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Introduction to Imaging Radar INF-GEO 4310

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Outline

- Introduction
- Radar waveforms
- Range Doppler Imaging
- ISAR – Inverse Synthetic Aperture Imaging
- Spotlight SAR – Synthetic Aperture Radar
- Stripmap SAR
- Interferometric SAR
- GPR – Ground Penetration Radar
- Example of SAR systems

RADAR = RAdio Detection And Ranging

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1886	Heinrich Hertz confirmed radio wave propagation
1904	Hülsmeyer patented ship collision-avoidance system
1922	Ship detection methods at NRL (Taylor & Young, 700MHz)
1930s	England and Germany radar programs developed:
	Chain Home early warning system (22-50 MHz)
	fire control systems
	aircraft navigation systems
	cavity magnetron to transmit high-power microwaves
1940s	Establishment of MIT Rad Lab (British + American) radar for tracking, U-boat detection

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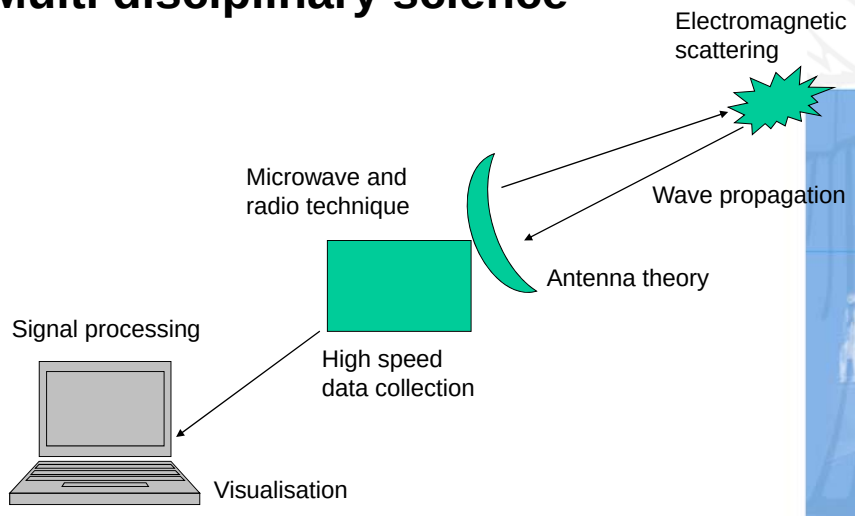
Multi disciplinary science



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Why Radar

- Works day or night (unlike optical imaging)
- Works in all weather
- Penetrates clouds and rain
- Some radars can penetrate foliage, buildings, soil, human tissue
- Can provide very accurate distance measurements
- Sensitive to objects whose length scales are cm to m
- Can measure velocities (Moving targets)

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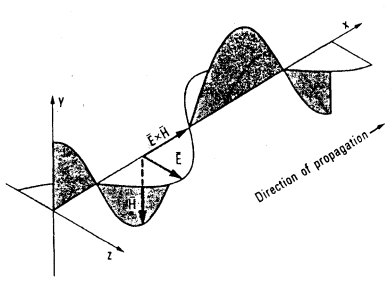
Electromagnetic Waves

- An electromagnetic wave comprises two orthogonal vector components:
  - Electric field intensity E
  - Magnetic field intensity H
- Sinusoidal EM wave:



- Electric field oscillates back and forth.
- EM wave propagation is in the direction orthogonal to oscillation of both electric and magnetic fields.

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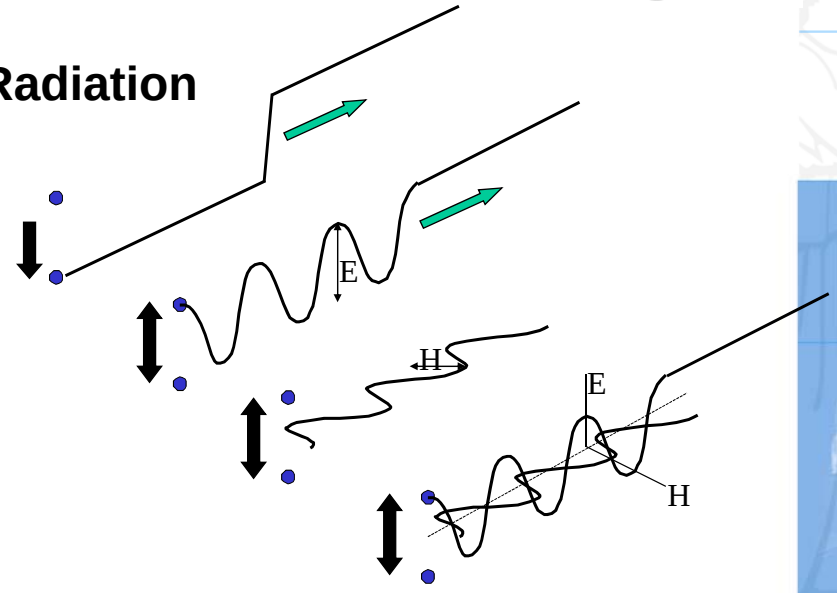
Radiation



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The Radio-Frequency Spectrum

Frequency band	EM-wavelength	Designation	Services
3-30 kHz	100-10 km	Very Low Frequency VLF	Navigation, submarine
30-300 kHz	10-1 km	Low Frequency LF	Radio beacons, navigation
300-3000 kHz	1000-100 m	Medium Frequency MF	AM broadcast, maritime radio
3-30 MHz	100-10 m	High Frequency HF	Amateur Radio, ship to coast comm.
30-300 MHz	10-1 m	Very High Frequency VHF	TV, FM, police air traffic control
300-3000 MHz	100-10 cm	Ultra High Frequency UHF	TV,satellite, radar mobile phone
3-30 GHz	10-1 cm	Super High Frequency SHF	Airborne radar, satcom
30-300 GHz	10-1 mm	Extremely High Frequency EHF	Radar

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Maxwell's equations

$$\mu\frac{\partial H}{\partial t}+\nabla\times E=0$$
$$\varepsilon\frac{\partial E}{\partial t}+\nabla\times H=\sigma E$$
$$\nabla\cdot\varepsilon E=\rho_f$$
$$\nabla\cdot\mu H=0$$

Wave equations

$$\nabla^2 E-\varepsilon\mu\frac{\partial^2 E}{\partial t^2}=0$$
$$\nabla^2 B-\varepsilon\mu\frac{\partial^2 B}{\partial t^2}=0$$

$$v=\frac{1}{\sqrt{\mu\varepsilon}}=\frac{1}{\sqrt{\mu_0\varepsilon_0}}\frac{1}{\sqrt{\varepsilon_r}}=\frac{c}{\sqrt{\varepsilon_r}}$$

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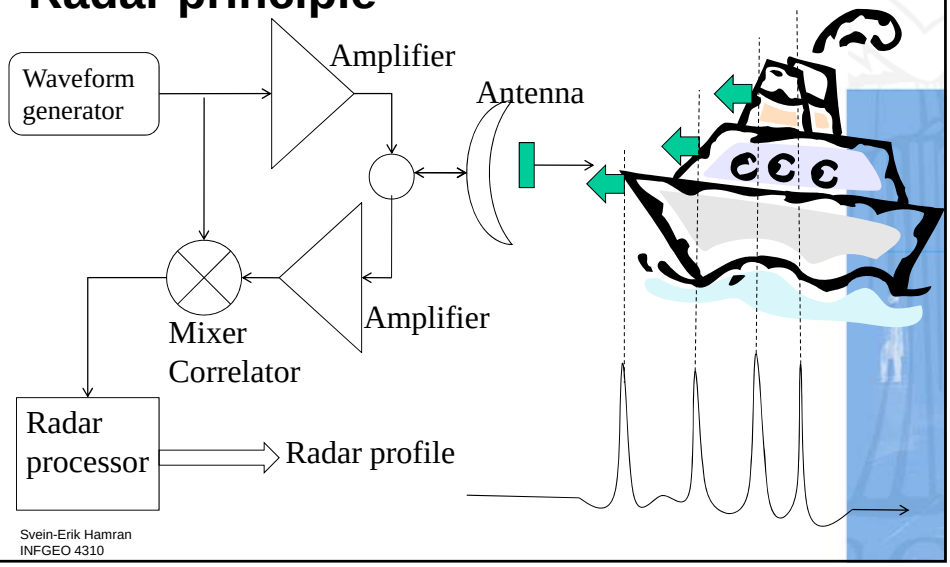
Radar principle



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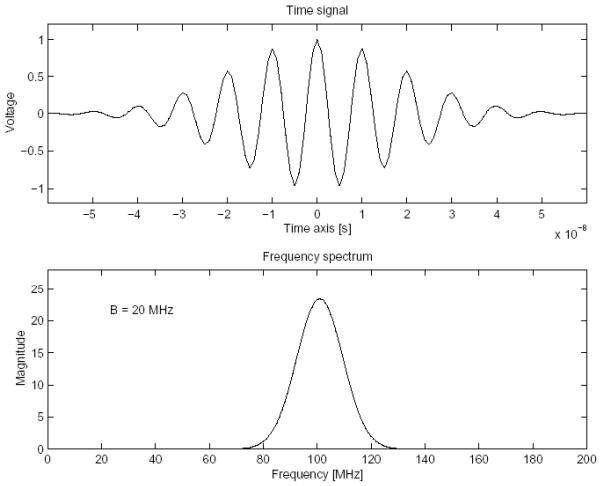
Resolution – Bandwidth FB = 20%



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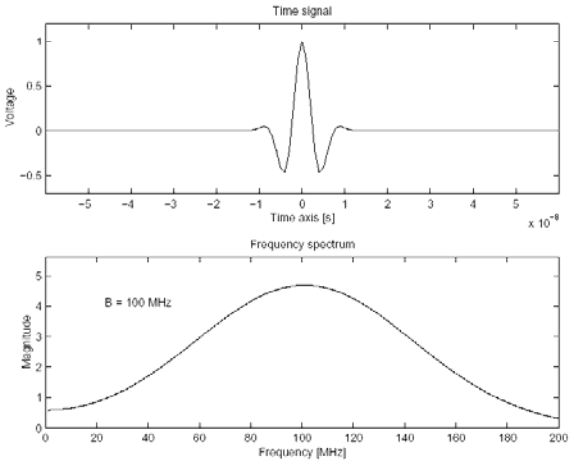
Resolution – Bandwidth FB = 100%



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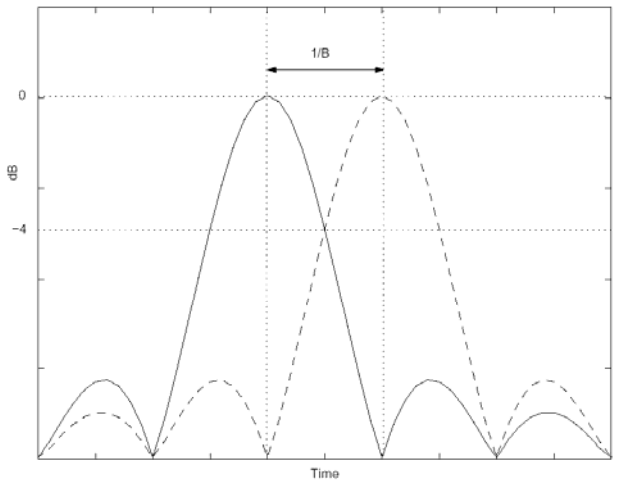
Range Resolution



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Radar waveforms

- Gated-CW
- Impulse
- Noise radar
- Chirp
- FMCW
- Step-frequency

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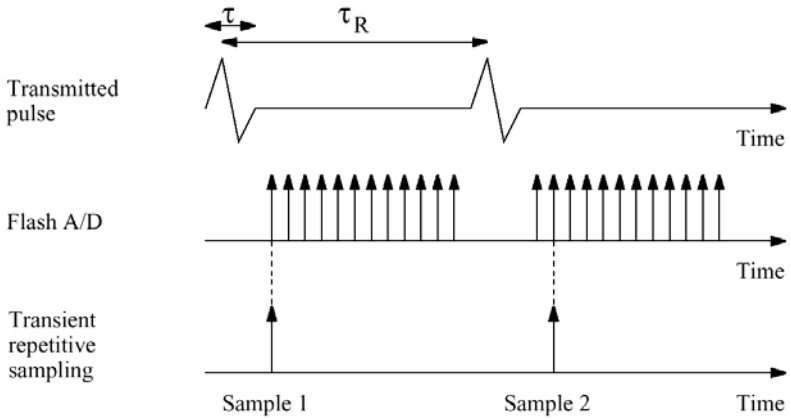
Impulse Radar



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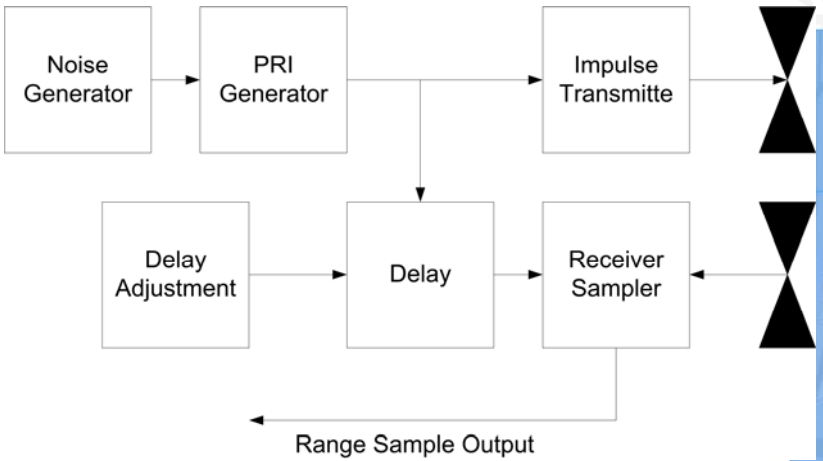
Sequential Sampling Receiver



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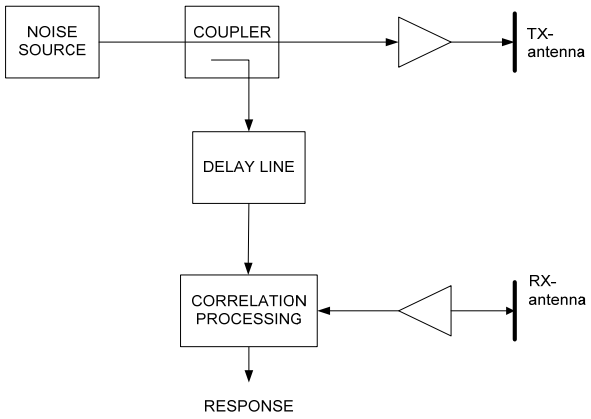
Block diagram of a noise radar



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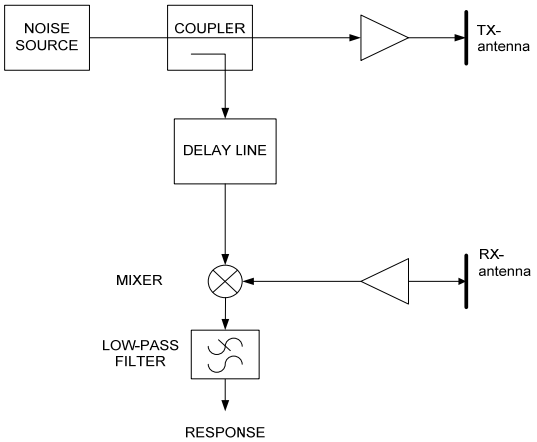
Analog correlation receiver



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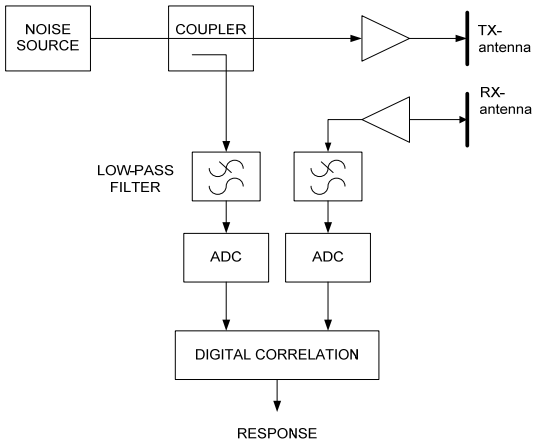
Digital correlation receiver



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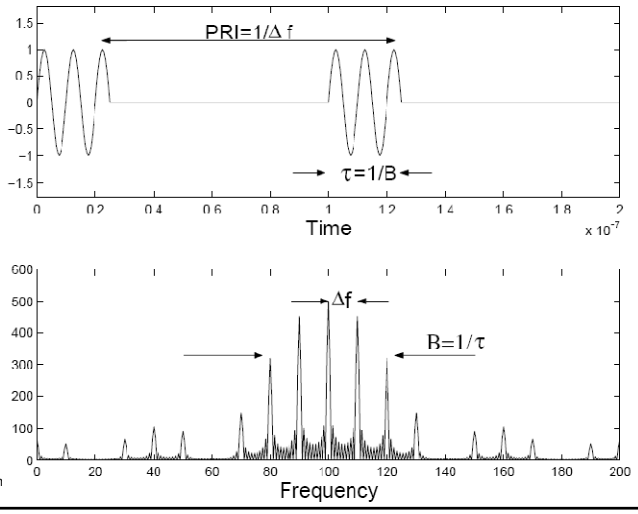
Pulse Train Spectrum



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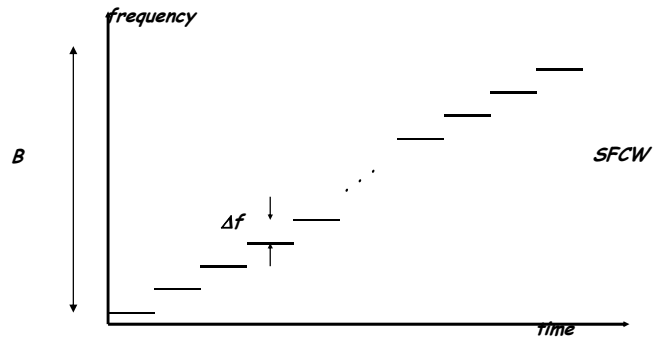
Step-frequency radar



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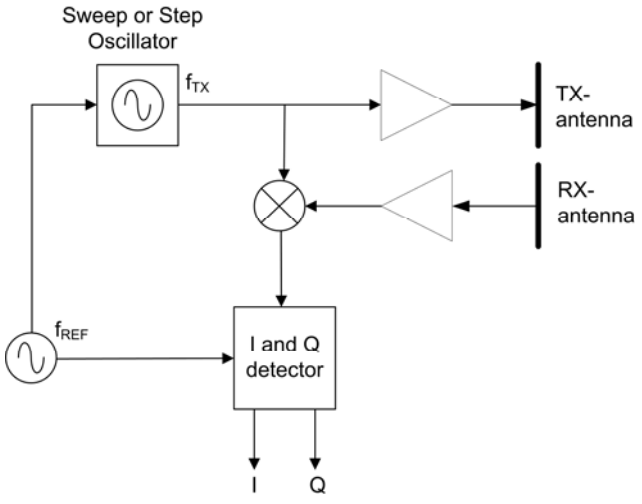
Step Frequency Waveform



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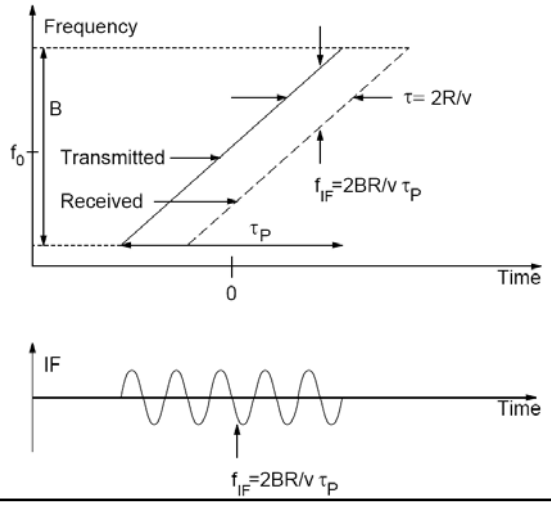
FMCW – Frequency Modulated Continous Wave



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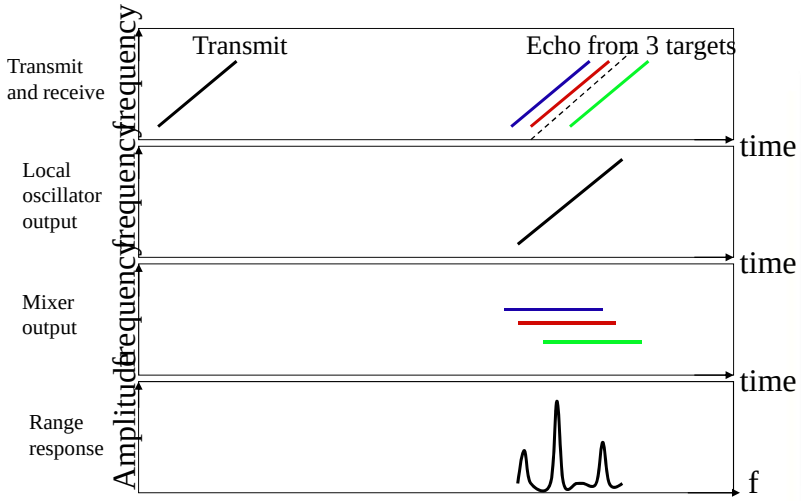
Chirp radar



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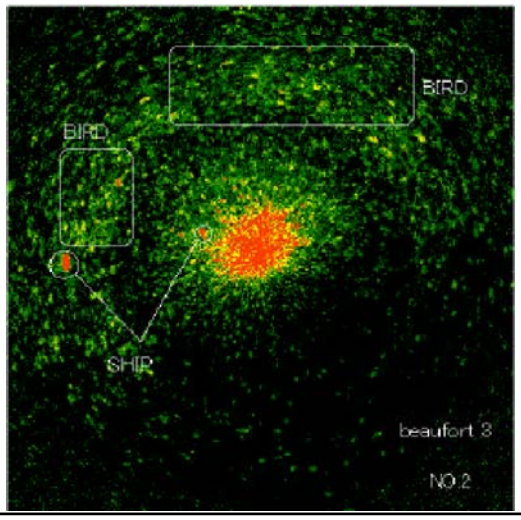
Classical radar image (PPI)



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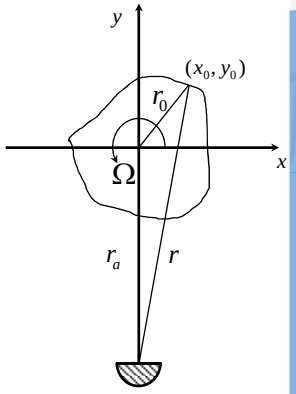
Range-Doppler Imaging

- **The object rotation gives cross range resolution**
- **Range**

$$r = r_a + x_0 \sin \Omega t + y_0 \cos \Omega t$$
$$\approx r_a + y_0$$

- **Doppler:**

$$f_d = \frac{2}{\lambda}\frac{dr}{dt} = \frac{2x_0\Omega}{\lambda}\cos \Omega t - \frac{2y_0\Omega}{\lambda}\sin \Omega t$$
$$\approx \frac{2x_0\Omega}{\lambda}$$



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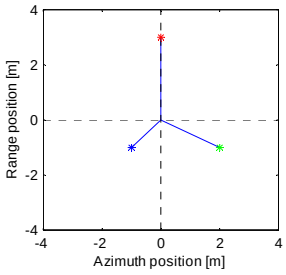
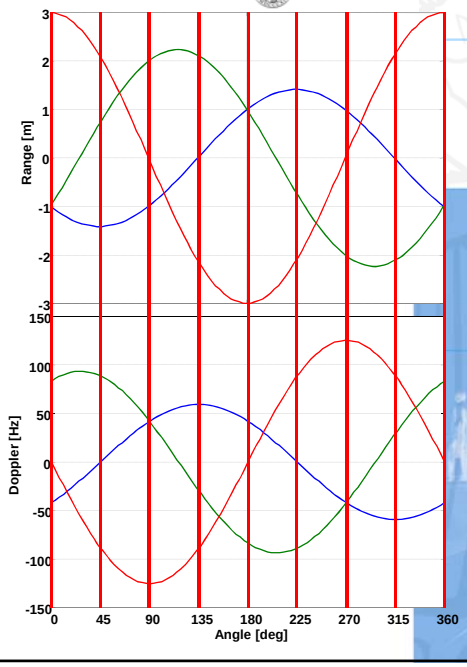
Range and Doppler

Single target, Ω = 36°/s





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Resolution

Distance (range) $\Delta y = \frac{c}{2B}$

Azimut (Doppler) $\Delta f = \frac{1}{T}$

$$\Delta x = \frac{\lambda}{2\Omega}\Delta f = \frac{\lambda}{2\Omega T} = \frac{\lambda}{2\theta_p}$$

Example: $B = 800\,\text{MHz}$ $\Delta y = 18.75\,\text{cm}$

$\lambda = 1.8\,\text{cm}, \Omega = 0.5°/\text{s}$ $\theta_p = 2.5°$ $\Delta x = 20.6\,\text{cm}$

$T = 5\,\text{s}$

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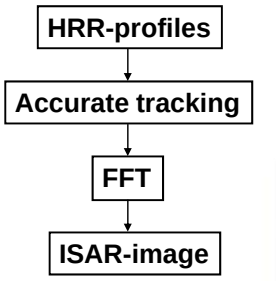
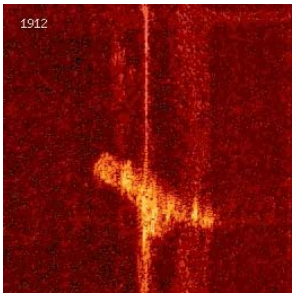
ISAR

- ISAR – Invers Synthetic Aperture Radar
- Methode that is using the targets motion
- Relative motion makes a change in aspect angle
- Starts with range profiles
- HRR – High Resolution Range

- Main difficulty is accurate tracks





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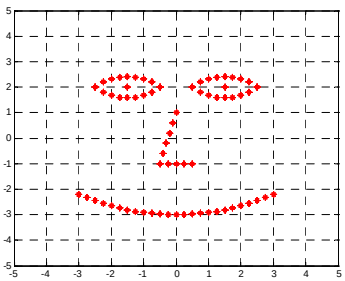
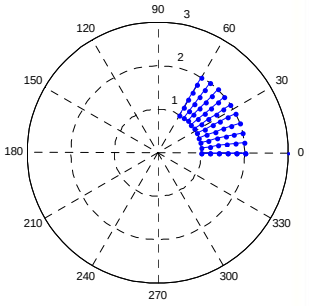
Simulation Example

- Frequency 1-2 GHz with 66 frequencies
- Angular coverage step every 1 degree for total of 60





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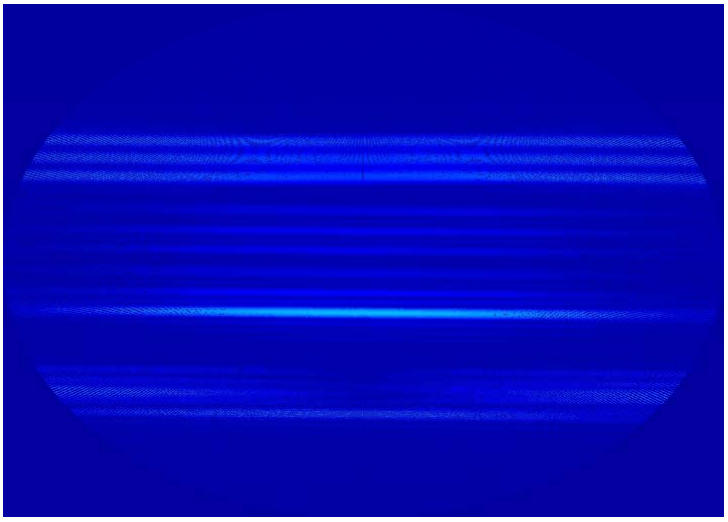

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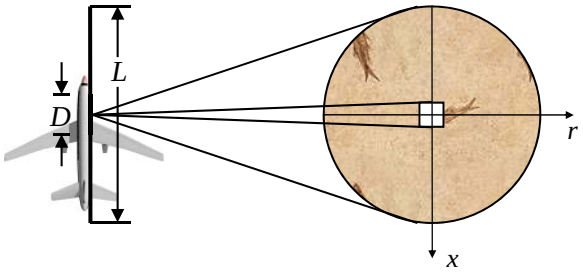
SAR-principle



$$\theta = \frac{\lambda}{D} \qquad \theta' = \frac{\lambda}{2L}$$

$$\Delta x = R\theta = \frac{R\lambda}{D} \qquad \Delta x' = R\theta' = \frac{R\lambda}{2L} = \frac{D}{2}$$

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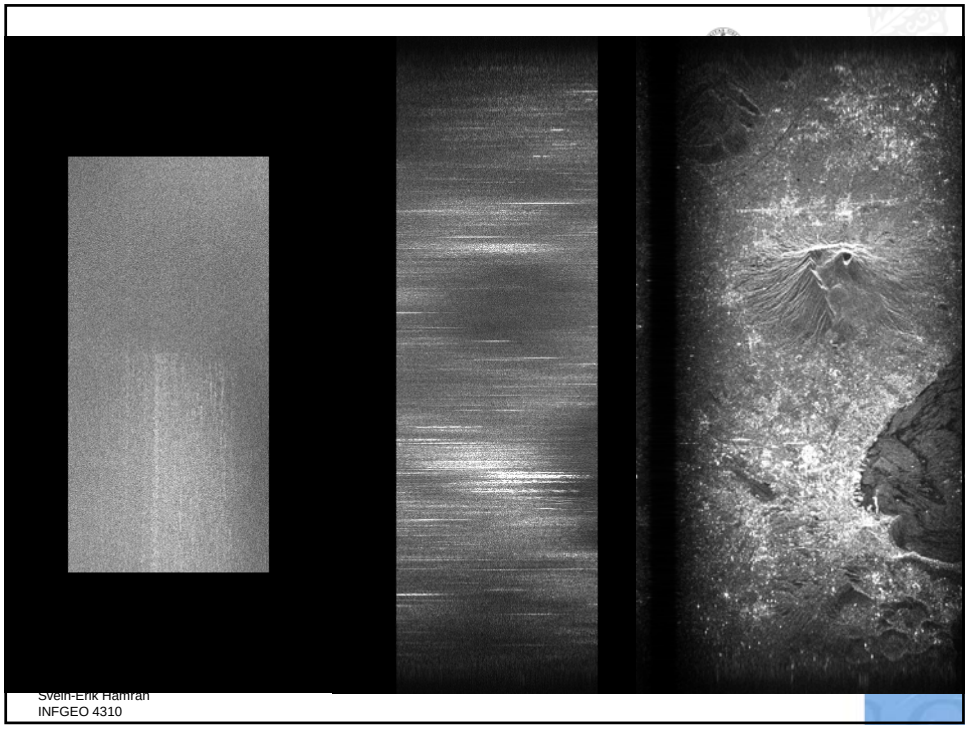
Comparison of resolution

Real aperture		Synthetic aperture	
Distance:	10 km	SAR (Stripmap)	
Antenna:	1 m	Antenna:	1 m
Wavelenght:	X-bånd	Wavelenght:	X-bånd
Resolution:	300 m	Resolution:	0.5 m
Distance:	100 km	SAR (Spotlight)	
Resolution:	3 km	Theoretical Resolution:	7.5 mm
Distance:	1000 km	Independent of distance!	
Resolution:	30 km		



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Special effects in SAR-images

- Geometrical distortion – 3 types:
  - Foreshortening
  - Layover
  - Shadow
- All related to that the ground is not flat.
- Can have a large influence for interpretation in areas where the topography is large.
- Speckle

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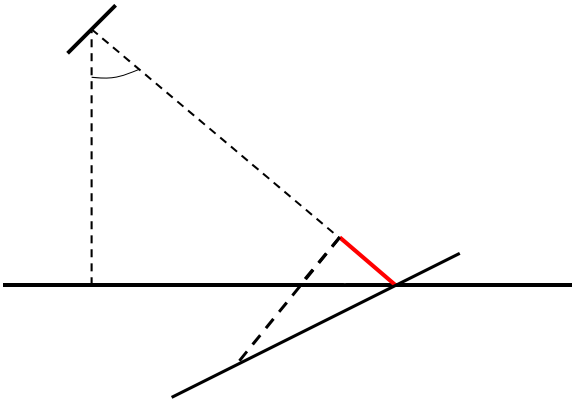
Foreshortening



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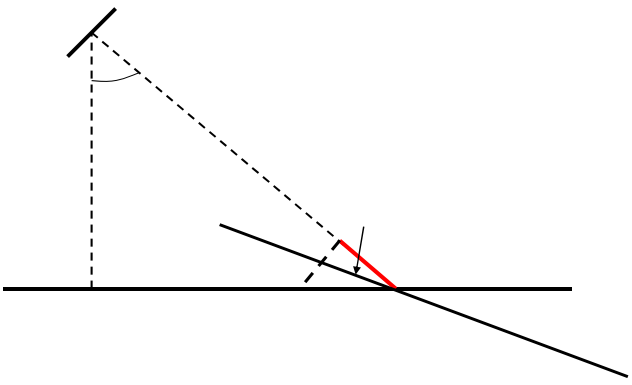
Foreshortening



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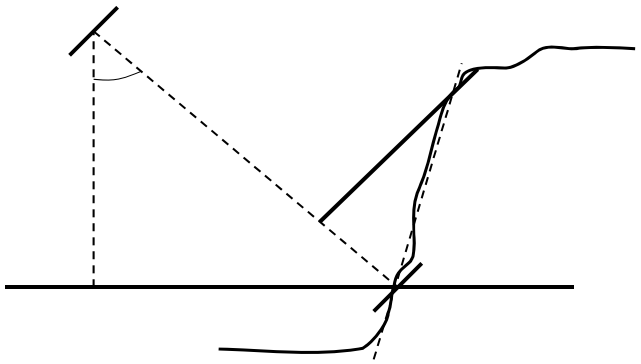
Layover



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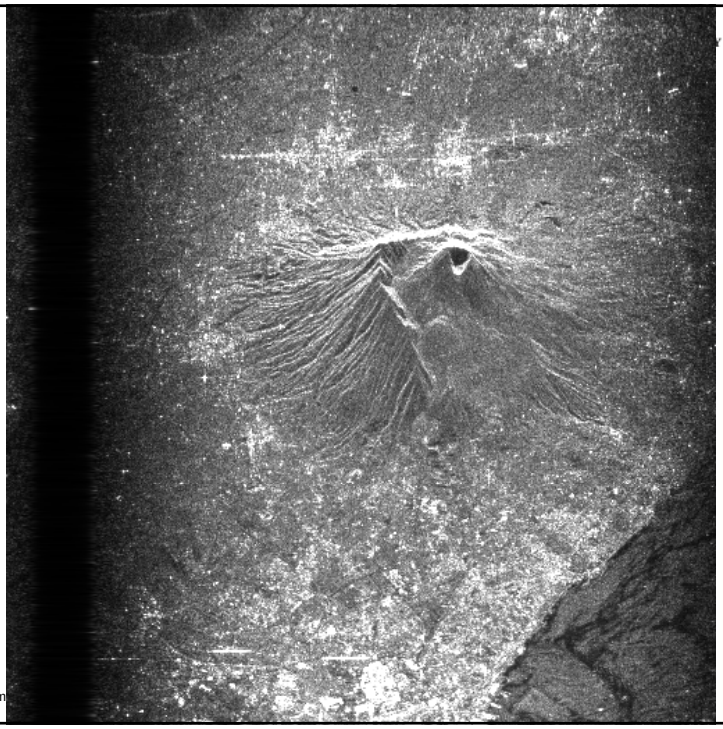

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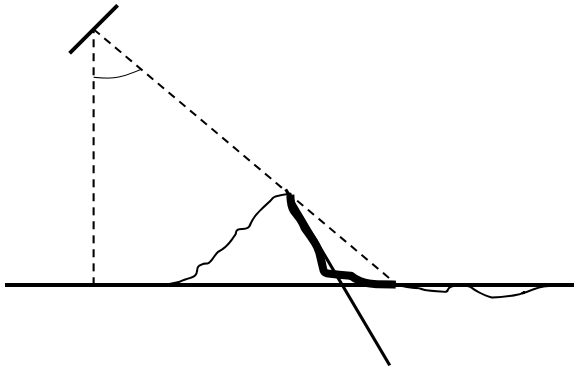
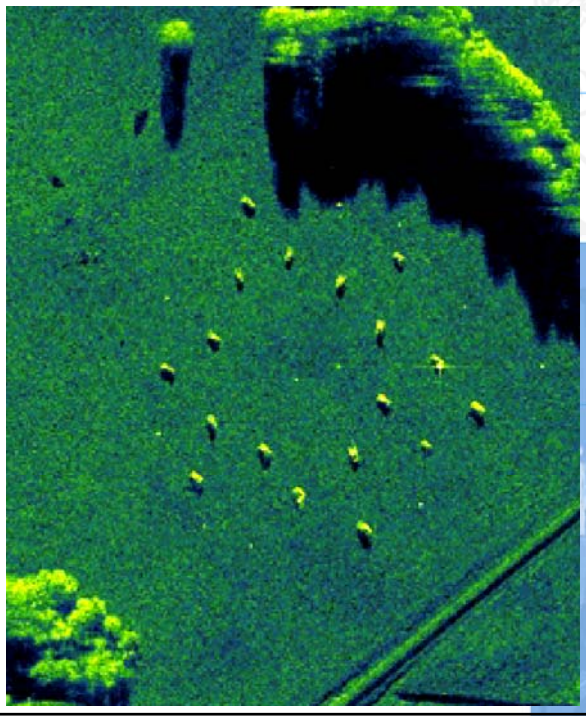
Shadow



MSTAR data
(L Novak
MIT Lincoln Lab)



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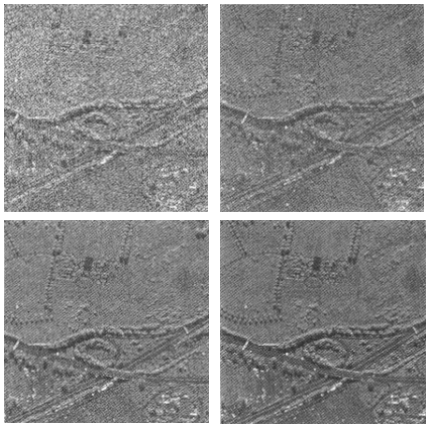
Speckle



Jakowatz & Co (1996)

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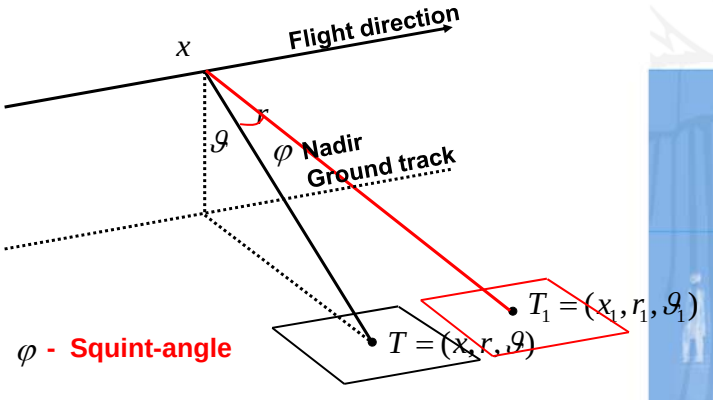
SAR geometry



φ - **Squint-angle**

$\varphi = 0$ - **Broad side**

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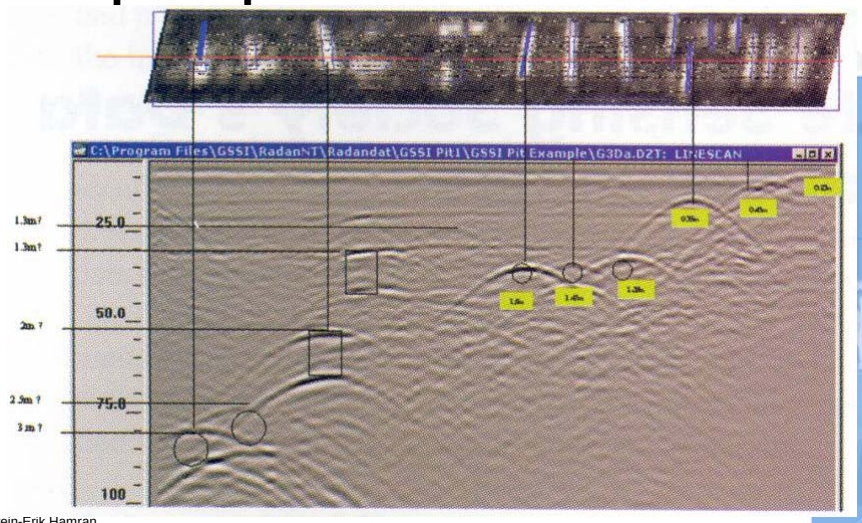
SAR-principle



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IEEE GRS Newsletter, Dec 2001.

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SAR-modes

- Stripmap – antenna fixed side looking
  - Reolution given by antennas size: ~ $d/2$
- Spotlight – antenna is steered against the target
  Resolution given by angular coverage, max: $\lambda/4$ for 2π
- Stripmap is used to continous mapping with average reolution.
- Spotlight used to image areas of special interest and with high resolution.
- ISAR – Invers SAR similar to spotlight but used to image moving targets

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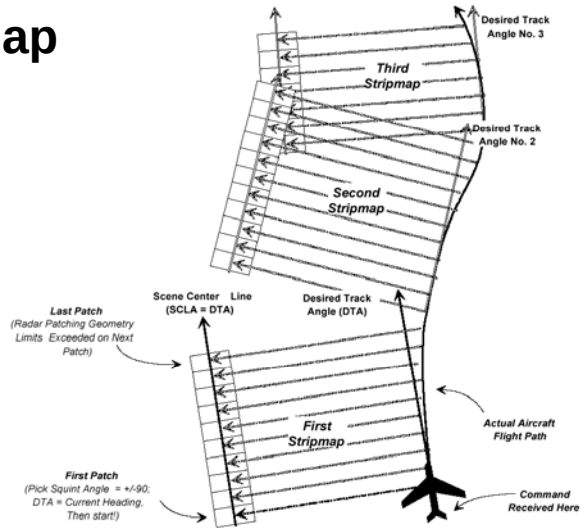
Stripmap



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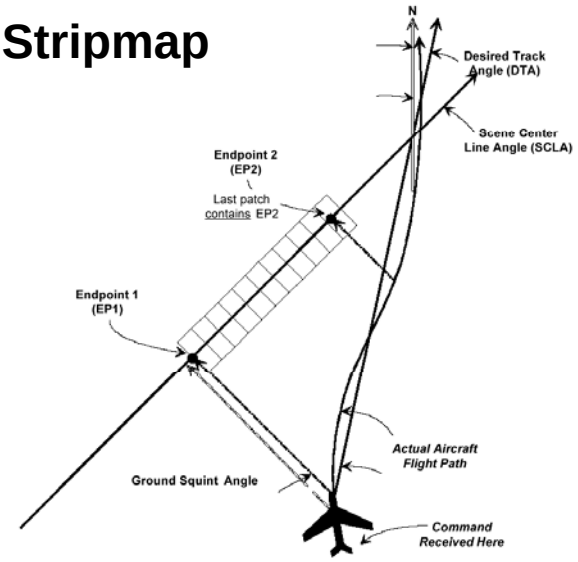
Georef Stripmap



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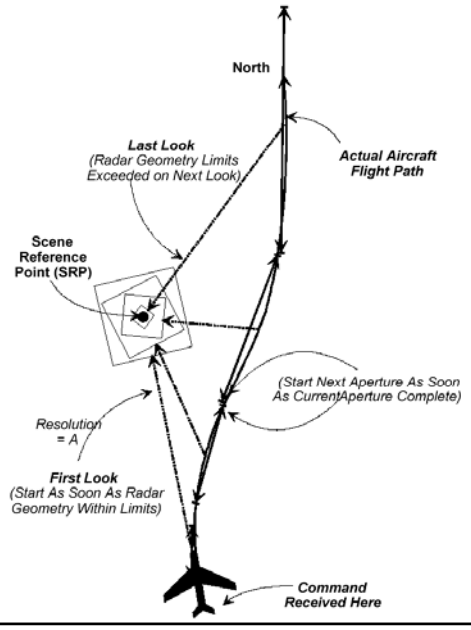
Spotlight



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PI-SAR (CRL/NASDA)

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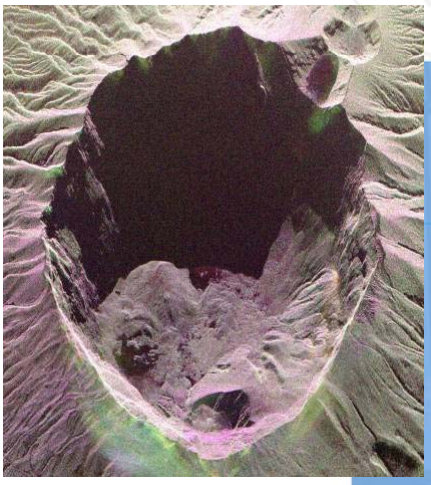
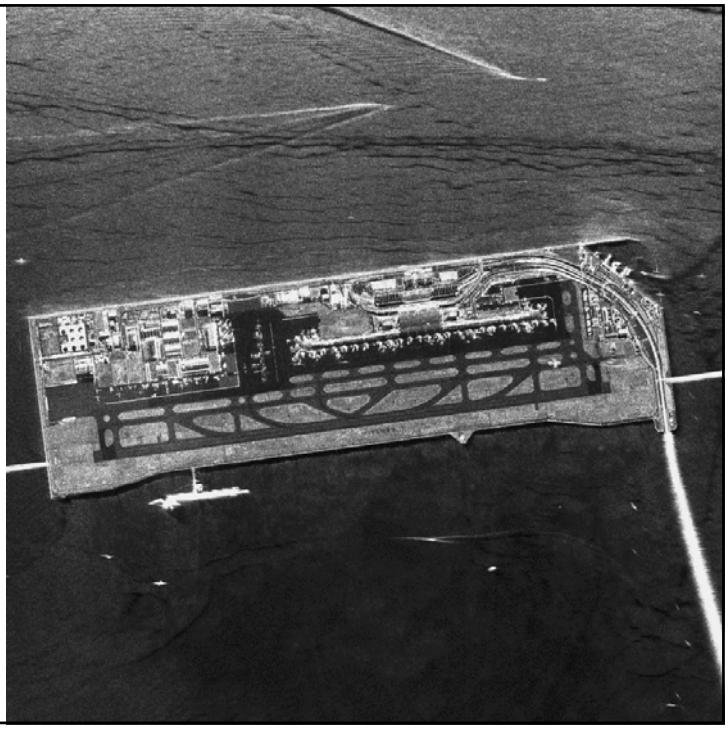
PI-SAR



PI-SAR



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Interferometry

- Interferometry is a method that use the phase difference resulting from two measurements taken at different observation points
  - General radar method not only usable for SAR
  - Very much used in SAR
- SAR-interferometry makes it possibly to resolve the altitude coordinate and thereby measure height.
  - Very sensitive since using the radar phase
  - The radar system needs to be accurate and stable
- Makes GEOCODING possible, that is reference image pixels to geographical reference system.

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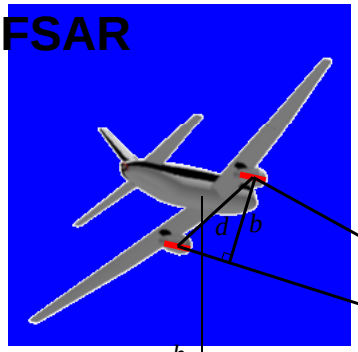
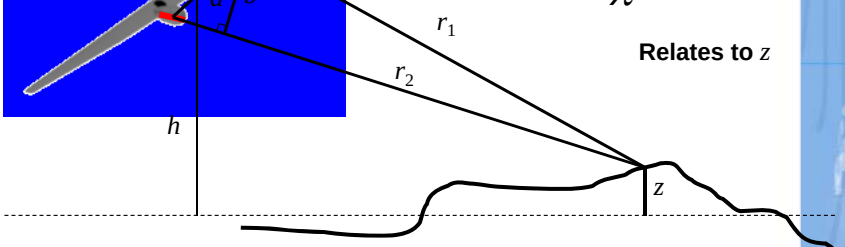
IFSAR



$$\Delta\varphi = \varphi_2 - \varphi_1$$
$$= \frac{2\pi}{\lambda}(r_2 - r_1)$$

Relates to z



Cross-track interferometry (CTI)

Two or Single pass interferometry

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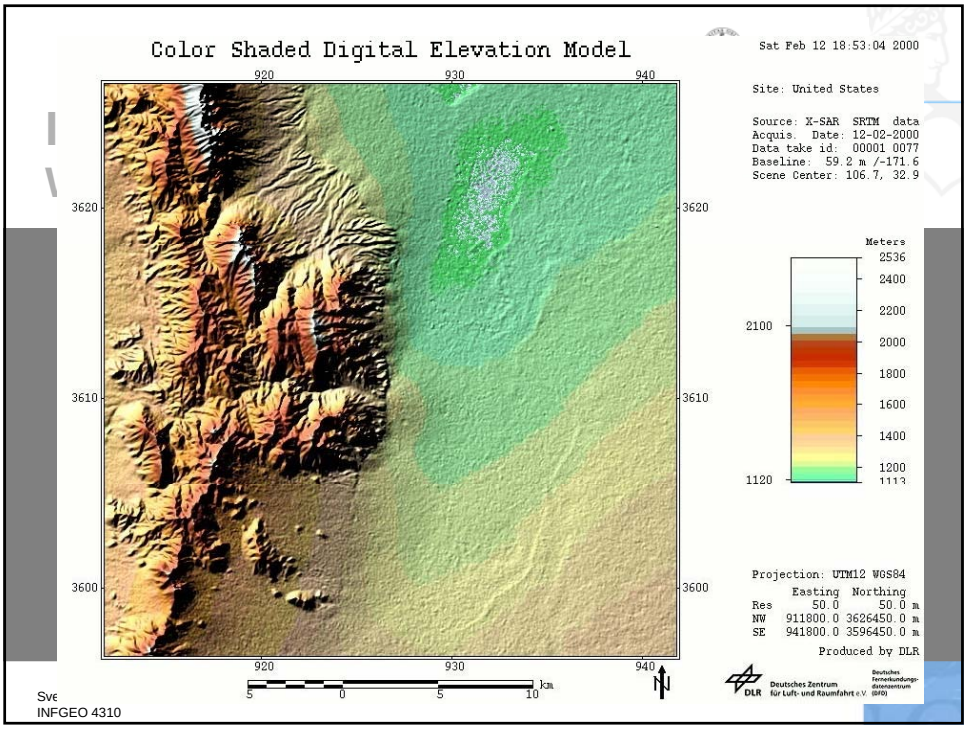

Sve
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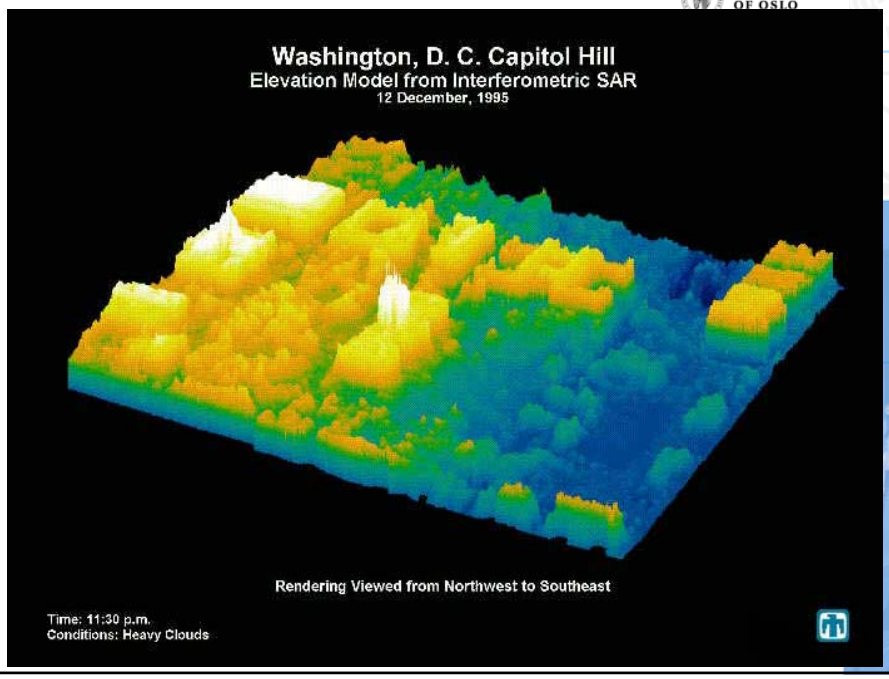

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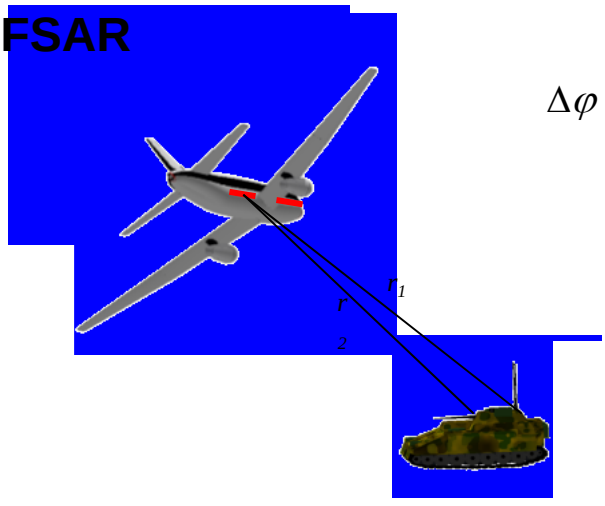
IFSAR



$$\Delta\varphi = \varphi_2 - \varphi_1$$
$$= \frac{2\pi}{\lambda}(r_2 - r_1)$$

Relates to Δr

Along-track interferometry (ATI)

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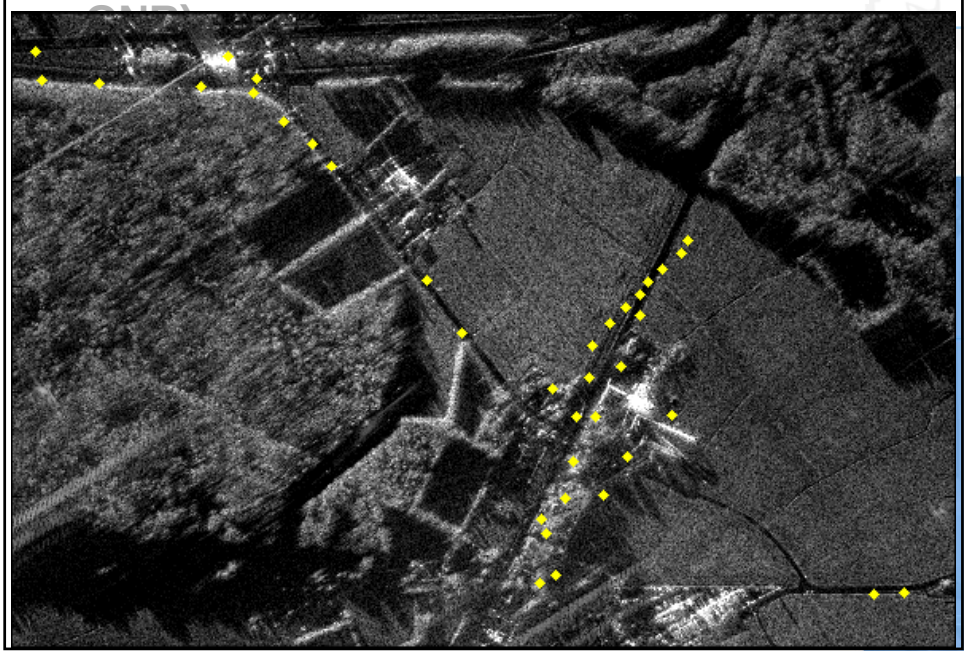
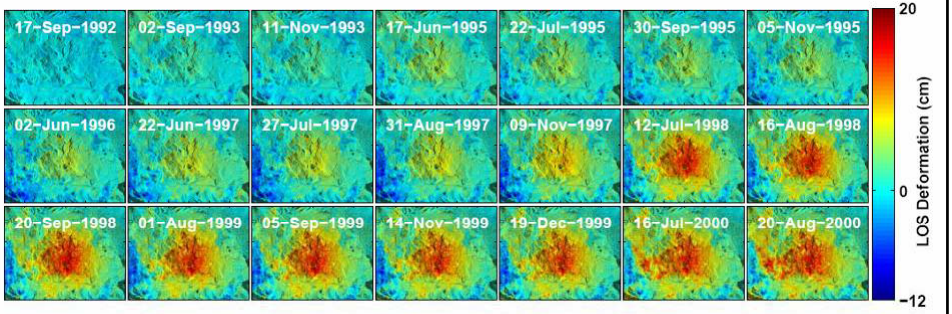
AN/APY-6 GMTI og SAR (W Miedl, GNR)



Differential IFSAR – Time series



Andrew Hooper, Howard Zebker, Paul Segall, Bert Kampes,
"A New Method for Measuring Deformation on Volcanoes and Other Natural Terrains Using InSAR Persistent Scatterers",
***Geophysical Research Letters*, (31) 23, 2004**

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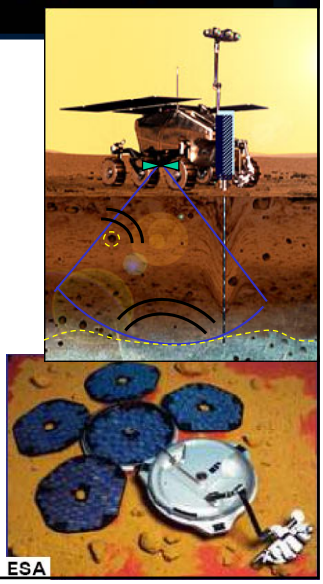
E X O M A R S

- Scientific objectives are:
  - To search for signs of past and present life on Mars;
  - To characterise the water/geochemical environment as a function of depth in the shallow subsurface;
  - To study the surface environment and identify hazards to future missions;
  - To investigate the planet's subsurface and deep interior to better understand the evolution and habitability of Mars.
- **Pasteur Rover** with instruments: Camera, Organics detector, Mass spectrometer, GPR, Raman/LIBS, Microscope, Drill.
- **ExoMet** Met-sensors, Dust, GPR, Electric field



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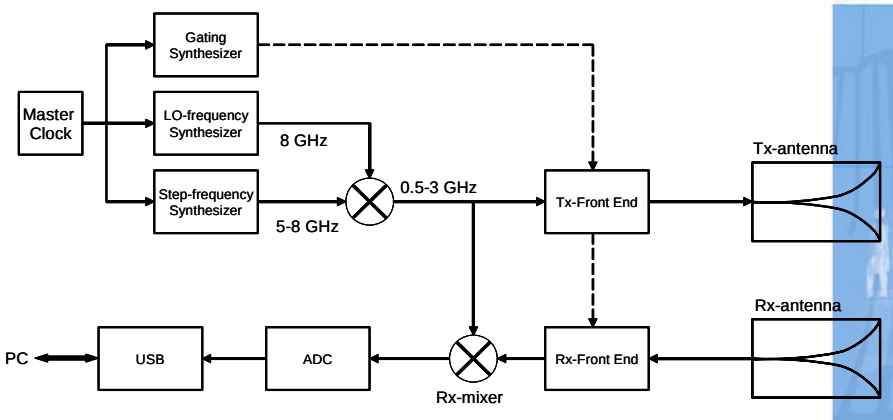
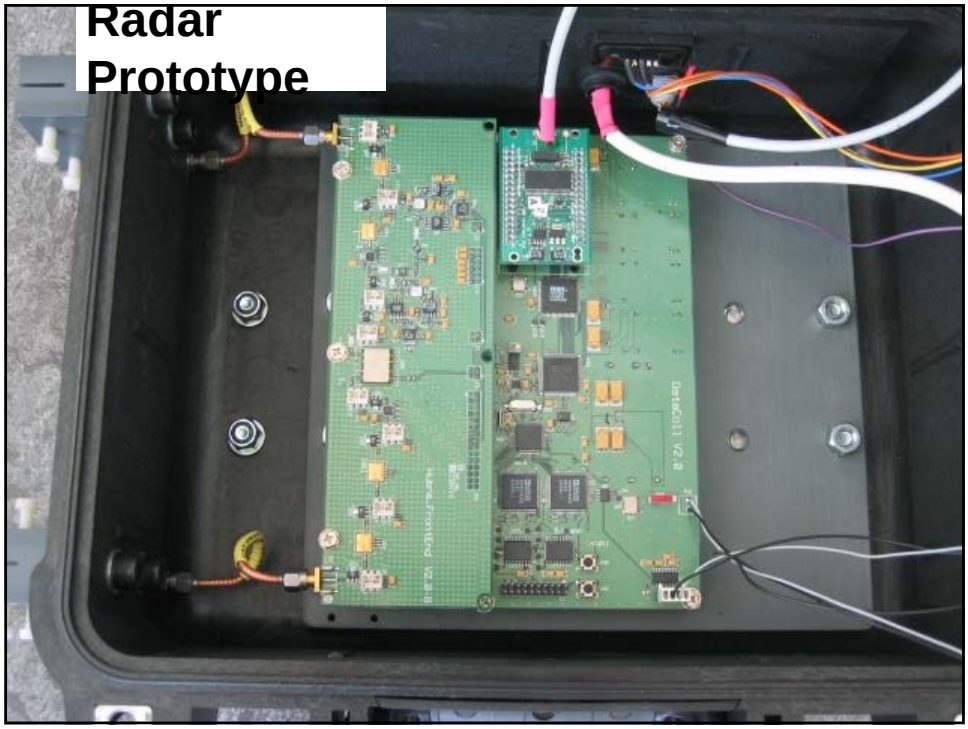
WISDOM GPR Prototype

– Frequency [500 MHz – 3 GHz]



Radar Prototype



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Step Frequency Waveform Parameters

- Number of Frequencies: 751
- IF-Bandwidth: 500kHz
- IF-Sampling Frequency 1 MHz
- IF-Samples pr frequency: 10
- Gating frequency: 5.12 MHz
- Gating delay: 0 ns Tx and Rx
- Gating
  - Transmitting Power 0 dBm
  - Receiver Gain 60 dB
- CW
  - Transmitting Power -30 dBm
  - Receiver Gain 30 dB
- Sampling Along Profile: 10 cm
- Time for each trace: 68 ms

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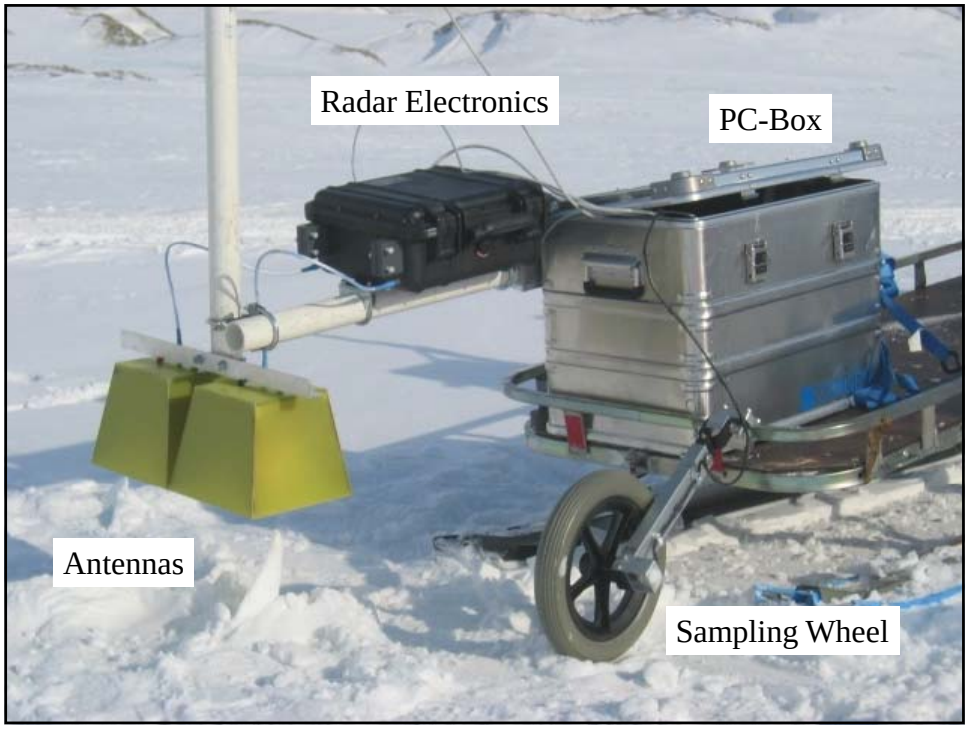
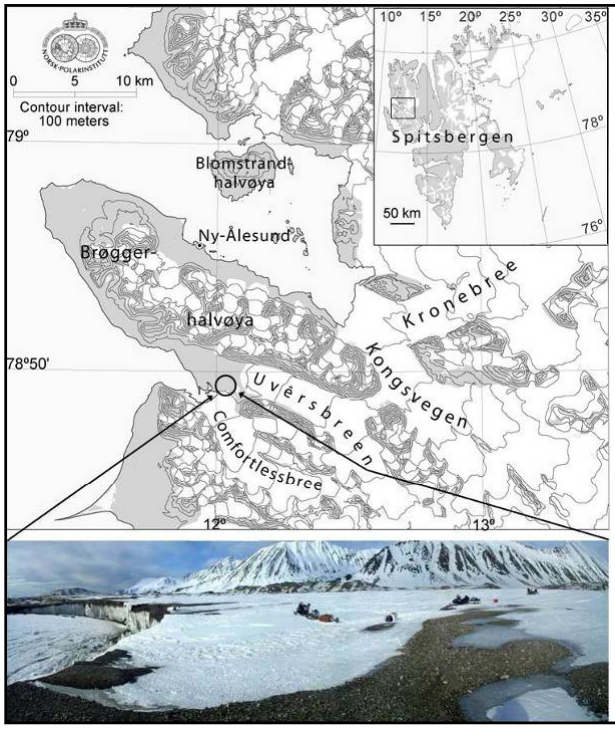

Radar Electronics
PC-Box
Antennas
Sampling Wheel



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- Mean annual air temperature in NÅ is -6.3°C.
- Permafrost depth is ~100 m in costal areas and >500 m in mountainous areas.
- Active layer depth at the field site is believed to be ~2 m.
- This layer experiences thawing in the summer/autumn.

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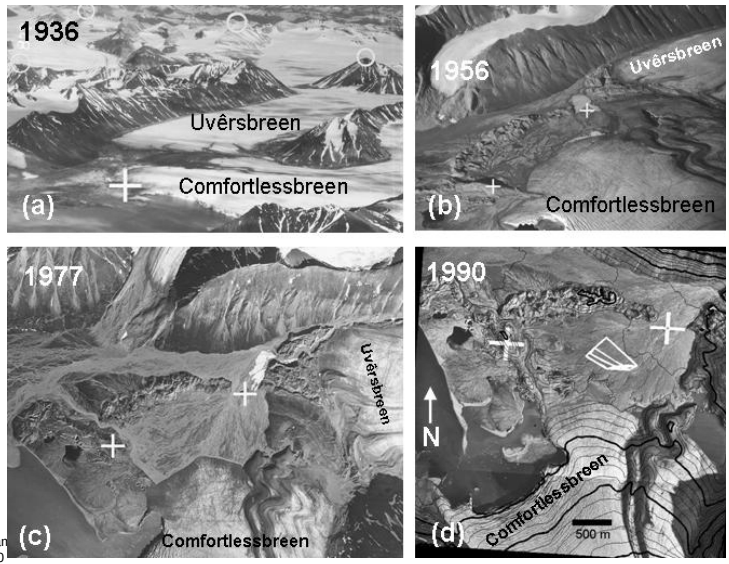
Aerial photographs



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Uversøyra Field Test Area

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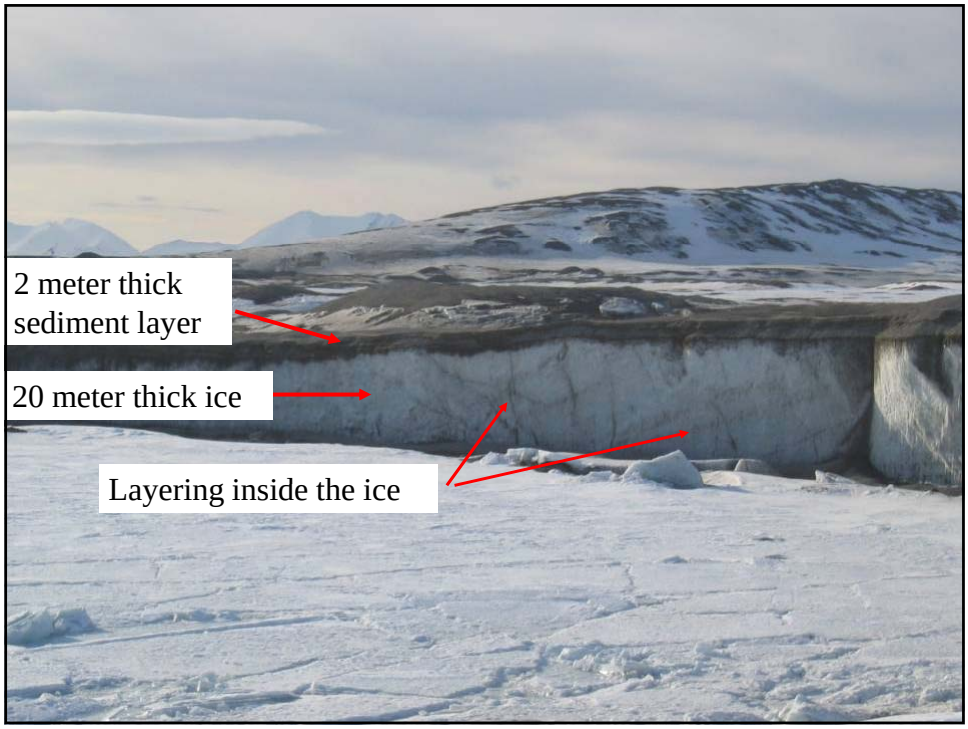
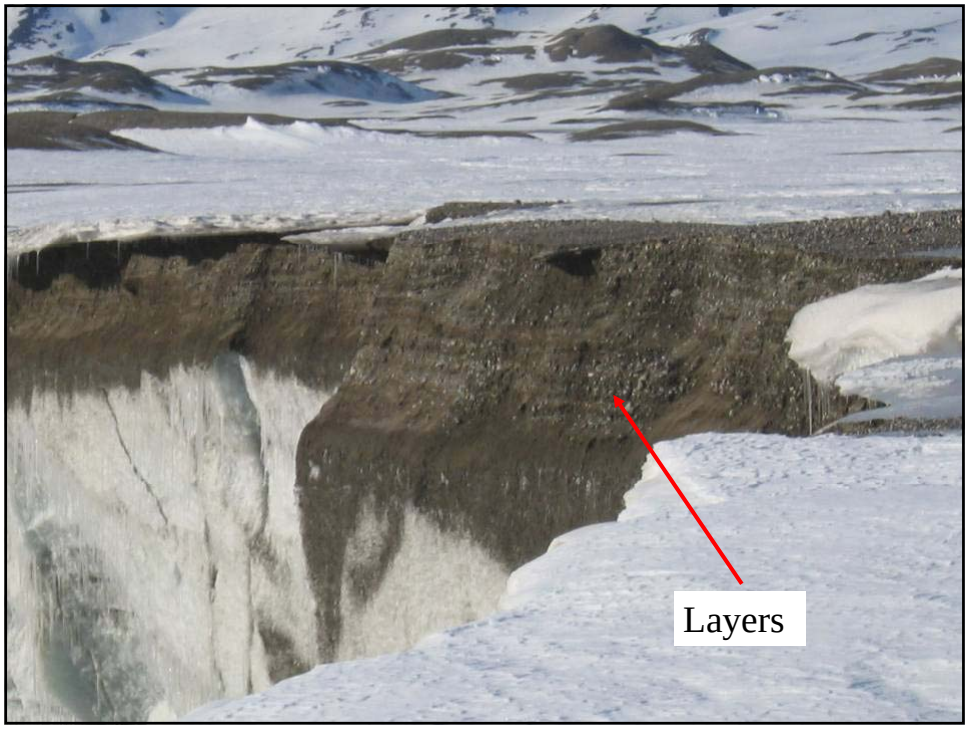
Sediment Layer on Top of Ice


2 meter thick
sediment layer
20 meter thick ice
Layering inside the ice


Layers

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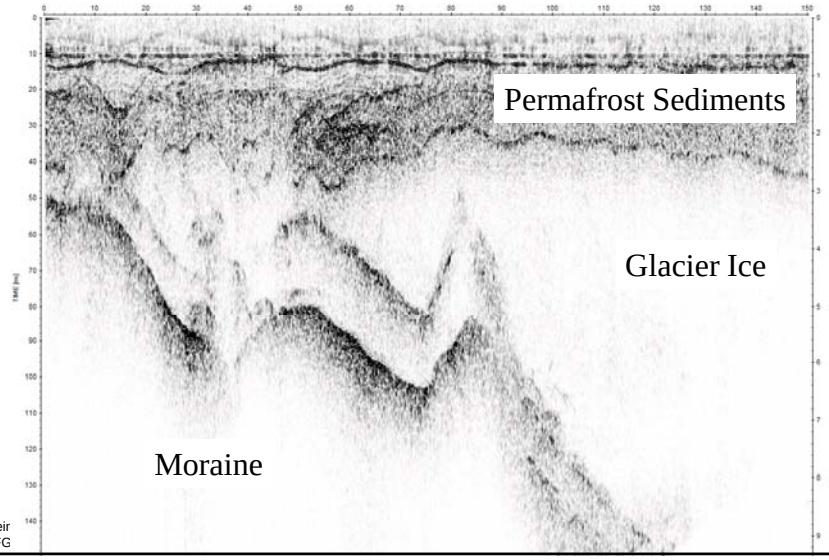
Interpretation



Sveir
INFG

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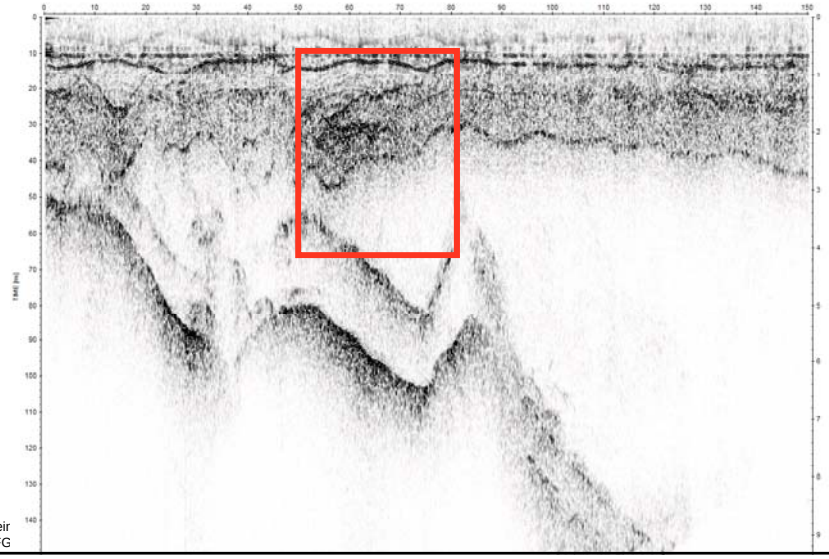
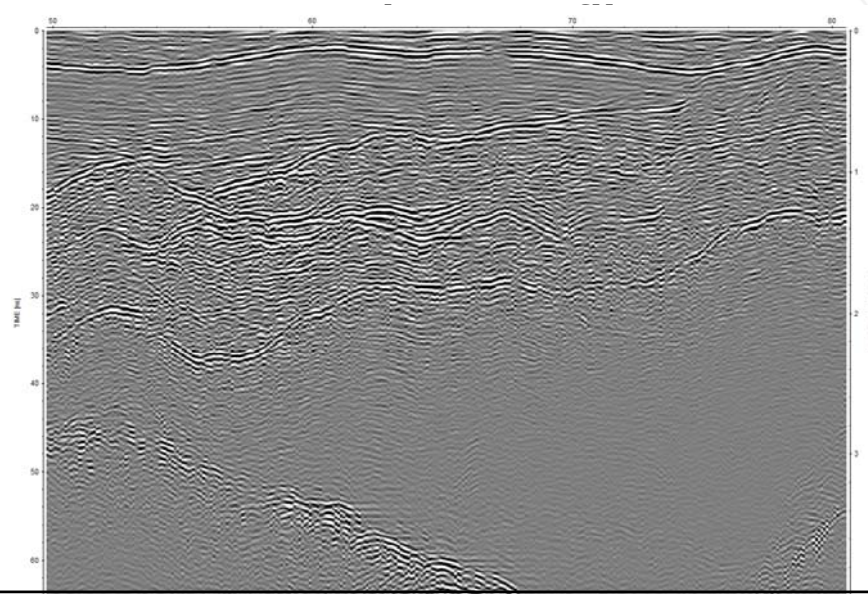
50 to 80 meter along profile



Sveir
INFG

UNIVERSITY OF OSLO



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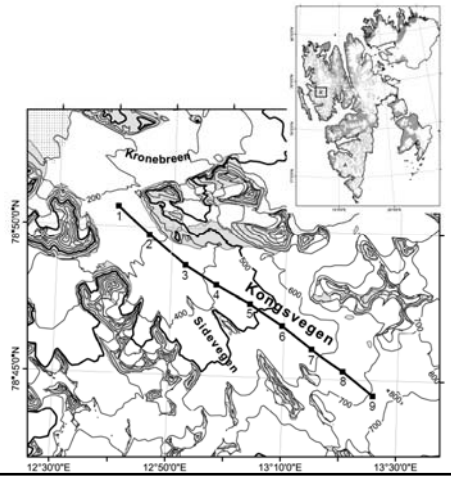
Kongsvegen Glacier Facies Characterization



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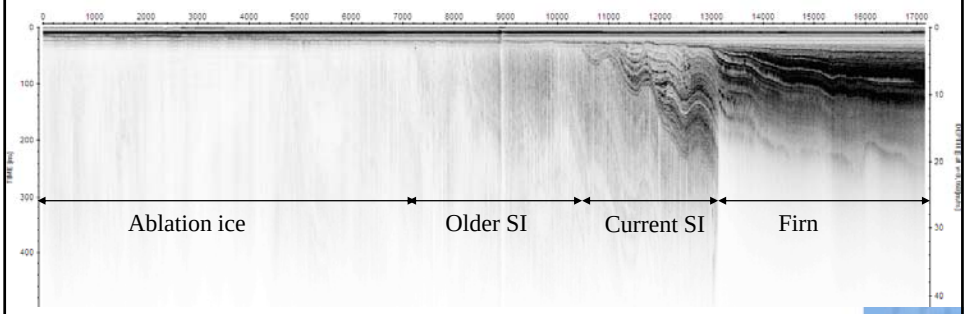
Radar Profile along stake line



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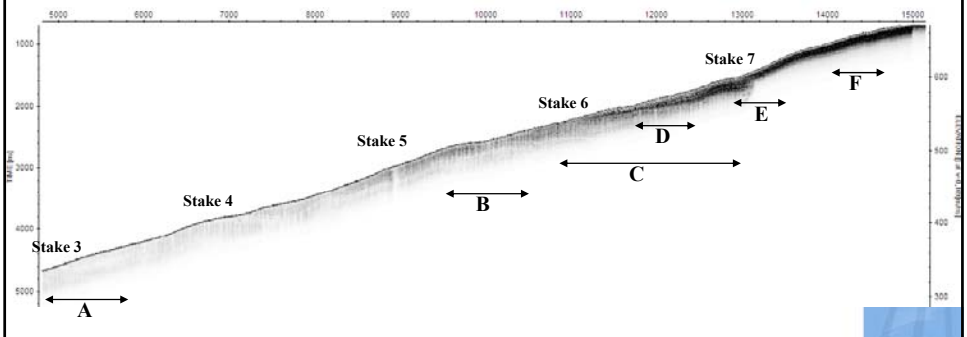

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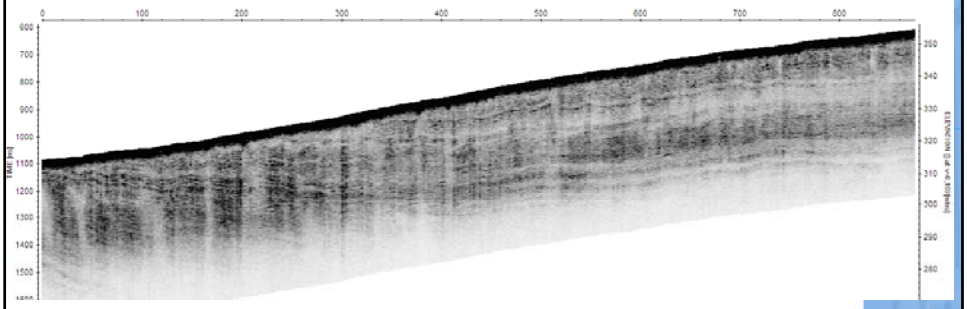
Ablation zone



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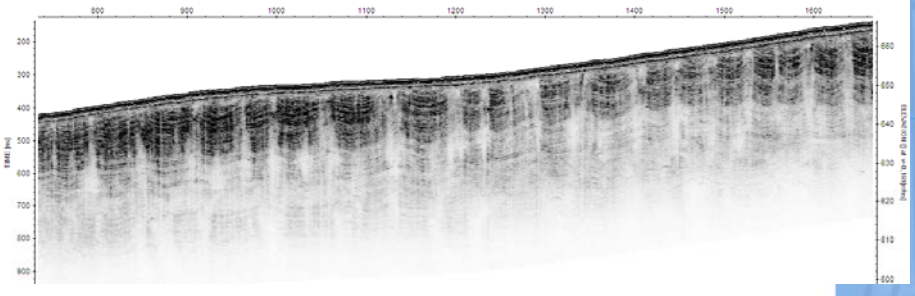
”Herring bone” zone



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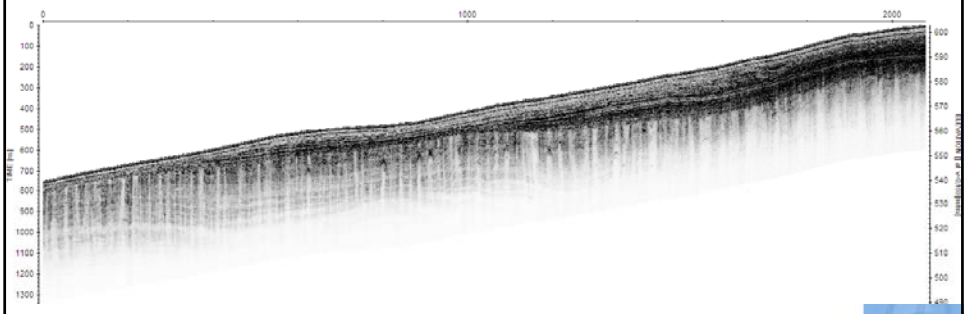
Superimposed Ice Zone



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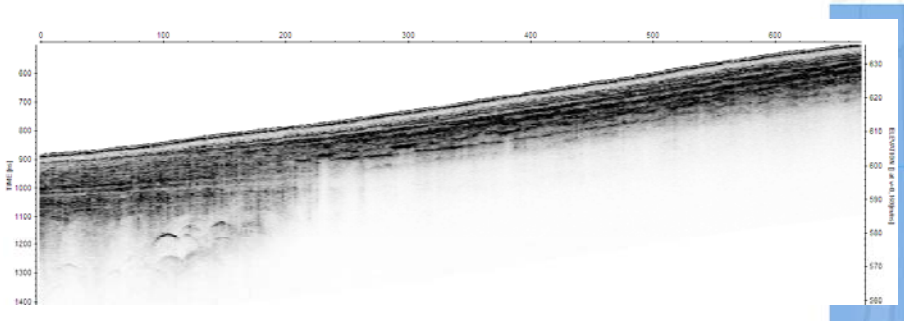
Transition Zone



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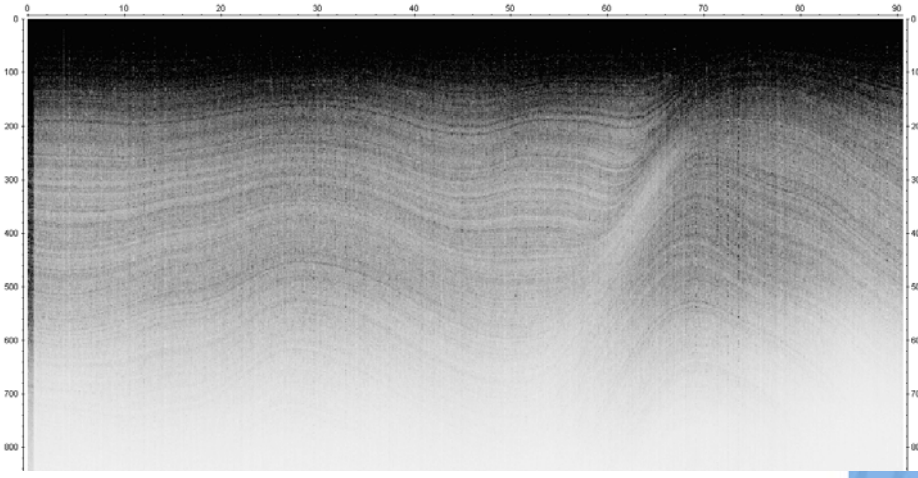
Example 1 – Antarctica



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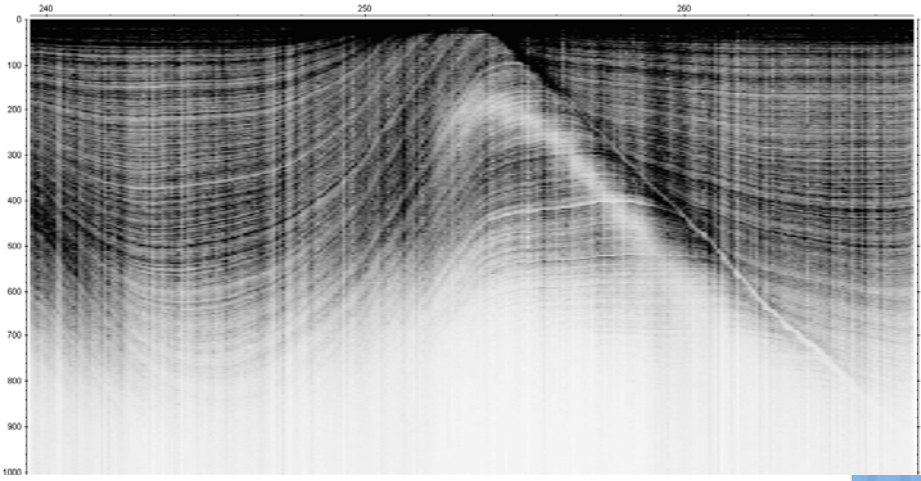
Example 2 – Antarctica



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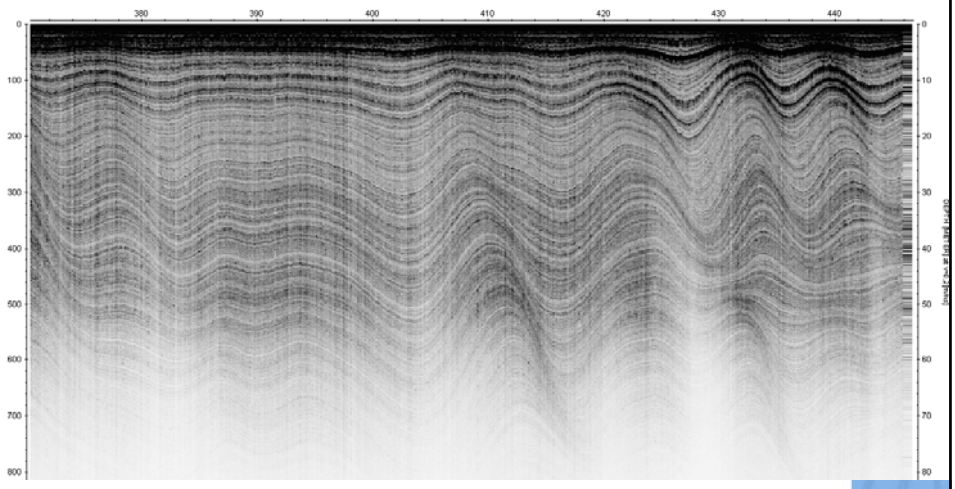
Example 3 – Antarctica



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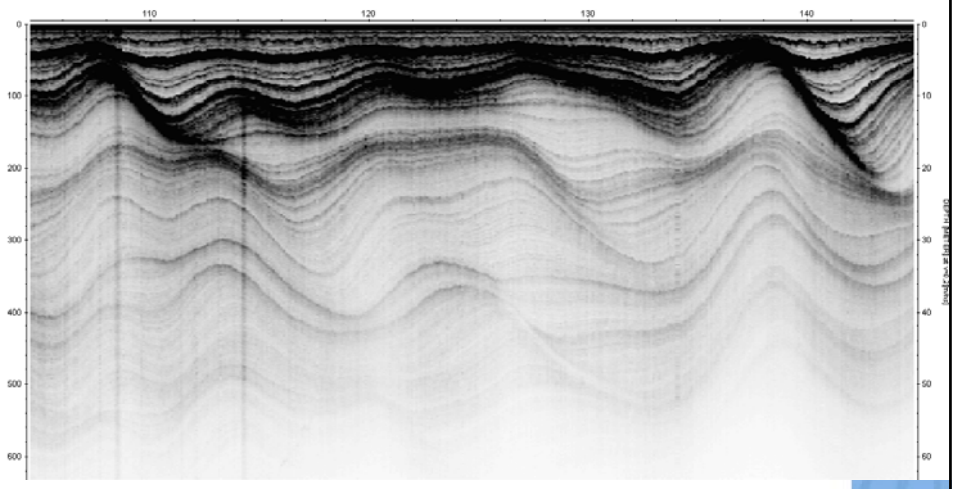
Example 4 – Antarctica



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ENVISAT – ASAR

- ENVISAT is and ESA earth observation satellite
- LAUNCH 28.02.2002, in orbit 03.04.2002
- Instruments: ASAR, MERIS, RA-2, AATSR, MIPAS, GOMOS, SCIAMACHY, MWR, DORIS
- ASAR – Advanced Synthetic Aperture Radar

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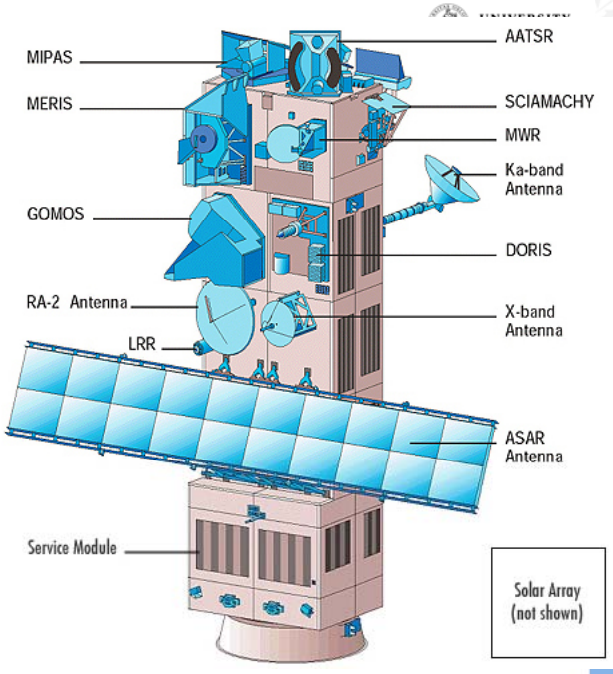
ENVISAT



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ASAR - antenna

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ASAR – Advanced Synthetic Aperture Radar

- C-band 5.331 GHz (5.6 cm wavelenght)
- Active phased array antenna 1.3 x 10 m
- Elementene kan sende med horisontal (H) og vertikal polarisasjon (V)
- Bandwidth 200 kHz – 16 MHz, Transmits linear chirp
- Nominel resolution 9.4 – 750 m, products 30 x 30 m up until 1 x 1 km
- Incidence angle 15-45º
- Swath 56 – 105 km (405 km with ScanSAR)

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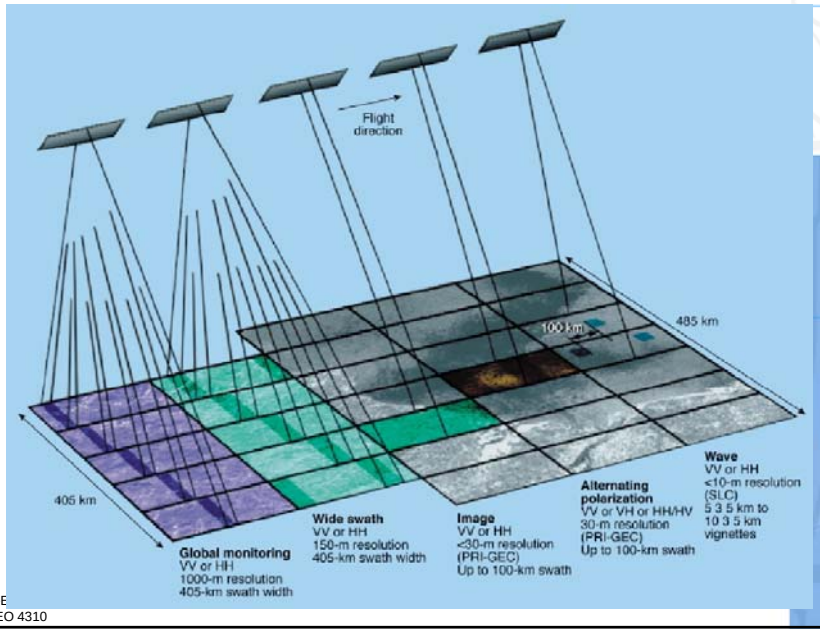
ASAR – modes



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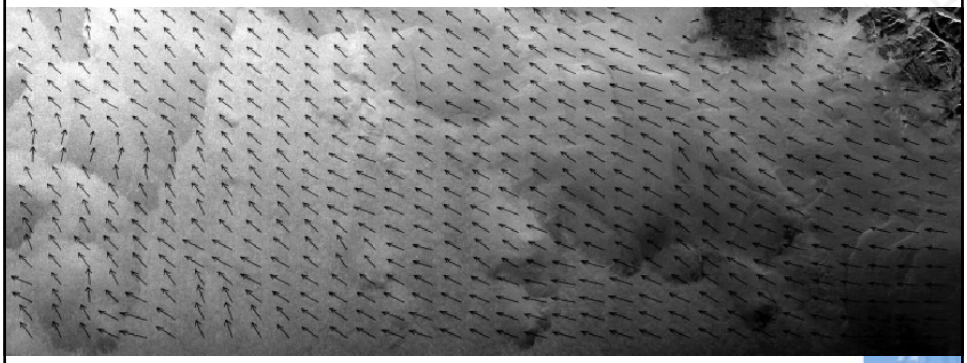
ERS2 – Wind field



Norut

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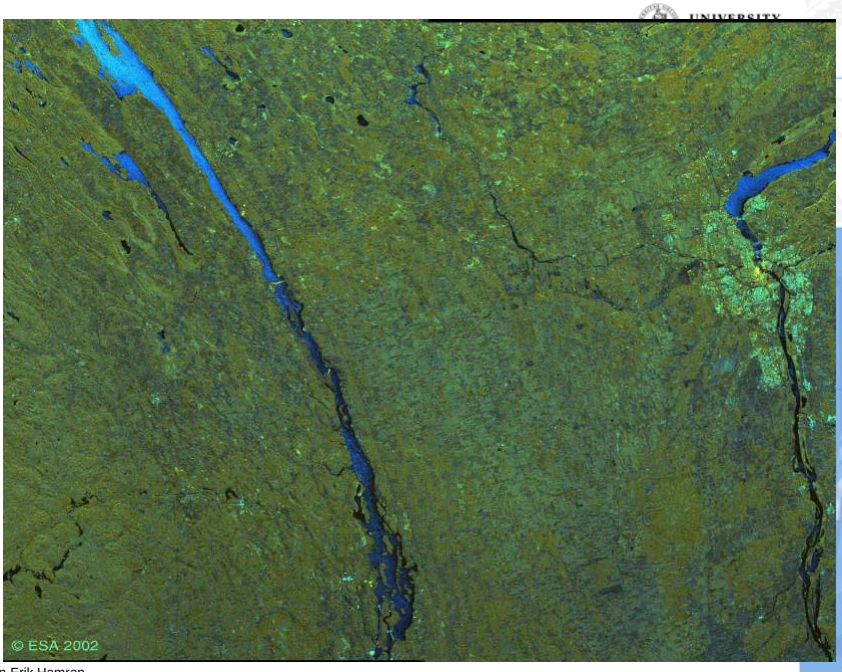

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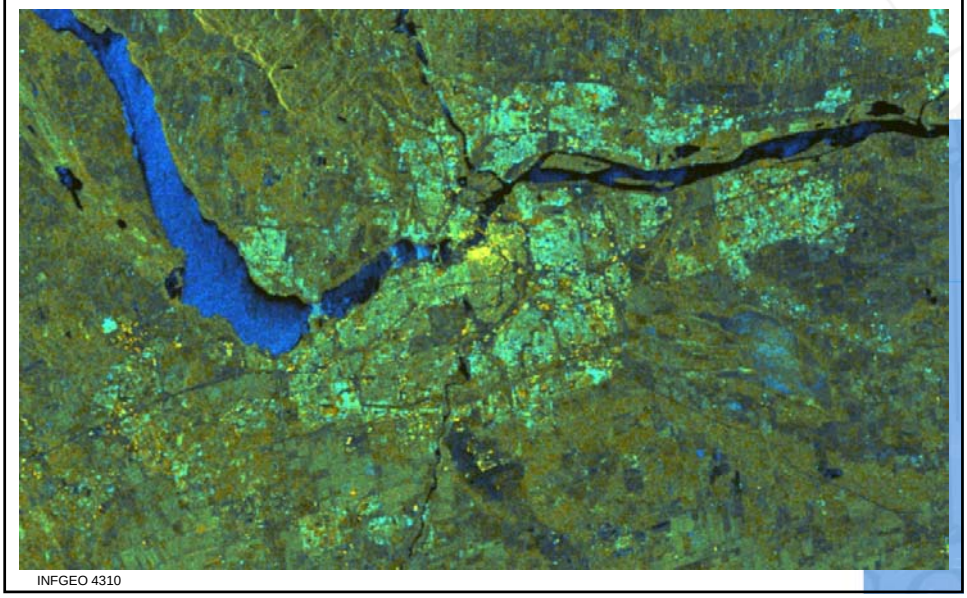
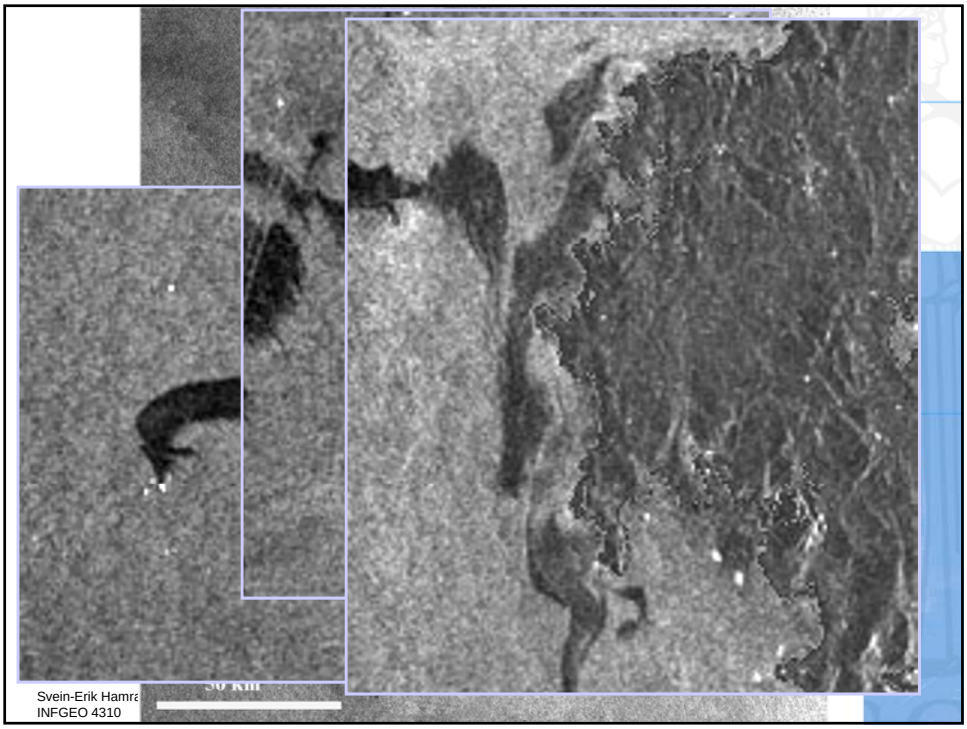
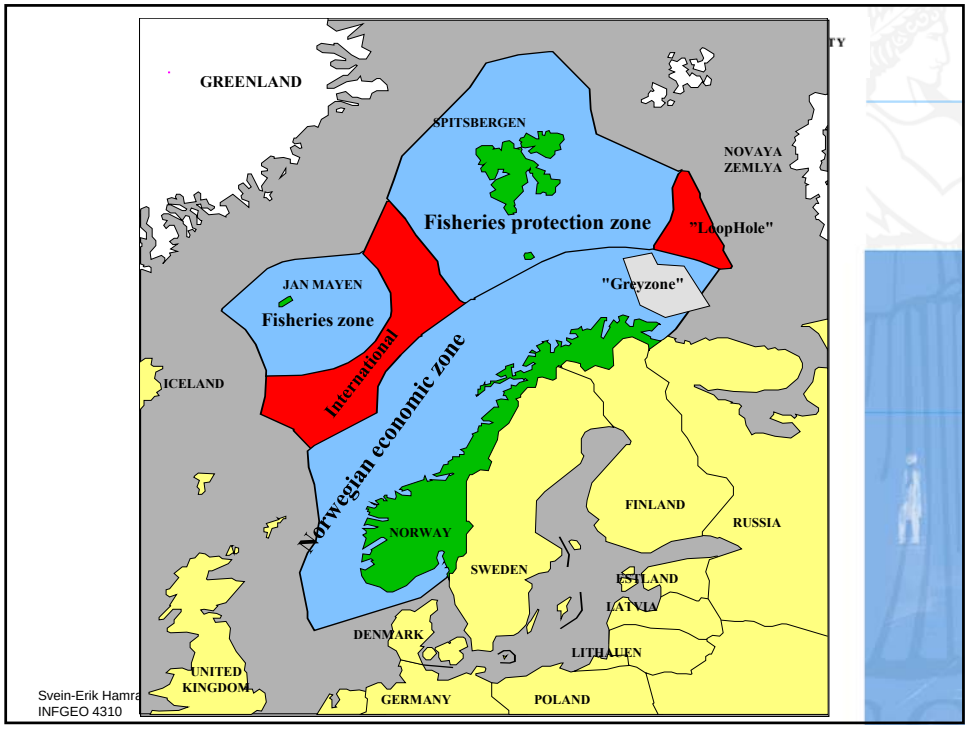
ASAR AP: Ottawa, Canada






GREENLAND
SPITSBERGEN
NOVAYA ZEMLYA
Fisheries protection zone
"LoopHole"
JAN MAYEN
Fisheries zone
"Greyzone"
International
Norwegian economic zone
ICELAND
FINLAND
RUSSIA
NORWAY
SWEDEN
ESTLAND
LATVIA
DENMARK
LITHAUEN
UNITED KINGDOM
GERMANY
POLAND
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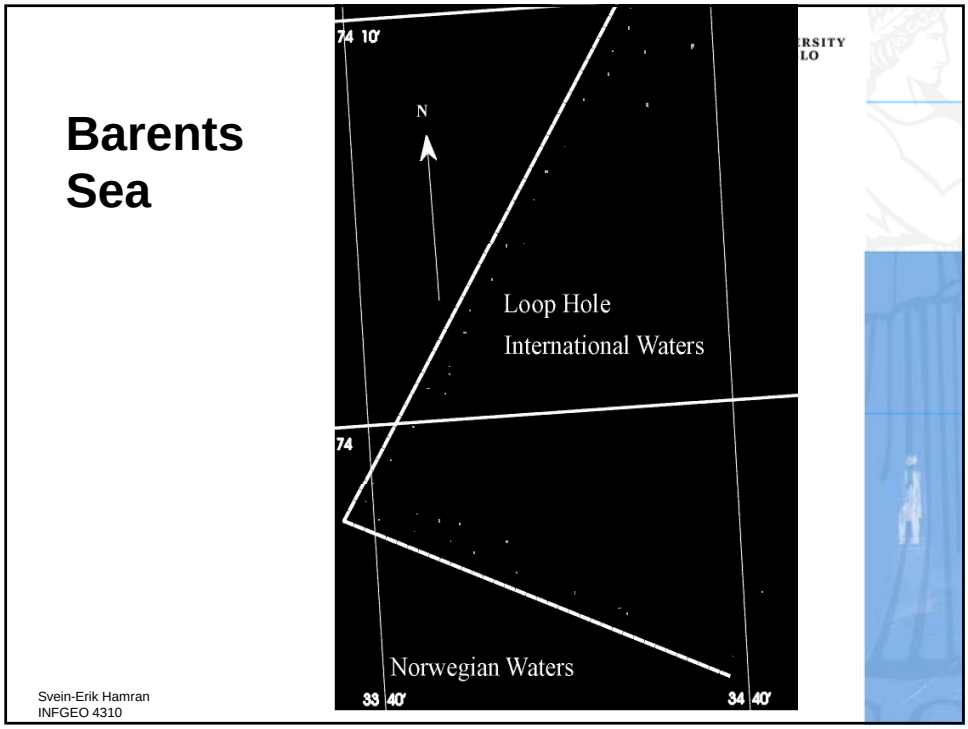
Barents Sea
74 10'
N
Loop Hole
International Waters
74
Norwegian Waters
33 40'
34 40'
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GA/SNL LynxSAR AN/APY-8

- Light weigth SAR-system with real time imaging
- Developed for UAVer: Predator, I-GNAT og Prowler II, weigth is 52 kg
- Four modes: Stripmap, spotlight, GMTI og CCD

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LynxSAR parametere

- Frekvens:	Ku-bånd 15.2 - 18.2 GHz
- Båndbredde:	1 GHz, (15 cm nominell oppløsning)
- Effekt:	350 W
- Oppløsninger:	0.3 - 3 m stripmap 0.1 - 3 m spotlight
- Rekkevidde:	7 - 30 km stripmap 4 - 25 km spotlight
- Sporbredde:	2600 piksel (934 m ved 0.3 m oppløsning, 45º)
- Squint:	± 45º - 135º
- GMTI:	3 m/s (ved 35 m/s), 4 - 25 km, 10 dBsm mål, -10 dBsm/m^2 clutter ,10 km sporbredde
- CCD:	Coherent Change Detection, Interferometri

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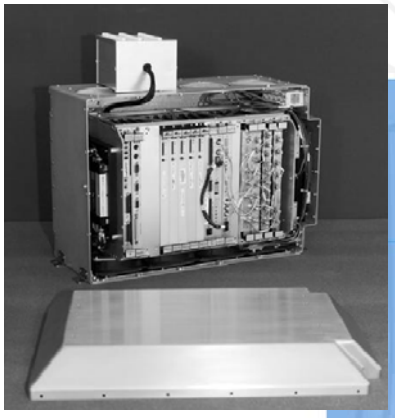
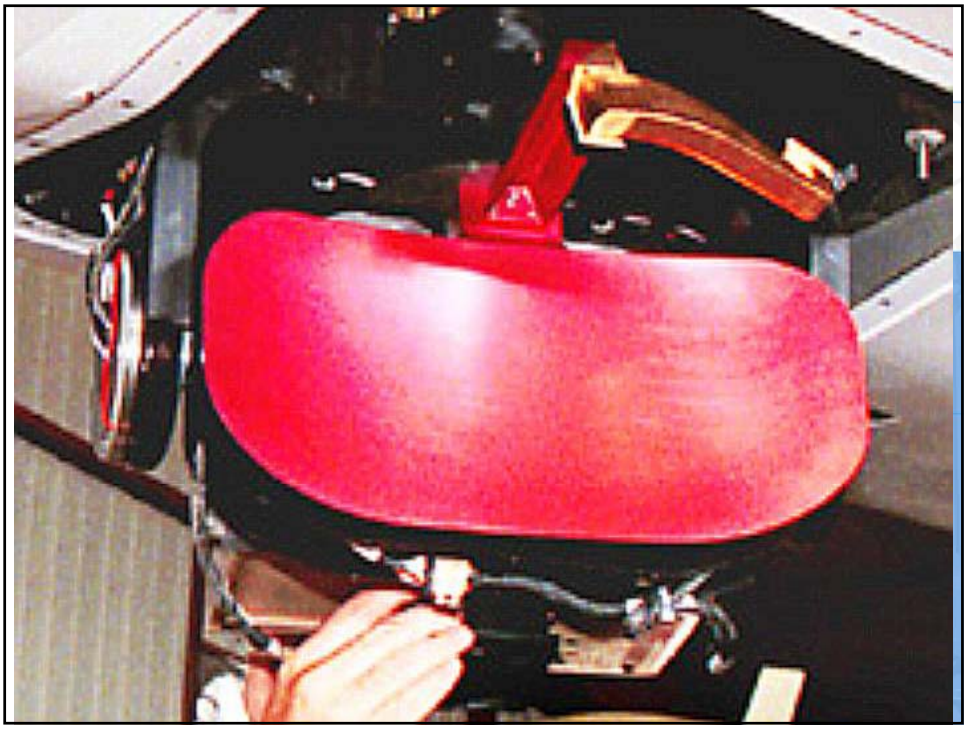
LynxSAR – UAV operations

Ground station



Electronics and Signal processing




Lincoln
Memorial
Sandia
National