basics of synthetic aperture radar

UNIS Glaciology Course

vår 2017

Today's Topics

- microwave radiation
- radar geometry
- synthetic aperture principles
- comparison of optical and sar imagery
- sar sensors and missions

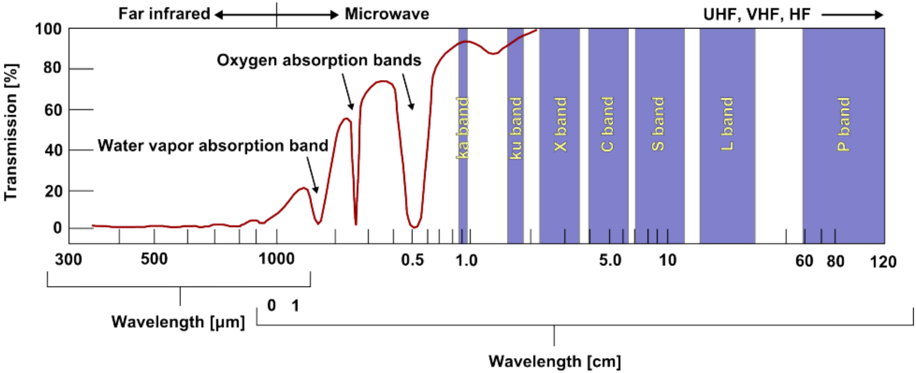
why use sar/microwave images?

- does not require illumination (i.e., can take images at night)
- almost complete penetration of clouds/atmosphere
- frequent repeat coverage (usually every pass is good)
- typically high-resolution (<20 m)

potential issues with microwave images

- interpretation can be difficult
- ability to "see" snow and ice depends on signal wavelength, properties of the surface
- some sensors are generally restricted to winter use for glaciological applications
- tends to require more specialized software, intense computing resources
- ionospheric effects

the electromagnetic spectrum



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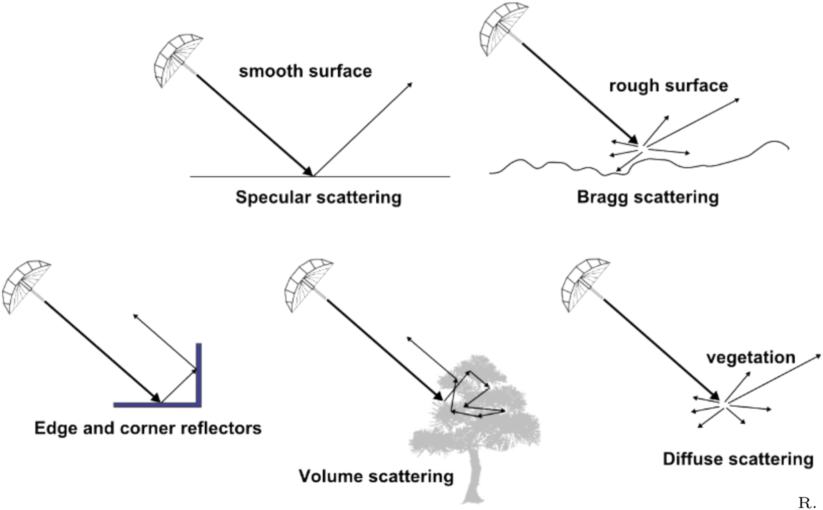
microwave interactions with objects

- properties of the surface determine how much energy is reflected to sensor
- surface roughness (relative to the signal wavelength)
- three basic material properties:
  - electric permittivity (ε)
  - magnetic permeability (μ)
  - electric conductivity (g)
- most of the objects we are interested in non-conductive (so-called dielectric materials)
- generally only interested in ε

microwave interactions with objects

- can generally split ε into two components
- real component defines whether the signal penetrates or reflects at surface of material
- imaginary component describes energy loss (i.e., absorption) on surface, inside of material
- i.e., how deep signal penetrates, how much of incoming energy is re-emitted
- microwave signals will penetrate most materials somewhat (water, very wet snow)

microwave interactions with objects



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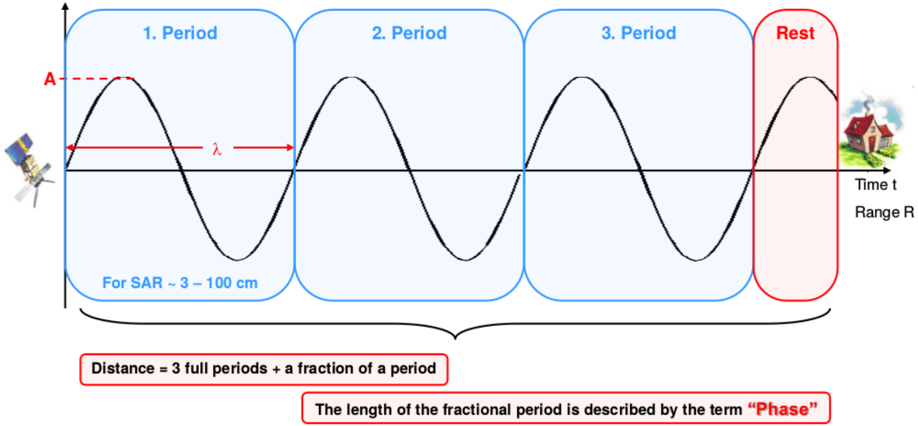
microwave interaction with snow, ice

- electric permittivity of snow, ice (ε) is highly dependent on the liquid water content
- also dependent on the wavelength/frequency of the signal
- dry snow (cold): very low permittivity
- wet snow: less signal penetration (can still see ice lenses, superimposed ice)
- ice: relatively transparent (features like cracks, debris can increase backscatter)

microwave signals

- radar (RAdio Detection And Ranging) is a way to measure distance to a target
- compared to passive remote sensing, we have more information about the signal that's being sent
- when we receive signal, we record amplitude (strength) and phase
- amplitude gives information about target
- phase gives information about distance to target*

amplitude and phase



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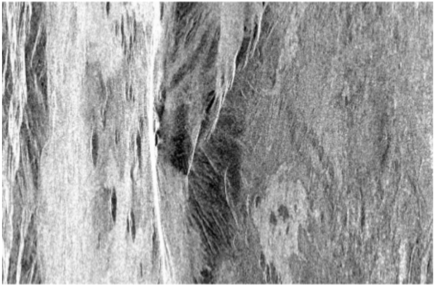
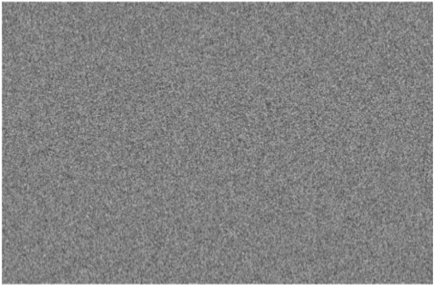
amplitude and phase

- so phase is sensitive to topography (i.e., changing distance between sensor and target)
- phase has a second component, based on the properties of scatterer(s) within a single pixel
- in other words, a sum of a deterministic and random component
- as a result, phase measured in a SAR scene looks like (almost) pure noise
- this also contributes to speckle (apparent noisiness in sar images)
- use coherence (correlation) to describe level of noise in phase data
- as long as the random component of phase is similar, we can measure topopgraphy, movement from two sar scenes (INterferometric SAR)

amplitude and phase





$$\psi = \psi(R) + \psi_{scatt}$$

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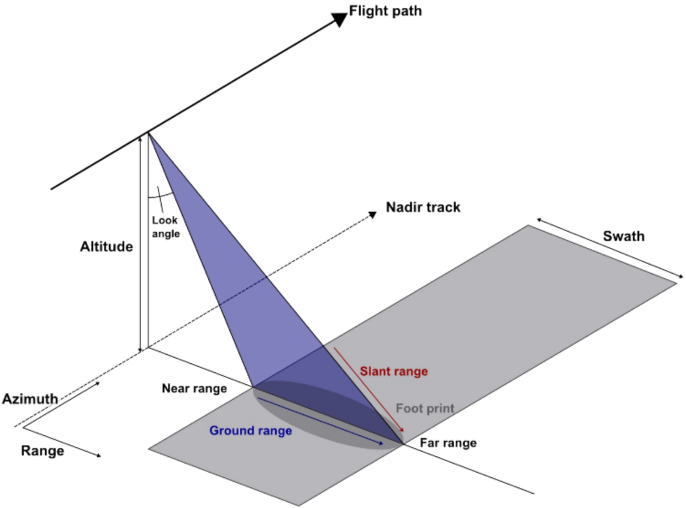
polarity

- recall that em radiation is two perpendicular waves oscillating in magnetic and electric field
- when describing the polarity of the signal, we refer to the orientation of electric field
- usually choose horizontal and vertical planes (relative to antenna, generally)
- can have linear, circular, and elliptical polarization
- sar sensors are typically labeled HH, VV, VH, or HV
- not generally used for glaciology, but very useful for studies of sea ice

radar geometry



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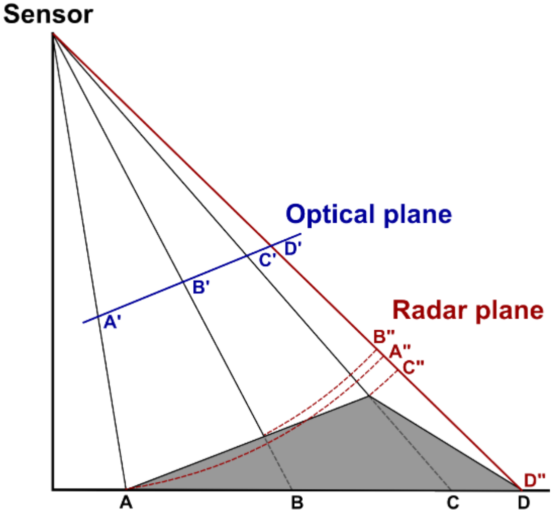
slant range



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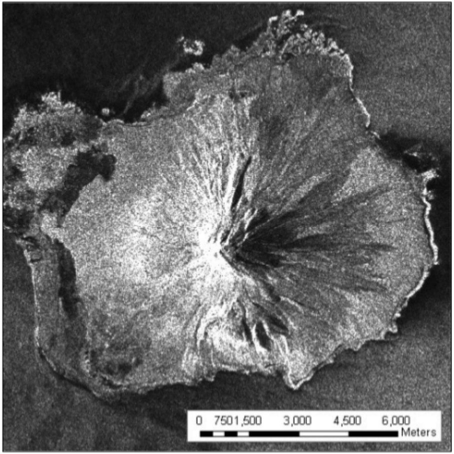
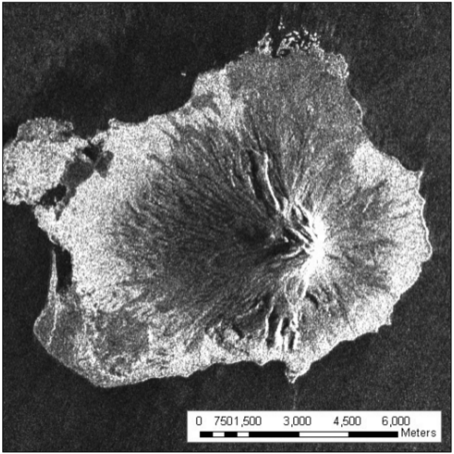
shadow, layover, foreshortening

due to steep/complex topography, we have image distortions:

- shadow: points on the lee side of slope are not seen by signal
- foreshortening: points on the stoss appear closer to summit than they are
- layover: points on the stoss side of the slope appear farther away than summit

shadow effects





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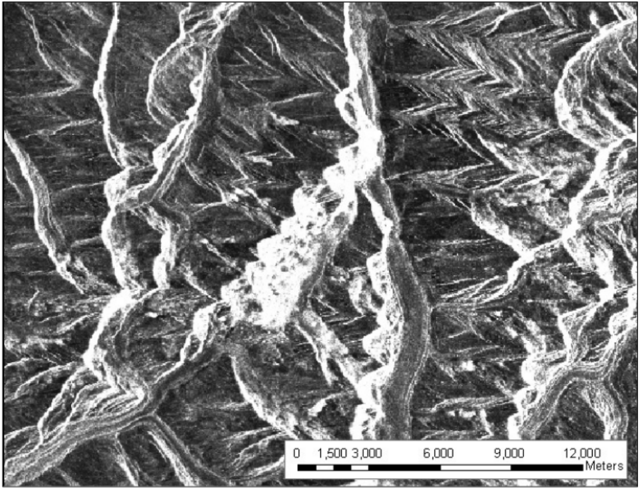
layover effects



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range resolution

a radar system sends out a signal (pulse) of duration τ (s)

- range resolution proportional to τ
- so, for a high range resolution, we have to send a powerful, but short, signal
- this is difficult.

range resolution

instead, we get very clever with our signals

- by sending a frequency-coded signal (chirp), we instead get a range resolution that is inversely proportional to the bandwidth of the signal
- when we receive a return (echo), we can decode by comparing with the original signal (correlation)
- enables us to send comparatively longer signals

azimuth resolution

the question: given two scatterers, what is the smallest possible separation between the two that we can distinguish two objects?

- depends on the antenna beamwidth
- depends on the wavelength of the system
- depends on the distance to the object

real aperture radar

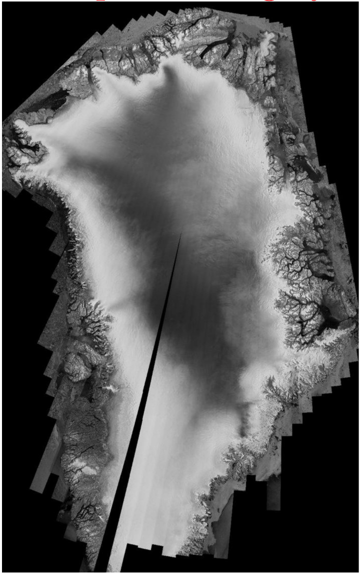
- for a radar system with wavelength λ and antenna size L, the antenna beamwidth θ is given by λ/L
- the azimuth resolution is θ multiplied by the range (distance to the target)
- for a C-band radar with $\lambda = 5.7$cm, orbiting at $\sim$800 km, we need an antenna nearly 10 km in length to obtain an azimuth resolution of 5 m
- not actually possible.

synthetic aperture radar

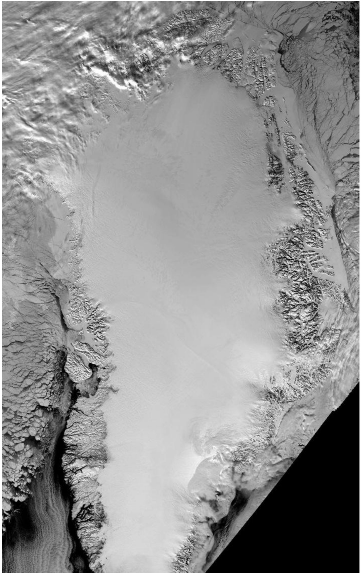
instead, we (again) get very clever with our signals

- by moving the antenna while transmitting coded signals, we get a much longer look at a given point target
- again, the resolution is inversely proportional to the bandwidth of the coded signal
- this bandwidth depends on how big the physical antenna is, and how fast the antenna is moving
- after some math, it turns out that the azimuth resolution is half of the physical antenna size.

sar vs optical imagery

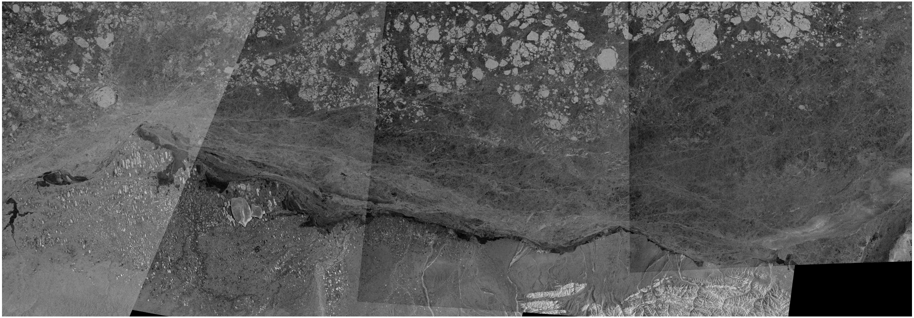


Greenland – RADARSAT-1 Mosaic
C-band – HH polarization

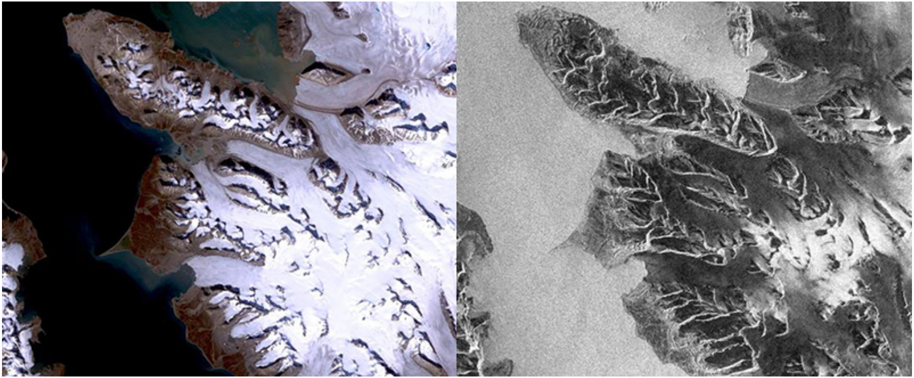


Greenland – MODIS Optical Mosaic

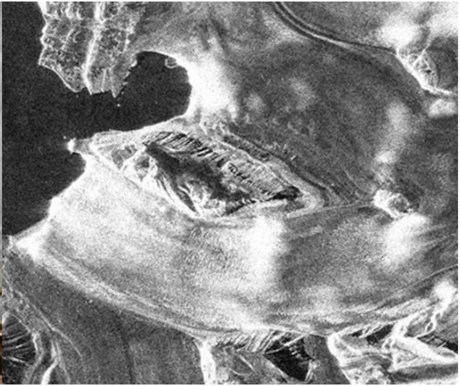
sar vs optical imagery



sar vs optical imagery



sar vs optical imagery



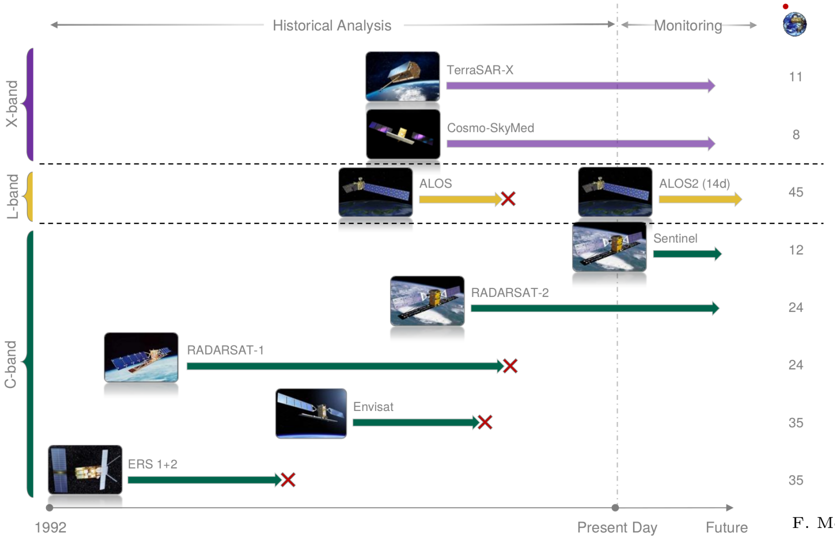
sar satellites

- European Remote-Sensing Satellite (ERS) 1, 2: C-band, ∼25m resolution, 100km swath, 35 day repeat*
  - ERS-1: 1991-2000; ERS-2: 1995-2011
- Radarsat-1: C-band, 10m-100m resolution, 50-500km swath, 24 day repeat; 1995-2013
- Envisat ASAR: C-band, 25m-150m resolution, 100-400km swath, 35 day repeat; 2002-2012
- ALOS PALSAR: L-band, 10m-100m resolution, 30-350km swath, 46 day repeat; 2006-2011

sar satellites

- TerraSAR-X: X-band, 1m-16m resolution, 10-100km swath, 11 day repeat; 2007-present
- Radarsat-2: C-band, 3m-100m resolution, 20-500km swath, 24 day repeat; 2007-present
- Sentinel-1: C-band, 5m-40m resolution, 20-400km swath, 12(6) day repeat; 2014-present
- ALOS-2 PALSAR-2: L-band, 1m-100m resolution, 25-490km swath, 14 day repeat; 2014-present

sar satellites



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questions?