SAR Instrument Principles and Processing

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with support from

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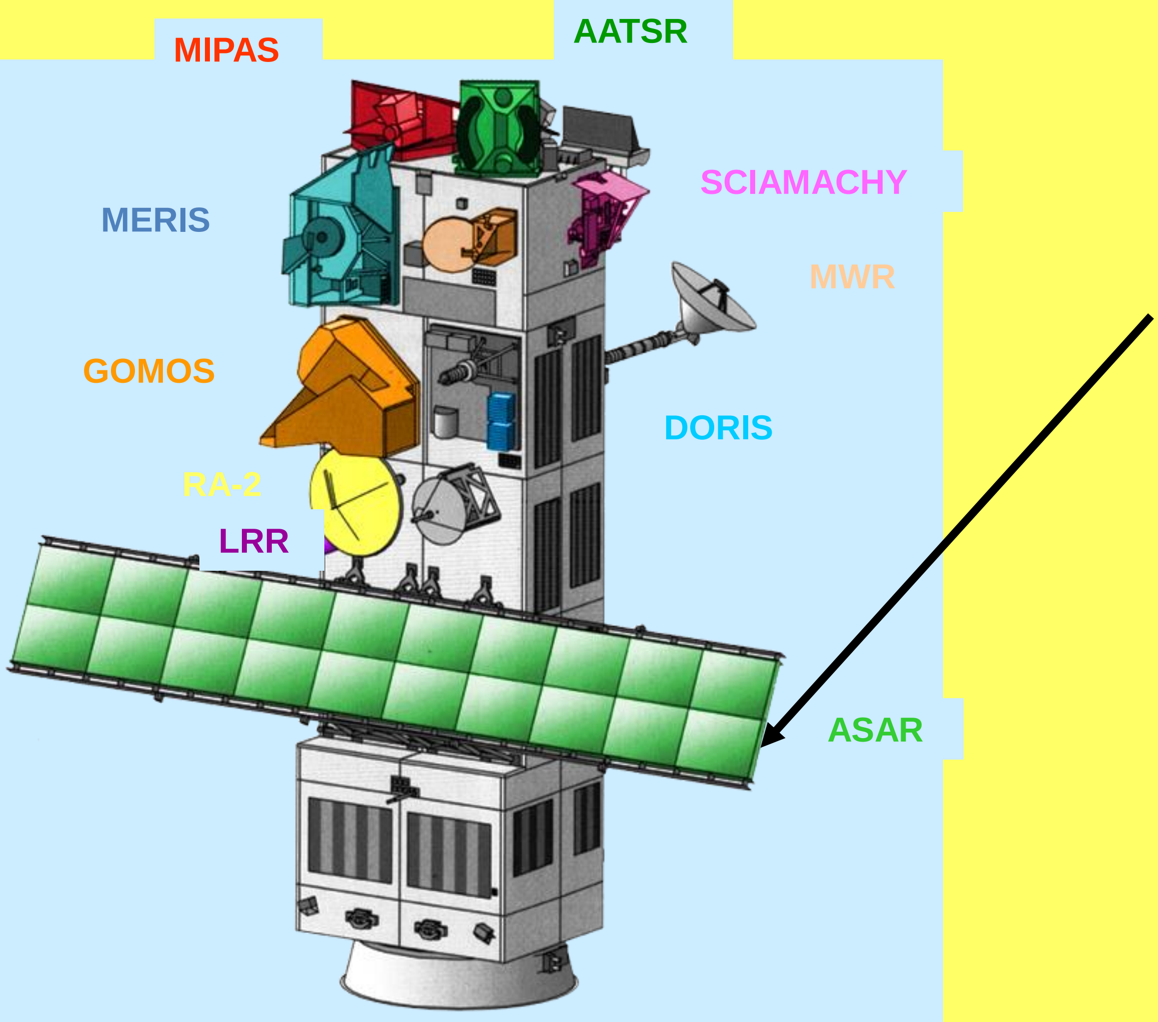
Content

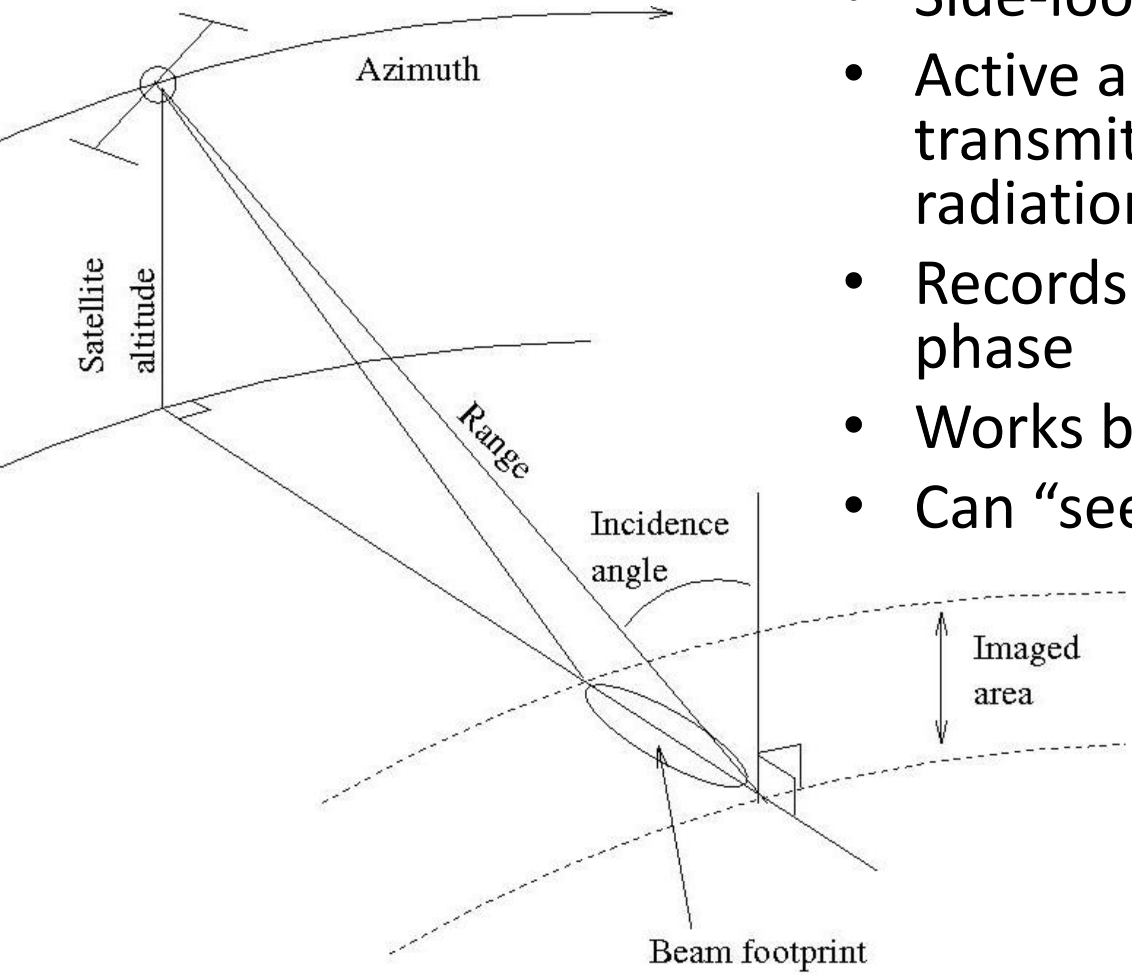
- SAR antenna
- Frequency domain – EM spectrum
- Incidence angles and Ranges
- Surface roughness and backscatter (NRCS)
- Bragg scattering and image formation
- Spatial Resolution
  - Range (across track)
  - Azimuth (along track)
- Processing from raw data to SAR image
- Range Doppler signal

ENVISAT ASAR Antenna



ASAR antenna
10 m x 1.33 m

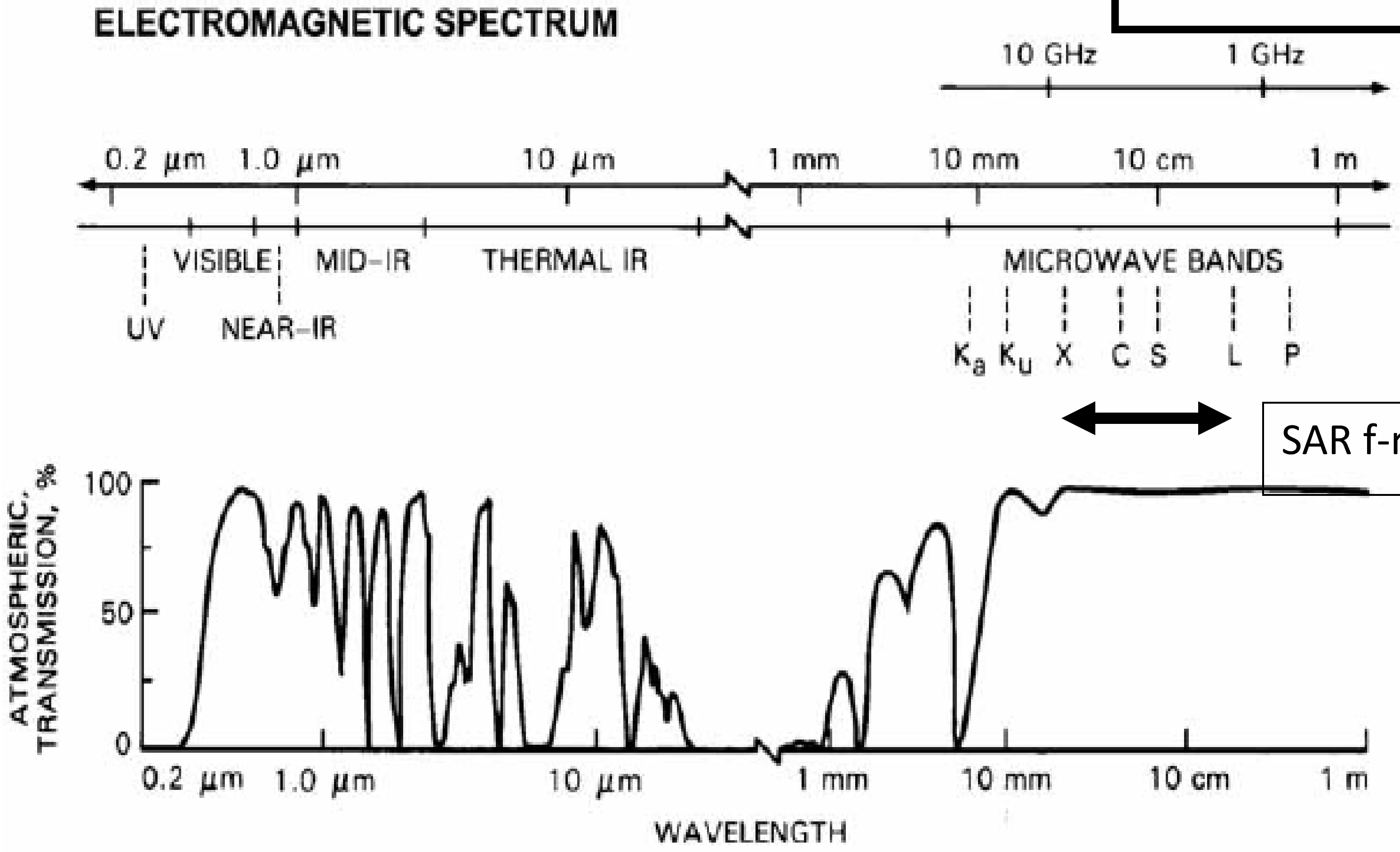
Synthetic Aperture Radar



- Side-looking
- Active antenna that transmits/receives electromagnetic radiation in VV, HH, VH, HV pol
- Records both signal amplitude and phase
- Works both day and night
- Can “see” through clouds

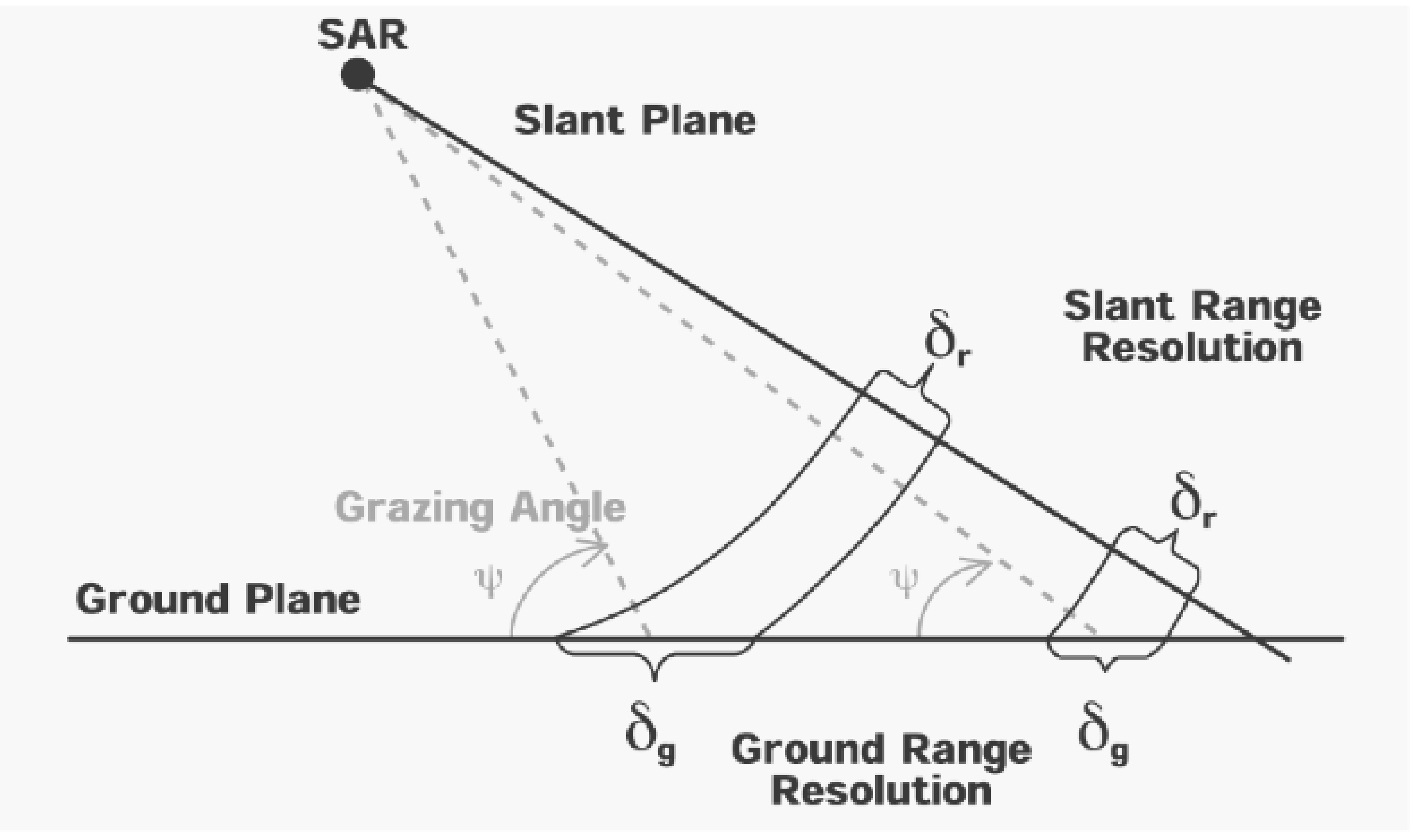
Electromagnetic Spectrum

$\lambda = c * T = c * 1/f$



SAR f-range

Angles and Ranges



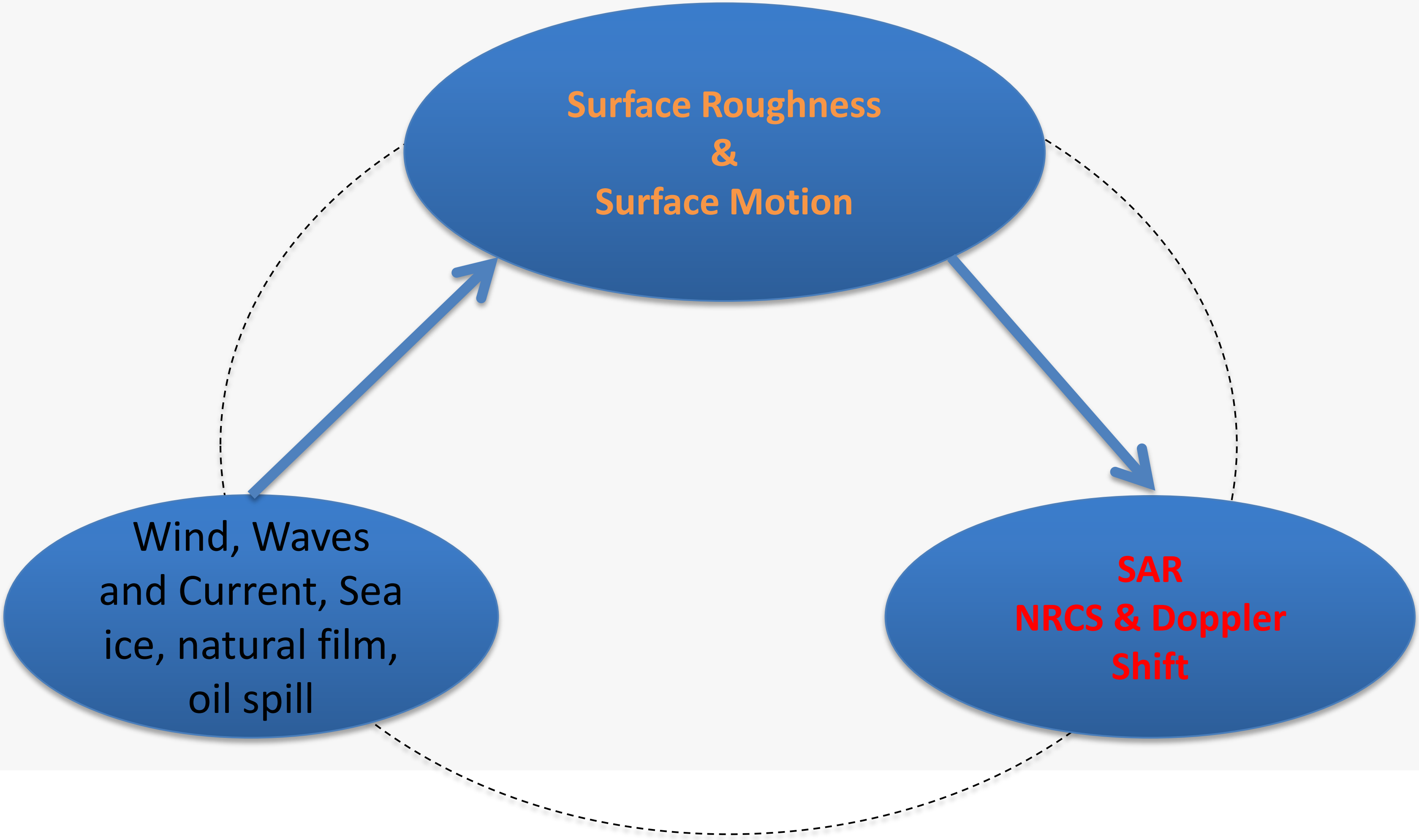
Surface Roughness and SAR backscatter

The ocean surface roughness is influenced by wind and waves, currents, surface slicks and sea ice and is often different in open ocean versus coastal or ice covered regions due to fetch effects

The surface roughness is the source for the backscatter of the SAR signal.

The signal that arrives at the antenna is registered both in *Amplitude and Phase*.

Surface Roughness and SAR backscatter

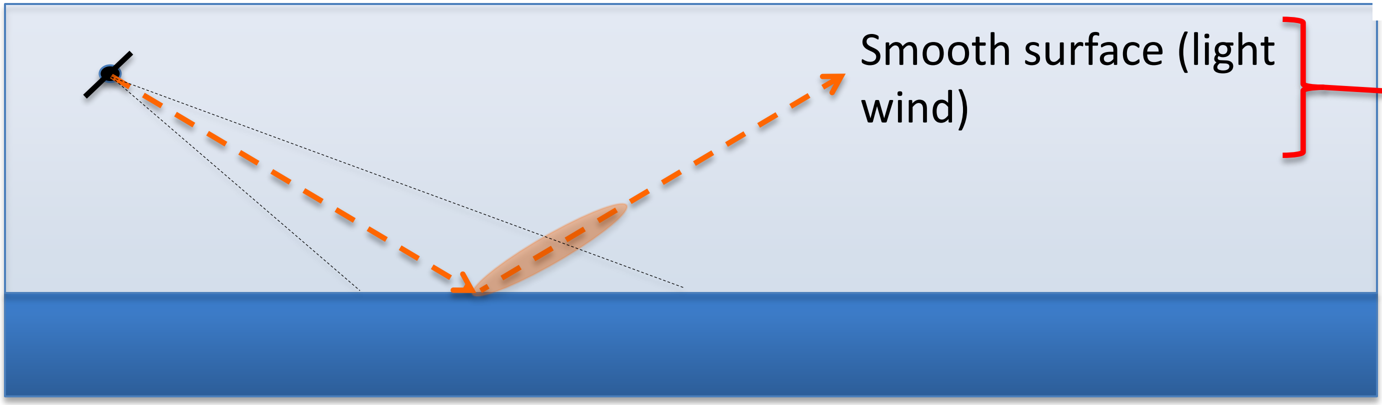


Surface Roughness
&
Surface Motion

Wind, Waves and Current, Sea ice, natural film, oil spill

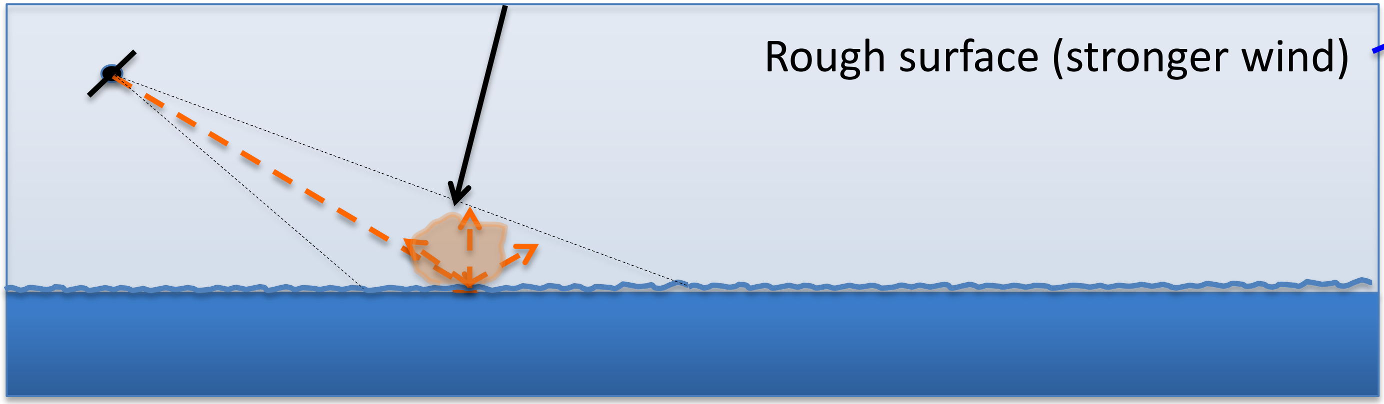
SAR
NRCS & Doppler Shift

Surface Roughness and SAR backscatter



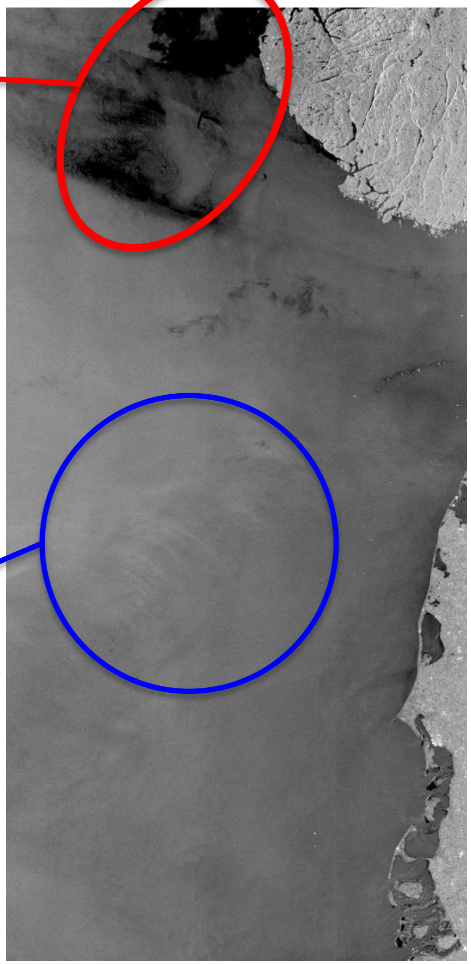
Smooth surface (light wind)

Enhanced backscatter



Rough surface (stronger wind)

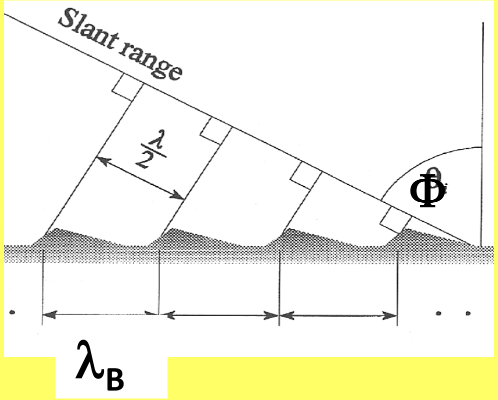
ASAR, 2.10.2011



Bragg Scattering

At oblique incidence angles, the SAR backscattering arising from the sea surface is caused by surface waves of the order of the radar wavelength.

These waves are called " Bragg waves". They obey the " Bragg resonance condition":



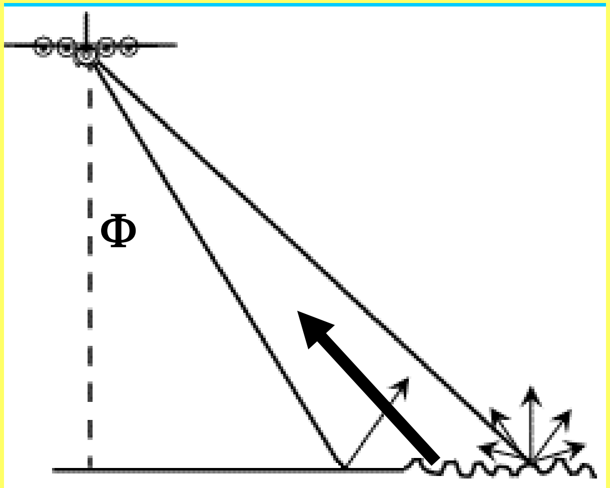
$$\lambda_B = \lambda_r / 2 \sin\Phi$$

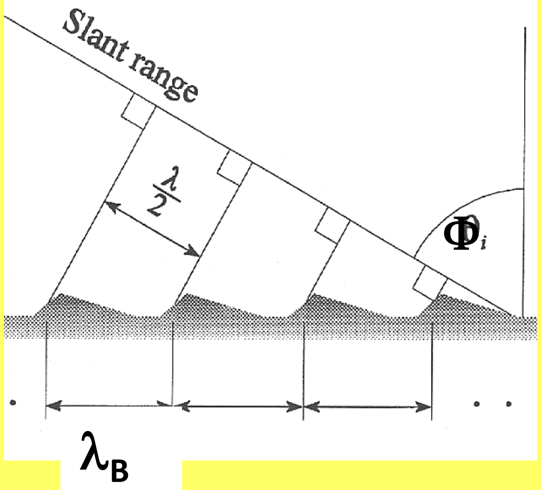
where λ_B = Bragg wavelength, λ_r = radar wavelength, and Φ= incidence angle

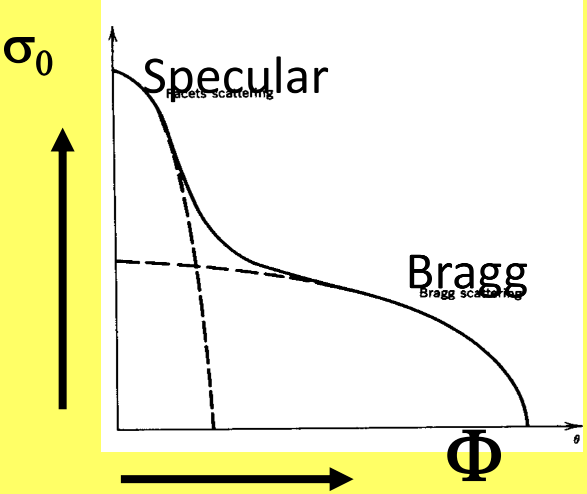
Bragg Scattering and Radar Cross-section

SYNTHETIC APERTURE RADAR

The radar backscatter is primarily determined by the Bragg scattering (*determined by the surface roughness*): $\lambda = 2\,\lambda_B \sin\Phi$ for incidence angles in the range of 20 to 50 degrees





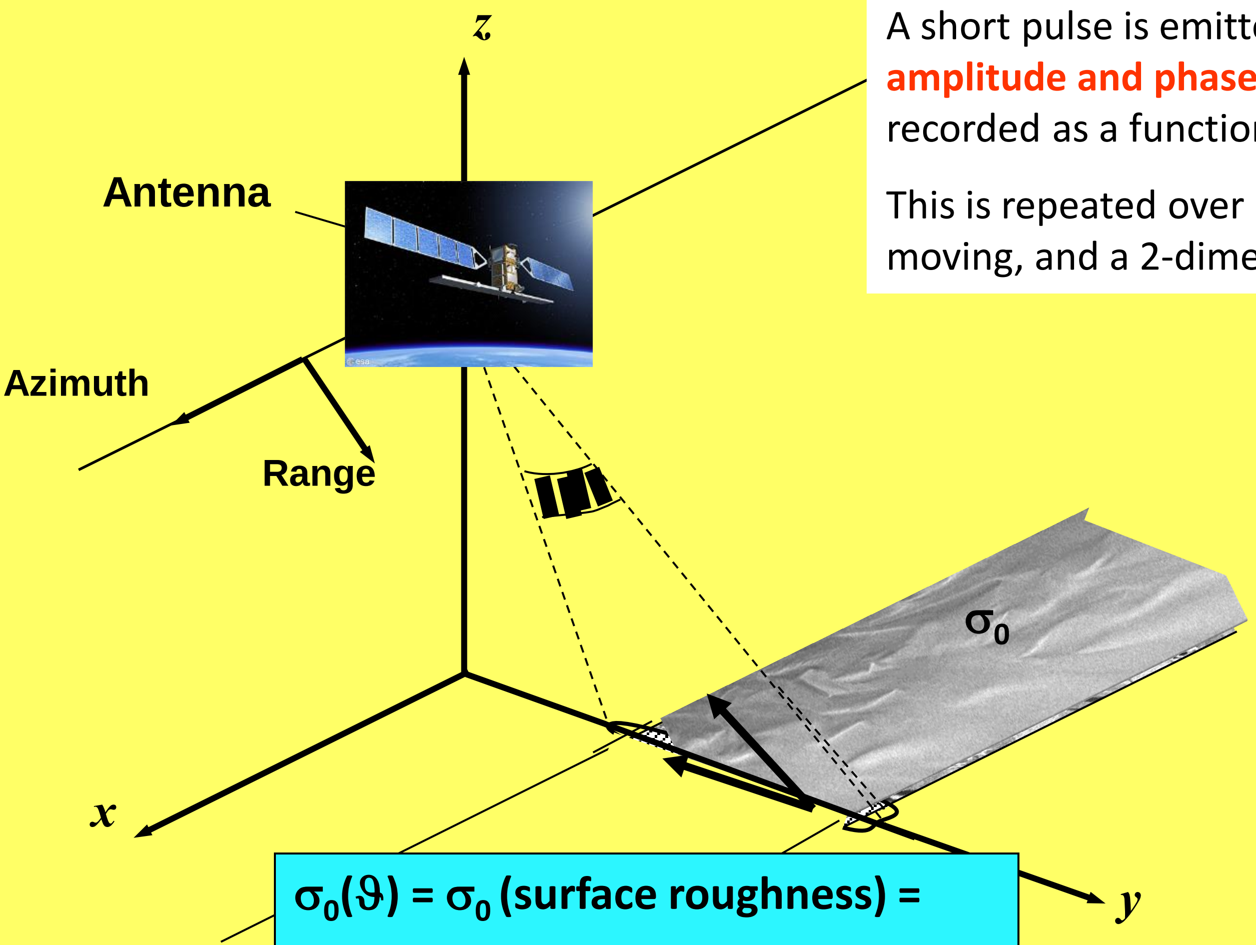


SAR is a transmitting-receiving instrument where

$$P_r = (P_t / 4\pi R^2)\ G\ (\sigma / 4\pi R^2)\ A$$

P (r=receive, t=transmit), R = range distance, G = antenna gain, σ = radar cross section, A = antenna area, $\sigma_0 = 10 \log_{10} (\sigma / A)$ is defined as radar backscatter (=function of surface roughness)

Image Formation of Surface Roughness



A short pulse is emitted by the antenna and then the **amplitude and phase** of the backscattered signal is recorded as a function of time.

This is repeated over again while the platform is moving, and a 2-dimensional image is thus generated.

$\sigma_0(\vartheta) = \sigma_0$ (surface roughness) =

σ_0(wind, waves, breaking, current)

Spatial Resolution

The SAR spatial resolution is independent of the platform height. This is remarkable and unique for SAR instruments.

In range $X_r = c\,\tau/2\sin\Phi$ (where c: speed of light, τ: pulse length, Φ:incidence angle)

In azimuth $X_a = D/2$ (D = antenna length)

A *frequency modulation - chirp* of the pulse in used in range. In azimuth a *synthetic aperture principle* is used whereby the motion of the platform induces a frequency modulation. In result a very long antenna is synthesized by the motion of the platform. For ASAR the length of the synthetic antenna is around 20 km!

Consequently, in both directions, the signals are frequency modulated. This modulation is sensed in the Doppler shift.

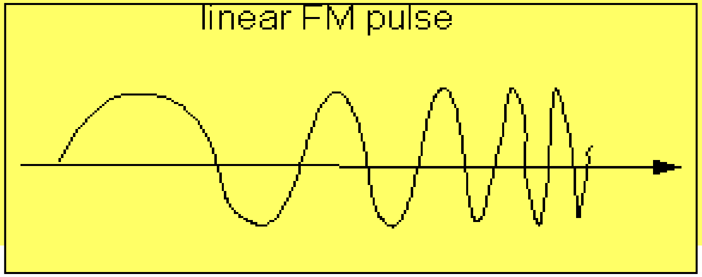
Range Resolution

Increase of the range resolution

We have noticed already that the range resolution $X_r = c\ \tau/2\ \sin\theta$ of a RAR or SAR is independent of the platform height.

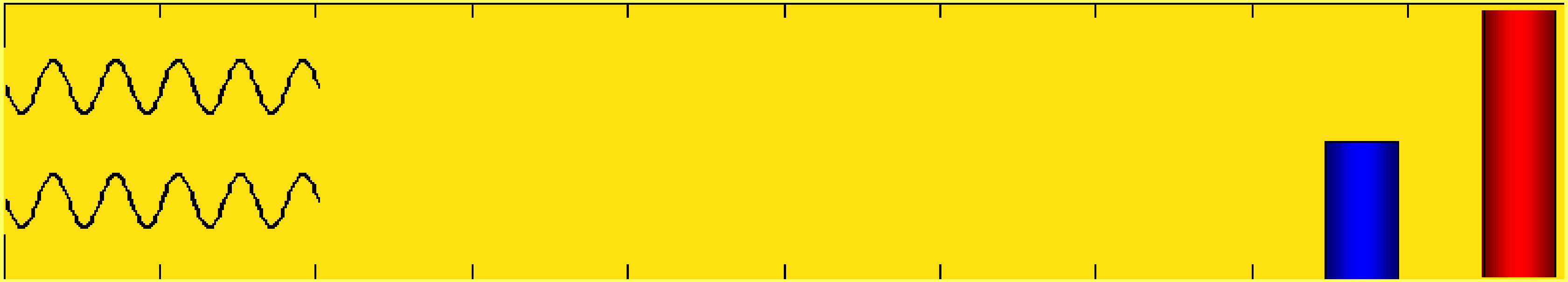
However, it is technically not possible to generate a radar pulse that has a length of only a few meters.

Radar engineers use a long pulse with a (linearly) modulated frequency - called a Chirp. With this technique it is possible to increase the range resolution



Range Resolution

Pulse is not frequency modulated



| L = cτ |

Target 1 Target 2

L/2

L=pulse length

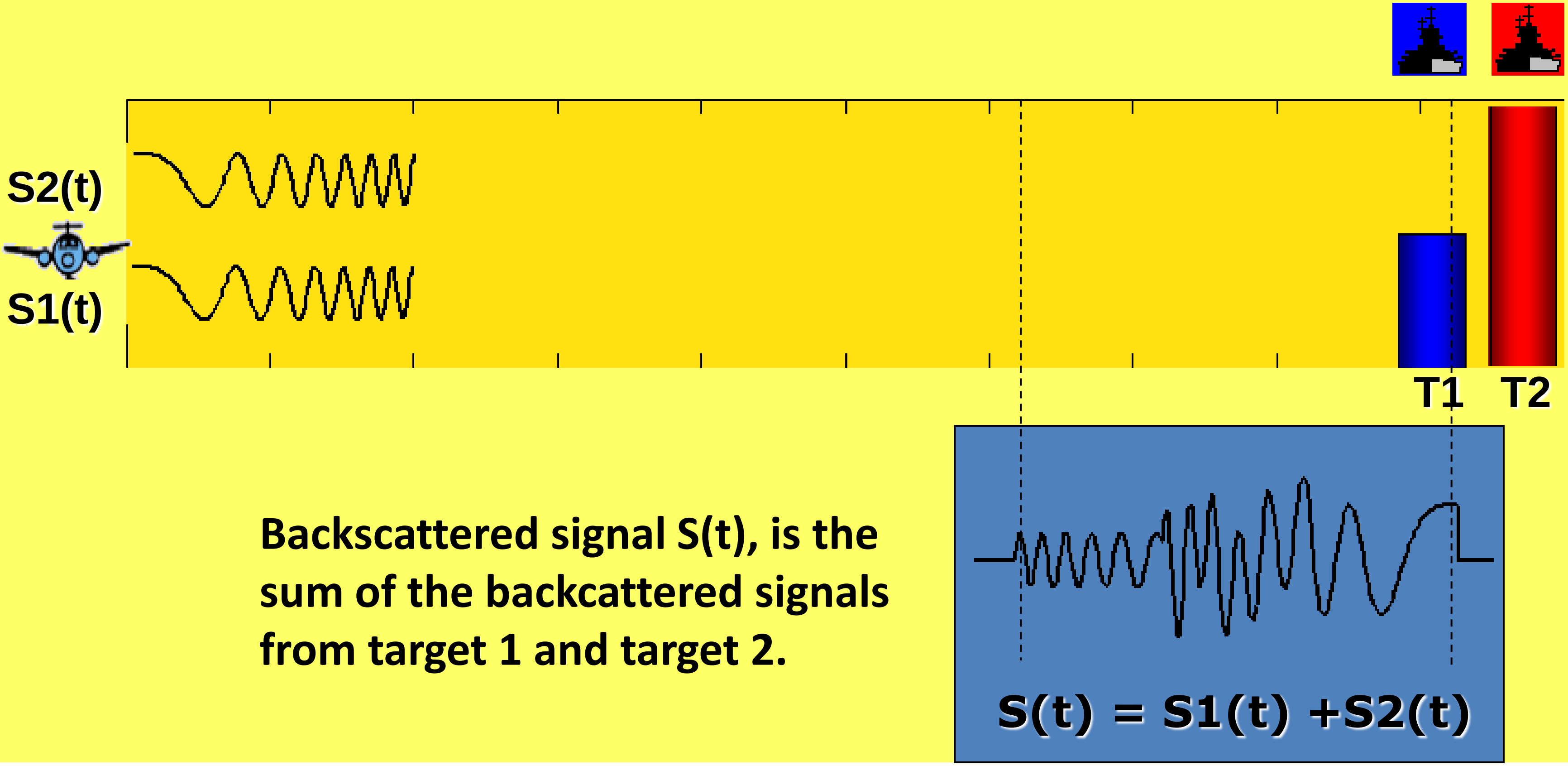
L/2 = separation of the targets

The two targets separated by L/2 can only be resolved when the pulse length cτ is equal to or smaller smaller than L/2.

Range resolution: $X_r = c\tau/2\sin\theta$

Range Resolution

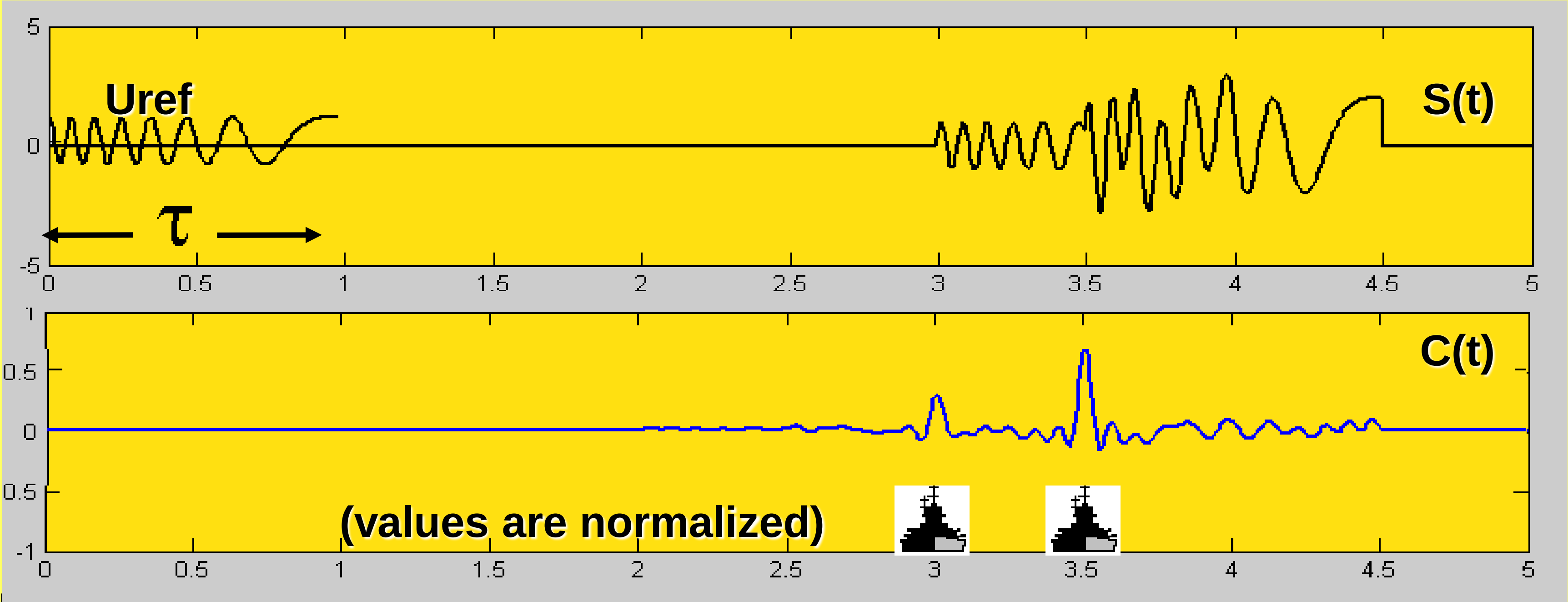
Improvement of the range resolution by using a frequency modulated pulse



Backscattered signal S(t), is the sum of the backscattered signals from target 1 and target 2.

Range Resolution

Improvement of the range resolution by using a frequency modulated pulse



The positions of the two targets show up in the correlation function c(t) as two separate peaks. The minimum distance of these peaks is given by $X_r = c\tau/2$

Range Resolution

A frequency modulated pulse can resolve targets which are separated by less than L/2.

This is achieved by cross-correlating the backscatterd pulse s(t) = s_1(t) + s_2(t) with a reference signal u_{ref} (t), which is the complex conjugate of the emitted signal:

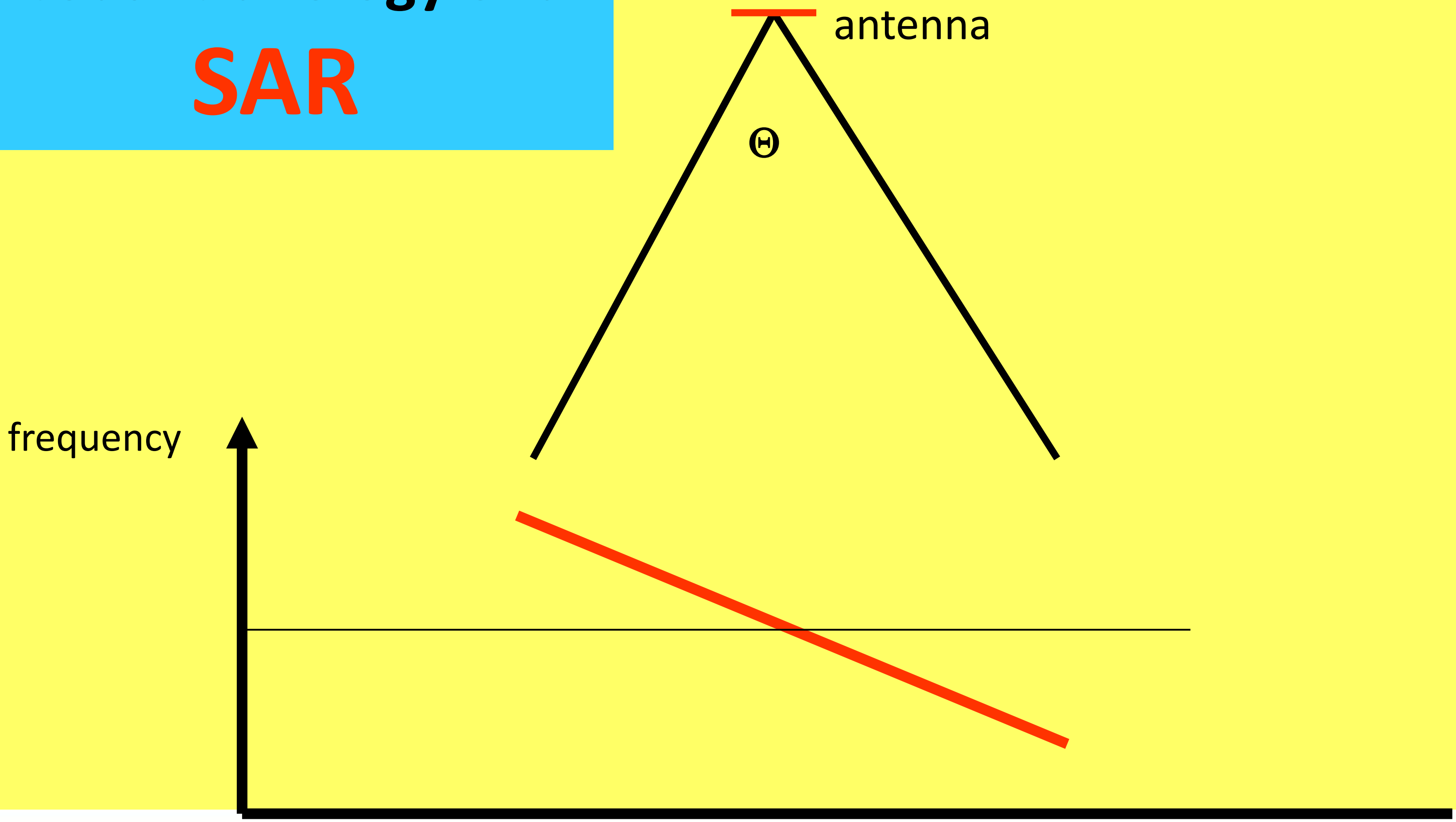
$$c(t) = \int_{-\infty}^{+\infty} s(t + t') \cdot u_{ref}(t') \, dt'$$

Azimuth Resolution

Deriving fine azimuth resolution (courtesy of Prof. Werner Alpers)

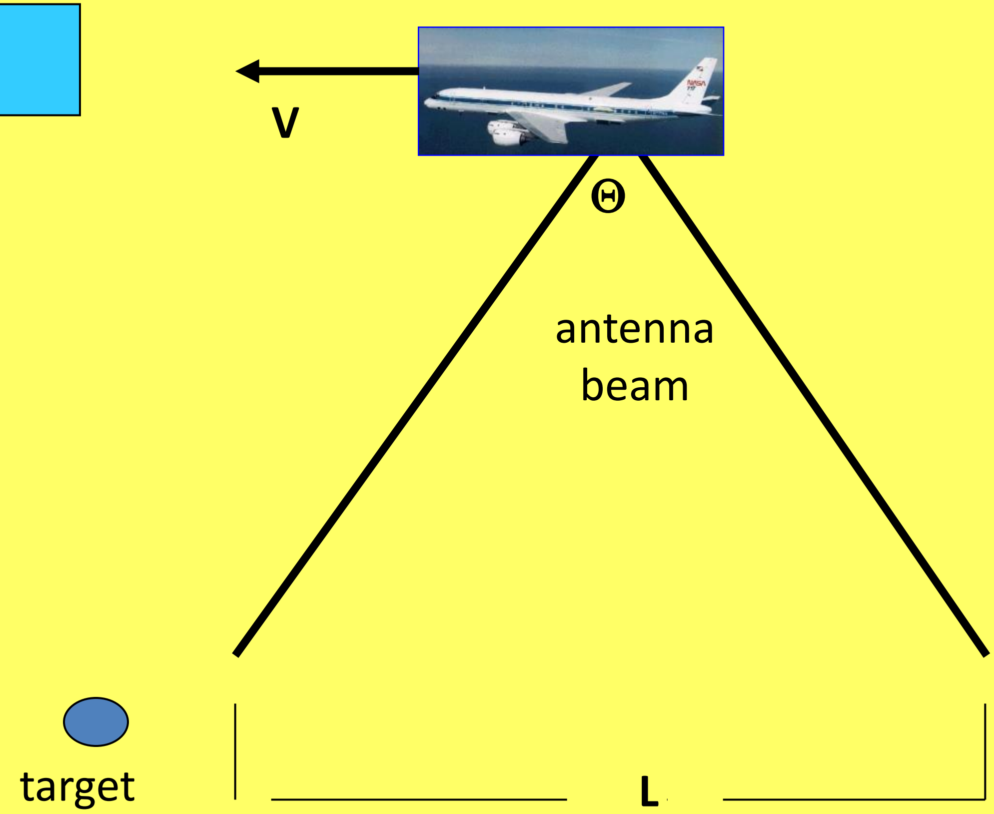
Acoustic anology of a

SAR



Azimuth Resolution

Synthetic aperture radar



V = platform velocity

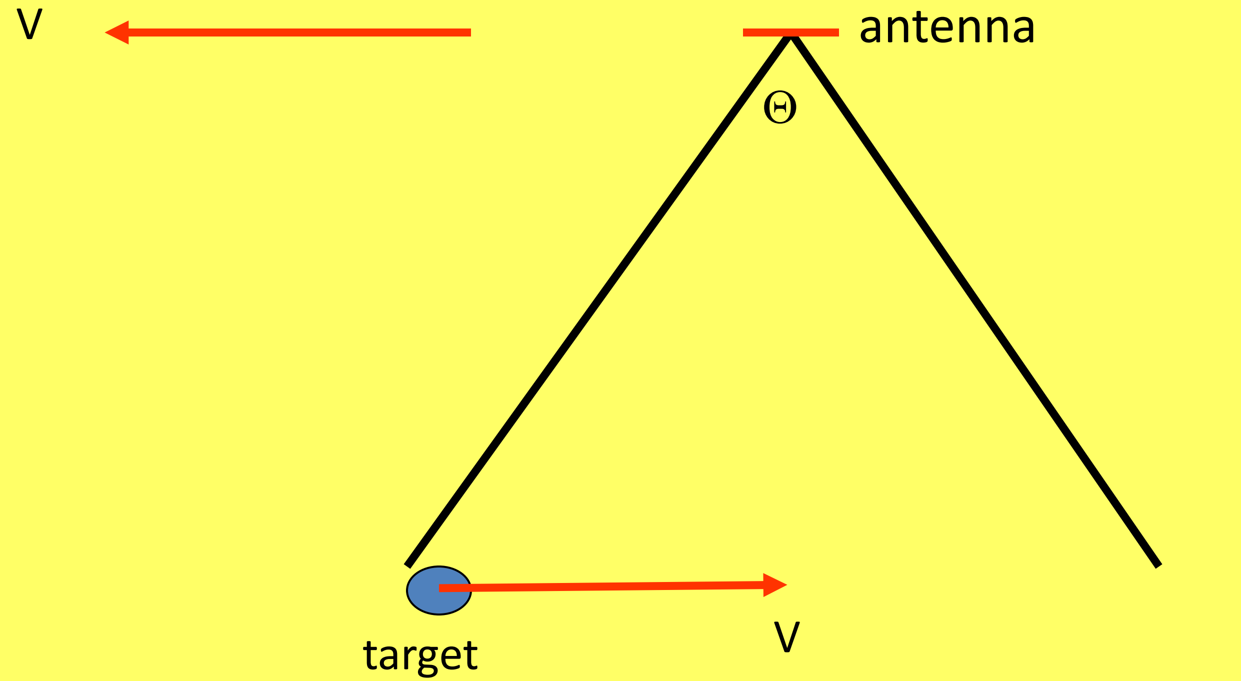
T = integration time

L = length of the synthetic antenna

The target is for T seconds (T = L/V) in the antenna beam

Azimuth Resolution

Synthetic aperture radar principle (more after Alpers)

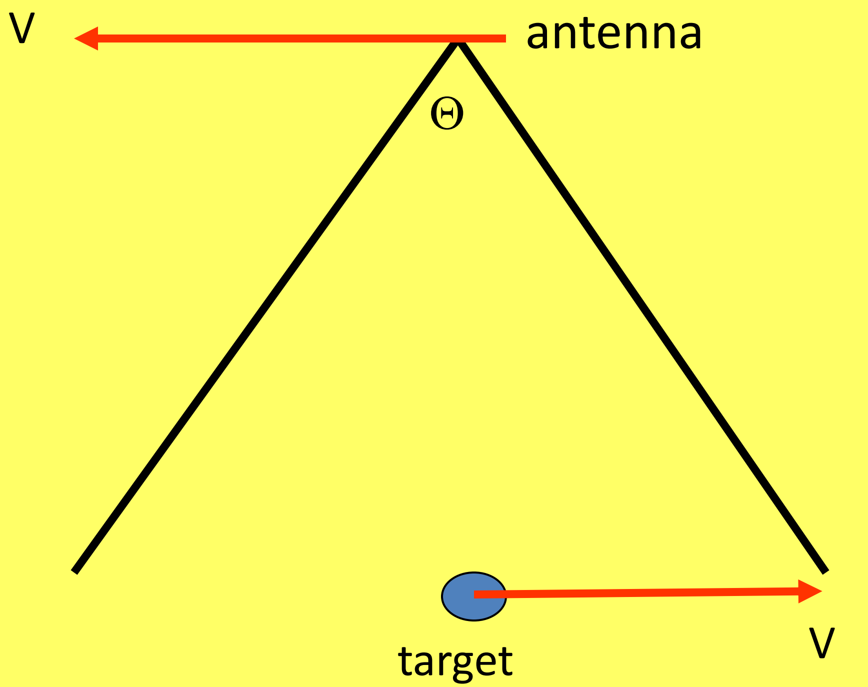


$\mathbf{f_d = + V\theta / \lambda}$

f_d = Doppler shift

Azimuth Resolution

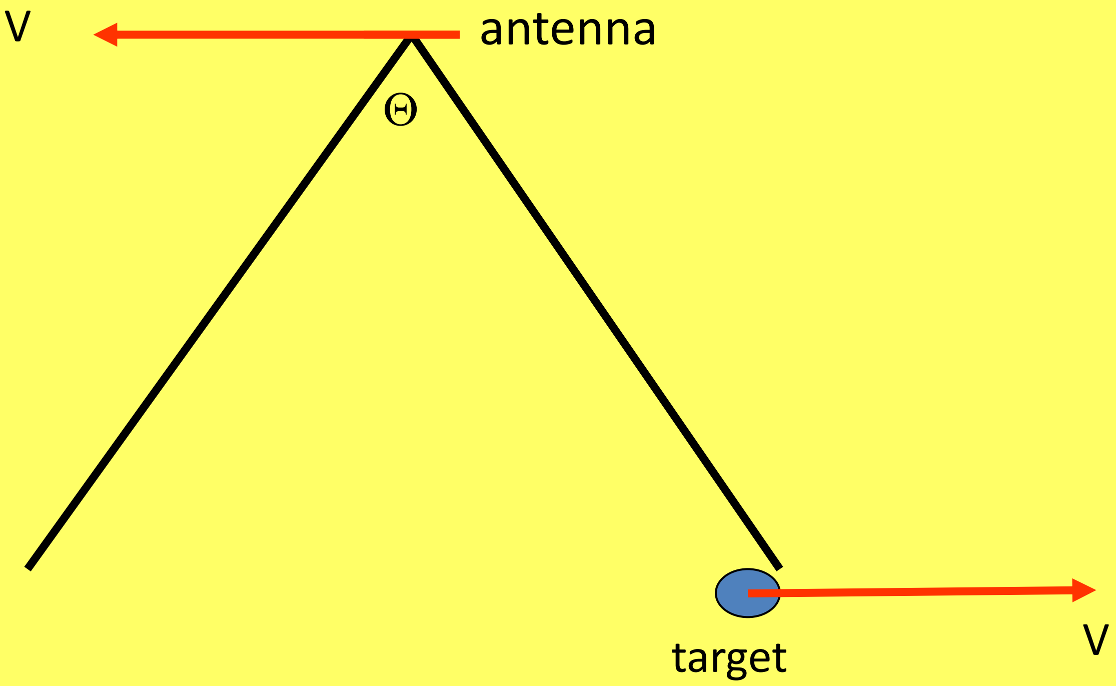
Synthetic aperture radar principle - 2



$\boxed{f_d = 0}$

Azimuth Resolution

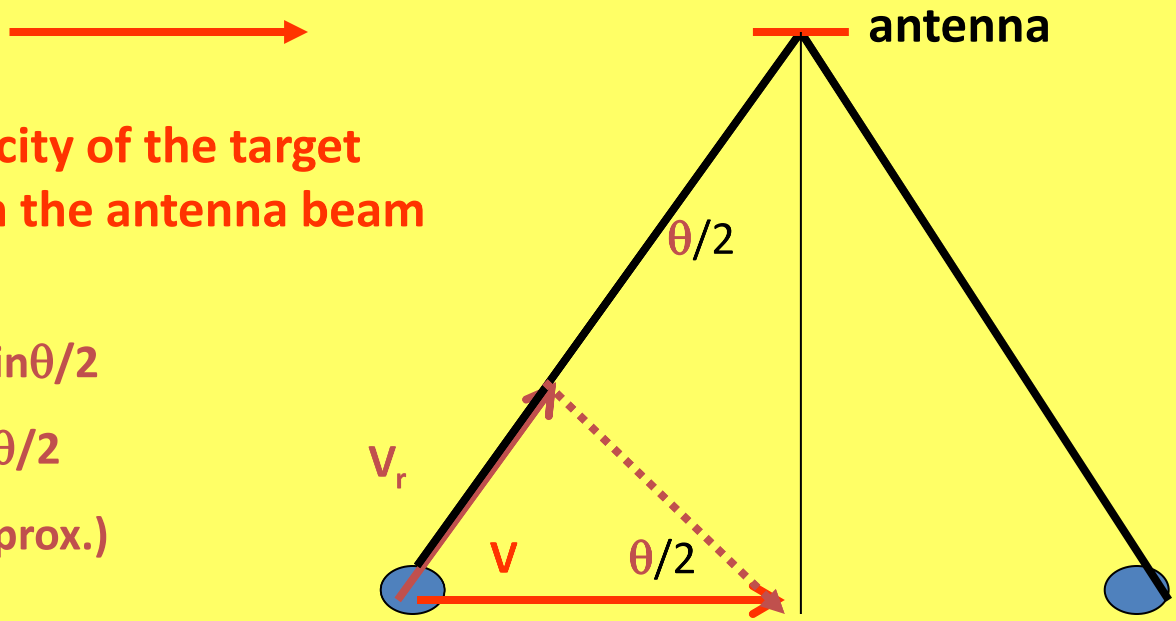
Synthetic aperture radar principle - 3



$f_d = - V\theta / \lambda$

Azimuth Resolution

Change of the Doppler shift f_d across the aperture



V= velocity of the target through the antenna beam

$V_r = V\sin\theta/2$

$= V\,\theta/2$

(approx.)

$f_d = +2V_r/\lambda$ (= $(2V_r/c)\,f$) $= +V\theta/\lambda$

Change of Doppler shift across the aperture = $f_d - (-f_d) = 2f_d = 4V_r/\lambda = 2V\theta/\lambda$

$2f_d$ = B is called the Azimuthal Bandwidth of the SAR

Azimuth Resolution

Application of the general rule in signal processing that, if an electrical system has a bandwidth B, then it can resolve a signal that has a time length of $\Delta t=1/B$, **to SAR:**

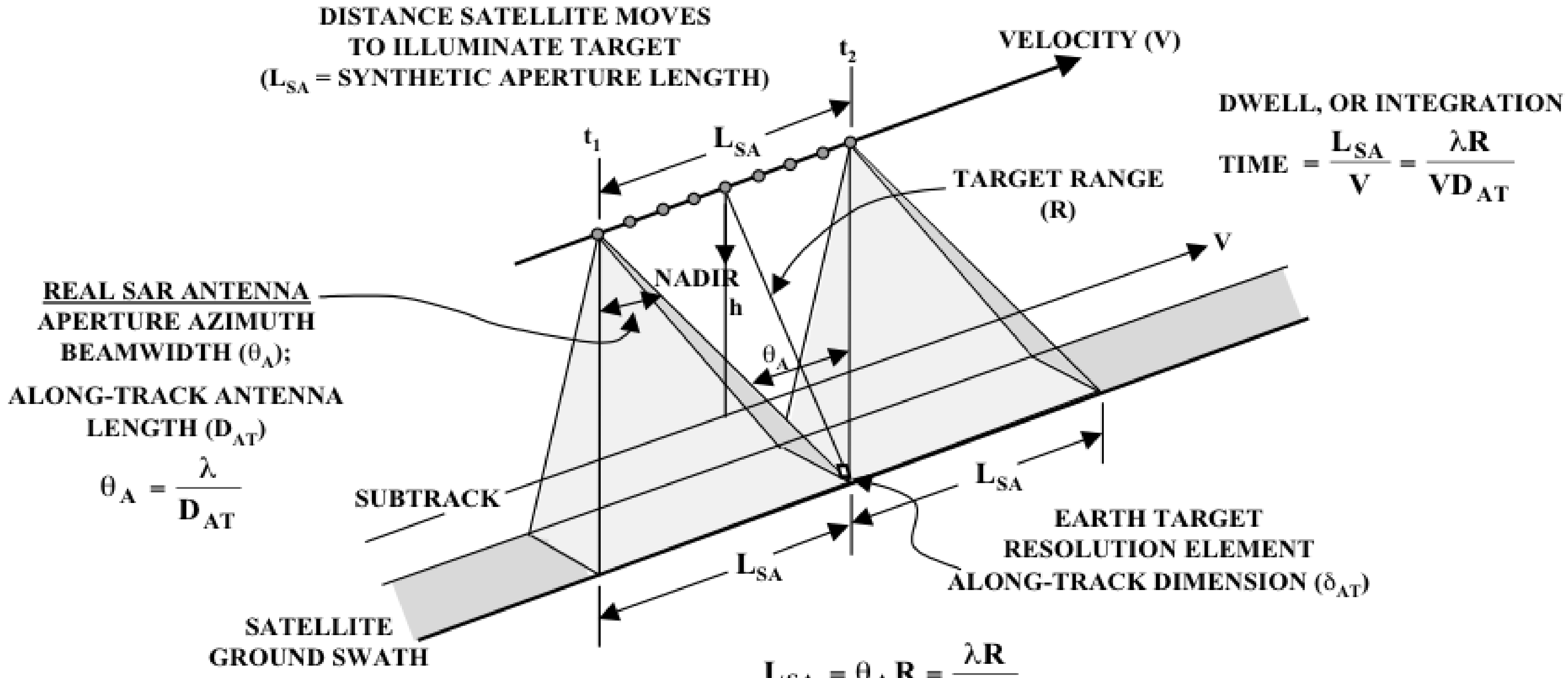
The time interval that can be resolved is

$$\Delta t=1/B=1/2f_d=\lambda/2V\theta=D/2V \text{ (because of } \theta=\lambda/D\text{).}$$

The spatial interval in flight direction that can be resolved =azimuthal resolution = $X_a = V\Delta t = D/2$.

Thus, the unique azimuthal resolution of a SAR is independent of range R and is proportional to the antenna length D

Schematic Summary of the SAR Image azimuth resolution



DWELL, OR INTEGRATION

$$\text{TIME} = \frac{L_{SA}}{V} = \frac{\lambda R}{V D_{AT}}$$

$$\theta_A = \frac{\lambda}{D_{AT}}$$

$$L_{SA} = \theta_A R = \frac{\lambda R}{D_{AT}}$$

$$\delta_{AT} = \frac{\lambda}{2L_{SA}} R = \frac{\lambda R}{\frac{2\lambda R}{D_{AT}}} = \frac{D_{AT}}{2}$$

Processing

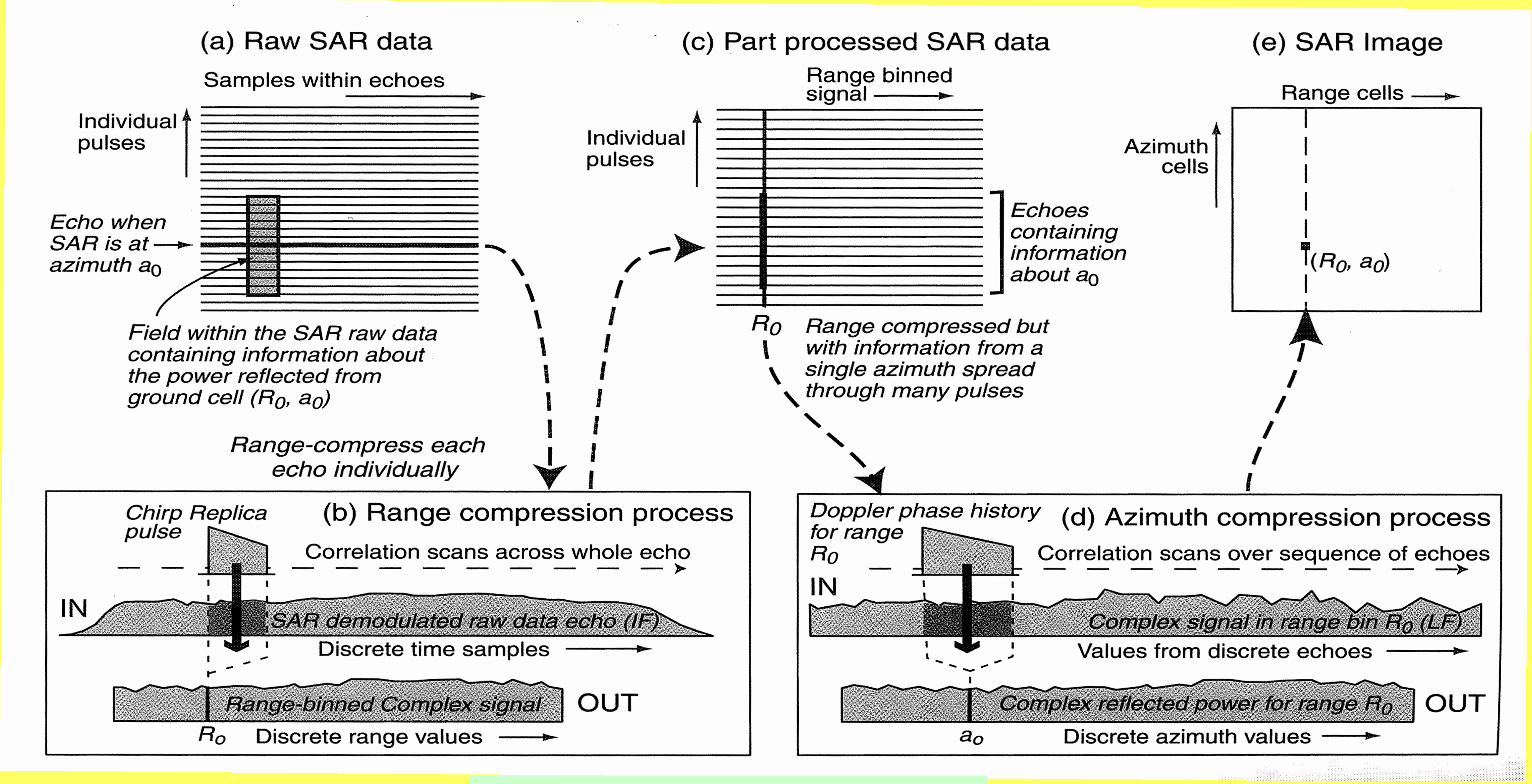
In the SAR processor these frequency modulated signals are used to improve the resolutions in range X_r and azimuth X_a. This is called range compression and azimuth compression, respectively.

$X_a = D/2$ $\qquad$ $X_r = c\,\tau/2\sin\Phi = c/2B\sin\Phi$

Therefore the SAR processor consists essentially of 2 correlators, one for range and one for azimuth.

Processing

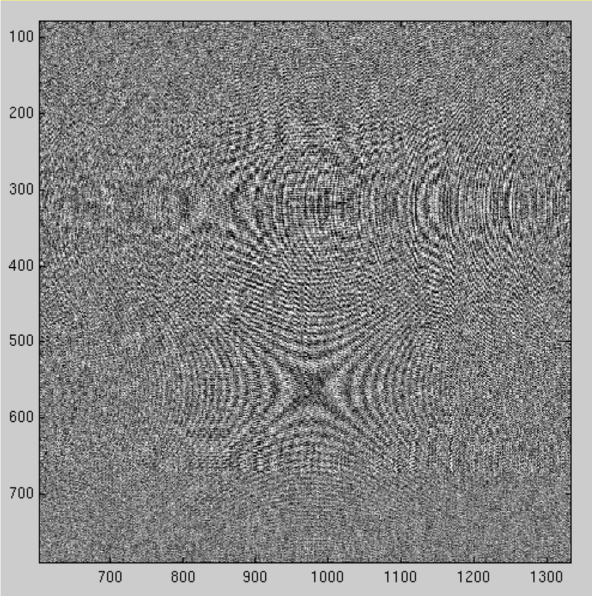
STAGES IN SAR IMAGE COMPRESSION



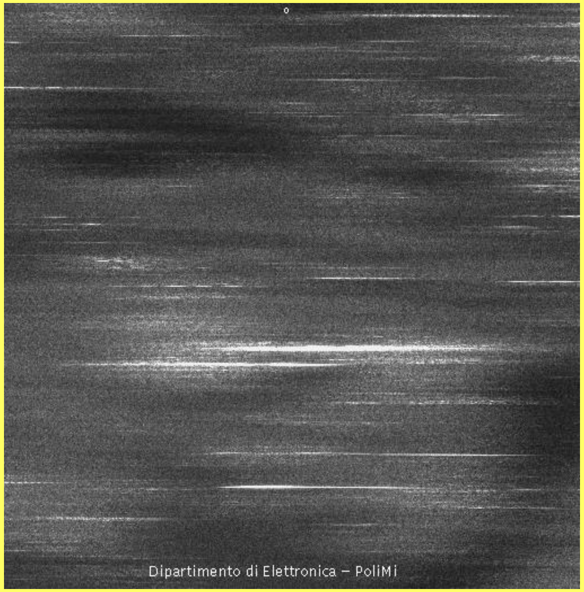
(after Robinson, 2004)

Processing

Raw SAR data

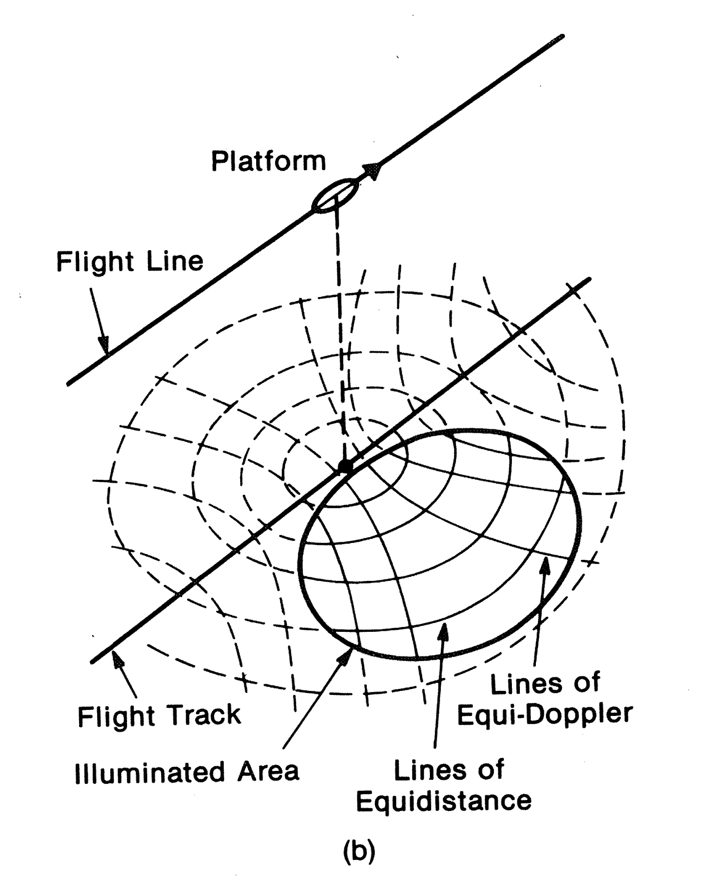


Range compressed data



Range + azimuth compressed data
= SAR image

SAR imaging coordinate system



The illuminated area can be referenced to a coordinate system of concentric circles (equidistances) and coaxial hyperbolas (equi-Doppler). Each point in the image plane can be uniquely identified by its time delay and Doppler shift.

Speckle Noise and Removal

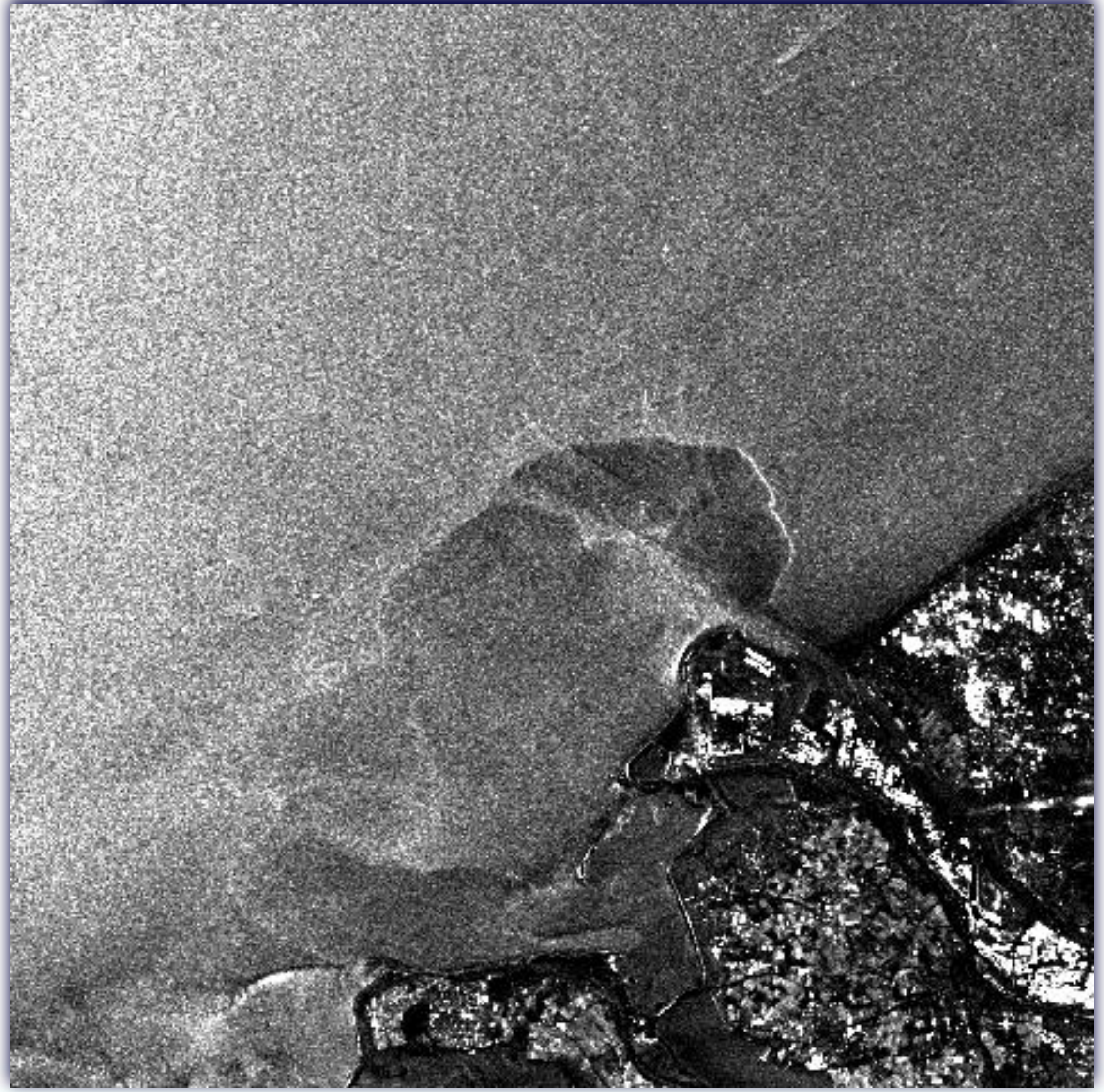
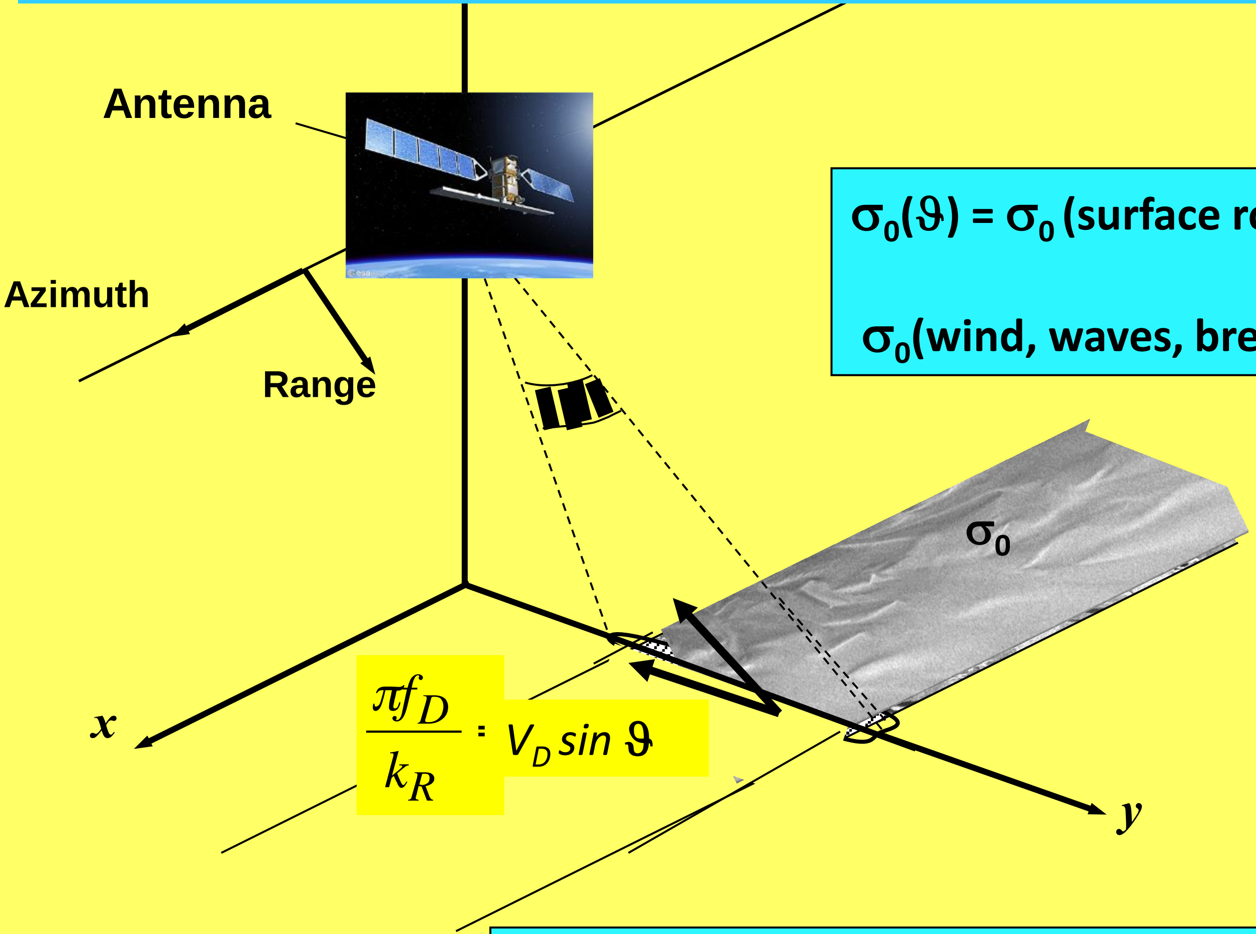


Image Formation and Doppler anomalies

APPROACH: SAR Imaging of Roughness and Doppler Shift



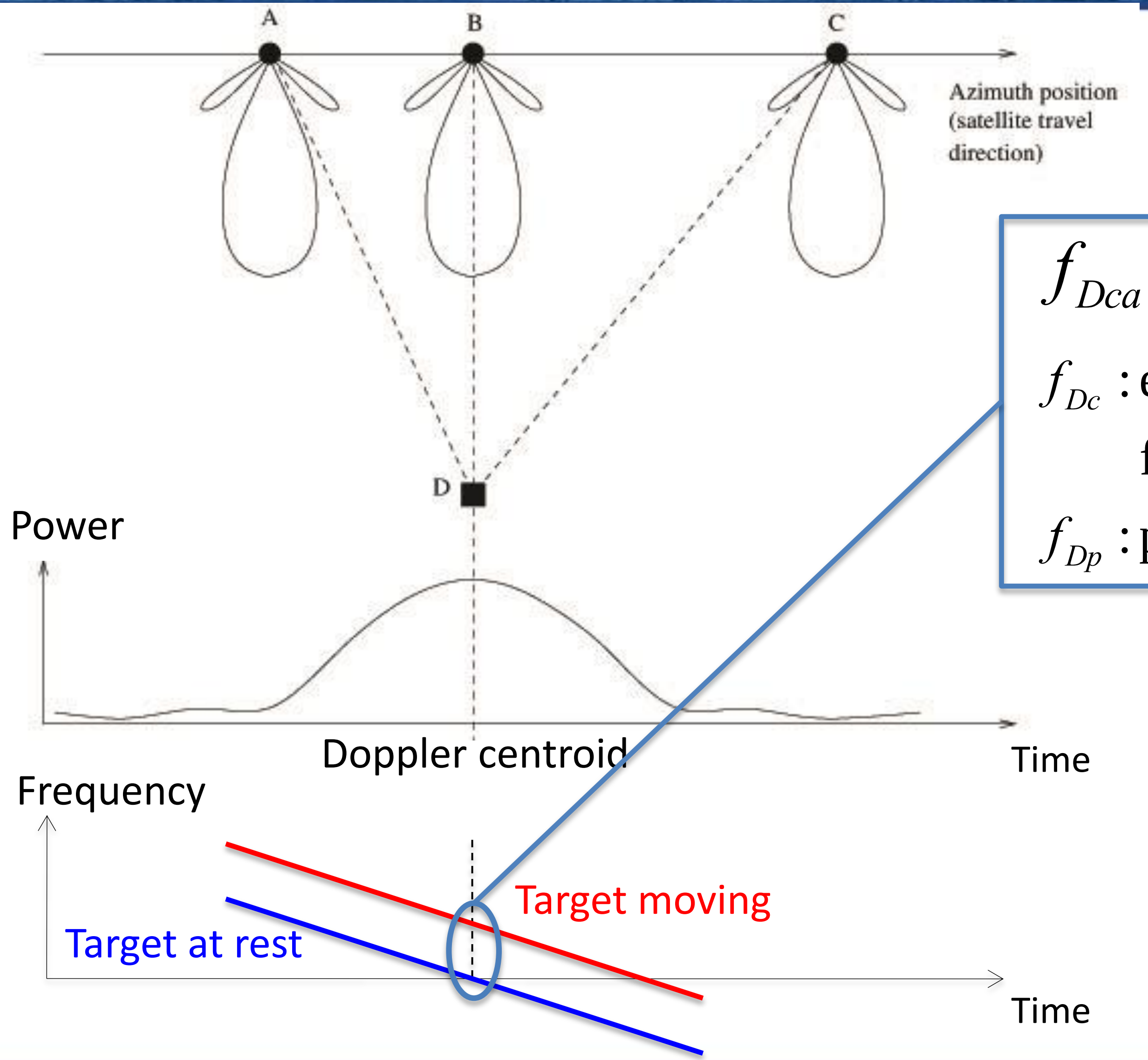
$\frac{\pi f_D}{k_R} : V_D \sin \vartheta$

$\sigma_0(\vartheta)$ = σ_0 (surface roughness) =

σ_0(wind, waves, breaking, current

V_D = V_D (wind driven scatterer, waves, breaking, current)

Doppler Centroid Anomaly

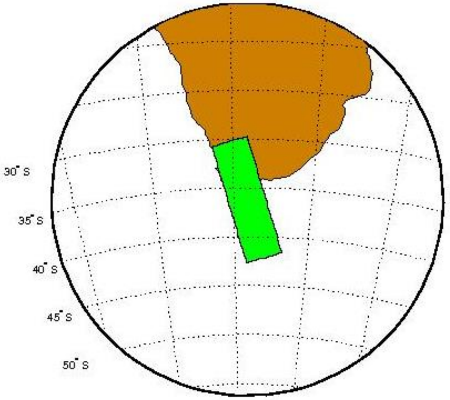


$$f_{Dca} = f_{Dc} - f_{Dp}$$

f_{Dc} : estimated Doppler centroid frequency shift

f_{Dp} : predicted Doppler shift

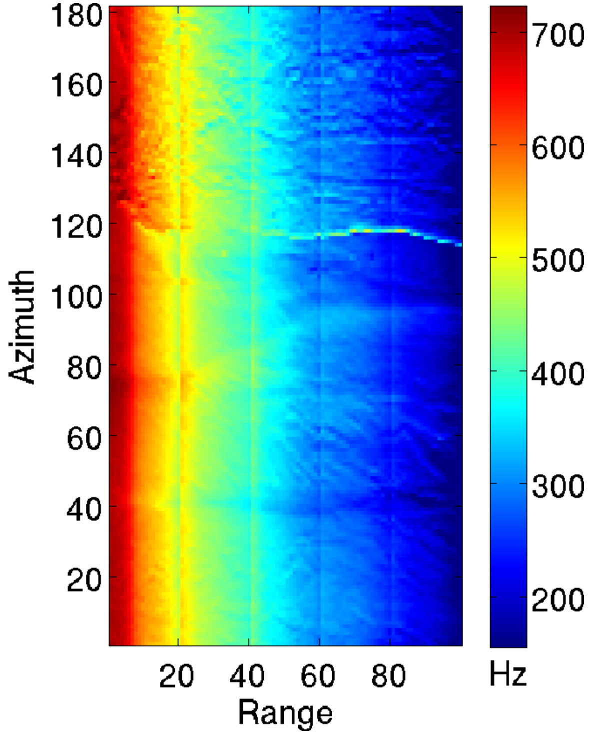
Chapron et al. (2003, 2005)



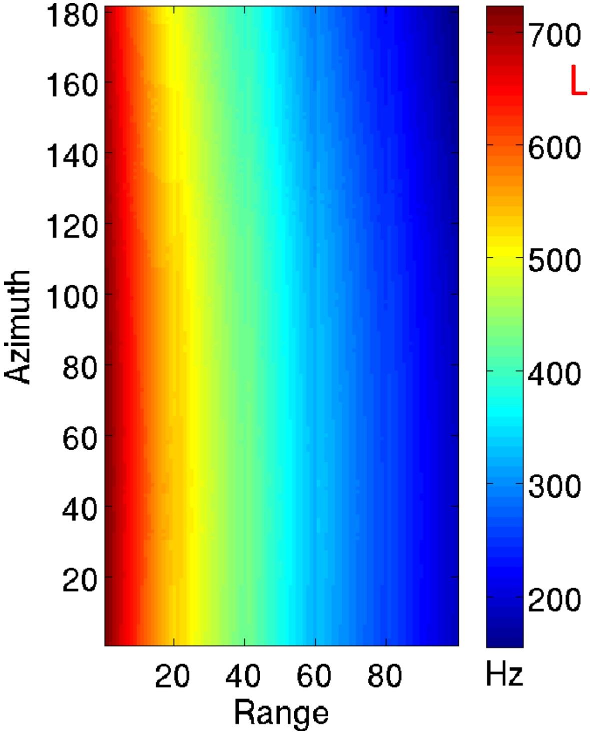
Doppler Processing

Envisat ASAR scene off the South African coast
14 September 2010, 21:15 UTC

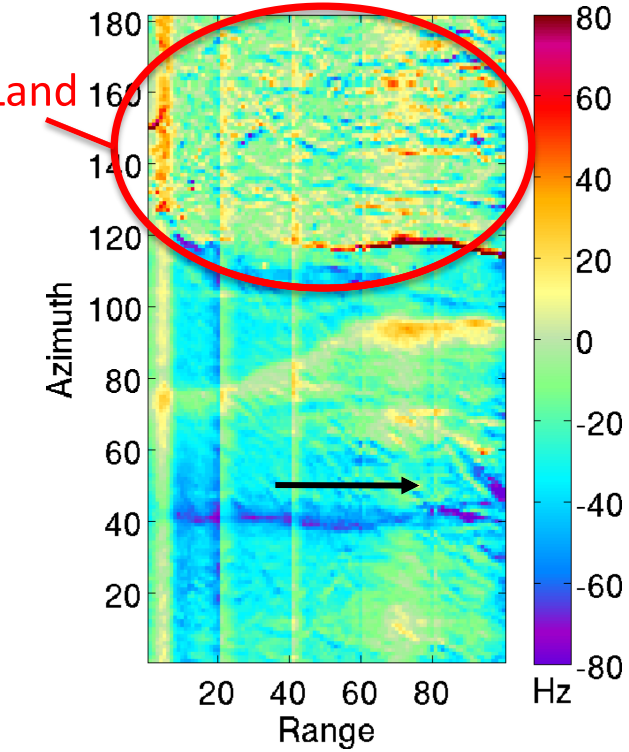
Observed



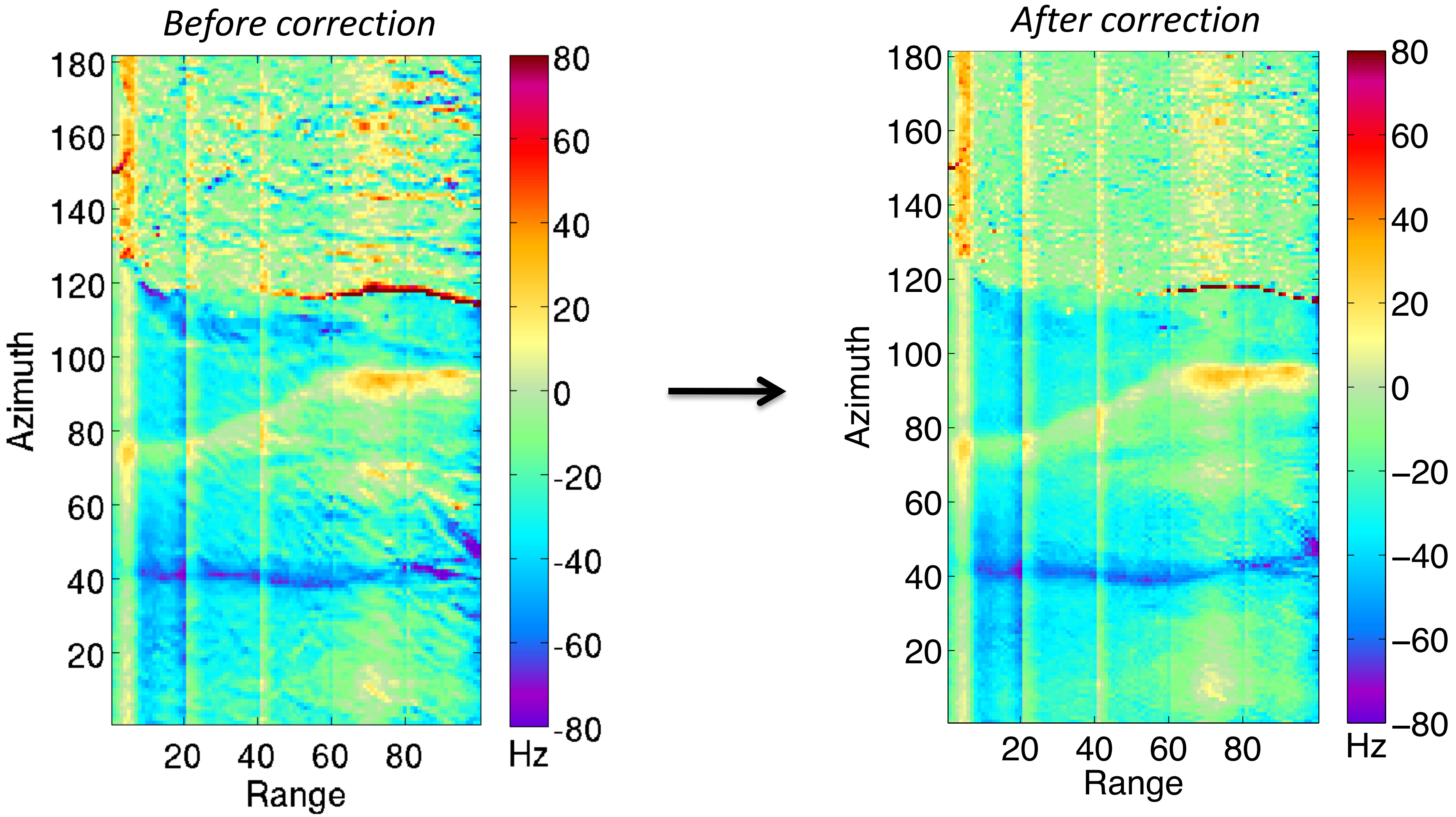
Predicted



Doppler centroid anomaly



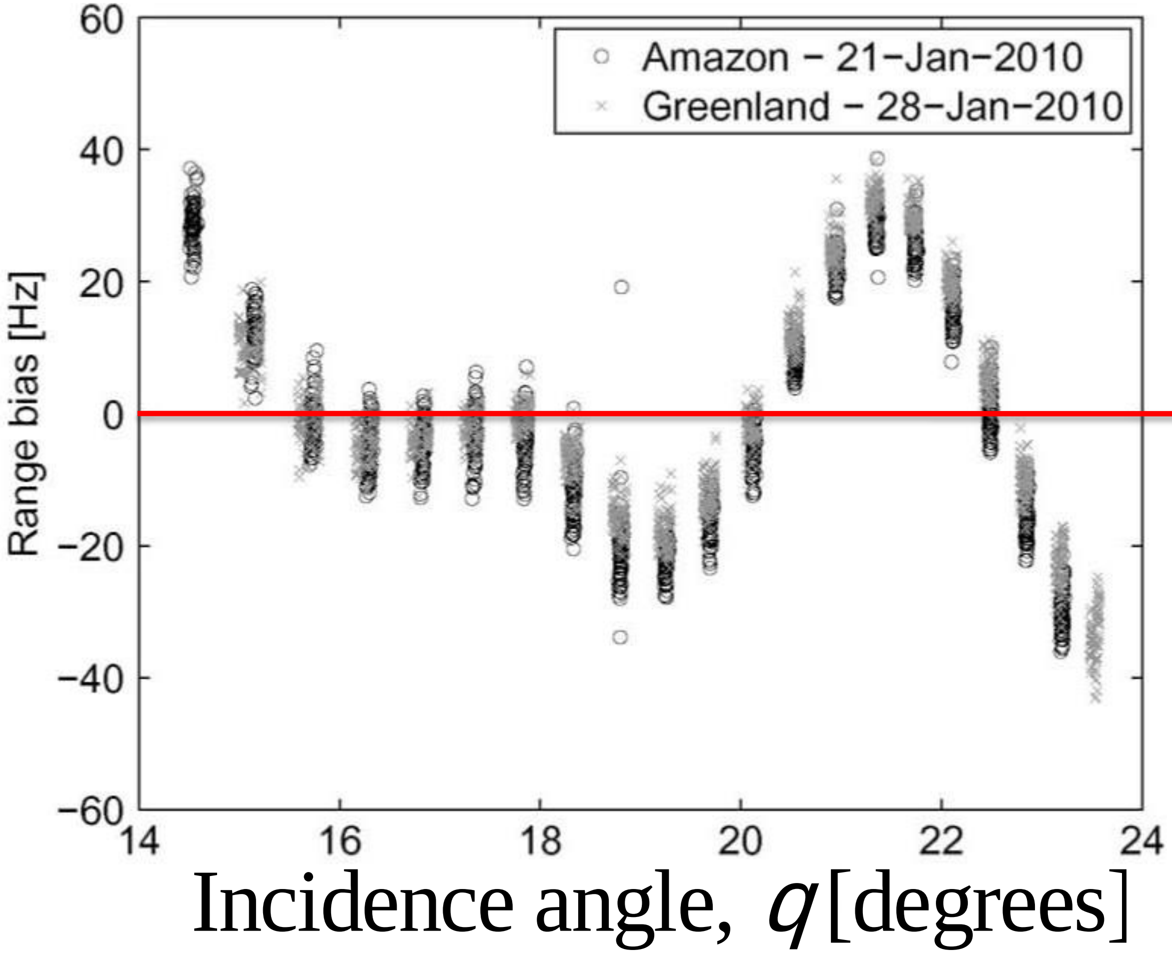
Azimuth Bias Correction



Before correction

After correction

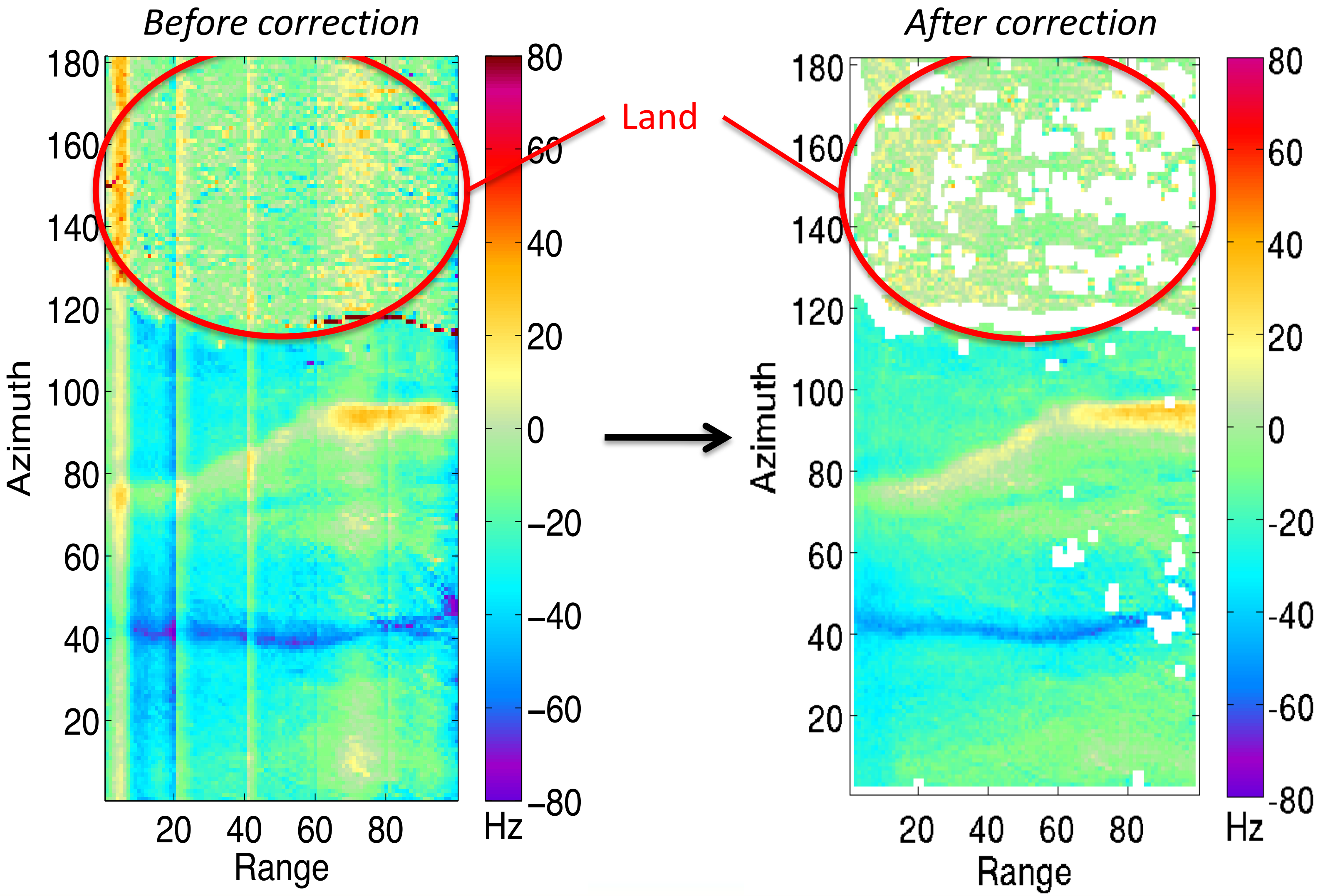
Range Bias Correction



Measurements over land, where the Doppler shift should be zero

Ideal antenna pointing

Range Bias Correction


Before correction

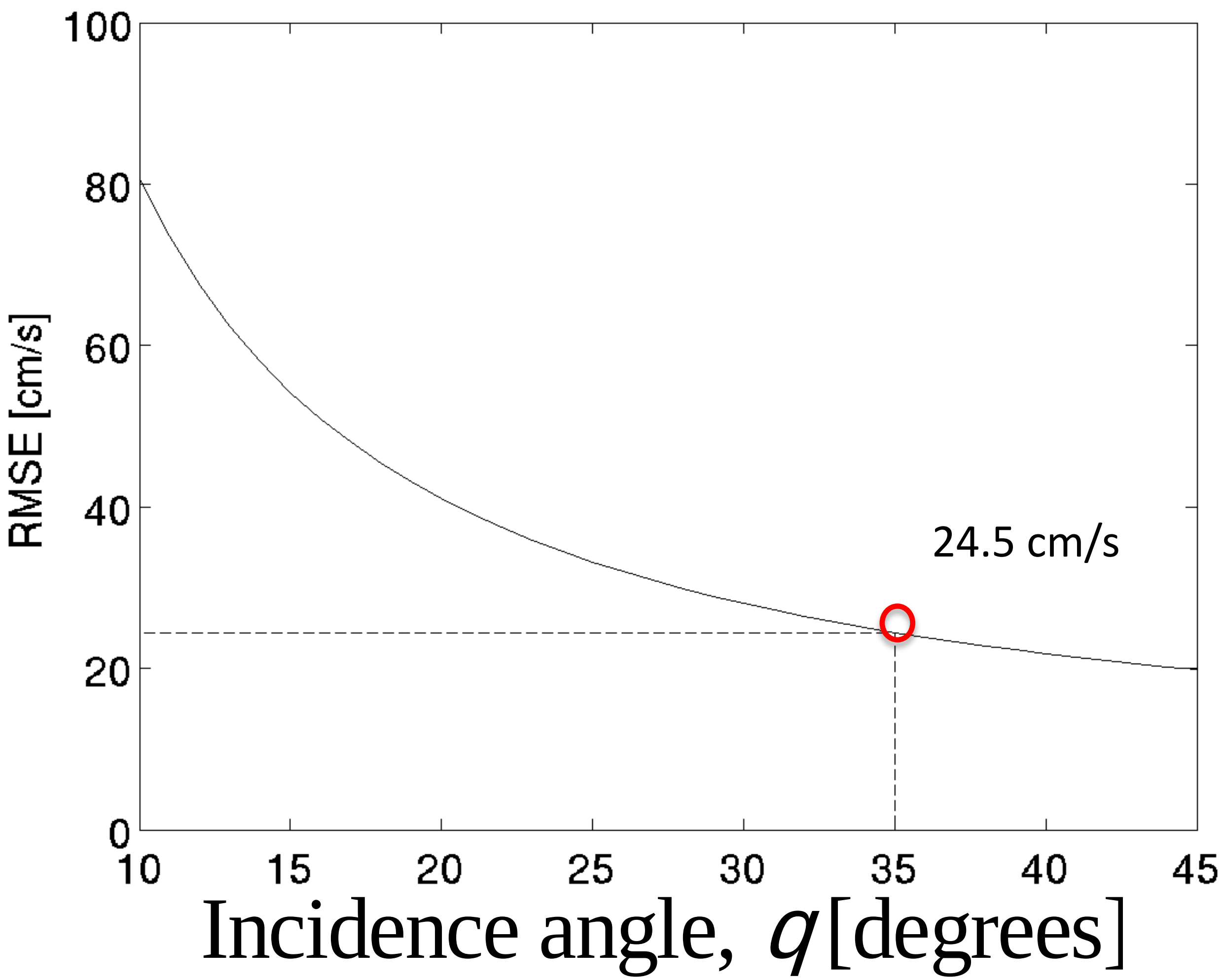
After correction

Land

Retrieval Accuracy

$$\Delta f = 5\ \mathrm{Hz}$$

$$\Delta V = \left| \frac{\pi \Delta f}{k_r \sin\theta} \right|$$



SAR backscatter and Doppler shift anomaly

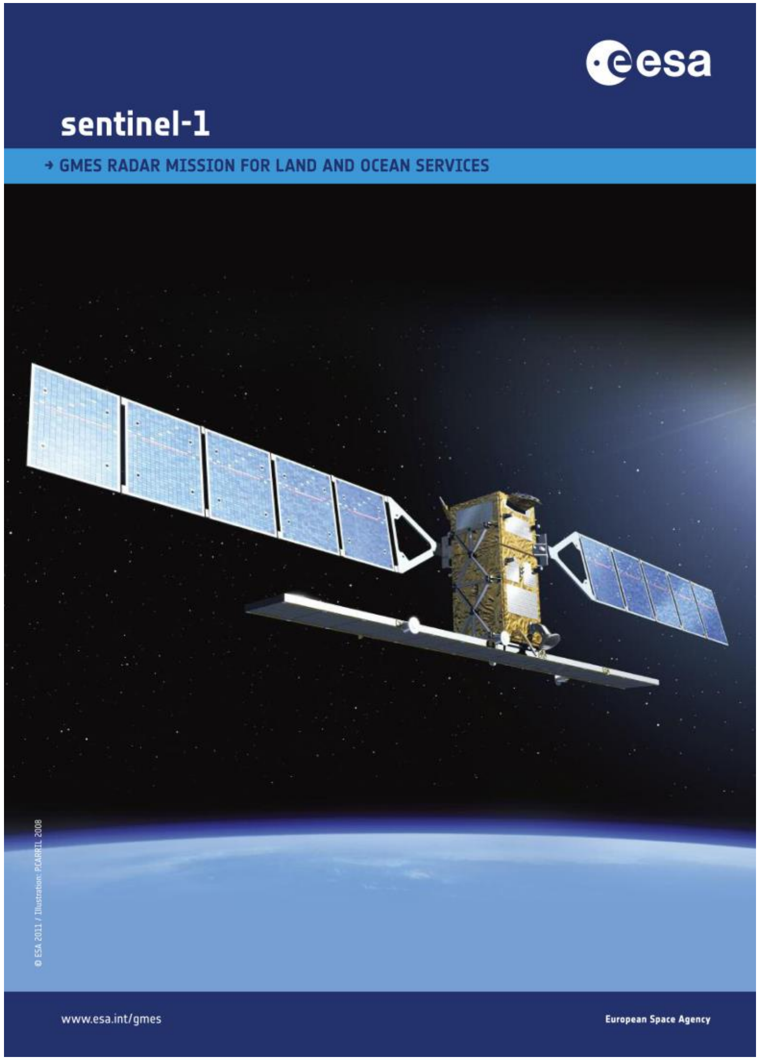
The ocean surface roughness is the sources of the SAR backscatter.

The SAR therefore sense the near surface wind and waves, currents, surface slicks and sea ice.

The SAR is also registering the Doppler centroid anomaly.

The challenge is to convert and partition the SAR backscatter signal and Doppler centroid anomaly reliable estimate of wind, waves and current.

Outlook



sentinel-1

→ GMES RADAR MISSION FOR LAND AND OCEAN SERVICES

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European Space Agency

- Sentinel-1A will be launched in early 2014
- The range Doppler shift is planned to become a standard product, with
  - Significantly better accuracies
  - Improved capability to monitor the temporal and spatial variability of the ocean surface circulation from SAR