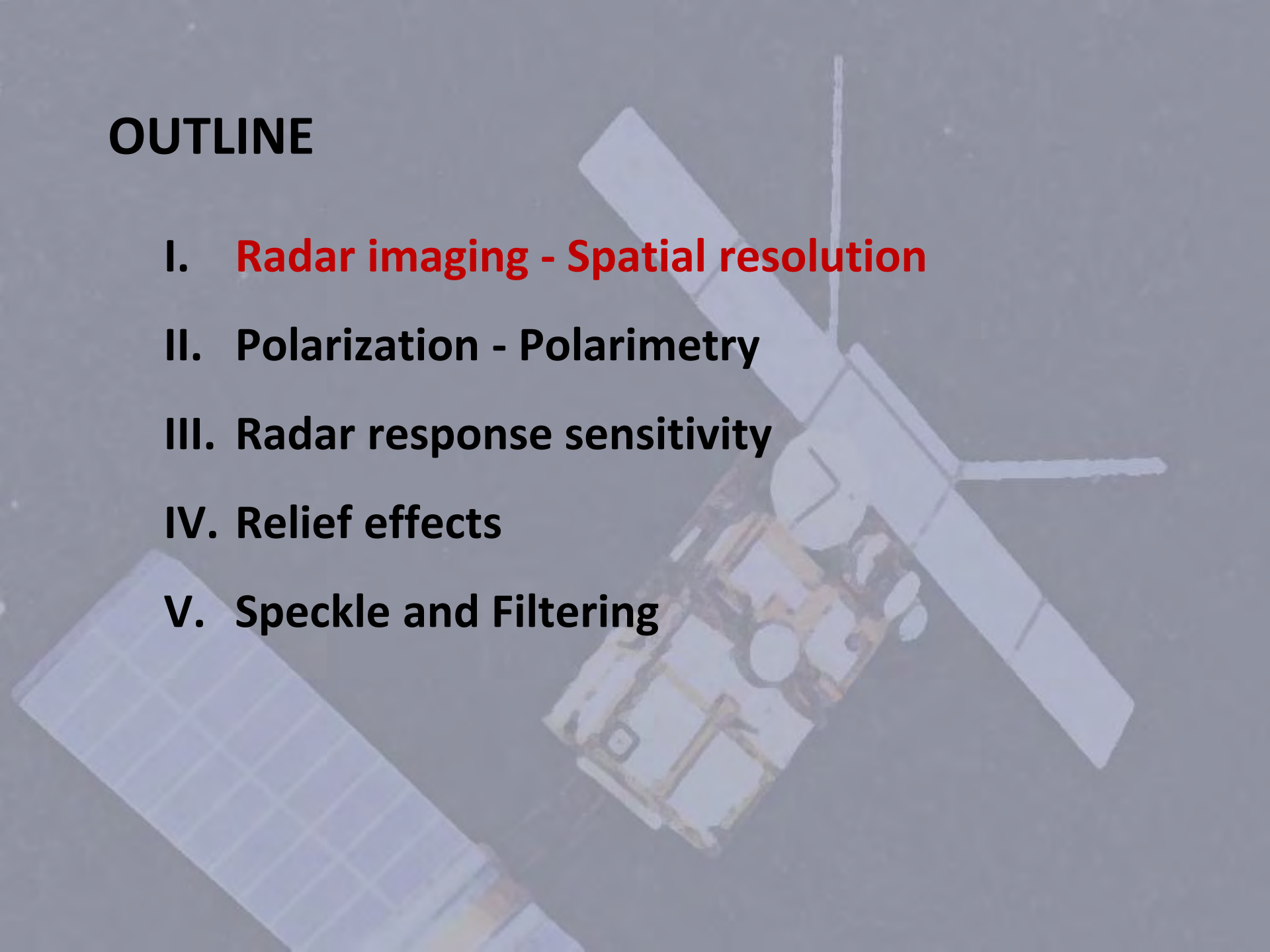
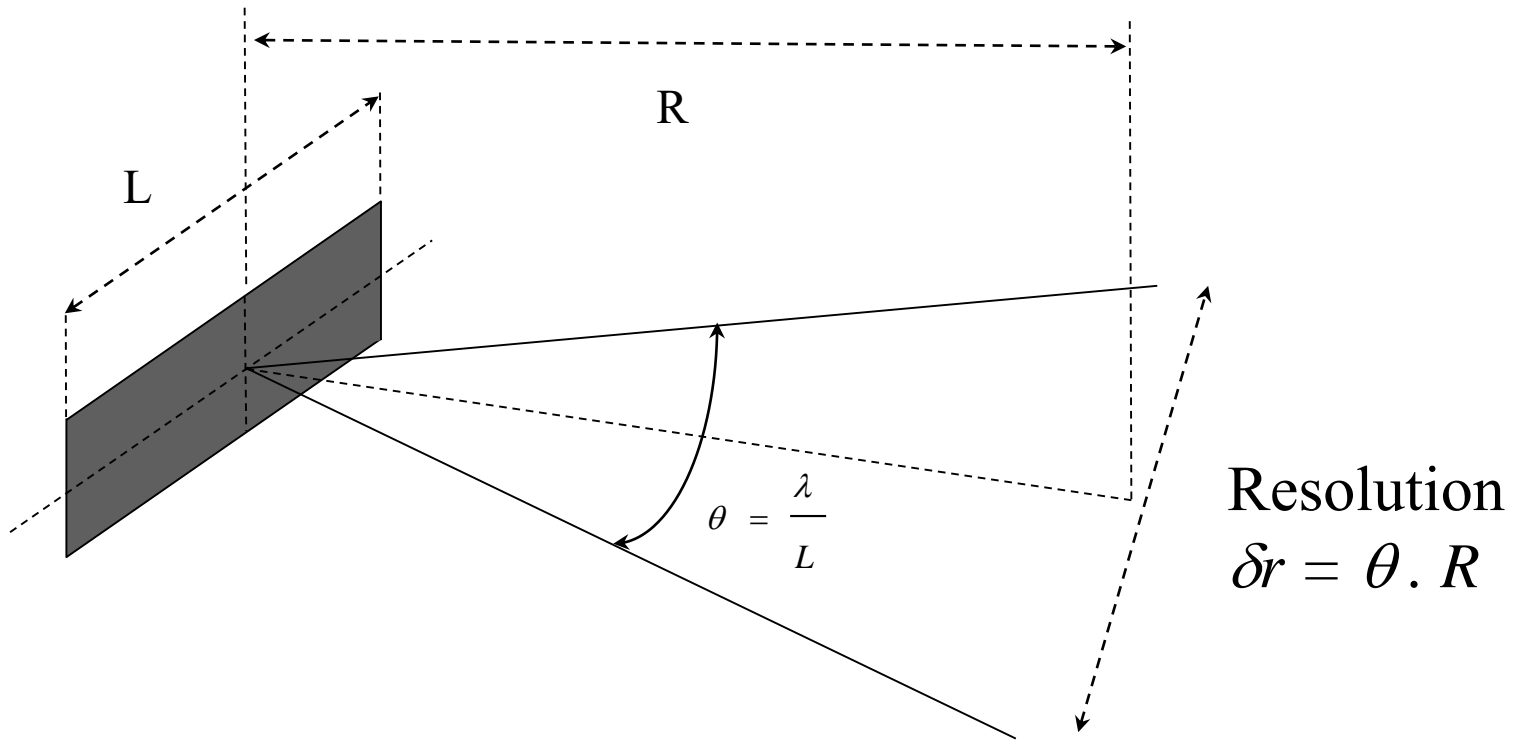


OUTLINE

- I. **Radar imaging - Spatial resolution**
- II. Polarization - Polarimetry
- III. Radar response sensitivity
- IV. Relief effects
- V. Speckle and Filtering



ANTENNA APERTURE



Ex.: $L = 4 \text{ m}$, $R = 4 \text{ km}$ (airborne), $\lambda = 3 \text{ cm}$ (X band) $\delta r = 30 \text{ m}$

$L = 10 \text{ m}$, $R = 800 \text{ km}$ (spaceborne), $\lambda = 6 \text{ cm}$ (C band) $\delta r = 4,5 \text{ km}$

Spatial resolution:

smallest distance allowing the separation of two objects

Optical data:

sensor spatial resolution $<$ image pixel size

\implies pixel size same as spatial resolution

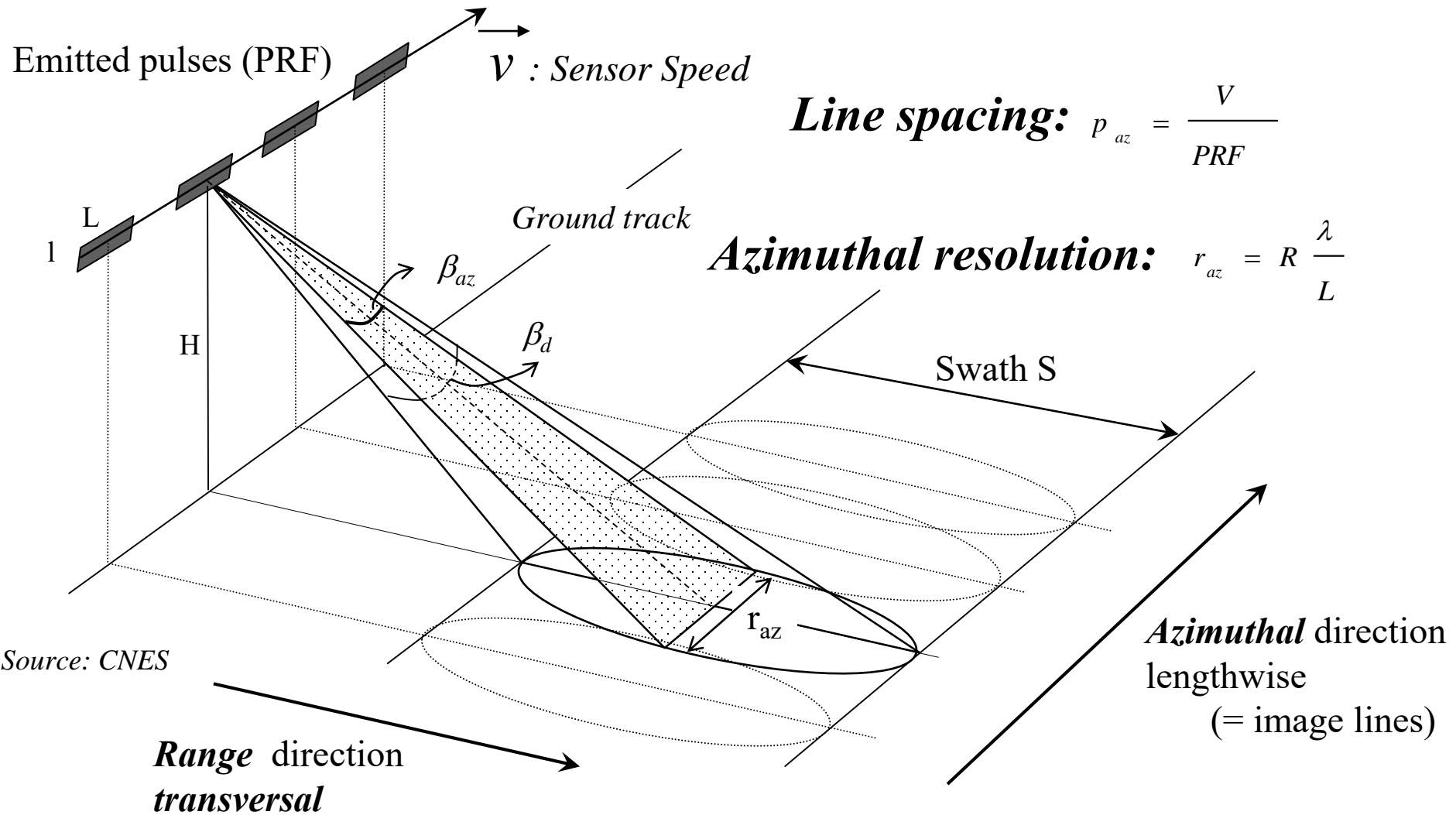
hence the use of one word for the other

Radar data:

sensor spatial resolution $>$ image pixel size

\implies these 2 notions remain different

Radar Imaging – spatial resolution



Numerical Application (ERS):

$$PRF = 1680 \text{ Hz}, V = 7 \text{ km/s}$$

$$p_{az} \approx 5 \text{ m}$$

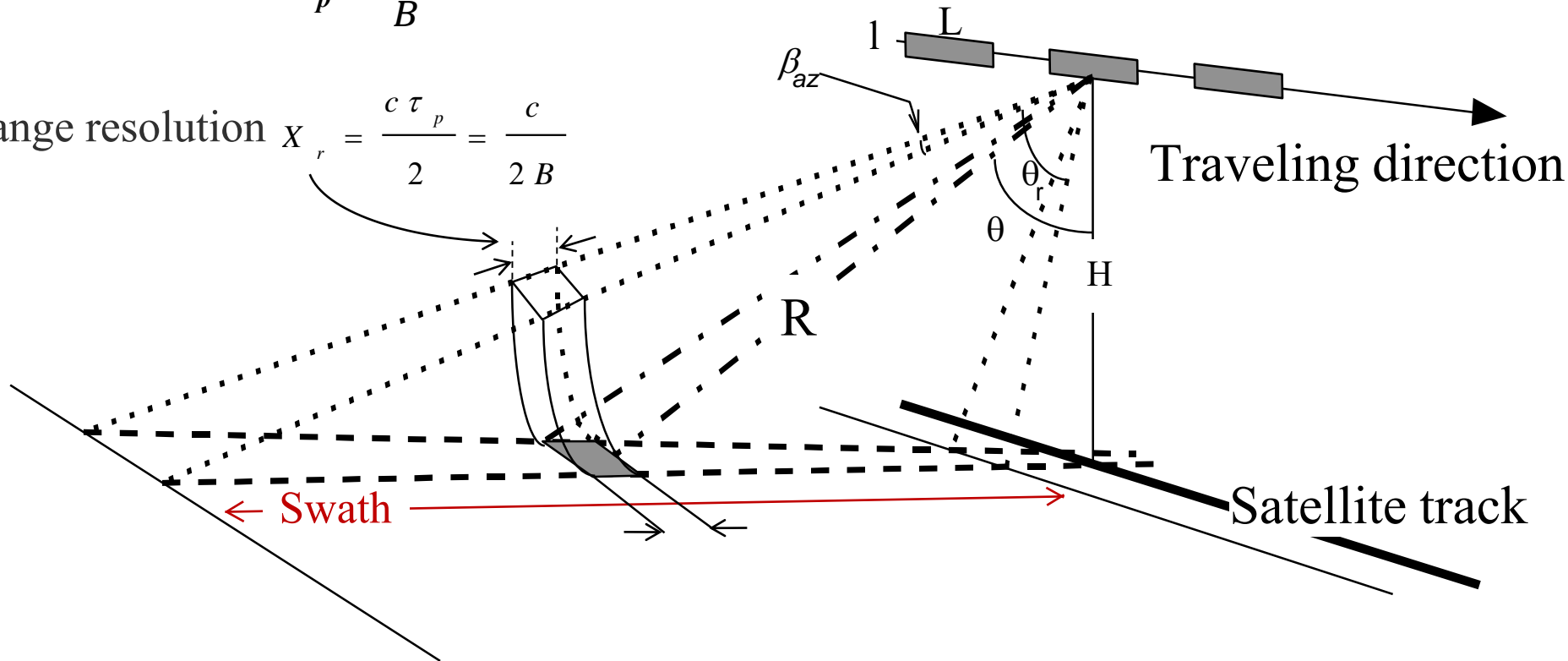
$$L = 10 \text{ m}, \lambda = 5.6 \text{ cm}, H = 700 \text{ km}, \theta = 23^\circ$$

$$r_{az} \approx 4.2 \text{ km}$$

Radar Imaging – spatial resolution

$$\text{Pulse duration} = \tau_p = \frac{1}{B}$$

$$\text{Range resolution } X_r = \frac{c \tau_p}{2} = \frac{c}{2B}$$



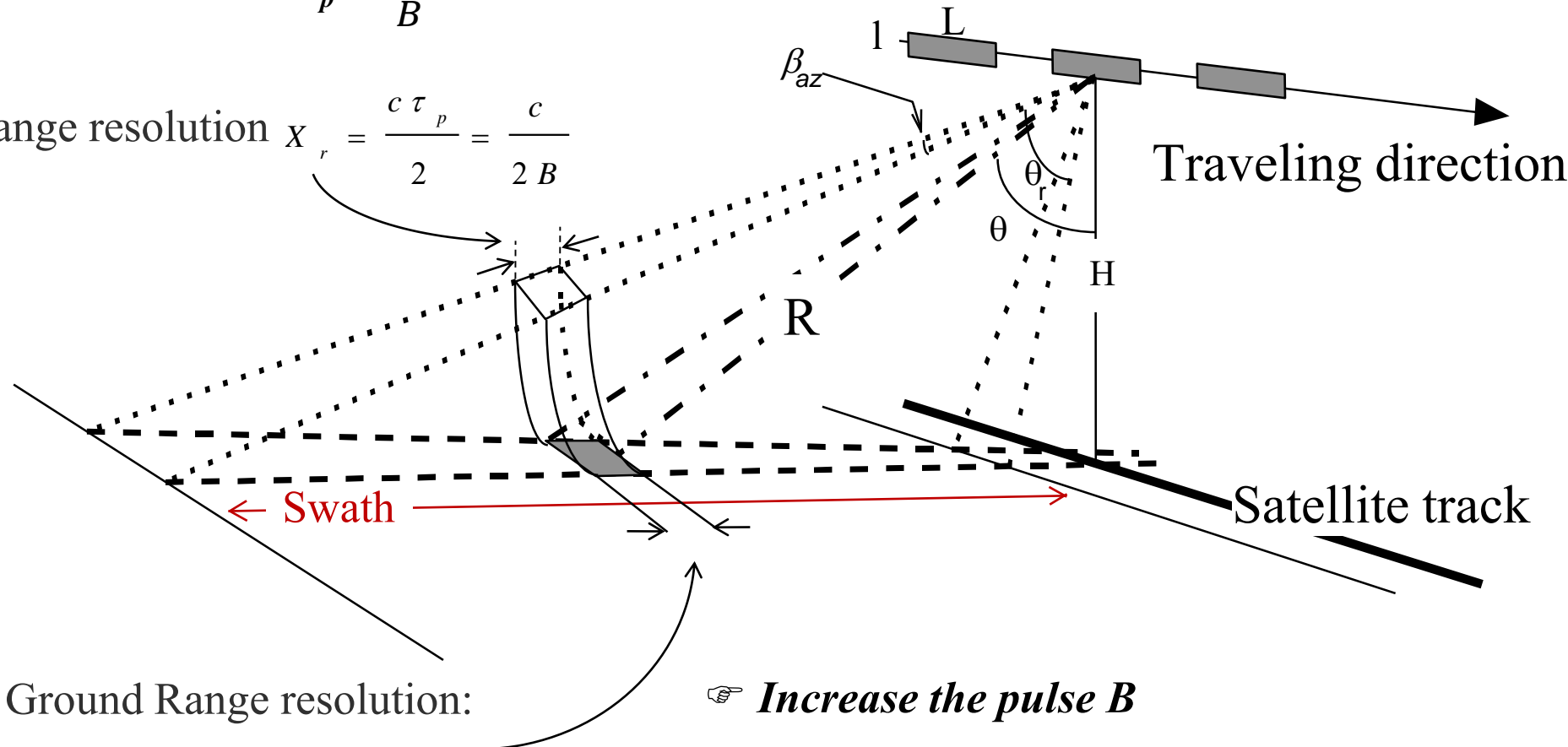
☞ *Increase the pulse B*

Num. Appl. (ERS): $\tau_p = 37 \mu s$ $B \approx \cancel{30 \text{ kHz}}$ 15.5 MHz
 $X_r \approx 10 \text{ m}$

Radar Imaging – spatial resolution

$$\text{Pulse duration} = \tau_p = \frac{1}{B}$$

$$\text{Range resolution } X_r = \frac{c \tau_p}{2} = \frac{c}{2B}$$



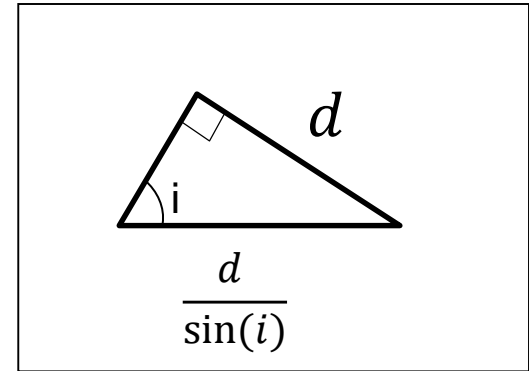
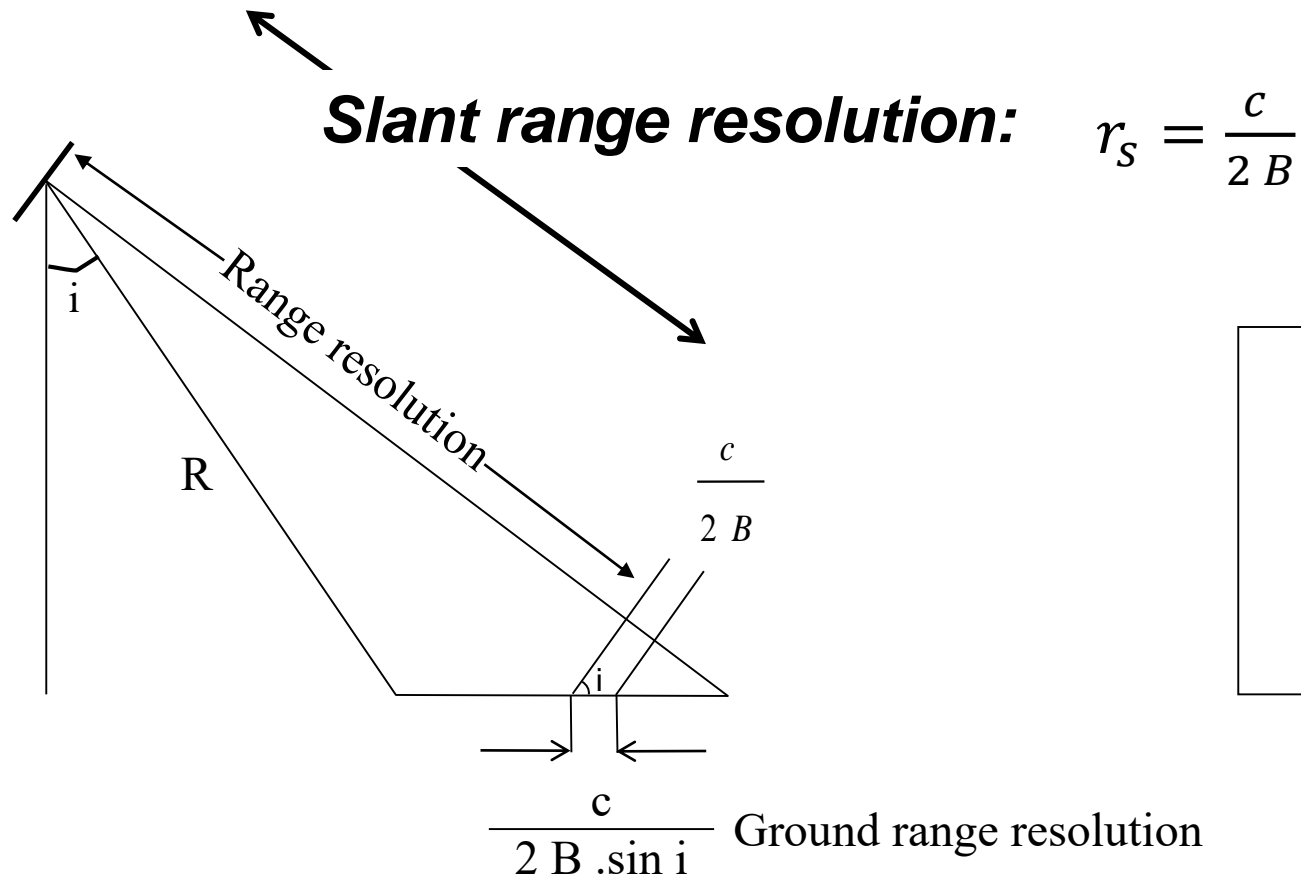
Ground Range resolution:

$$X_{gr} = \frac{c \tau_p}{2 \sin \theta} = \frac{c}{2B \sin \theta}$$

☞ *Increase the pulse B*

Num. Appl. (ERS): $\tau_p = 37 \mu s$ $B \approx \cancel{30 \text{ kHz}}$ 15.5 MHz
 $X_r \approx 10 \text{ m}$

Radar Imaging – spatial resolution

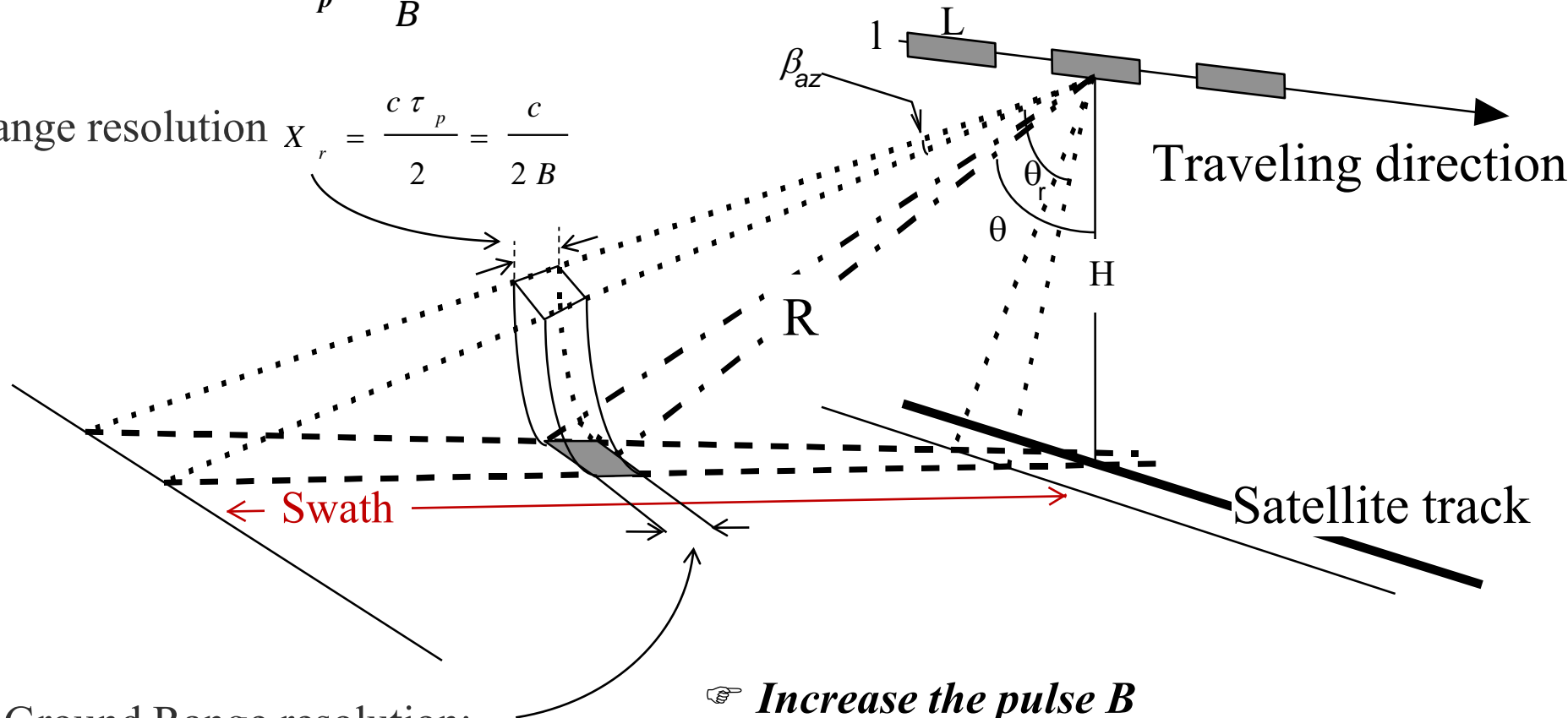


Ground range resolution: $X_{gr} = \frac{c}{2 B \sin (i)}$

Radar Imaging – spatial resolution

$$\text{Pulse duration} = \tau_p = \frac{1}{B}$$

$$\text{Range resolution } X_r = \frac{c \tau_p}{2} = \frac{c}{2B}$$



Ground Range resolution:

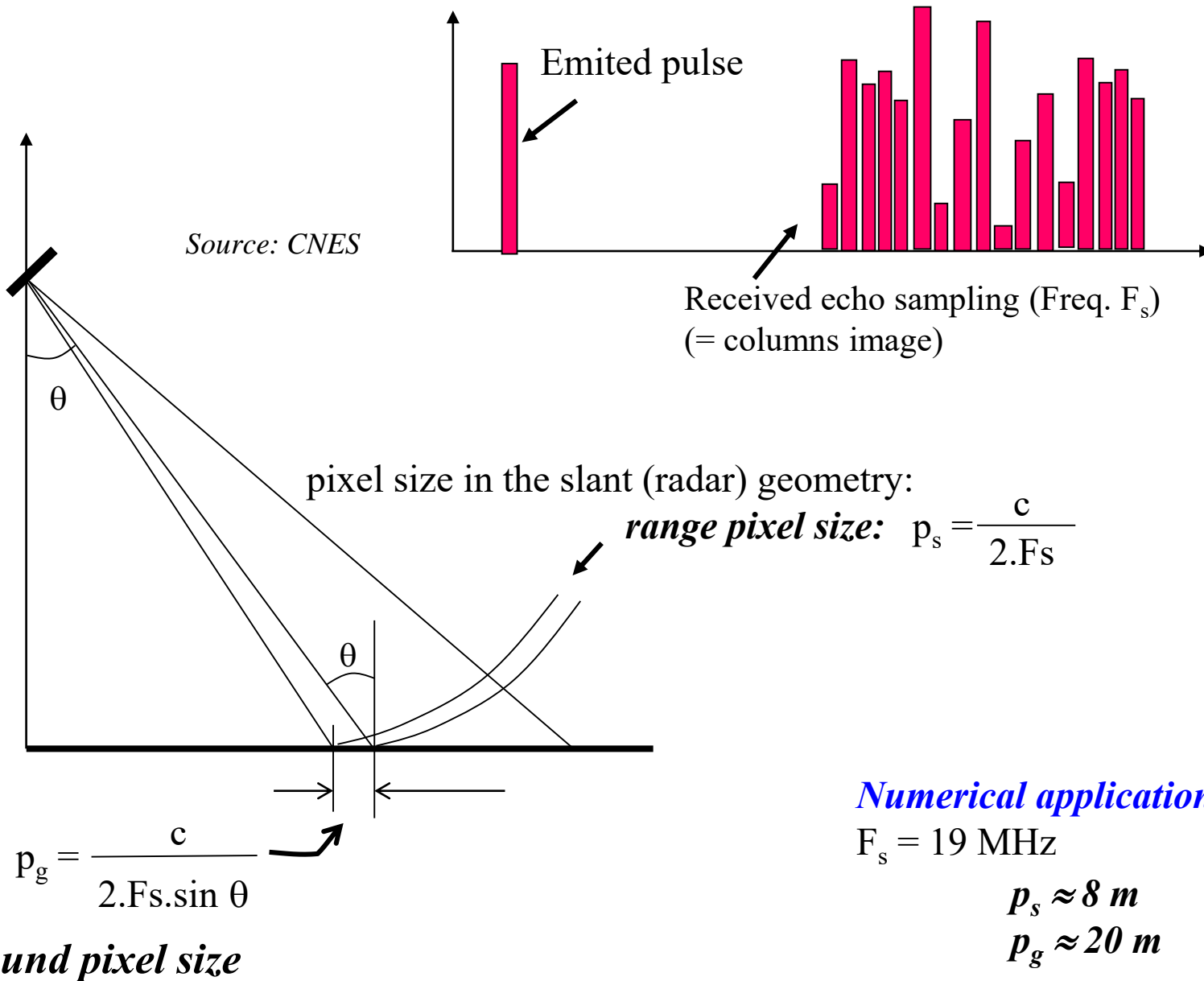
$$X_{gr} = \frac{c \tau_p}{2 \sin \theta} = \frac{c}{2B \sin \theta}$$

👉 *Increase the pulse B*

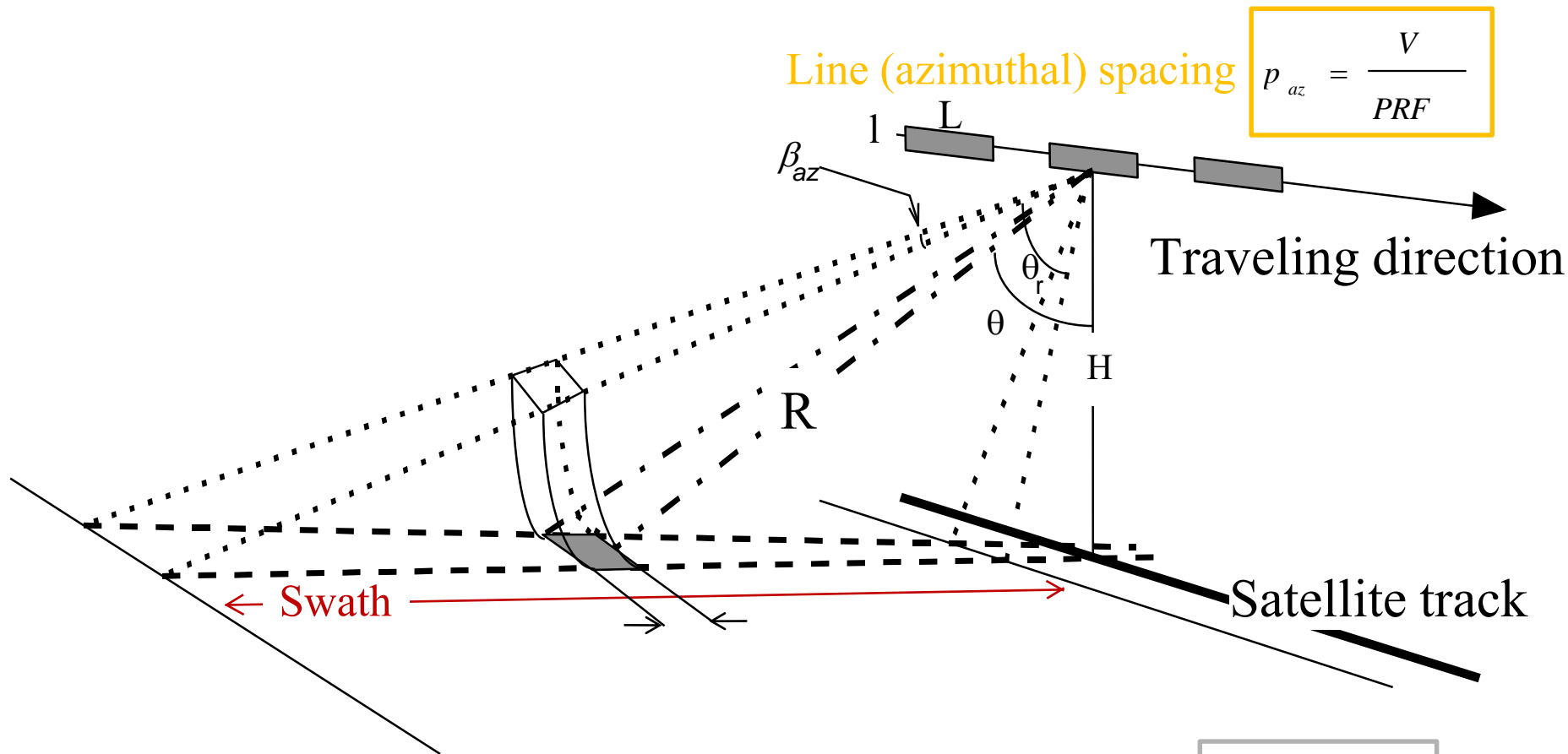
Num. Appl. (ERS): $\tau_p = 37 \mu s$ $B \approx \cancel{30 \text{ kHz}}$ 15.5 MHz

$X_r \approx 10 \text{ m}$ $X_{gr} \approx 25 \text{ m}$

Radar Imaging – spatial resolution



Radar Imaging – spatial resolution



Line (azimuthal) spacing

$$p_{az} = \frac{V}{PRF}$$

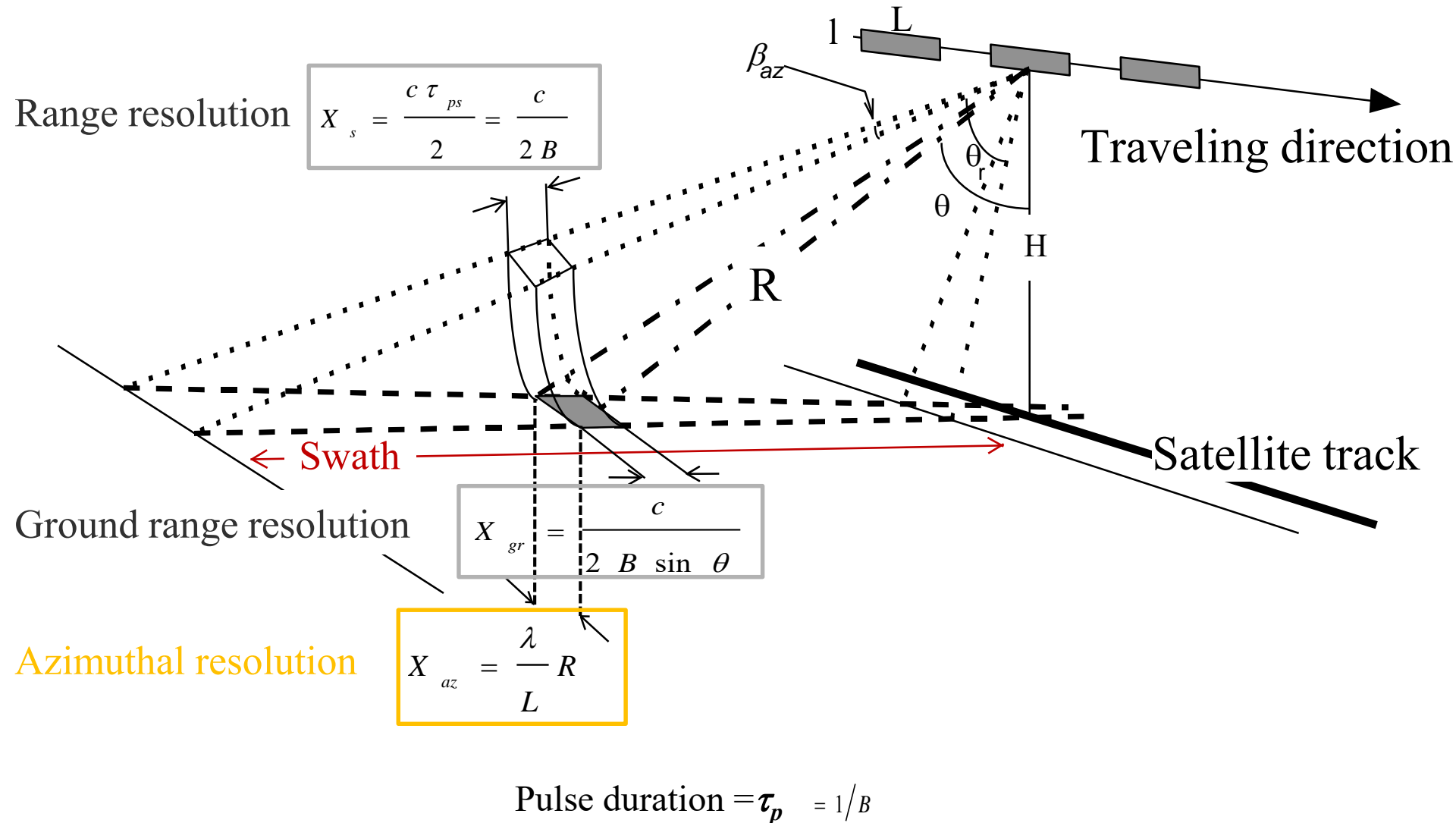
Range pixel (column) size

$$p_s = \frac{c}{2 F_s}$$

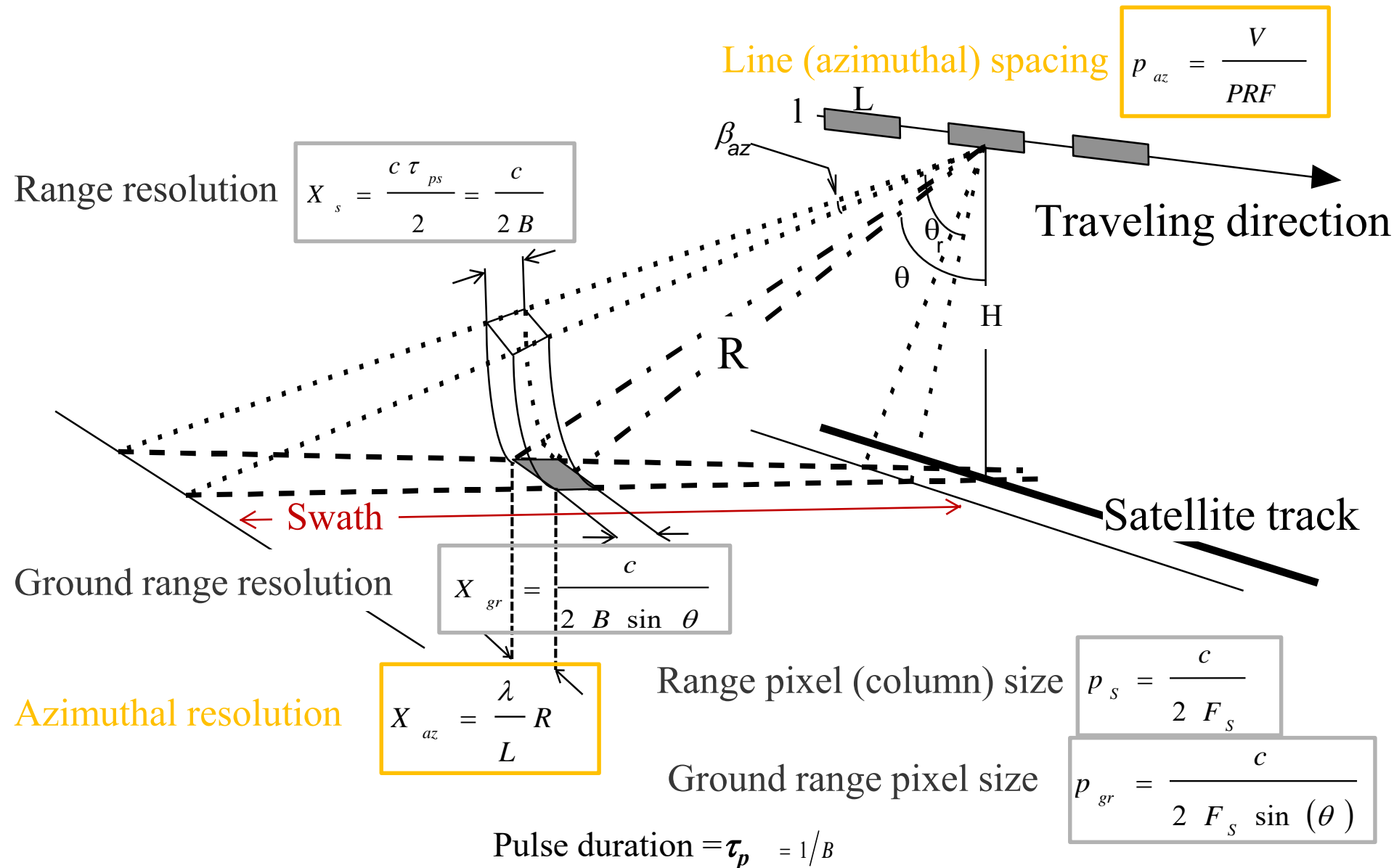
Ground range pixel size

$$p_{gr} = \frac{c}{2 F_s \sin(\theta)}$$

Radar Imaging – spatial resolution



Radar Imaging – spatial resolution



Radar Imaging – spatial resolution

Case of ERS

	Range		Azimuth
	Slant (radar)	Ground	
Resolution	$X_s = \frac{c}{2 B} = 10 \text{ m}$	$X_{gr} = \frac{c}{2 B \sin(\theta)} = 25 \text{ m} - 32 \text{ m}$	$X_{az} = \frac{\lambda}{L} R \quad \sim 5 \text{ km}$
Pixel size	$p_s = \frac{c}{2 F_s} = 8 \text{ m}$	$p_{gr} = \frac{c}{2 F_s \sin(\theta)} = 20 \text{ m} - 26 \text{ m}$	$p_{az} = \frac{V}{PRF} = 4 \text{ m}$

$$\lambda = 5.6 \text{ cm}$$

$$V = 7 \text{ km/s}$$

$$PRF = 1680 \text{ Hz}$$

$$F_s = 19 \text{ MHz}$$

$$\theta = 18-24^\circ$$

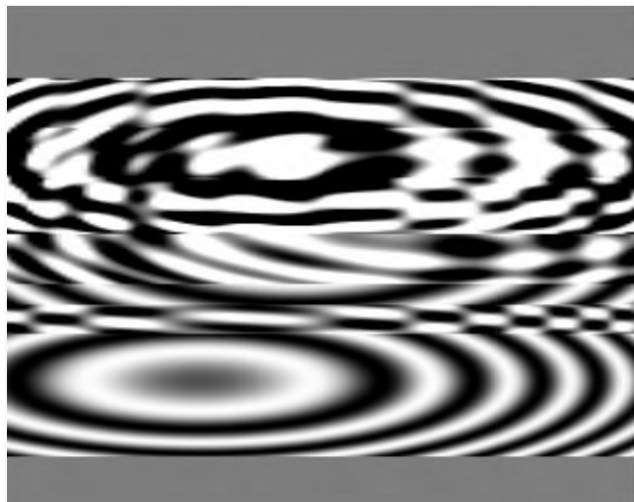
$$B = 15.5 \text{ MHz}$$

$$R = 15.5 \text{ MHz}$$

$$L = 10 \text{ m}$$

FLIGHT DIRECTION

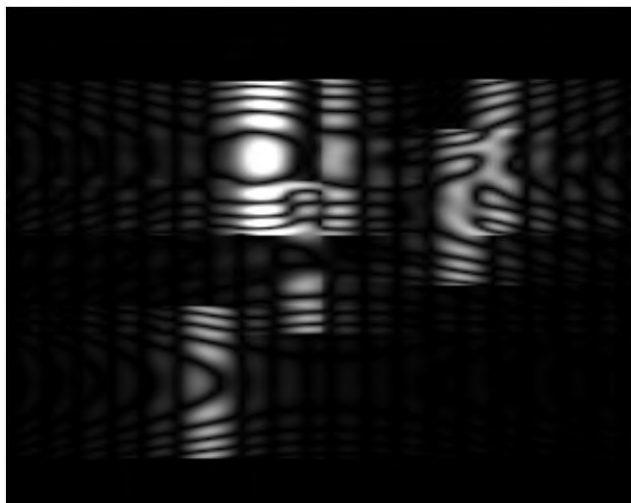
Raw echoes



Ideal scene



Compression in distance



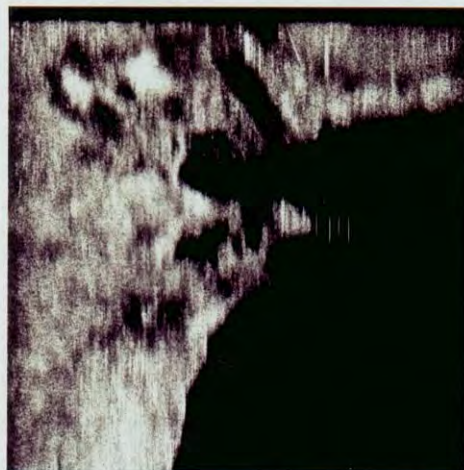
RANGE (Viewing) DIRECTION

FLIGHT DIRECTION ————— ↑



NON COMPRIME DISTANCE
NON COMPRIME AZIMUT

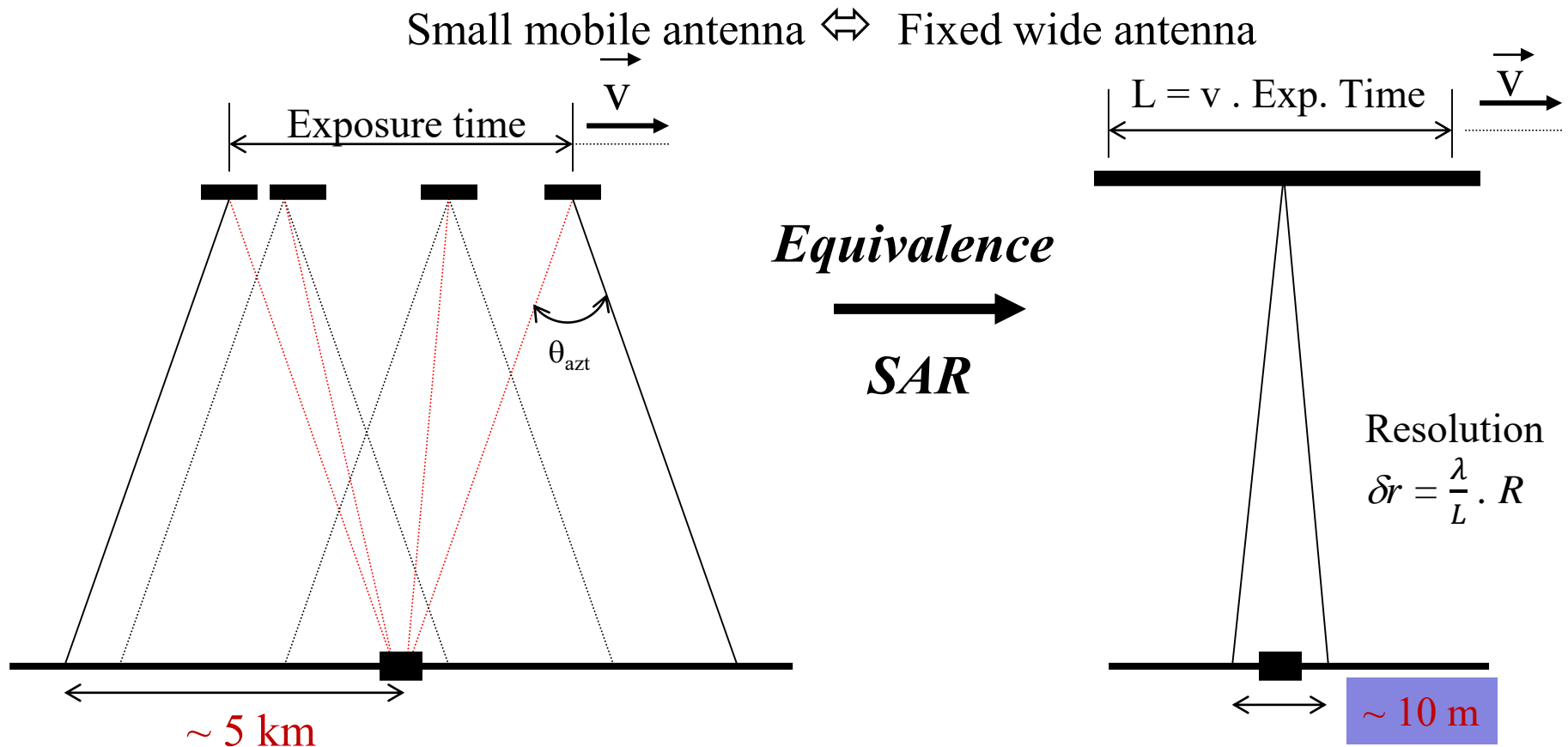
Document



COMPRIME DISTANCE
NON COMPRIME AZIMUT

Radar Imaging – spatial resolution

Synthetic Aperture Radar: (i.e. improvment of azimuthal resolution)



Coherent sum of the successive echoes

Adaptive filtering (Doppler Bandwidth)

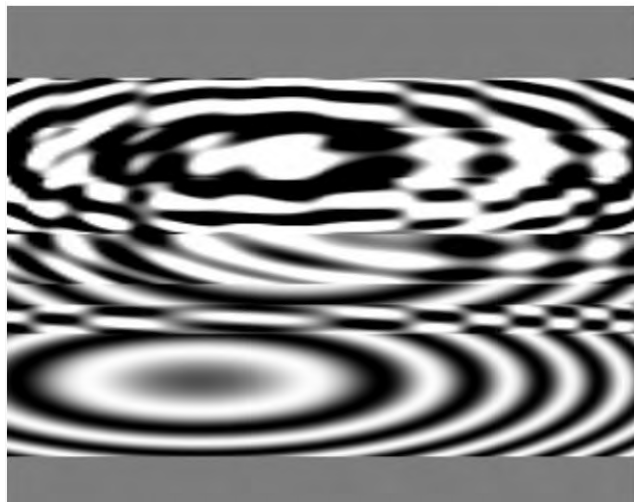
$$B_D = \frac{2V}{L}$$

Gain in azimuthal resolution

$$X_{az} = \frac{V}{B_D} \Rightarrow X_{az} = \frac{L}{2}$$

FLIGHT DIRECTION

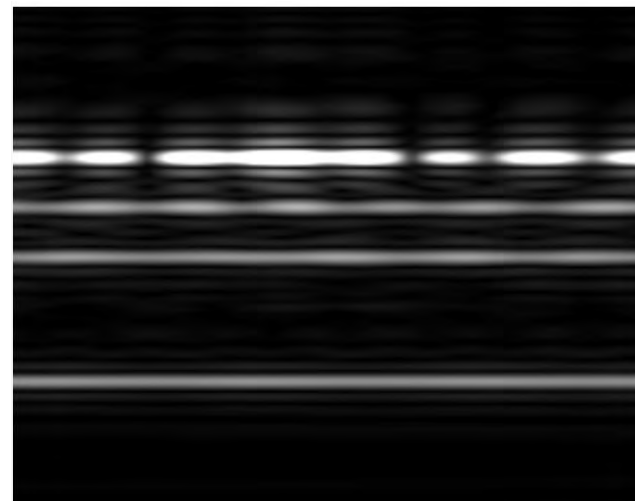
Raw echoes



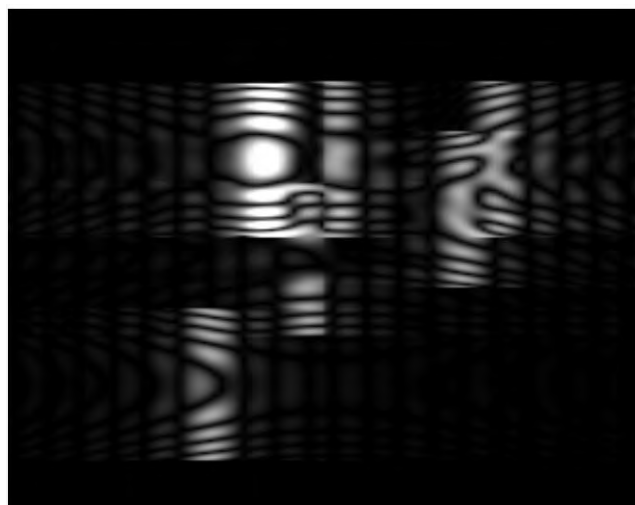
Ideal scene



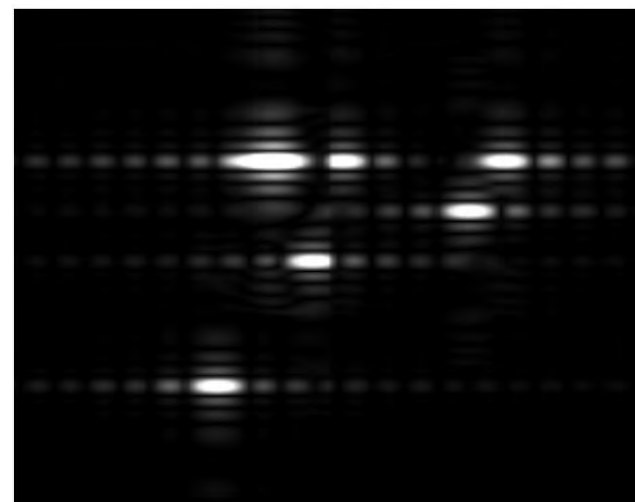
Compression in Azimuth



Compression in distance



radar Image Single Look Complex (SLC)



RANGE (Viewing) DIRECTION

FLIGHT DIRECTION

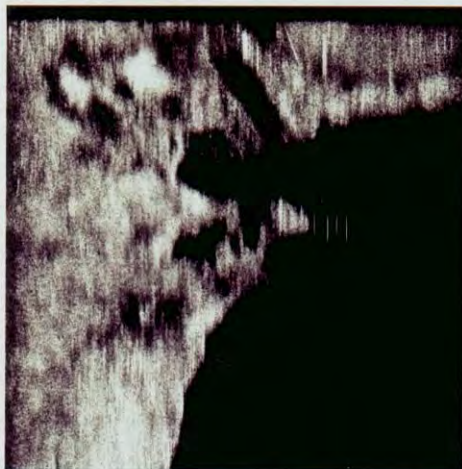


NON COMPRIME DISTANCE
NON COMPRIME AZIMUT



NON COMPRIME DISTANCE
COMPRIME AZIMUT

Document CNES



COMPRIME DISTANCE
NON COMPRIME AZIMUT



COMPRIME DISTANCE
COMPRIME AZIMUT

RANGE (Viewing) DIRECTION

Radar Imaging – spatial resolution

Case of ERS SAR (after aperture synthesis)

	Range		Azimuth
	Slant (radar)	Ground	
Resolution	$X_r = \frac{c}{2 B} = 10 \text{ m}$	$X_r = \frac{c}{2 B \sin(\theta)} = 25 \text{ m} - 32 \text{ m}$	$X_{az} = \frac{\lambda}{L_{synth}} R = 10 \text{ m}$
Pixel size	$p_s = \frac{c}{2 F_s} = 8 \text{ m}$	$p_{gr} = \frac{c}{2 F_s \sin(\theta)} = 19 \text{ m} - 26 \text{ m}$	$p_{az} = \frac{V}{PRF} = 4 \text{ m}$

Case of TERRASAR-X

	Range		Azimuth
	Slant (radar)	Ground	
Resolution	1.2 m	1.5 m – 3.5 m	1.1 m
Pixel size	0.6 m	0.75 m – 1.75 m	0.6 m

RADARSAT - Scansar Wide : 27 mars 1999



Spat. res. 150 m

The Ouessant Rail

RADARSAT - Standard 6 : 3 Aug.1999



Spat. res. 30 m

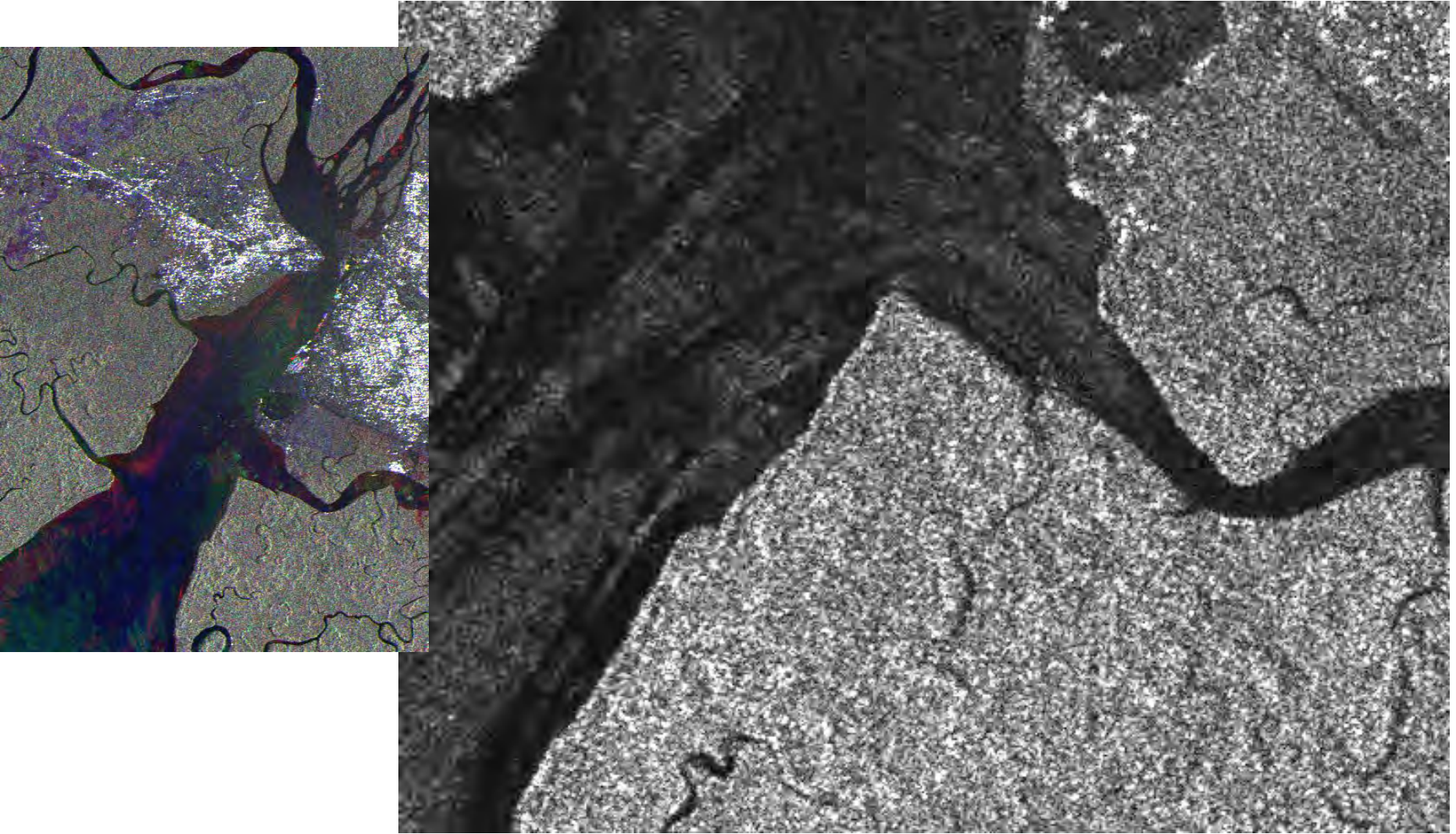


The Channel
ASAR
22 novembre 2003

© ESA 2004

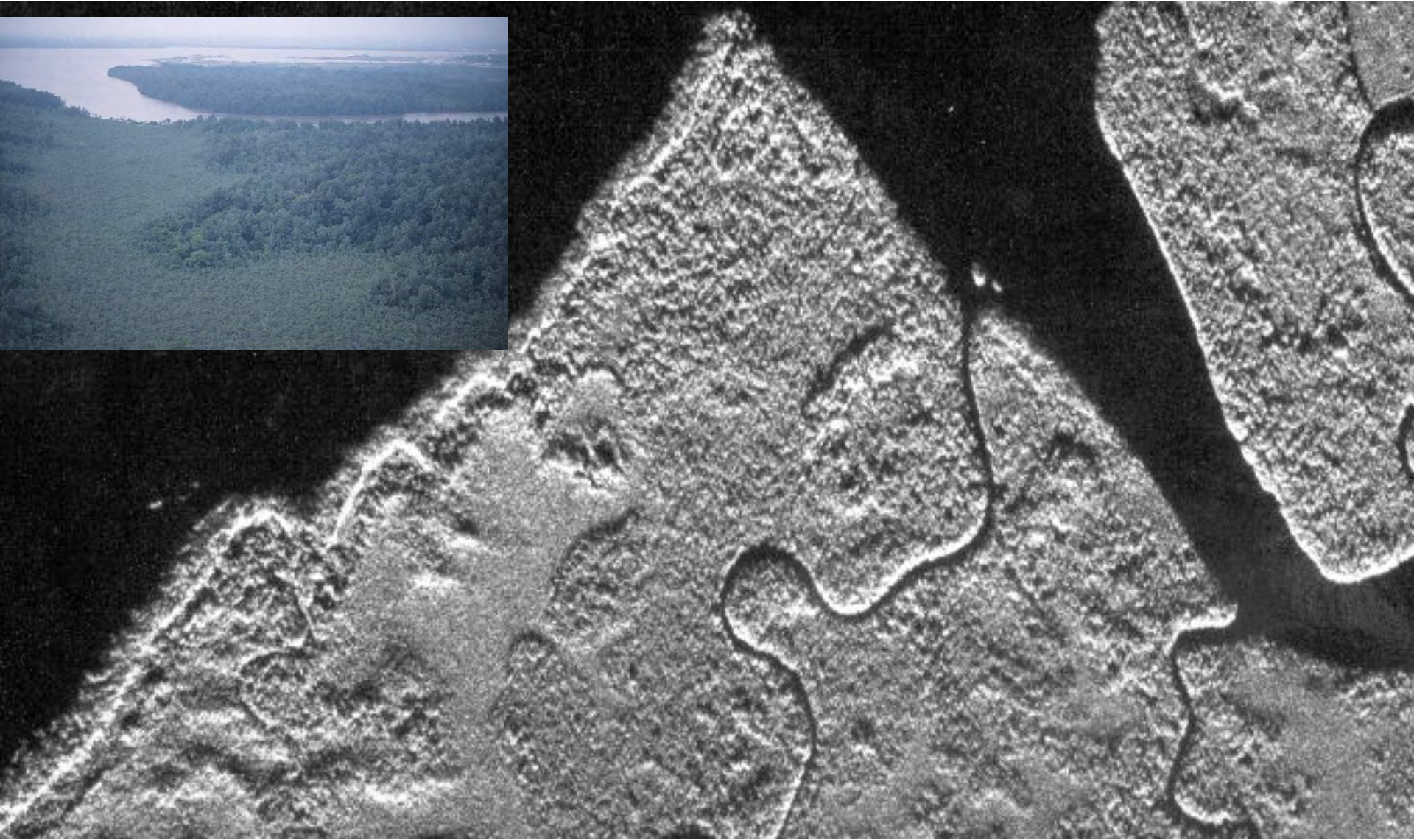
spat. res. 150 m

Radar Imaging – spatial resolution



ERS Resolution ~ 25 m, pixel 12,5m

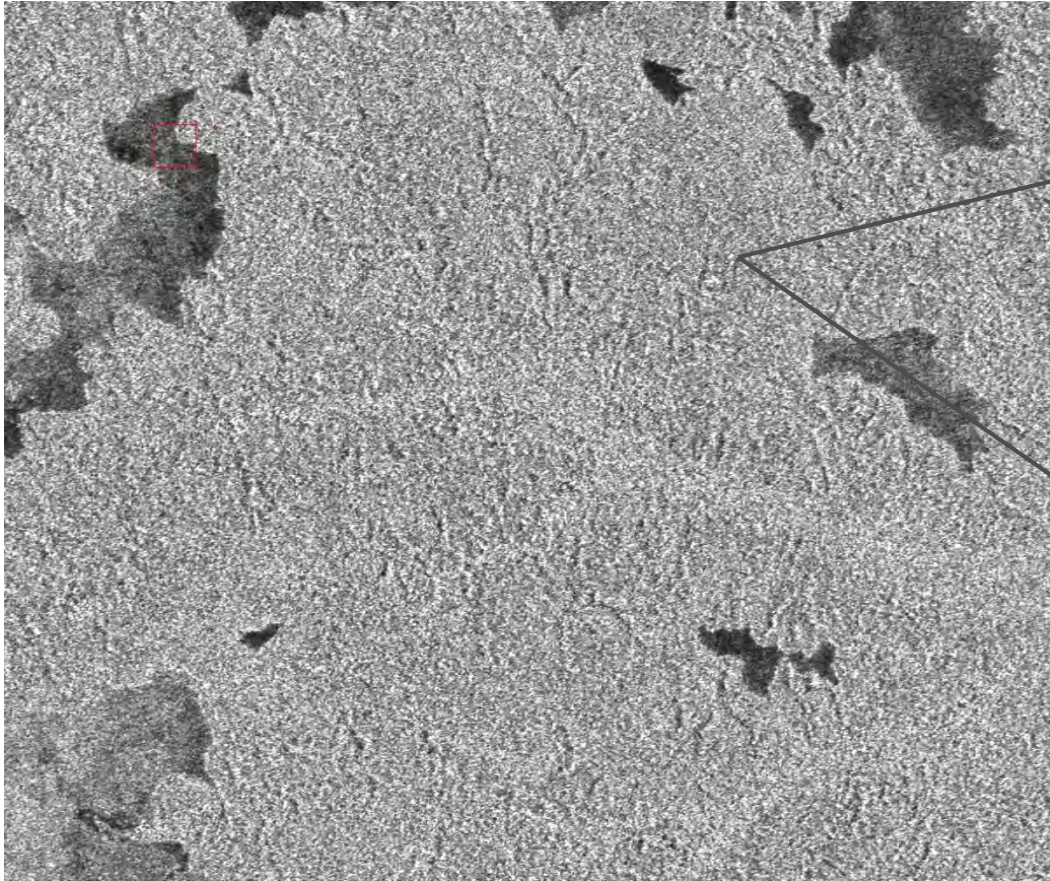
Radar Imaging – spatial resolution



DLR airplane radar resolution ~ 3 m

Radar Imaging – spatial resolution

Radar data

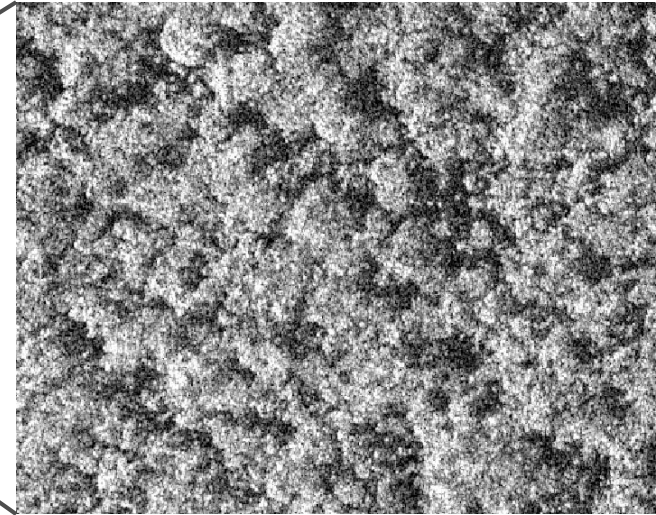


Forest in Congo Bassin,
PALSAR,
Polar: HH,
Spat.Resolution: 20 m

Radar Imaging – spatial resolution



Radar data

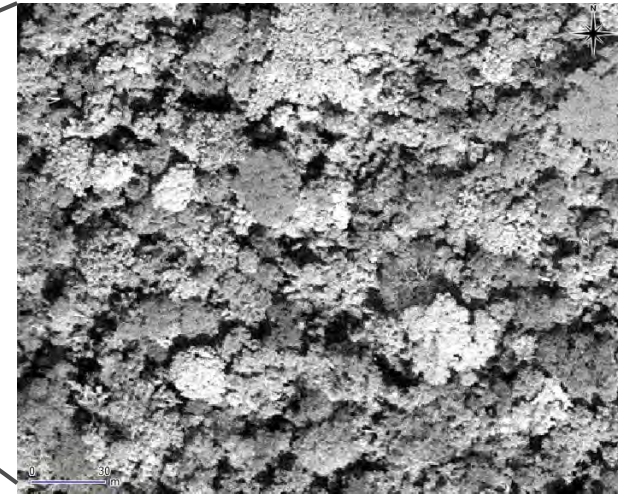


Forest in Cameroon,
TerraSAR-X, Spot
Light,
Polar: HH,
Spat.Resolution: 1 m

Radar Imaging – spatial resolution



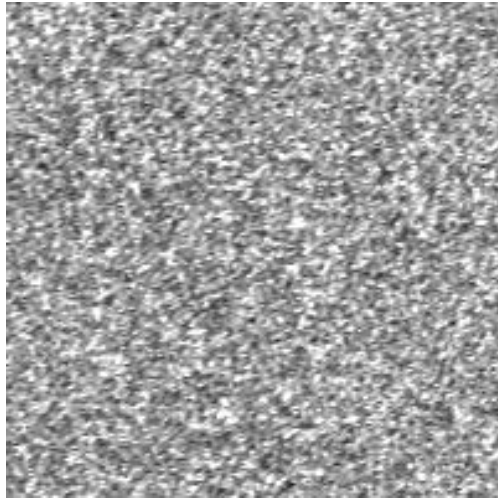
Optical data



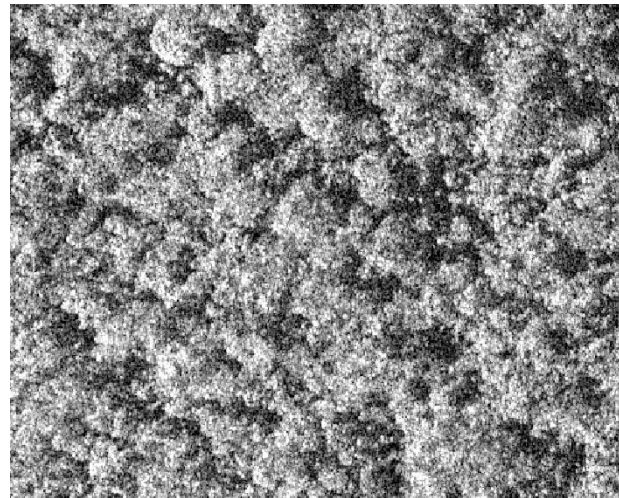
Forest in Cameroon,
Geoeye, Panchromatic,
Spat.Resolution: 0.5 m

Radar Imaging – spatial resolution

RADAR Data

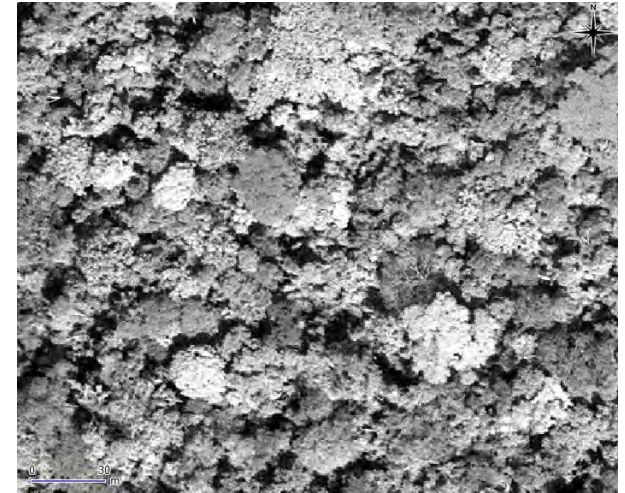


Forest in Congo Bassin,
PALSAR,
Polar: HH,
Spat.Resolution: 15 m



Forest in Cameroon,
TerraSAR-X, Spot
Light,
Polar: HH,
Spat.Resolution: 1 m

Optical Data



Forest in Cameroon,
Geoeye, Panchromatic,
Spat.Resolution: 0.5 m

TAKE HOME MESSAGE

Radar image:

*spatial resolution $\approx 2 * \text{pixel size}$*

ex: Sentinel-1 GRD products:

spat. res.: 20 m vs pixel :10 m

range direction (columns)

radar geometry (slant direction)

d

ground geometry (horizontal flat ground)

$d / \sin(i)$

azimuth direction (lines)

