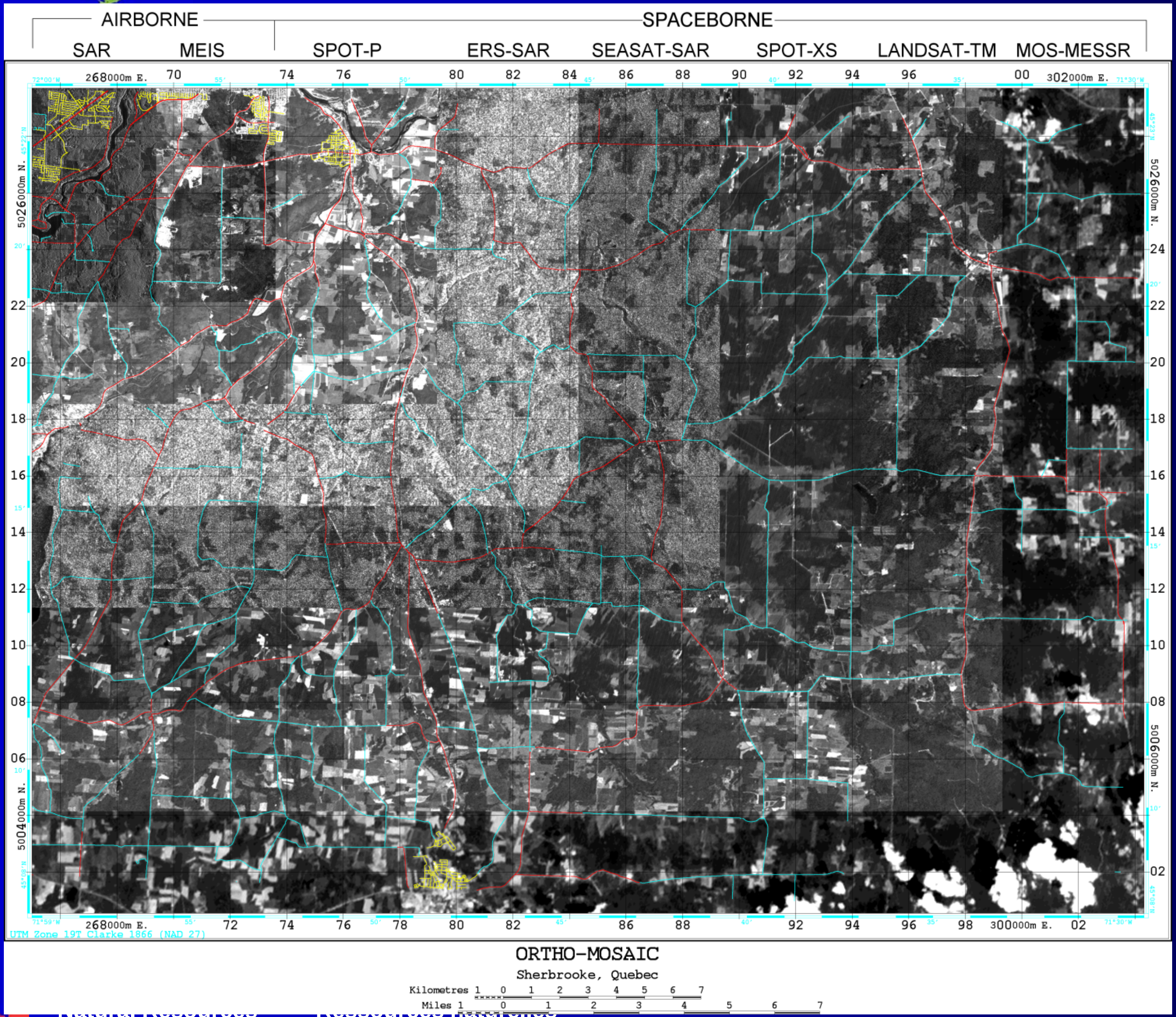




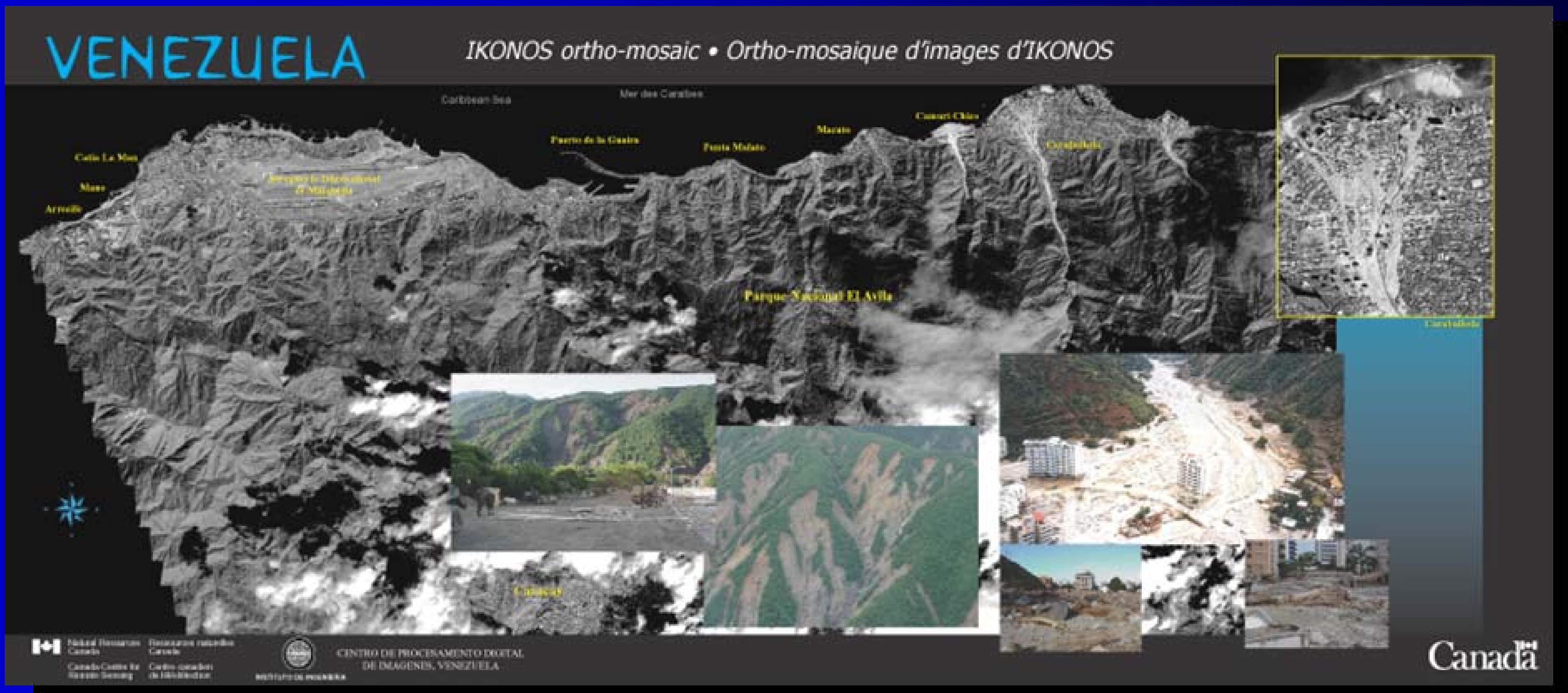
Map updating: 2D/3D products



Multi-platform multi-sensor space map with 50,000-scale vector overlaid

Map updating: 2D/3D products

Mapping with Ikonos for 99's flooding in Venezuela



Four in-track IKONOS pan images

Map updating:

2D/3D products

QuickBird Map Image Product over Voisey's Bay

Potential applications

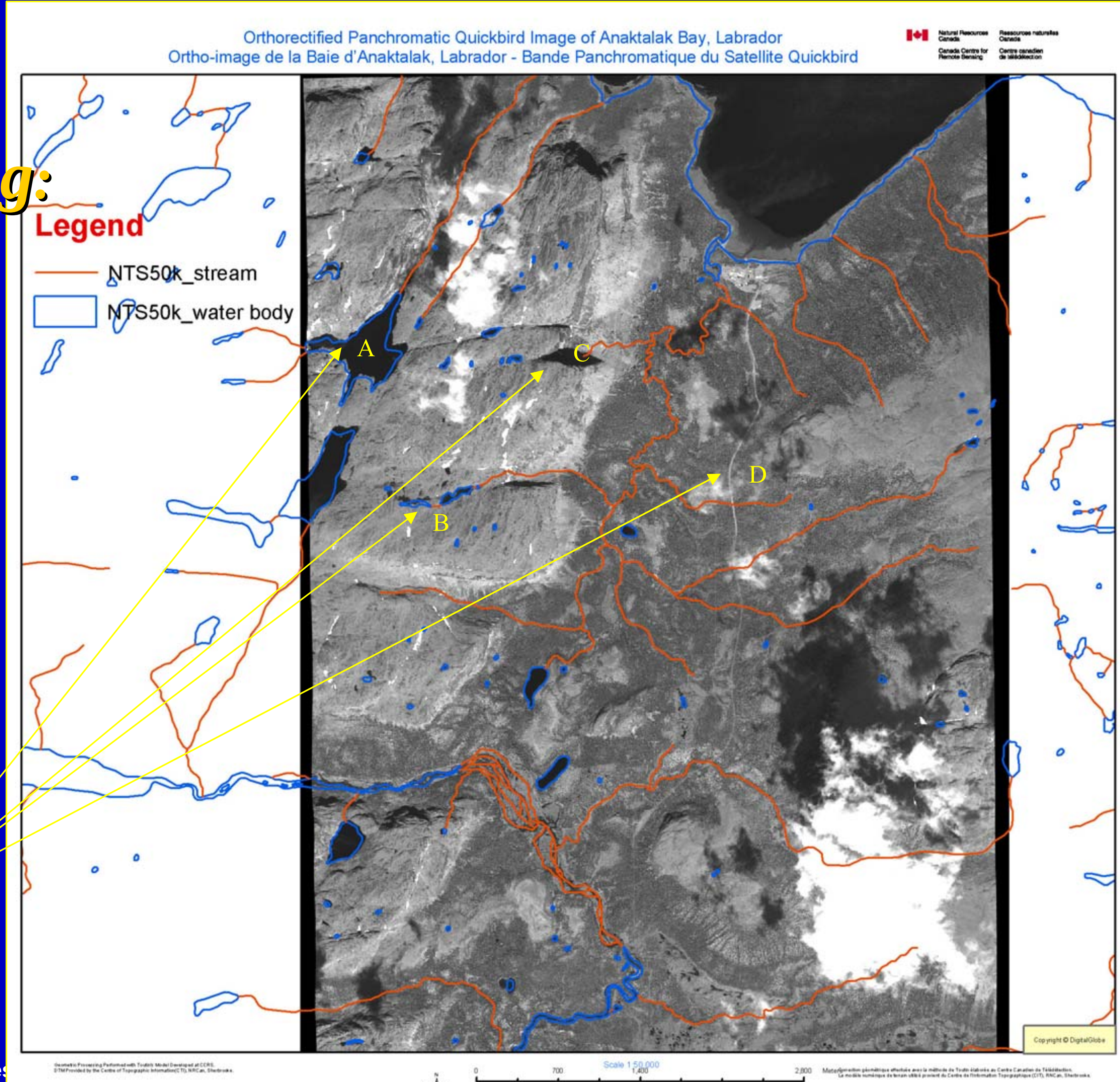
<u>Map updating:</u>

A: Positioning

B: Feature shape

C: Absent feature

D: New feature



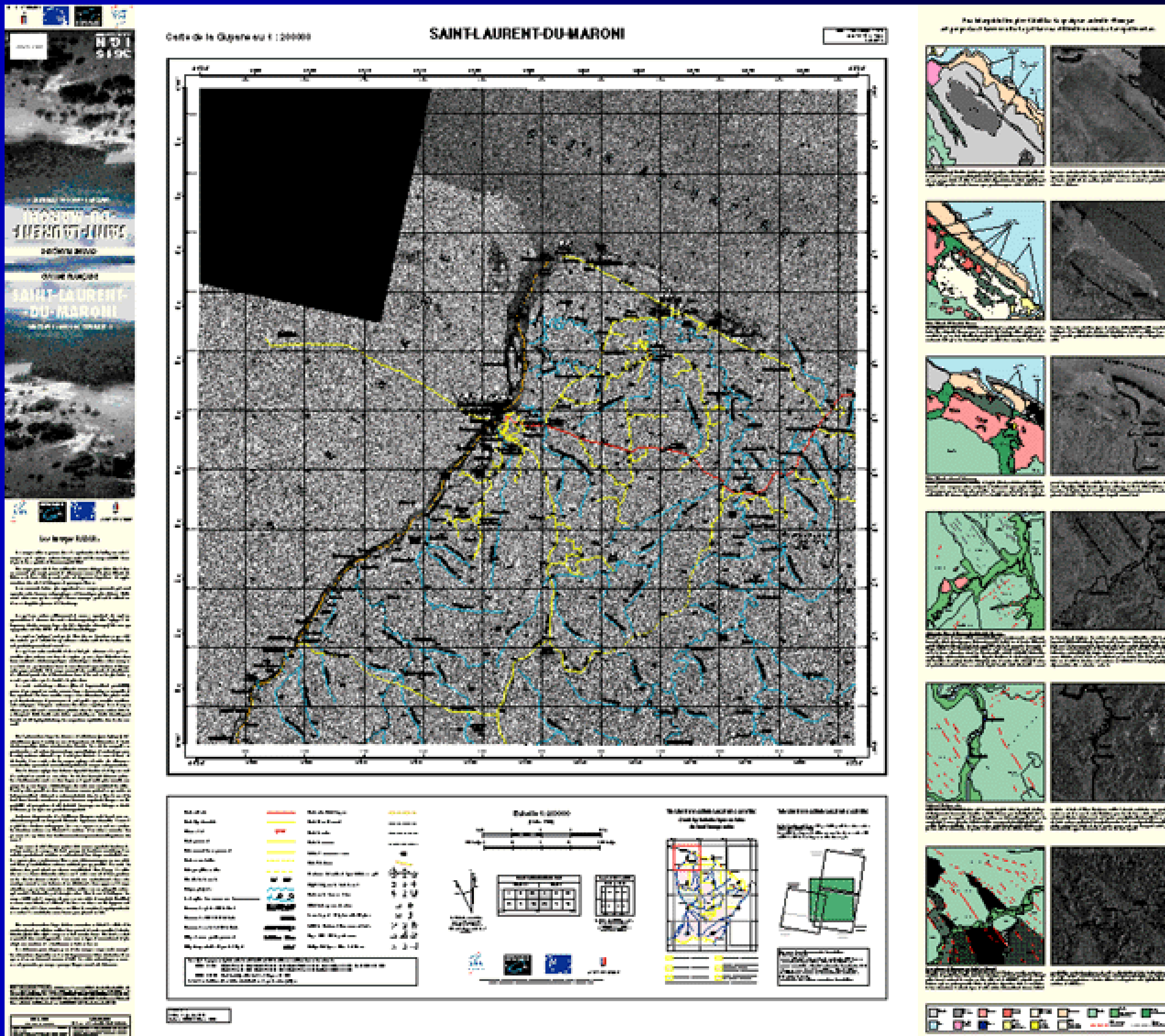
Original IKONOS images © Space Imaging LLC 2001

Map updating: *2D/3D products*

RADAR MAP

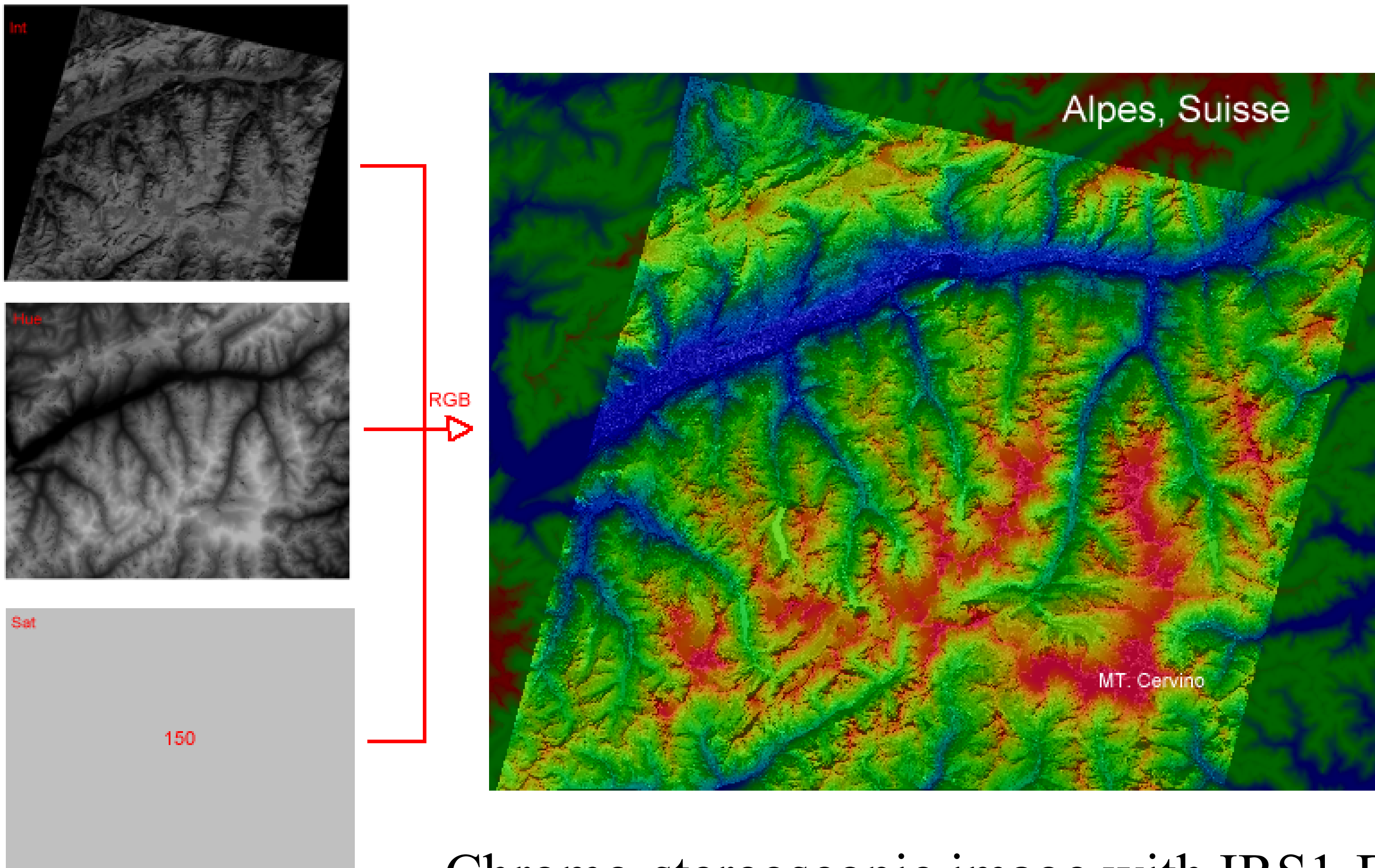
French Guyana
1:200 000

Block adjustment of
40 ERS-SAR images
Contour lines ⇒ DTM
Ortho-mosaicking
Speckle filtering
Image interpretation
Map compilation



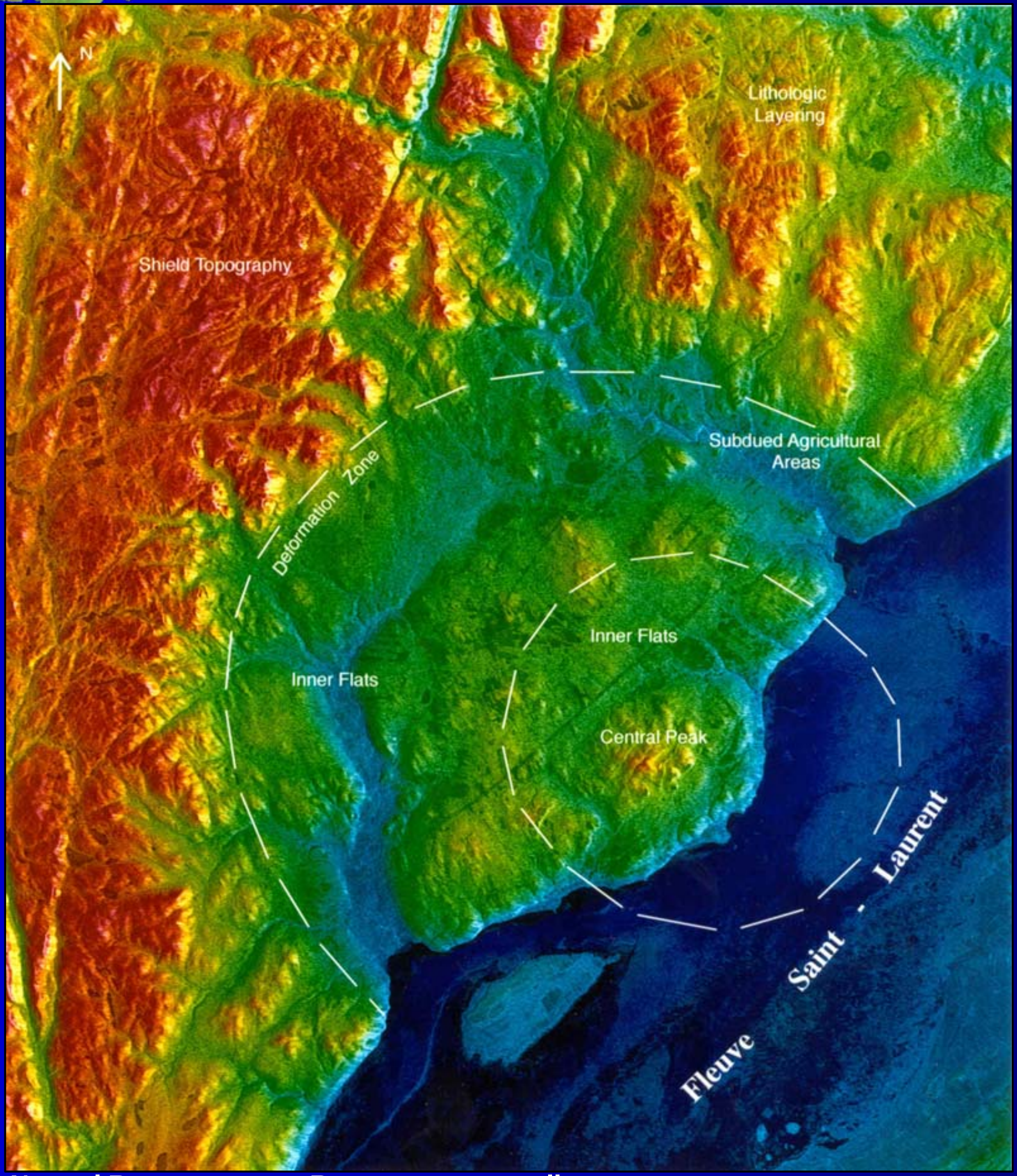
http://sirius-ci.cst.cnes.fr:8100/cdrom-97/ceos1/casestud/spot/carto/ang/ucr_guya.htm

Map updating: 2D/3D products



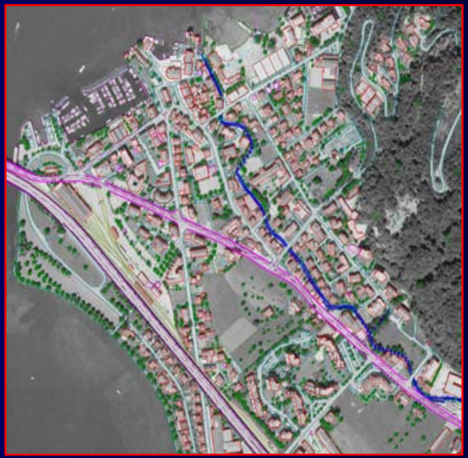
Chromo-stereoscopic image with IRS1-D

Map updating: 2D/3D products



Chromo-stereoscopic image with R-1 fine mode for geoscientific applications

Map updating



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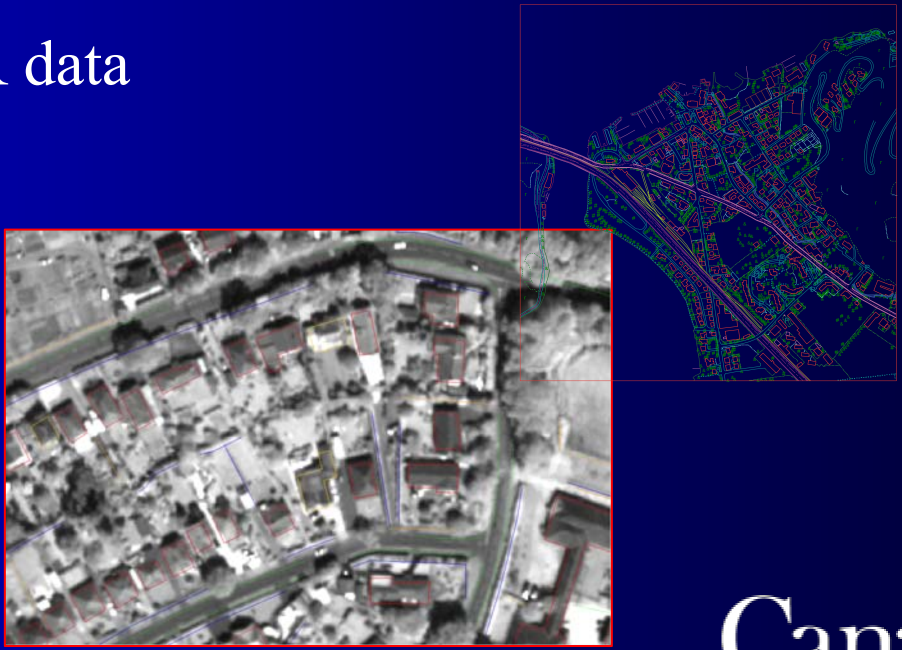
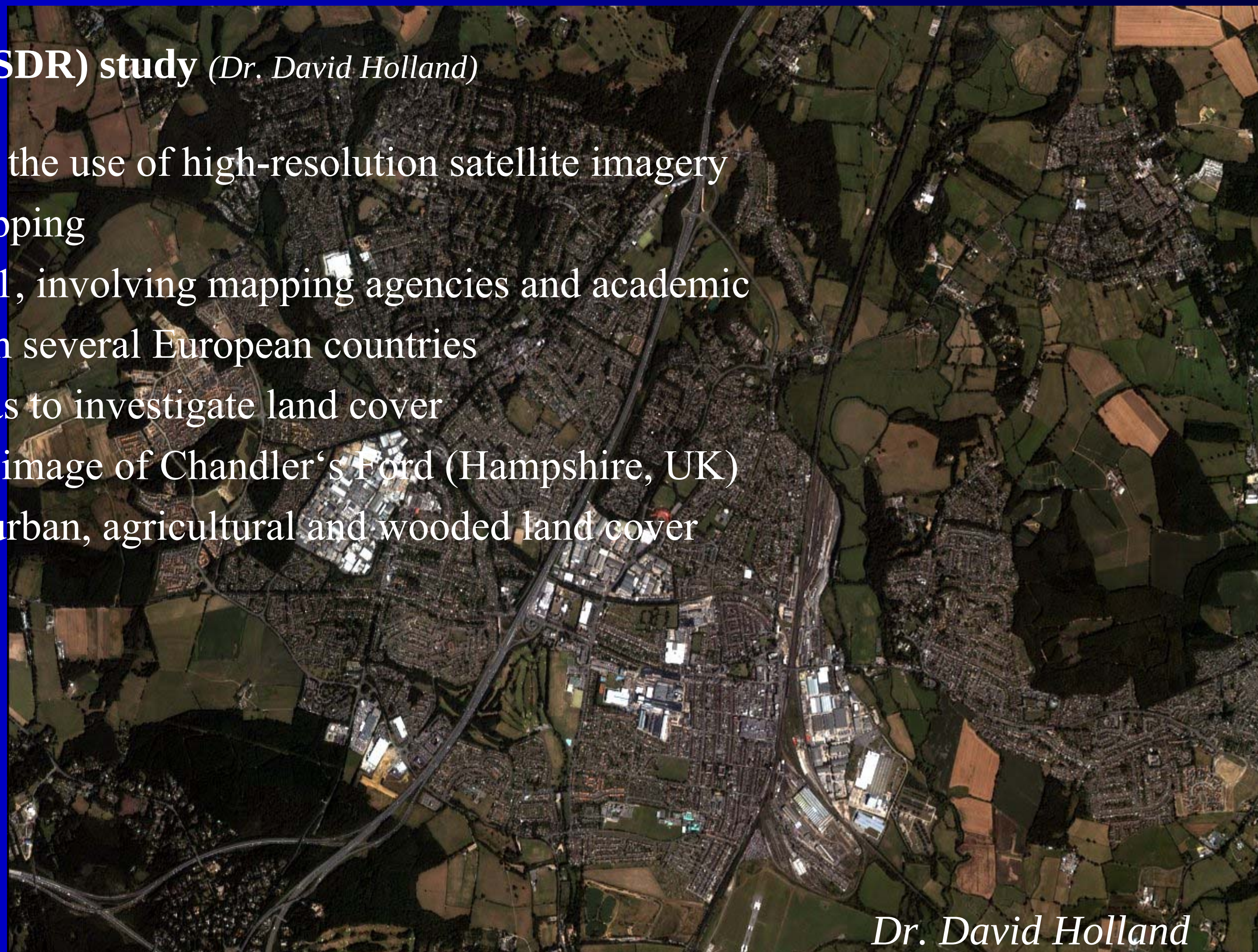


Map updating: VIR data

OEEPE (EuroSDR) study *(Dr. David Holland)*

- To investigate the use of high-resolution satellite imagery for national mapping
- Started in 2001, involving mapping agencies and academic institutions from several European countries
- One aspect was to investigate land cover
- Ikonos 4m XS image of Chandler's Ford (Hampshire, UK)
- A mixture of urban, agricultural and wooded land cover



Map updating: VIR data

OEEPE results - Some comments

(Dr. David Holland)

- High-resolution imagery introduces shadows, which are generalised out of lower resoluton imagery. These shadows:
  - Could be used to identify shadow-casting objects (clinometry)
  - Could be seen as a barrier to accurate classification

Map updating: VIR data

Land cover from 4m Ikonos data – OEEPE results *(Dr. David Holland)*

- **Sweden**: Ikonos suitable for identification and capture of land cover types found in Swedish 1:10 000 scale mapping
- **UK**: Ikonos, when combined with national mapping vector data (OS MasterMap) suitable for identifying most of the CORINE land cover/land use classes
- **Germany**: Identified several problems when trying to classify the imagery on its own.

Map updating: VIR data

OEEPE results - Some comments *(Dr. David Holland)*

- High-resolution imagery is very heterogeneous – a single residential property may have building, road, low vegetation, high vegetation, and water pixels within its boundary. These are usually averaged out in lower resolution imagery.
- This leads to **lower** accuracy when assessing pixel classification techniques
- ...sounds counter-intuitive.

Map updating: VIR data

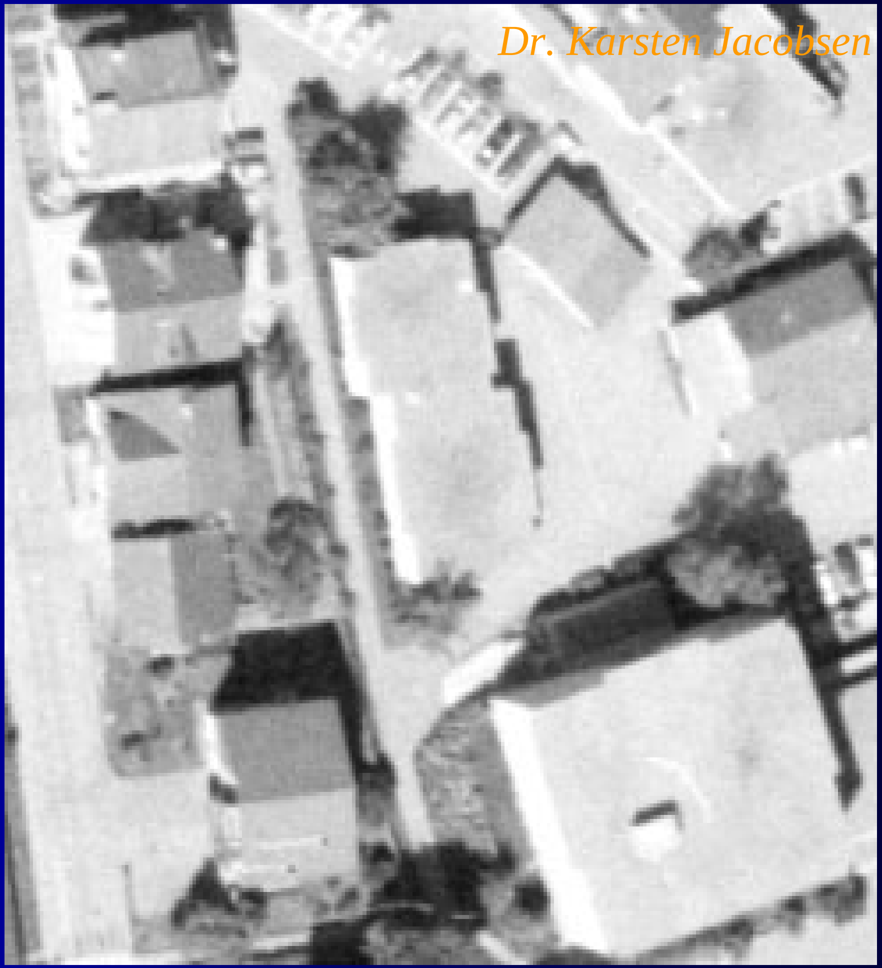
Mapping with IKONOS OEEPE test Lucerne *(Dr. Karsten Jacobsen)*

Ikonos 1-m GSD

Orthophoto 0.35m GSD

Map updating: VIR data

Ikonos 1m GSD



Orthophoto 0.35-m GSD

Map updating: *VIR data*

IKONOS 1-m GSD

Dr. K. Jacobsen

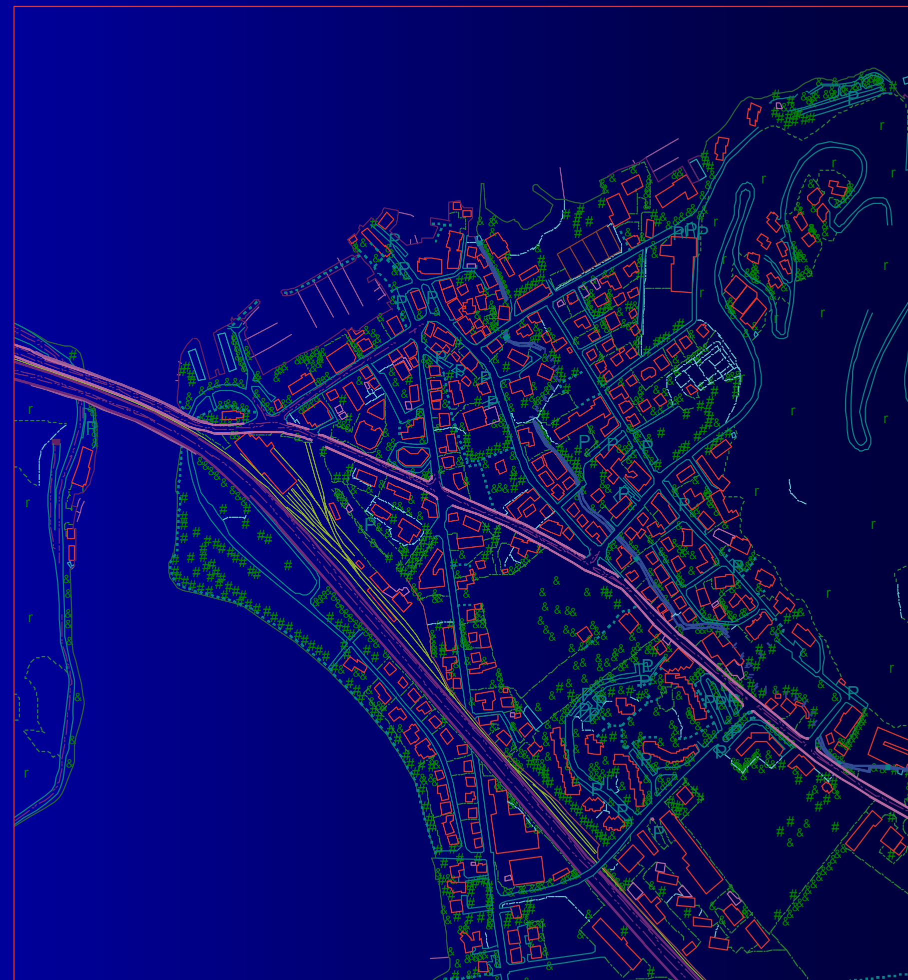
Orthophoto (0.35-m GSD)

Map updating: VIR data

Ikonos Pan Map 1 : 25 000

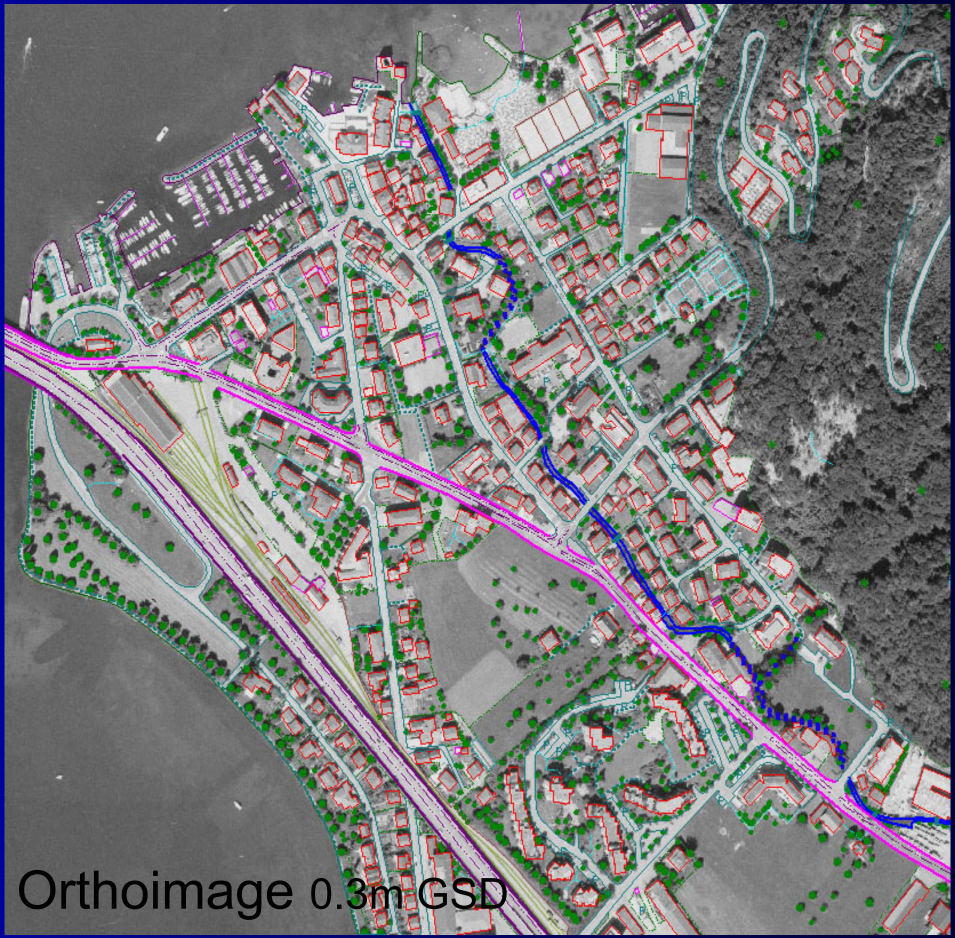
Map updating: VIR data

Map based on Ikonos Pan 1m GSD



Map based on orthoimage 0.3-m GSD

Map updating: ***VIR data***

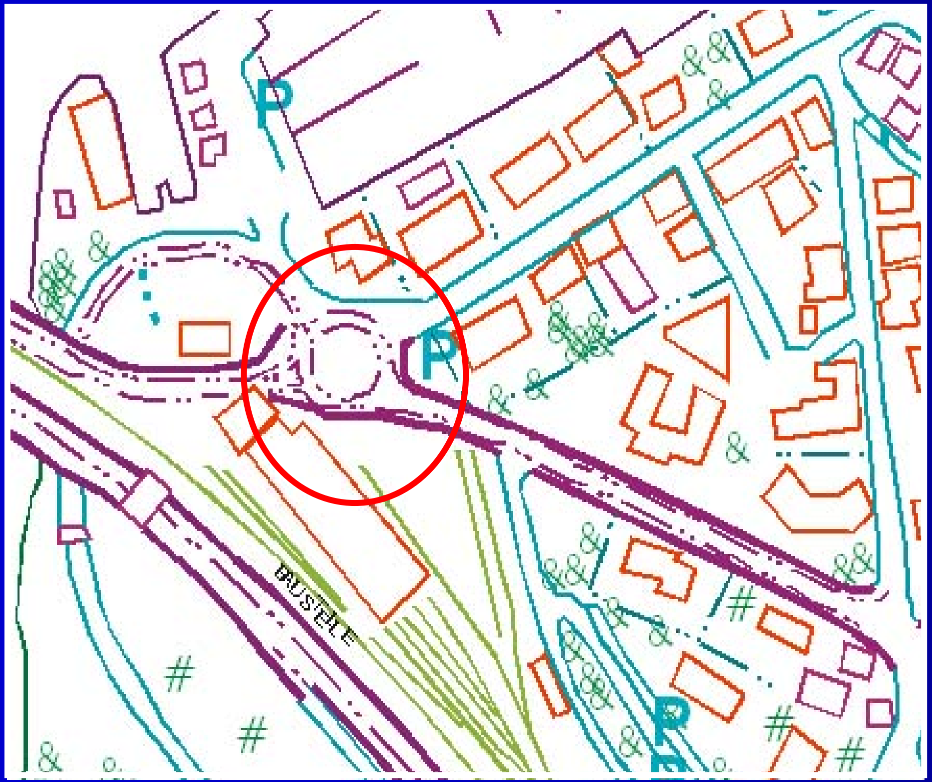


Combination orthoimage + vectors include more information than just map

Ortho-image + only important vectors most economic solution

Map updating: VIR data

Dr. Karsten Jacobsen



Map based on Ikonos pan

more actual image (new traffic circle)

Map based on orthophoto 0.3m

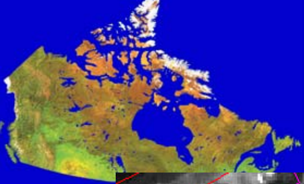
more details, less misidentifications

Map updating: *VIR data*

Aerial photo 0.3 m

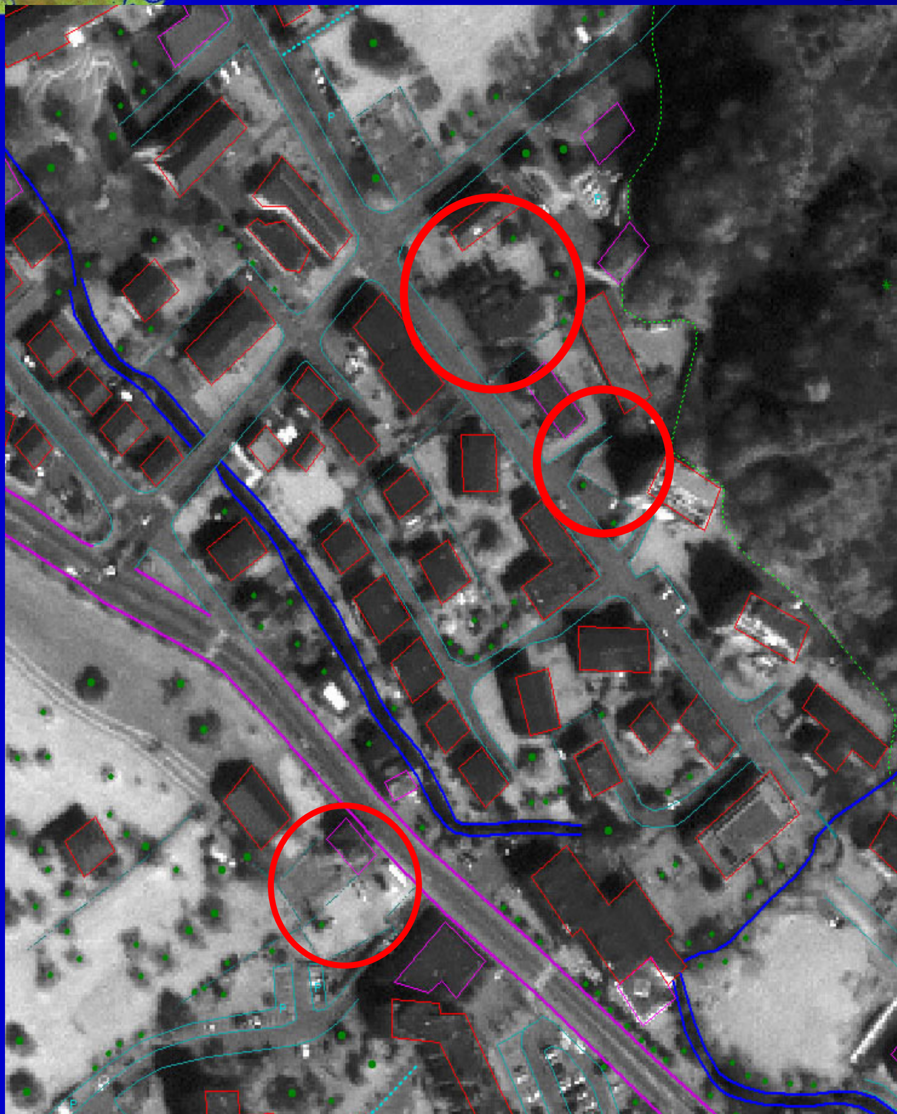
Map based on Ikonos pan

Ikonos

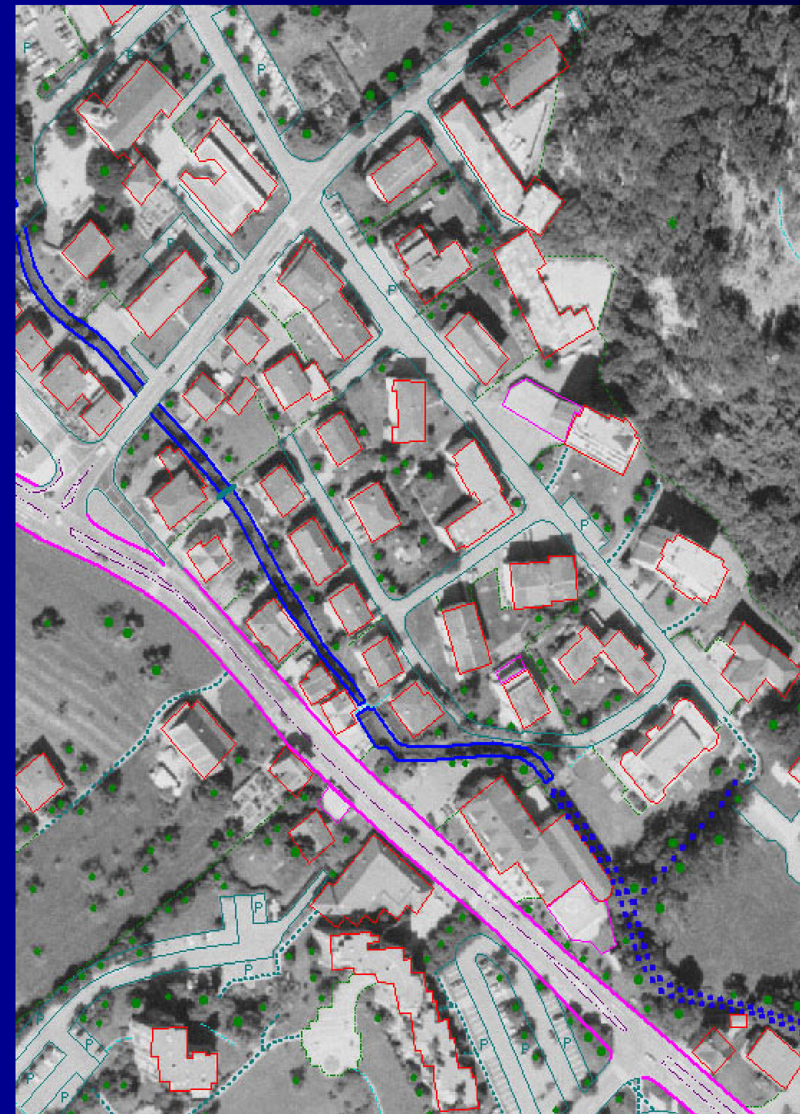


Map updating: VIR data

Dr. Karsten Jacobsen



Ikonos pan



Orthophoto 0.3m

Map updating: VIR data

Dr. Karsten Jacobsen

Ikonos pan

Orthophoto 0.3m

Map updating: *VIR data*

Rule of thumb: 0.05 - 0.1mm/pixel in the map required for sufficient map (*c.f. Dr. Jacobsen, Hannover University*)

→ Ikonos 1m GSD can be used for map scale 1 : 10 000

→ Aerial ortho-image with 0.3-m GSD – map 1 : 3000

Test area Lucerne confirms the rule of thumb – only few buildings and parts of buildings missed

Main problem of Ikonos in the area of Lucerne: radiometric quality worse like aerial images, contrast enhancement required – in other areas reverse

Mono-plotting has some disadvantages especially in urban area, with stereo no problems of identification of missing objects

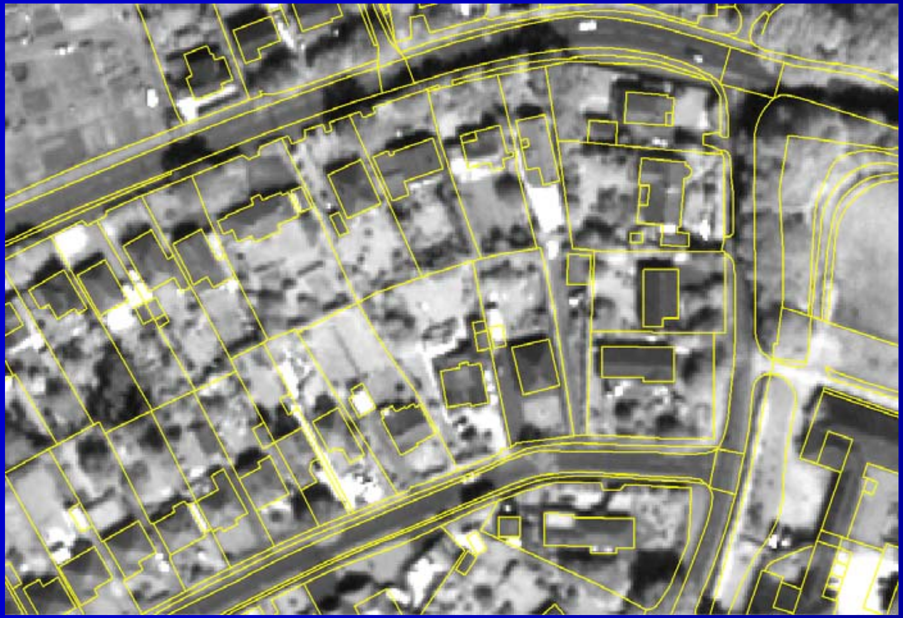
Map updating: VIR data

Large Scale mapping - example of OS MasterMap in UK
Dr. David Holland OS, UK

Example of data captured from QB

Map updating: VIR data

QuickBird plus existing map vectors

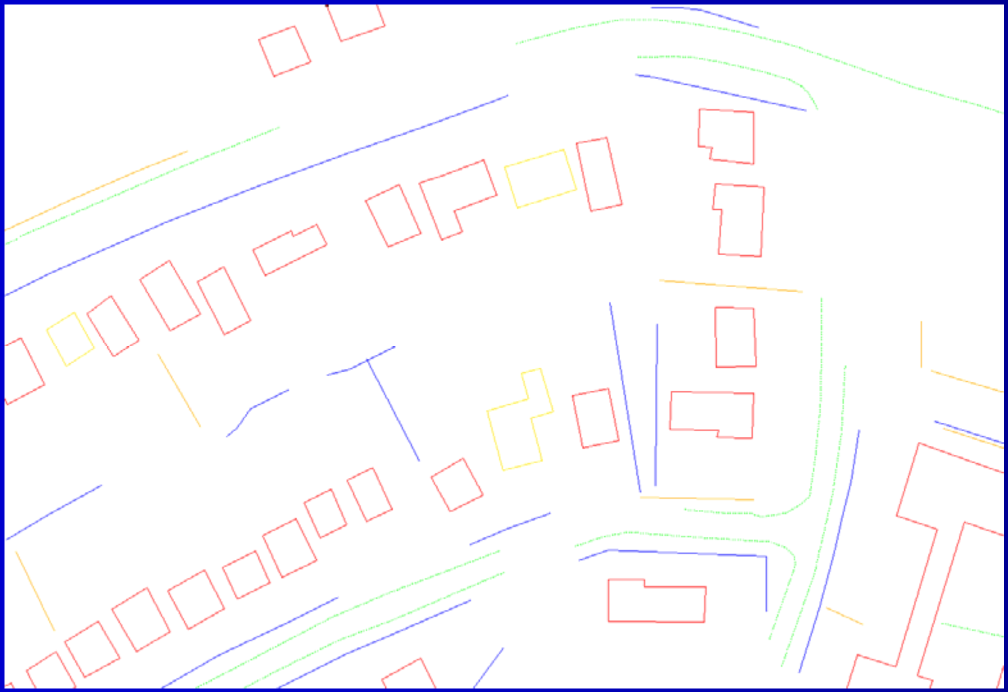


Map data captured from QuickBird

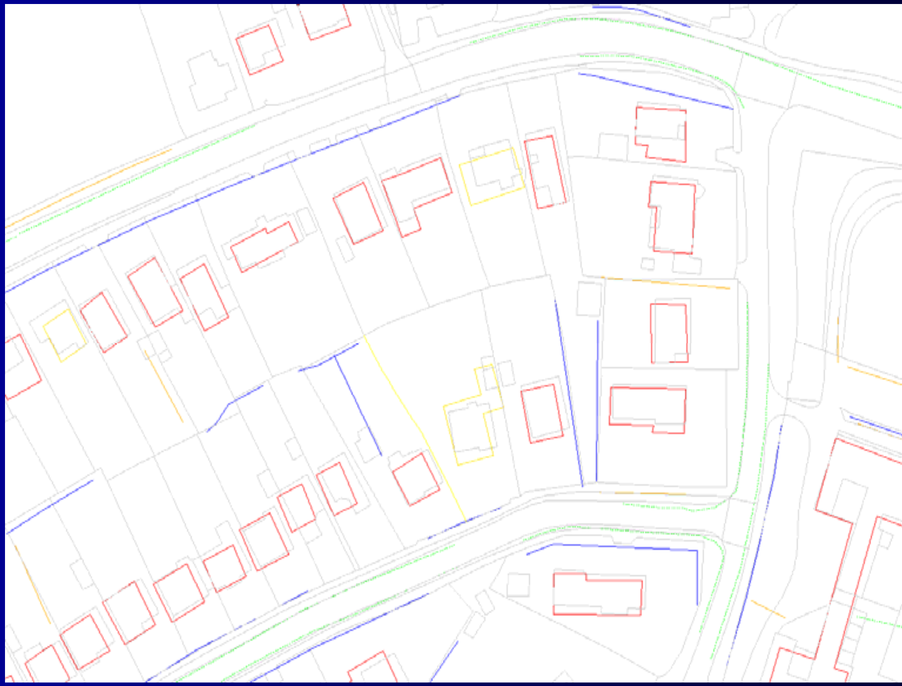
Dr. David Holland

Map updating: VIR data

Vectors Captured from QuickBird



Existing vectors and QB captured vectors



Dr. David Holland

Map updating: ***VIR data***

Feature identification results

	Quickbird			Air photo		
Level of requirement:	High	Medium	Low	High	Medium	Low
No of tests	86	65	63	86	65	63
No. of features present	38	38	25	38	38	25
Number correctly identified	35	26	11	37	32	22
Number not identified	3	12	14	1	6	3
Success rate %	92	68	44	97	84	88

- High: **must** be identifiable at this scale of mapping (e.g. boundary feature)
- Medium: **desirable** to be identifiable at this scale of mapping (e.g. type of boundary – hedge)
- Low: **some interest** at this scale of mapping (e.g. nature of boundary – permanent or temporary)

Map updating: VIR data

Feature geometric accuracy results

Feature type	No. of points	Min	Max	Mean	SD	RMSE
House corners	218	0.24	6.57	1.98	1.22	2.32
Fence junctions	28	0.24	3.06	1.37	0.81	1.59

Comparison between house corners and fence junctions on the map, and the equivalent point on the QuickBird image.

Map updating: VIR data

What we can/can't capture using QuickBird imagery *(Dr. David Holland)*

- We can successfully identify and capture the following, to meet the 1:10 000 scale specification:
  - Roads, railways, airports
- We can usually capture:
  - Buildings
  - Lakes, rivers, streams
- Tracks & paths
- It is not usually possible to capture:
  - Fences, walls
  - Narrow tracks & paths
  - Electricity Transmission Lines
  - Field and property boundaries

Map updating: VIR data

Other things you cannot collect *(Dr. David Holland)*

- Small geometric objects:
  - juts, recesses on buildings
  - fence posts
  - pylons
- High and low tide lines
- (And, of course, non-topographic attributes such as place names, road classifications, addresses – but these are also fairly difficult to capture from aerial photography!)

Map updating: VIR data

What sort of map could be produced? *(Dr. David Holland)*

- Using only a satellite image, a satisfactory cartographic map could be produced at a scale of 1:6000 or smaller.
- By changing the specification (e.g. not requiring fences, small paths, streams) larger scale maps could be produced.
- Image maps – i.e. georeferenced background images with added attribution – could be produced very easily
- Other information would be needed to populate the attributes (but much of this information may already be available in well-mapped countries)

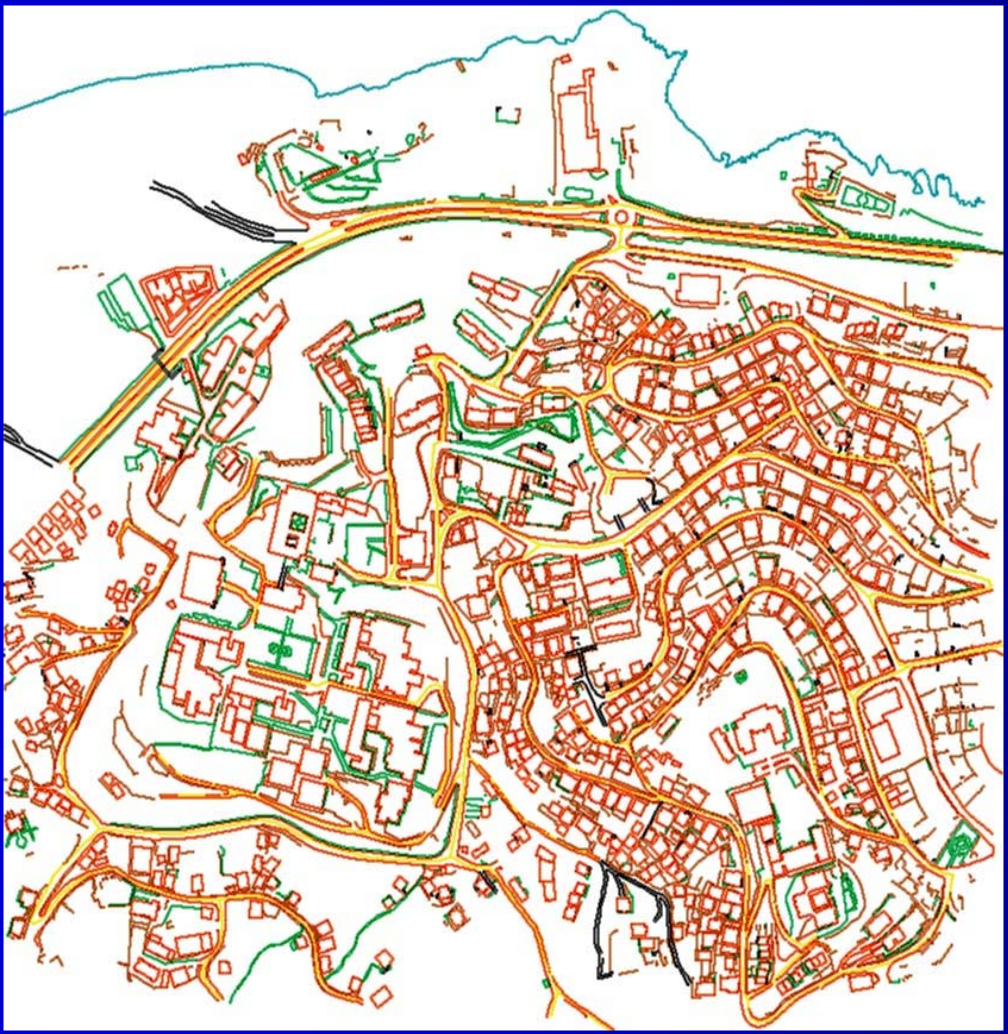
Map updating: VIR data

Change Detection

- Probably the most viable use of satellite imagery for Ordnance Survey
- In both urban and rural areas, QuickBird imagery was successfully used to detect change
- Urban – new housing, industrial buildings, roads
- Rural – fences, tracks, vegetation boundaries
- Main drawback is the cost of the images

Dr. David Holland

Map updating: VIR data



Topographic map 1 : 5000

Completeness of mapping

	Iko pan	Iko XS	QB pan	QB XS
Buildings	66%	70%	67%	68%
Roads	95%	95%	111%	111%
Sidewalks	41%	53%	46%	**100%**

For buildings and roads in relation to topographic map 1 : 5000

For sidewalks in relation to pan-sharpened QuickBird

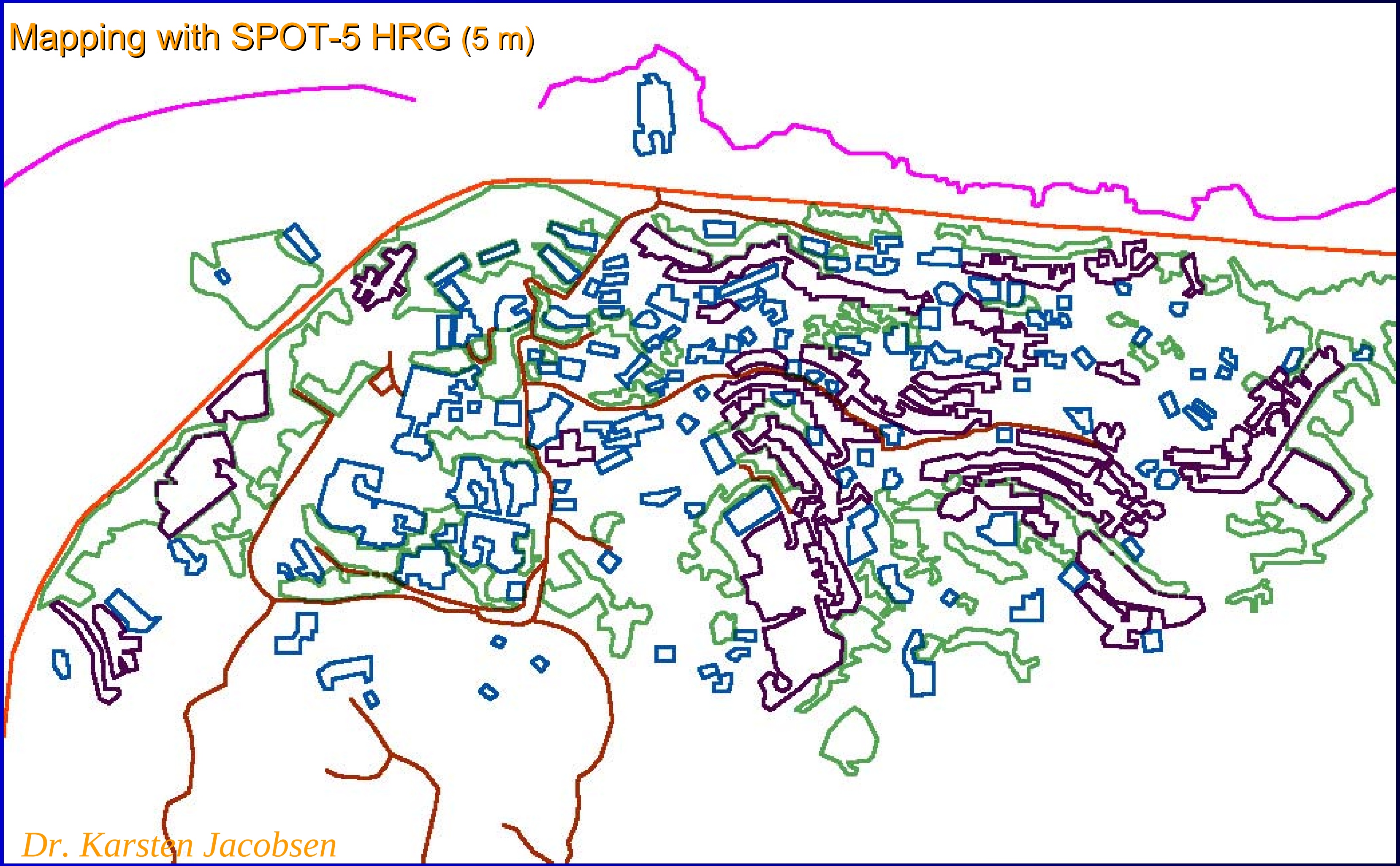
Dr. Karsten Jacobsen

Map updating: *VIR data*

With 5-m GSD the roads can be identified, but sometimes back yards and roads are mixed

Dr. K. Jacobsen

Map updating: VIR data



Suitable for topographic map 1 : 50 000

most buildings can be seen but not individually mapped

Map updating: VIR data

Cartographic features	Required GSD
Urban buildings	2 m
Foot path	2 m
Minor road network	5 m
Rail road	5 m
Fine hydrology	5 m
Major road network	10 m
Building blocks	10 m

Required GSD for object identification in panchromatic images under usual conditions

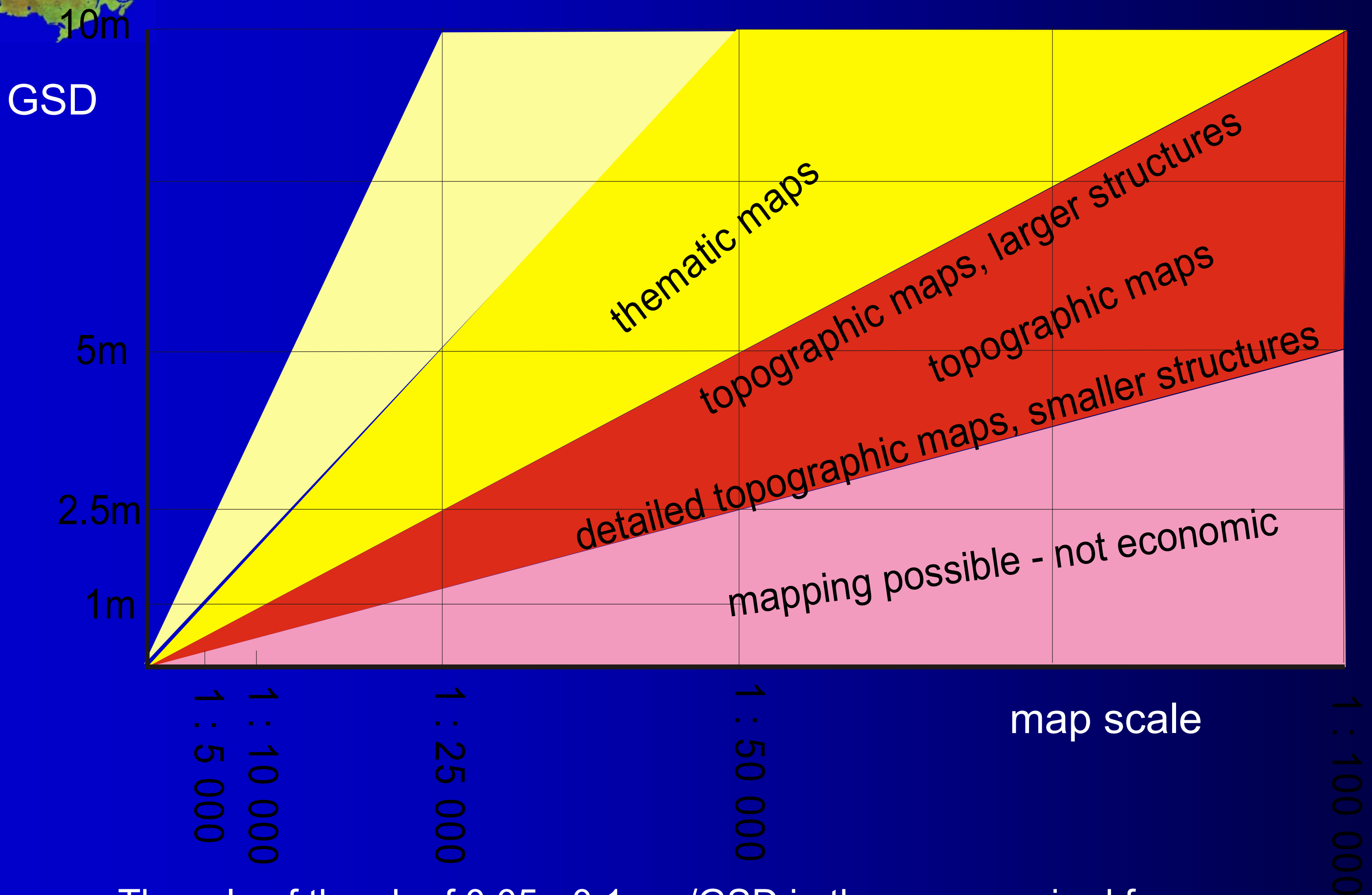
(c.f. Dr. K. Jacobsen, Hannover University)

Problems may be caused by shadows and trees hiding objects

In general easier if objects are straight and are not directly at streets

more difficult if objects are curved and hidden by vegetation

Map updating: VIR data



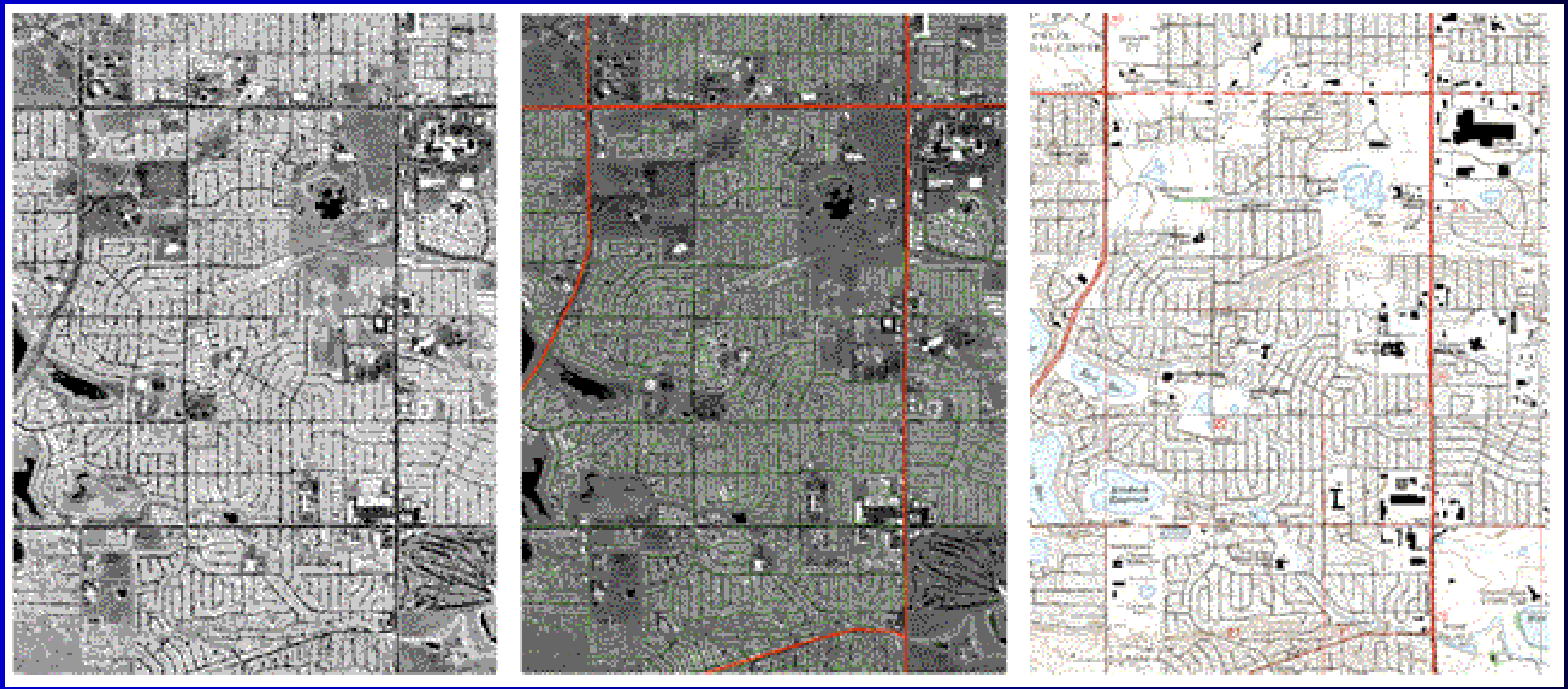
The rule of thumb of 0.05 - 0.1mm/GSD in the map required for sufficient map contents seems to be confirmed by mapping in different areas *(Dr. Karsten Jacobsen, Hannover University)*

Map updating

1. Techniques and processes
2. Examples of 2D/3D products for map updating
3. Applications with VIR data
4. Applications with SAR data

Map updating: SAR data

Ortho SAR mapping



© Intermap, 2000

Geocoded radar (2.5 m)

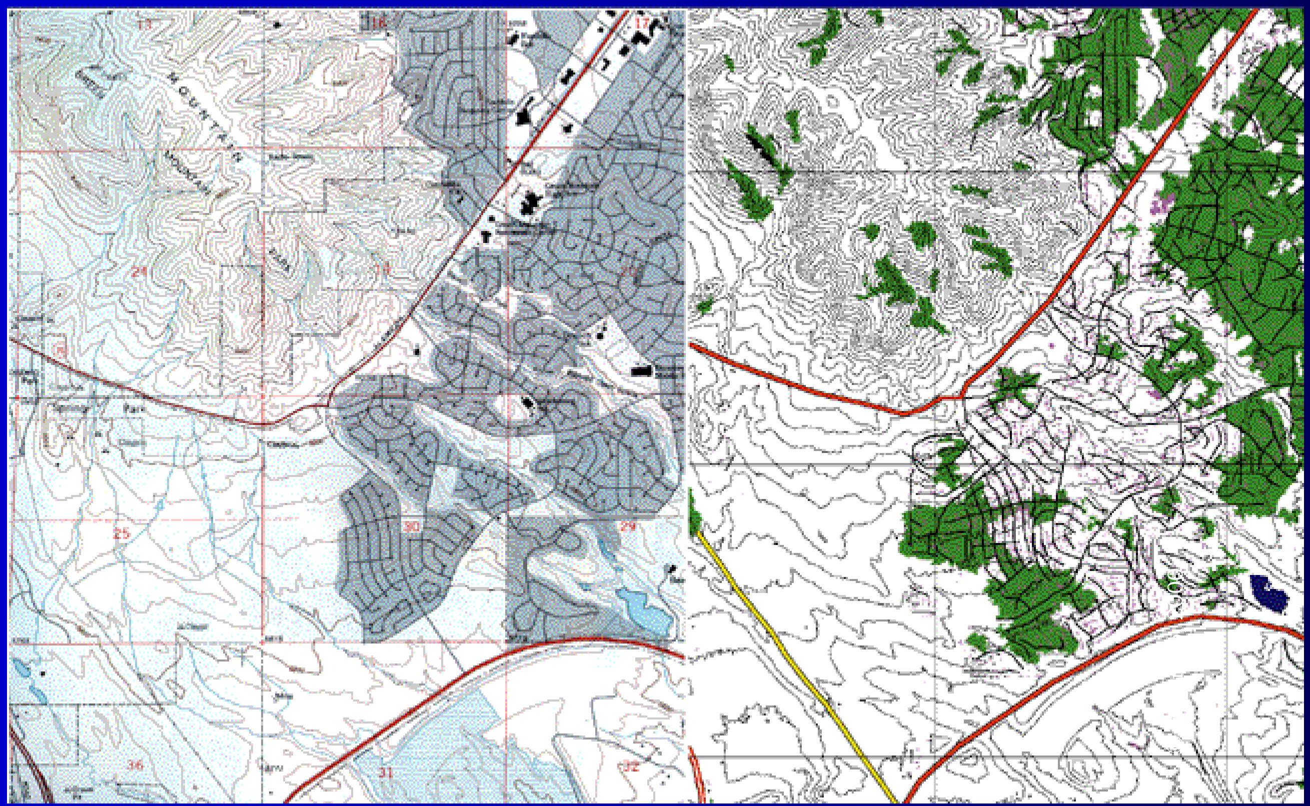
STAR3i airborne IFSAR of Intermap

Geocoded radar with roads automatically extracted

1:24,000 USGS map

Map updating: SAR data

Ortho SAR mapping



© Intermap, 2000

1:24,000 USGS map

Symbolic map (contours, roads, land use, power lines) produced from STAR3i airborne IFSAR of Intermap

Quantitative evaluation (omission, commission, 90% error) has to be performed on the final map product.

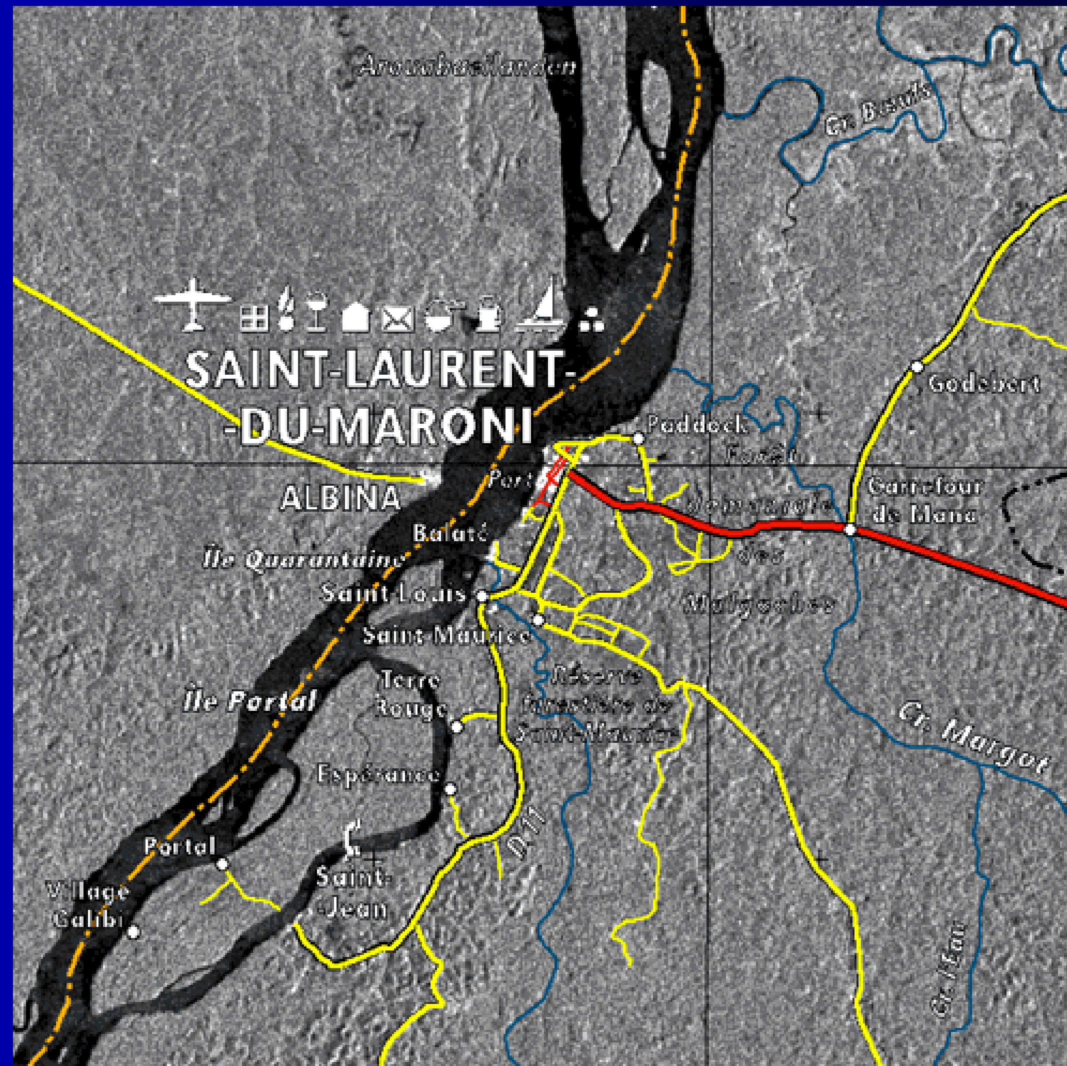
Field check should be used for quality control

Map updating: SAR data

Ortho SAR mapping

Sub-area of the previous ERS-SAR spacemap of IGN, France in French Guyana at 200k scale

DTM were generated from existing contour lines. Vectors come from the radar interpretation combined with the old maps

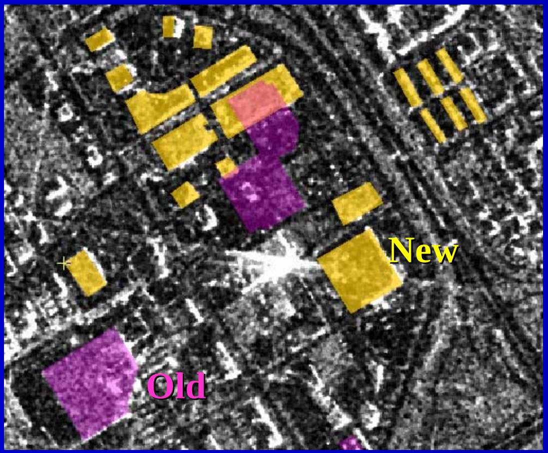


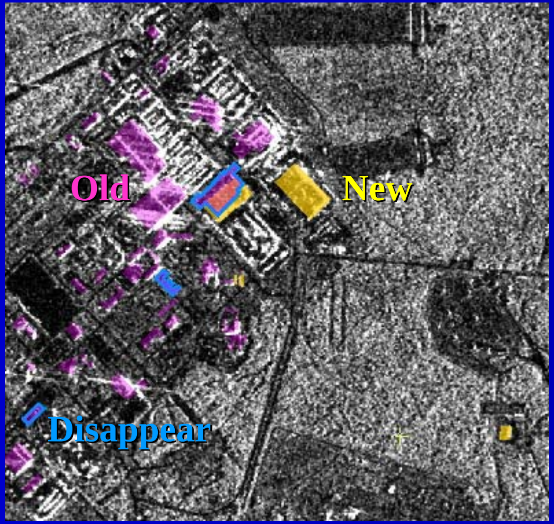
ERS-1 Images © ESA, 1993-1994; Radar Spacemap © Institut Géographique National, France, 1997

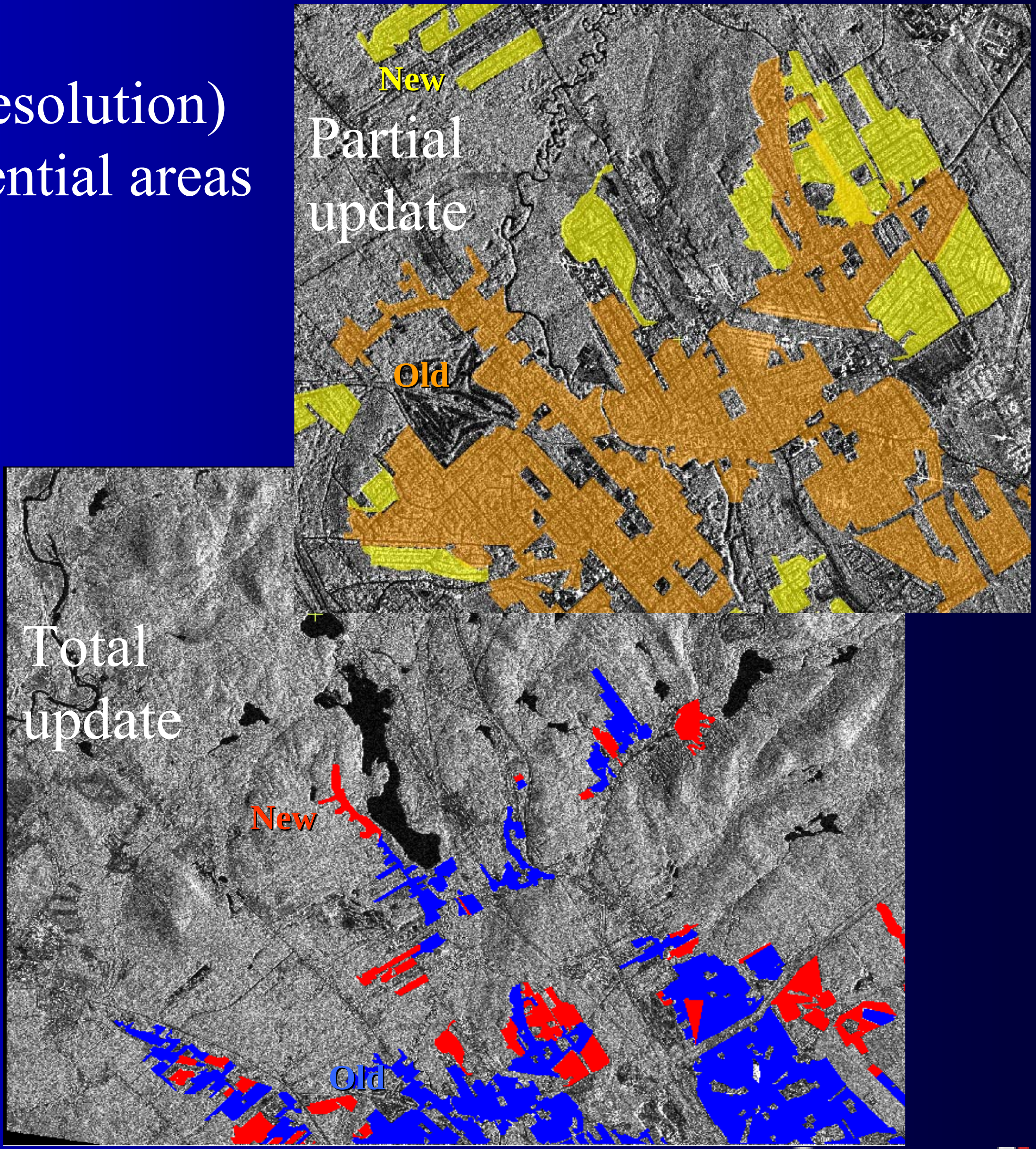
http://sirius-ci.cst.cnes.fr:8100/cdrom-97/ceos1/casestud/spot/carto/ang/ucr_guya.htm

Map updating: Radarsat-2 SAR data

Ultra-fine mode (3-m resolution)
Large buildings & residential areas



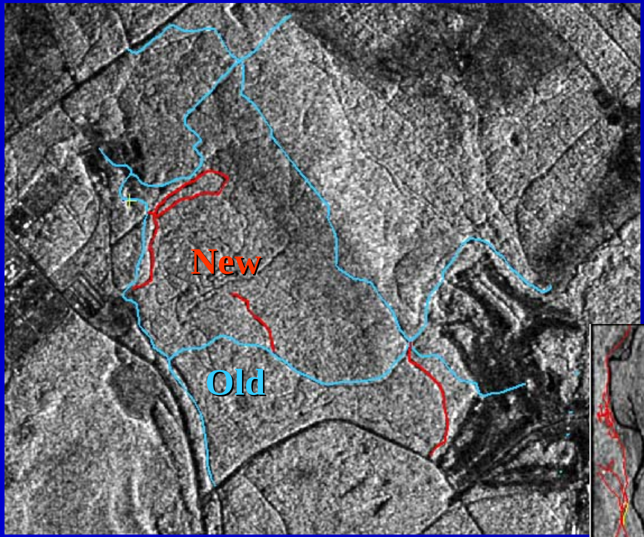




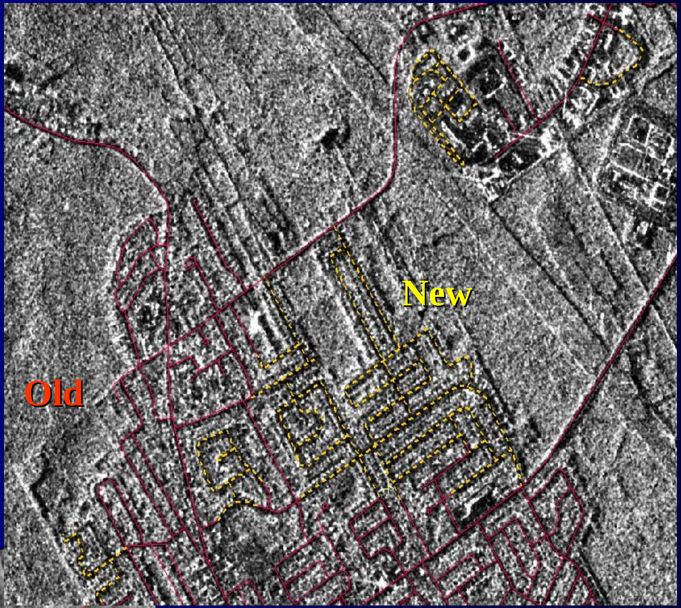
F. Happi Mangoua, NRCan

Map updating: Radarsat-2 SAR data

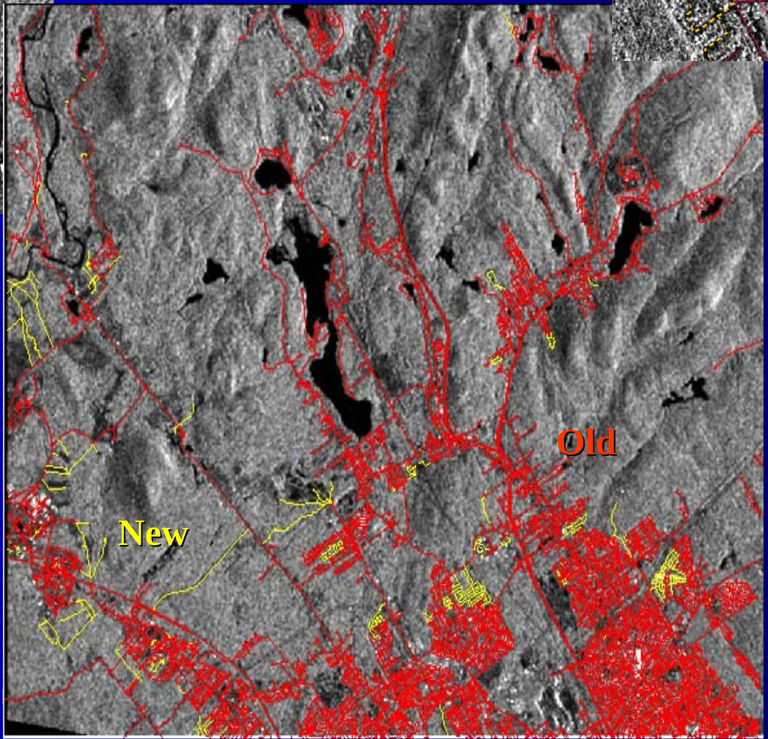
Ultra-fine mode (3-m resolution)
Forest paths & residential roads



Partial update
for forest paths



Partial update for
residential roads



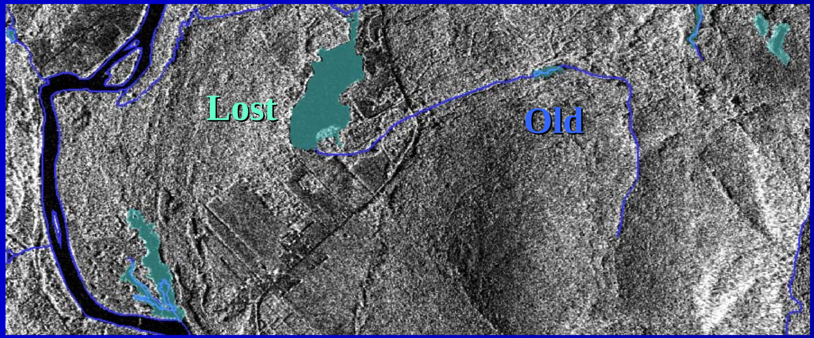
Total
update

F. Happi Mangoua, NRCan

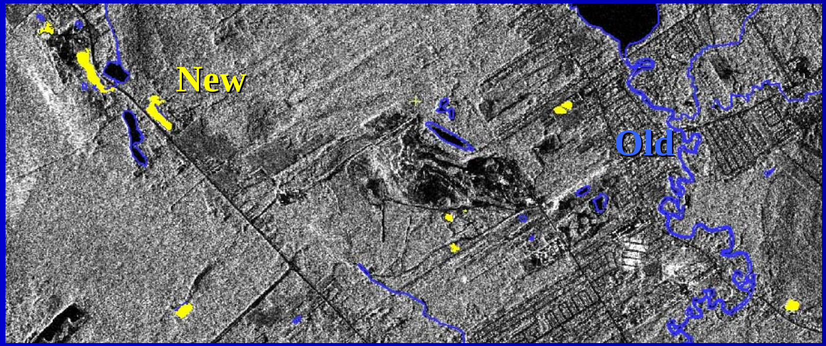
Map updating: Radarsat-2 SAR data

Ultra-fine mode (3-m resolution)

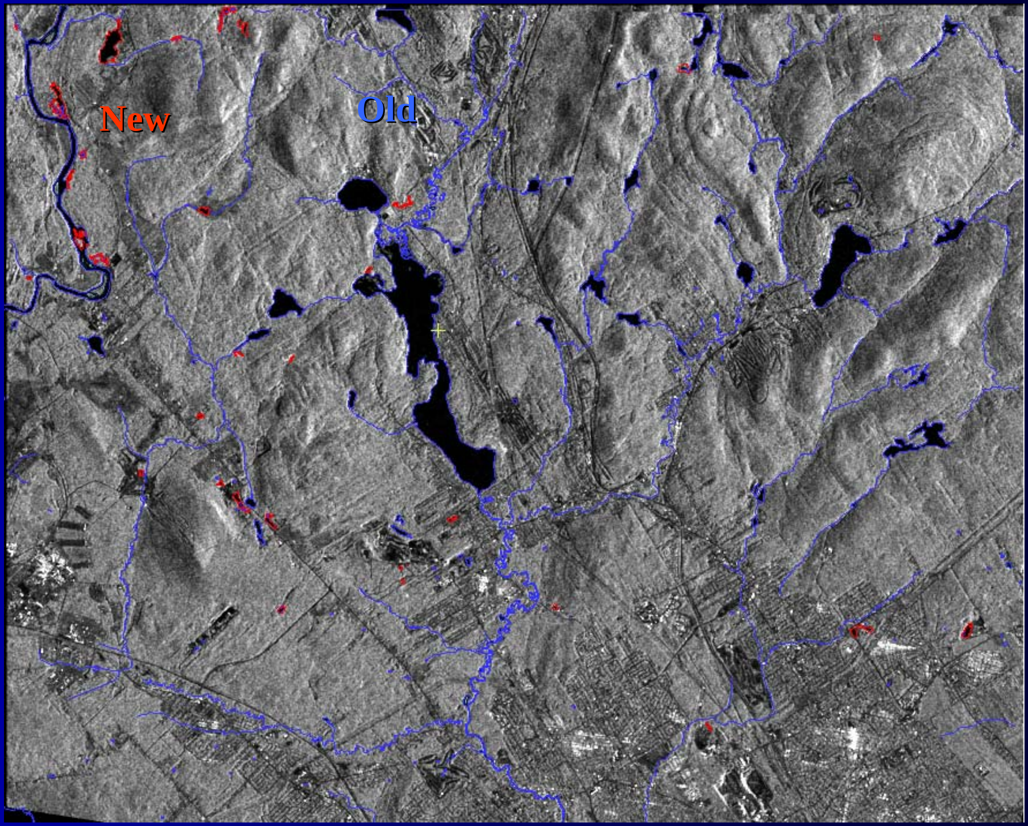
Hydrography



Partial update



Total update

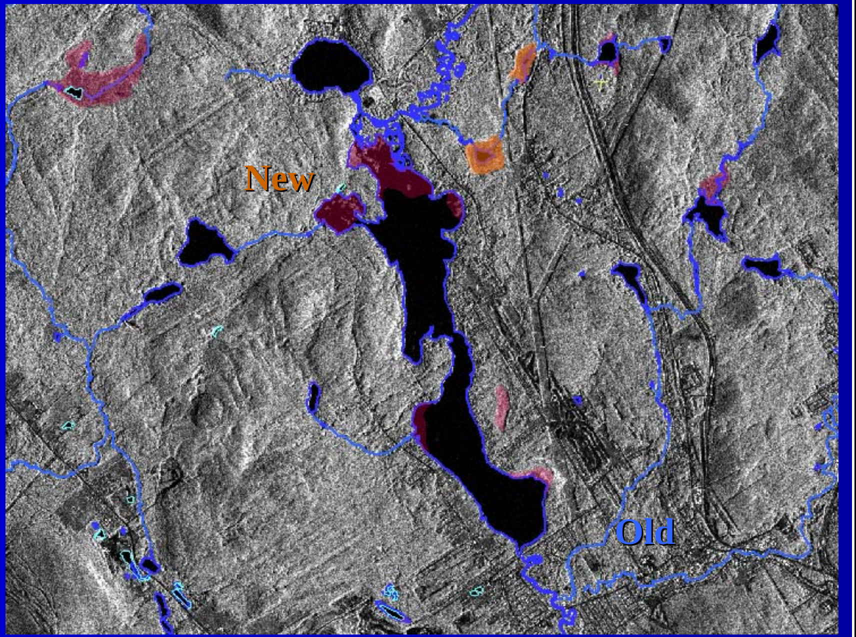


F. Happi Mangoua, NRCan

Map updating: Radarsat-2 SAR data

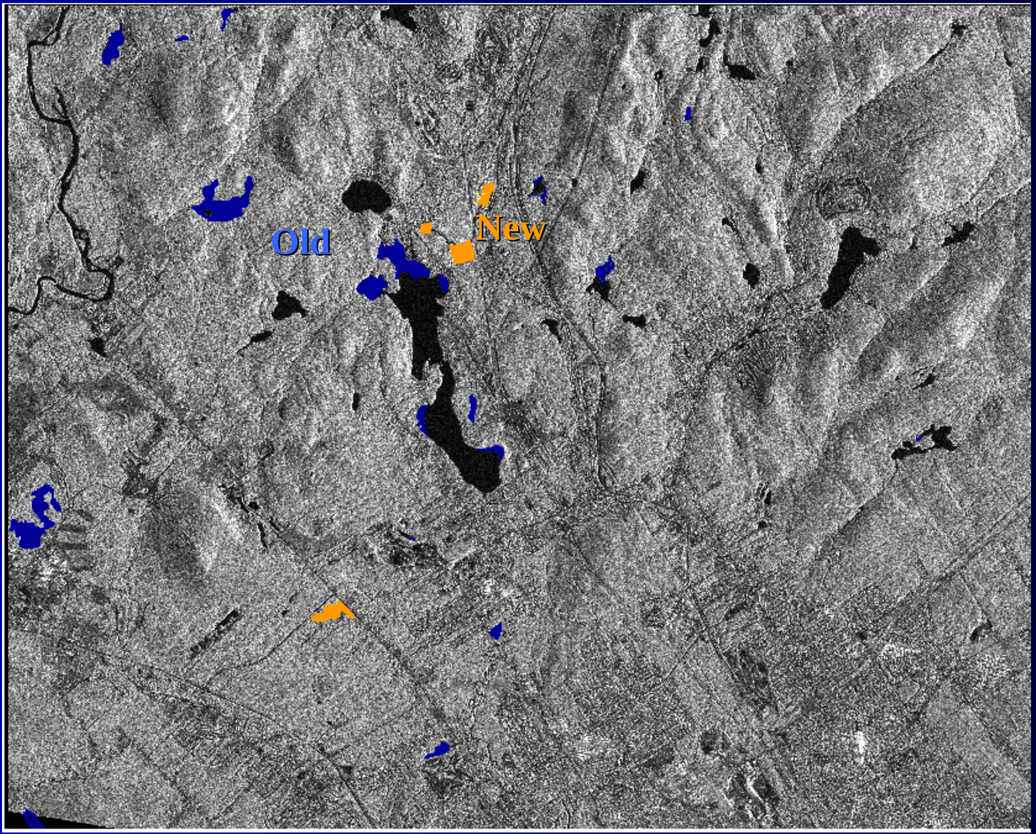
Ultra-fine mode (3-m resolution)

Wetlands



Partial update

Total update



F. Happi Mangoua, NRCan

Map updating: Radarsat-2 SAR data

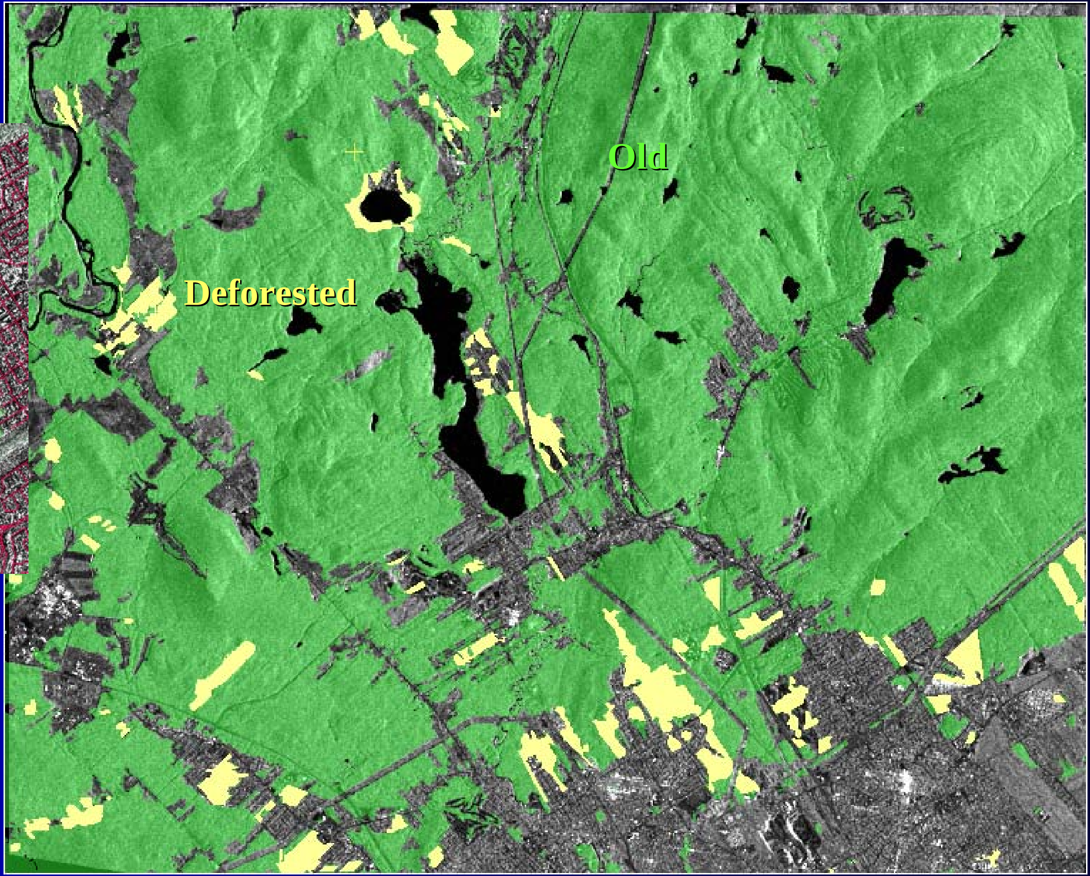
Ultra-fine mode (3-m resolution)

Forest areas

Partial update

New urban developments
in old forest areas

Total update



F. Happi Mangoua, NRCan

Map updating: SAR data

3D map updating using stereo SAR workstation

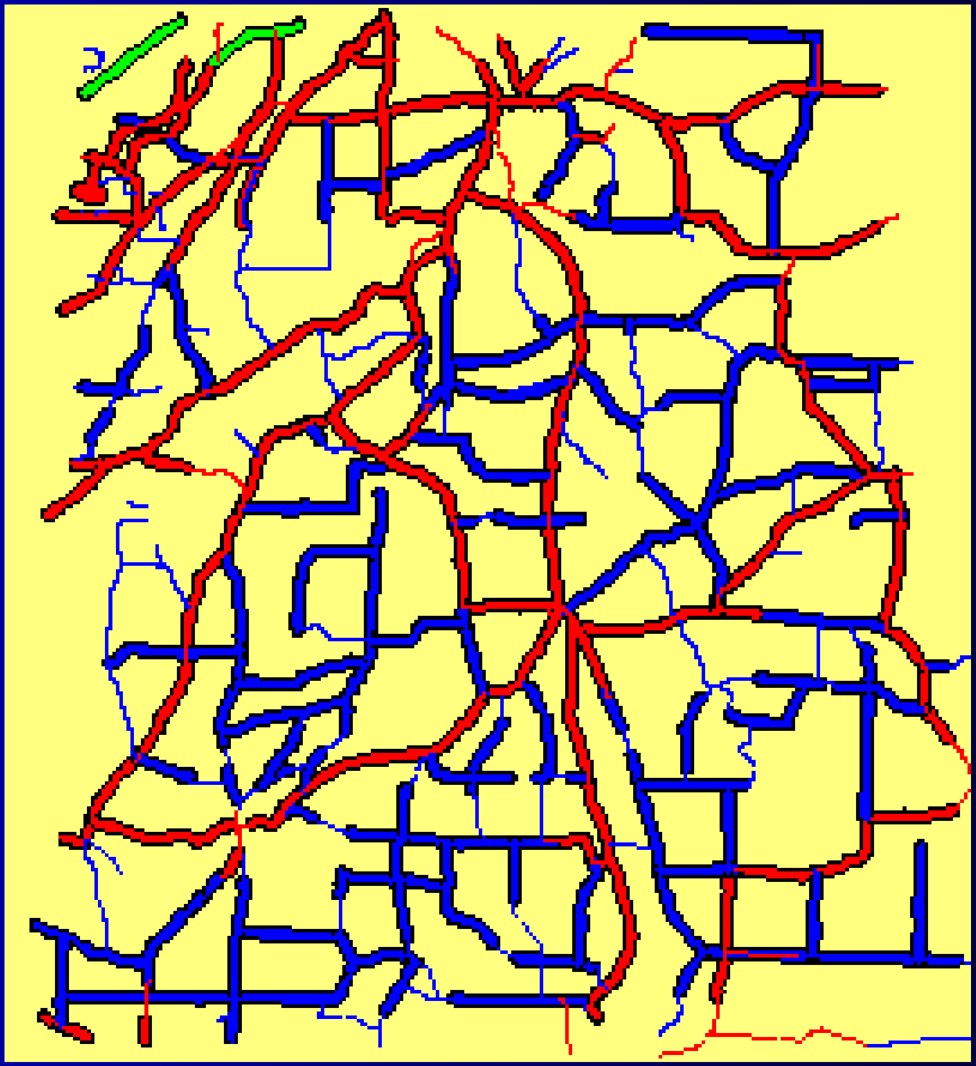
Radarsat-1 F1-F5 Stereo-Pair

Colour coding

Highways: green
Main roads: red
Secondary roads: blue

Extraction coding

Wide lines: extracted
Narrow lines: omission



Map updating: SAR data

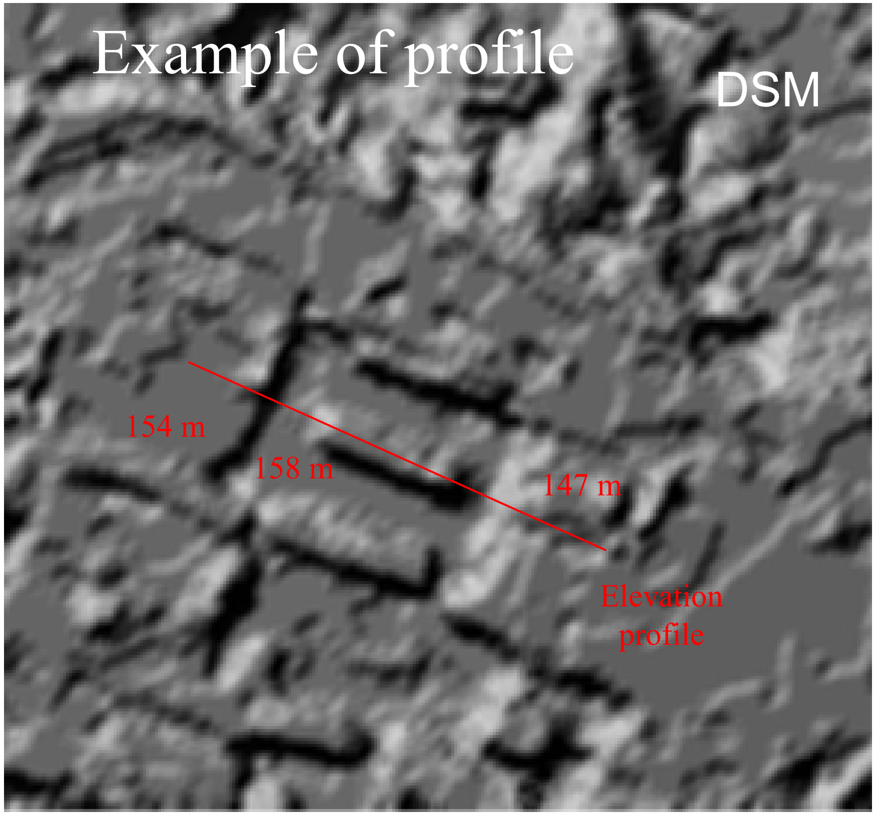
Map updating using stereo SAR workstation

Radarsat-1 fine mode stereo pair F1-F5

- Highways (6 km)
  - No omission
  - CE68 = 6 m & CE90 = 12 m
- Main roads (210 km)
  - 8% omission
  - CE68 = 10 m & CE90 = 20 m
- Secondary roads (310 km)
  - 31% omission
  - CE68 = 11 m & CE90 = 24 m
- City streets (91 km)
  - 5% omission
  - CE68 = 9 m & CE90 = 17 m

Map updating: SAR data

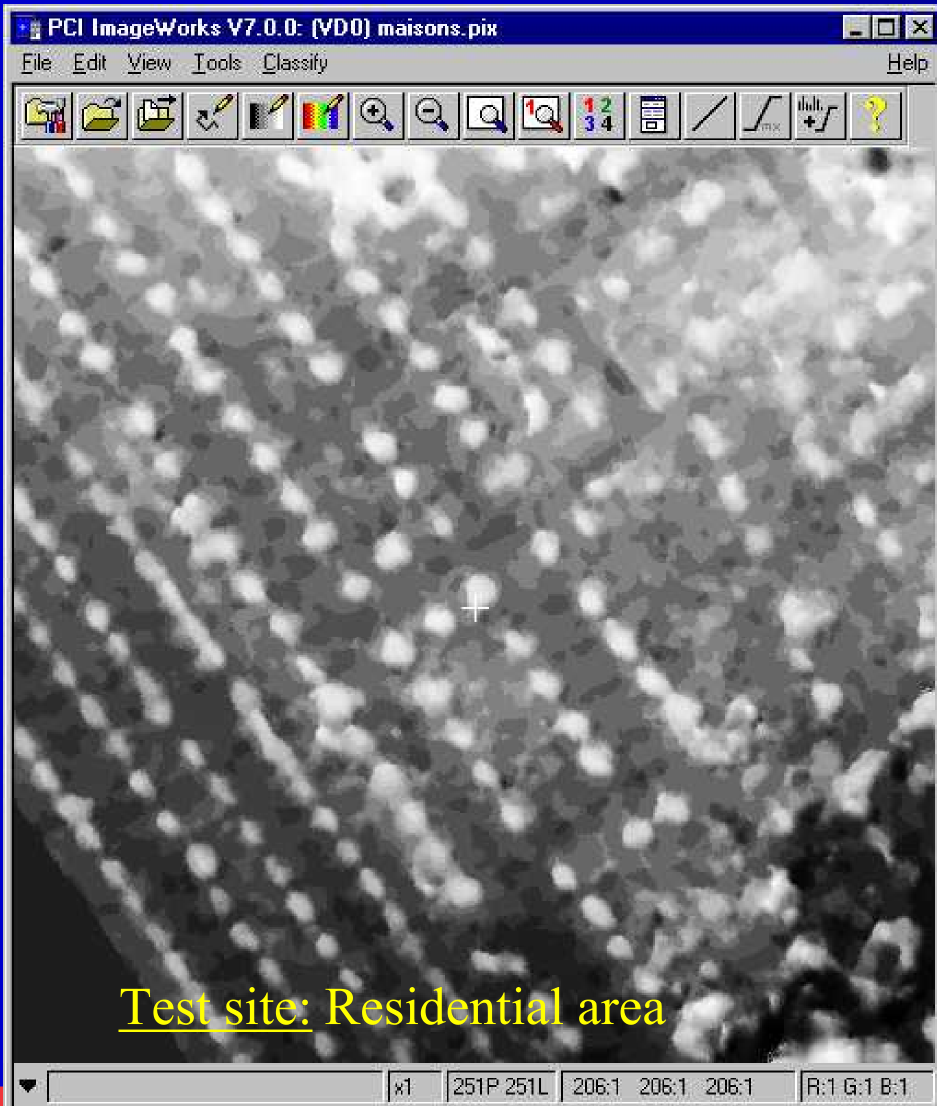
Building detection & extraction from IKONOS DSM

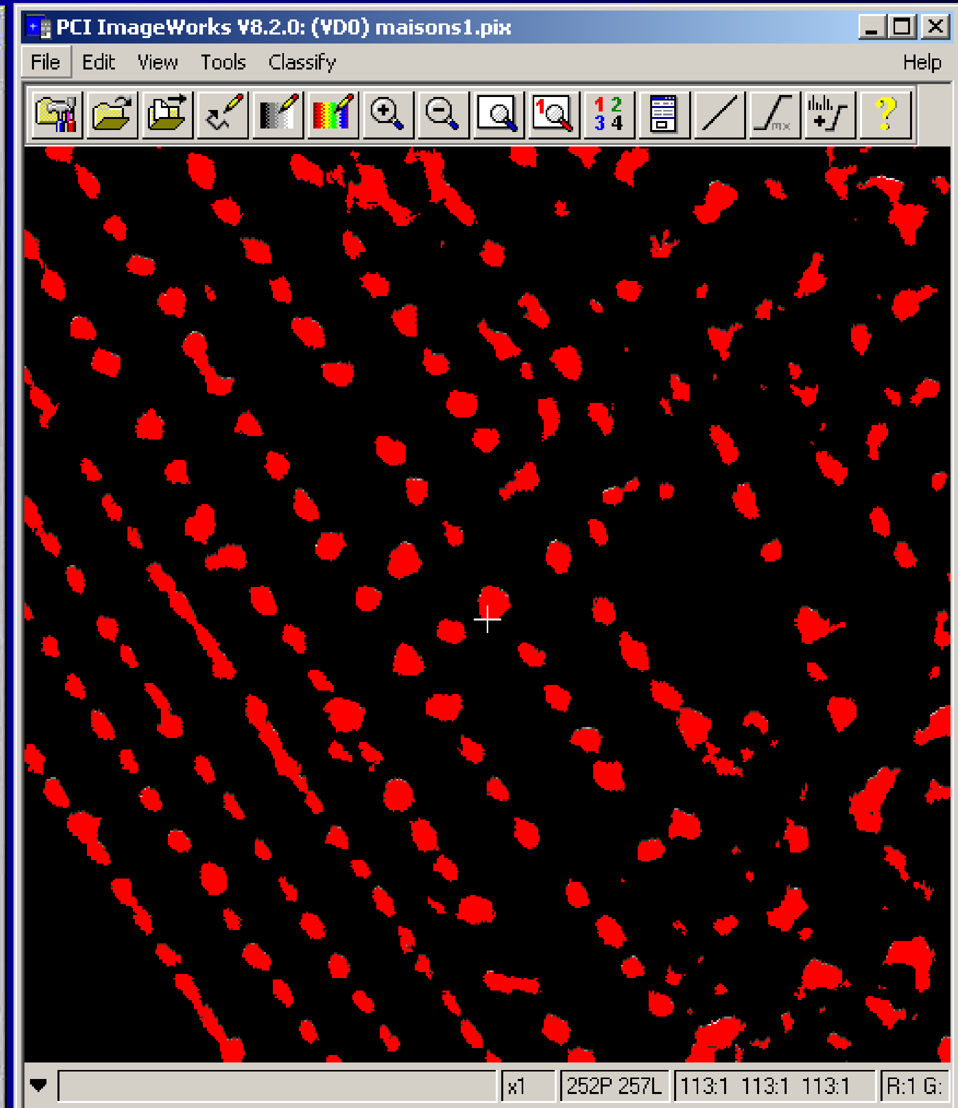


200 m x 200 m
100 m x 100 m

Map updating: SAR data

Extracted buildings surface from Ikonos DSM





Map updating: SAR data

Extracted building surface from Ikonos DSM

Test site:

Industrial area

Stone wall

Sun direction

Map updating: SAR data

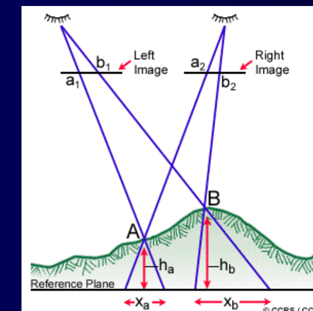
Database of buildings

Required a priori knowledge on buidings

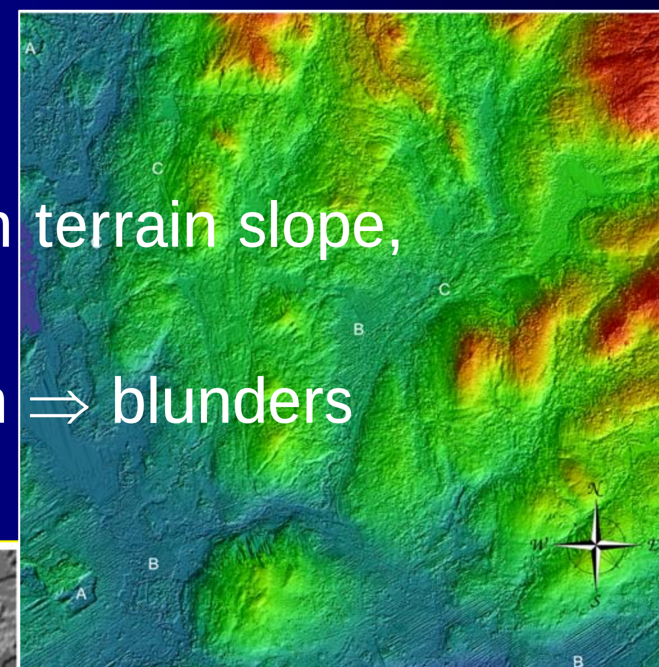
Generation of database:

- Surface (min./max.)
- Height (min./max., RMS)
- Shape
- Proximity or density

Conclusions: geometry + DSM



- *Subpixel accuracy georeferencing is a solved problem*
- *Bias-corrected **RPCs** & rigorous **collinearity-based** models **with same results***
- *Surface height should be added to DEM for the ortho-rectification process*



- DEM accuracy: 1-5 pixels depending on terrain slope, land cover and temporal change
- Low image quality + time decorrelation ⇒ blunders
- DSM ⇒ DTM reduction not solved yet

Conclusions: mapping & map updating

- Problems of low image quality, contrast, shadow, hidden objects due to view angles
- Low image quality + time decorrelation ⇒ blunders
- Depend on information content, standard, context, specification… for each country
- Rule of thumb: 0.05 - 0.1mm/pixel in the map required
- Stereo plotting better than mono-plotting (less omission especially in urban area)
- Better for map updating than new mapping

Acknowledgments

- Drs. Manuel Baltsavias & Armin Grün, ETH Zürich, Switzerland
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- Paul Briand, Canadian Space Agency, Canada
- Rani Hellerman, ImageSat Intl., Israel
- Marc Bernard, Didier Giacobbo, SPOT-Image, France
- Digital Globe, USA
- Ressources naturelles Québec, Canada

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OrthoEngine

Workflow of the processing