GEOS 639 – INSAR AND ITS APPLICATIONS

GEODETIC IMAGING AND ITS APPLICATIONS IN THE GEOSCIENCES

Lecturer:

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Lecture 2: Introduction to Geodetic Imaging

COLLEGE OF NATURAL SCIENCE & MATHEMATICS
University of Alaska Fairbanks

THE PROBLEM OF GEODESY

What is Geodesy

- Classical definition by F. R. Helmert (1880): **Geodesy is the "science of the measurement and mapping of the earth's surface."** It includes determination of earth's shape (**Geometric Geodesy**), and gravity field (**Physical Geodesy**), as well as temporal variations of these variables.

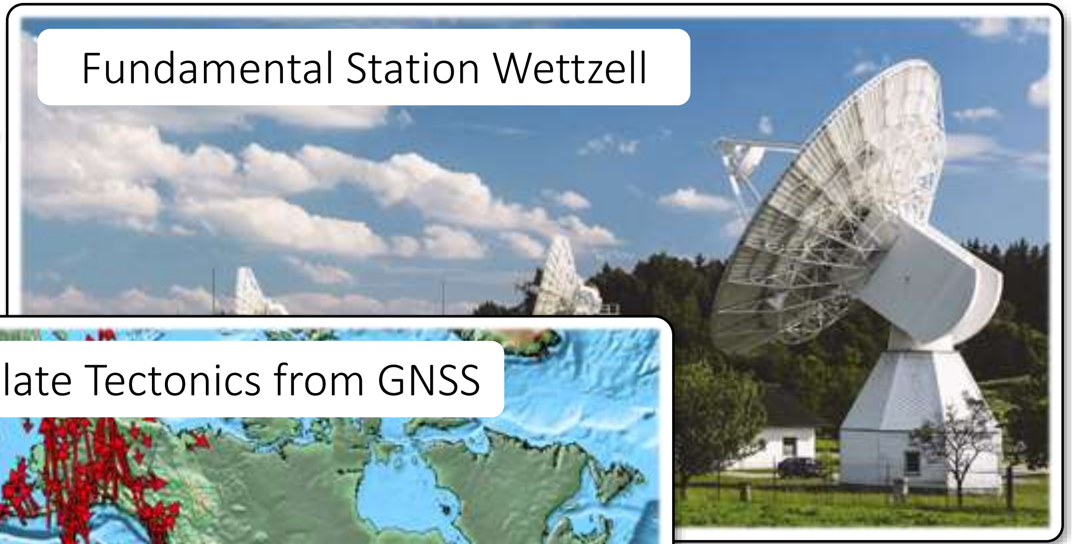
The Problem of Geodesy

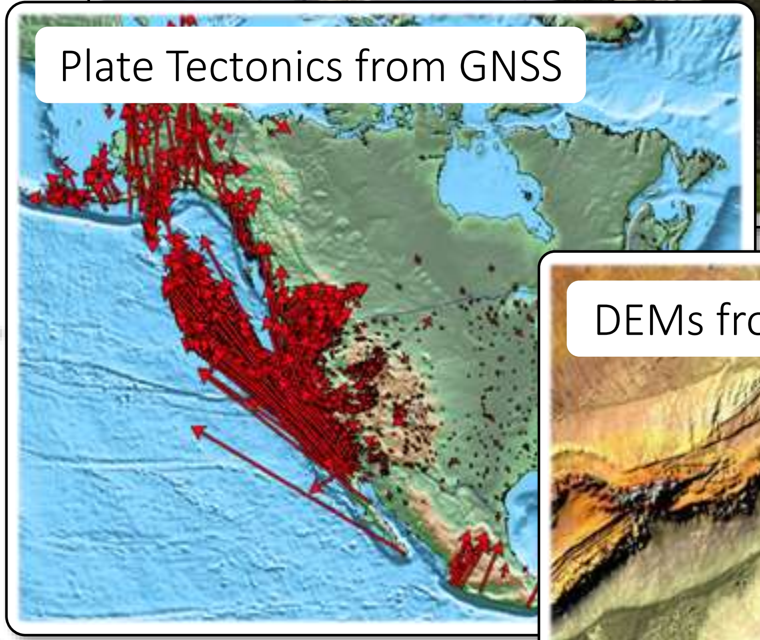
"The problem of geodesy is to determine the figure of the earth [and of other celestial bodies] as functions of time." [Fischer, 1975]

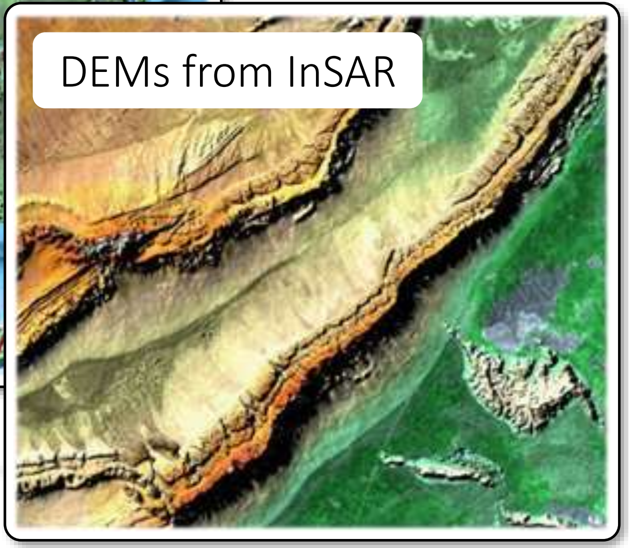
- **Determining the figure of the earth includes measuring its *physical* and *mathematical* surface**
  - Physical surface of the earth is the border between solid earth and atmosphere → Geometrical Geodesy is concerned with establishing coordinate systems and assigning coordinates to locations on the physical surface
  - Physical geodesy is concerned with determining the Earth's gravity field, which is necessary for establishing heights. It establishes the Geoid (surface of constant gravity potential) as the earth's mathematical surface.

Applications of Geodesy

- Typical applications of Geodesy include:
  - Satellite orbit determination
  - Position the earth in a reference system based on quasars
  - Use spaceborne sensors to study variations in mean sea level, ocean circulation, ground water & ice sheet changes
  - Measure earths gravity field and its temporal changes
  - Use Global Navigation Satellite Systems (GNSS) to study plate tectonics, volcanic activity, post-glacial rebound, …
  - Use remote sensing to map the earth's topography & motion
  - Geodesy plays an active role in disciplines of land surveying, photogrammetry, remote sensing, hydrography, cartography, geographic information science, and geospatial computing.





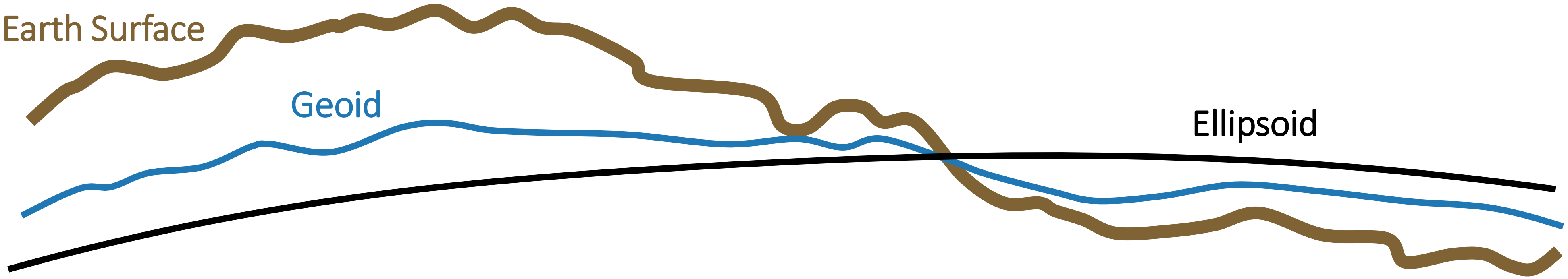


GEODETIC REFERENCE SYSTEMS

Geodetic Reference Systems

- **Reference systems are needed to describe the motion of the earth in space (celestial system), and quantify earth's surface geometry and its change (terrestrial system)**
- For global geodesy, the use of three-dimensional Cartesian coordinates in Euclidian space is adequate

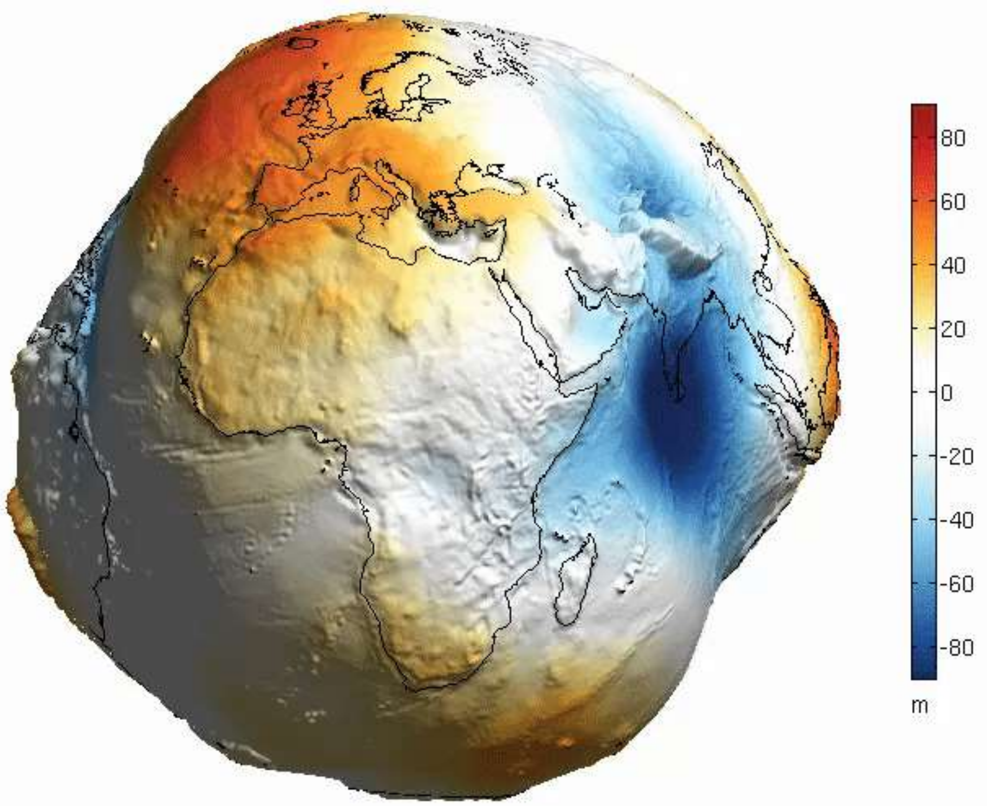
- Large variations in surface topography make it impossible to approximate the shape of the Earth with simple mathematical models → two main reference surfaces were established to approximate the shape of Earth
  - One reference surface is called the ***Geoid***,
  - the other reference surface is the ***Ellipsoid***



Earth Surface and Reference Surfaces

The Geoid and the Vertical Datum

- We can simplify matters by imagining that the entire Earth's surface is covered by water.
- If we ignore tidal and current effects on this 'global ocean', the resultant water surface is affected only by gravity.
- This has an effect on the shape of this surface because the direction of gravity - more commonly known as plumb line - is dependent on the mass distribution inside the Earth.
- Due to irregularities or mass anomalies in this distribution the 'global ocean' results in an undulated surface.
- **This surface is called the *Geoid*.**

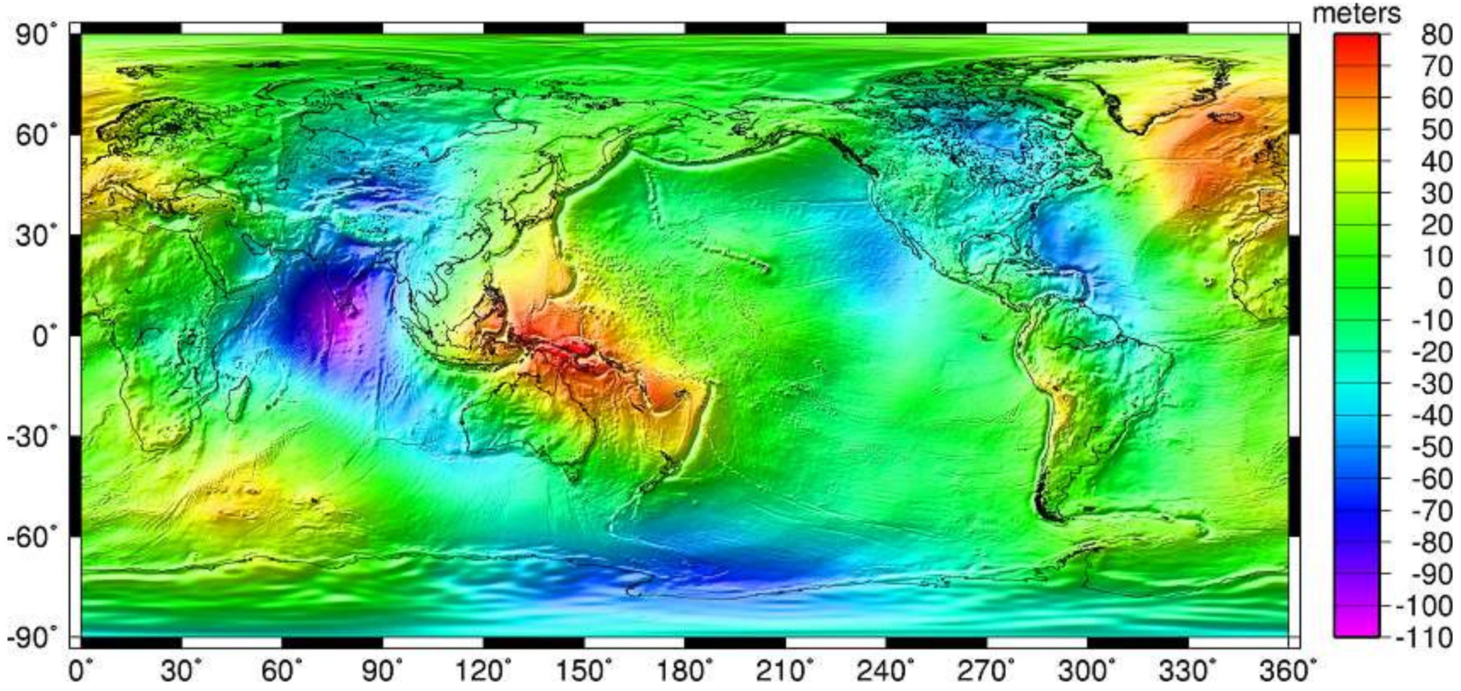


Geoid height (EGM2008, nmax=500)

The Geoid and the Vertical Datum

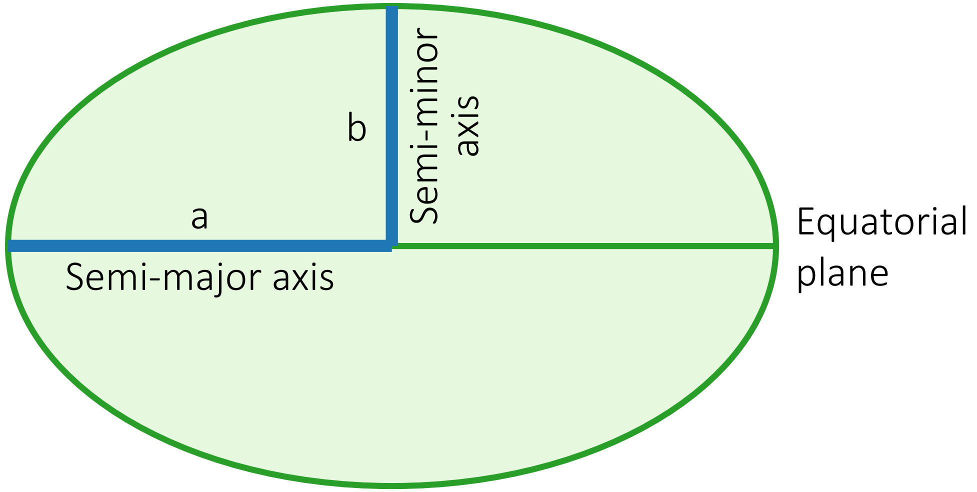
- Where a mass deficiency exists, the Geoid will dip below the mean ellipsoid and vice versa
- These influences cause the Geoid to deviate from a mean ellipsoidal shape by up to +/- 100 meters.
- The biggest undulations are: minimum in the Indian Ocean (N = -100 meters) and maximum in the northern part of the Atlantic Ocean with N = +70 meters (figure below).

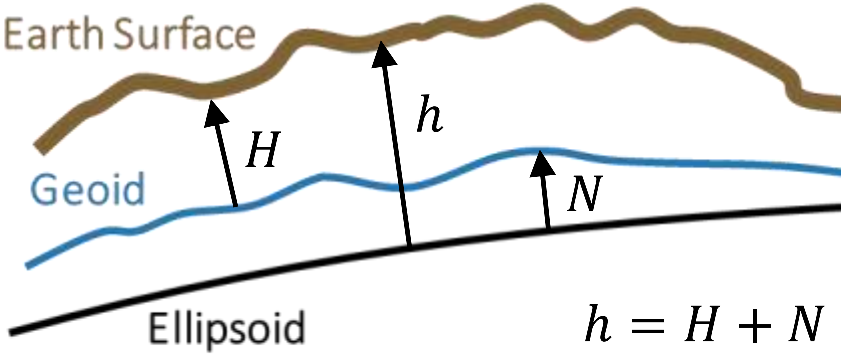
- Heights measured relative to the Geoid are called **orthometric heights**



The Ellipsoid

- We also need a reference surface for the description of the horizontal coordinates (i.e. geographic coordinates) of points of interest.
- The most convenient geometric reference is the ***oblate ellipsoid*** (left figure). It Is chosen to fit the Geoid to a first order approximation.
- Heights measured relative to the Ellipsoid are called **ellipsoid heights**
- Ellipsoid h, orthometric H, and geoid heights N are related via: $h = H + N$





Relationship between ellipsoid, orthometric, and geoid heights

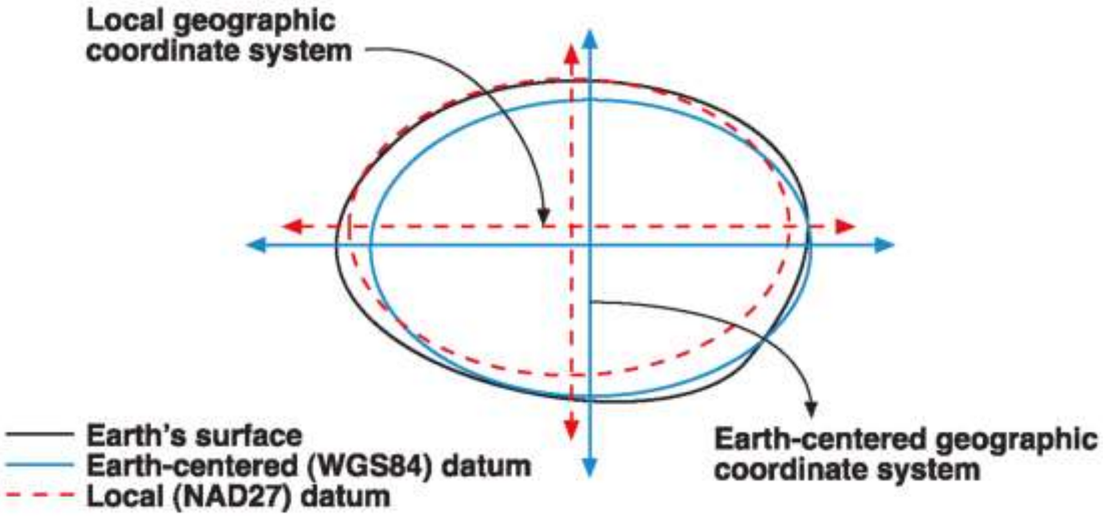
Local Ellipsoids and Local Datums

- ***Local ellipsoids*** were established to fit the Geoid over an area of local interest
- In contrast, ***global reference ellipsoids*** approximate the Geoid as a mean Earth ellipsoid.
- Popular global ellipsoids include WGS-72 (World Geodetic System 1972 established by the National Geospatial Intelligence Agency in 1972), GRS-80 (Geodetic Reference System 1980; originally used by WGS-84; now WGS-84 differs from GRS-80), and WGS-84 established by NGA as reference coordinate system for the Global Positioning System (GPS)
- A local datum aligns its spheroid to closely fit the earth's surface in a particular area

Datum	Ellipsoid	Datum shift (m)* (Dx,	Dy,	Dz)
Alaska (NAD-27)	Clarke 1866	-5	135	172
Bahamas (NAD-27)	Clarke 1866	-4	154	178
Bermuda 1957	Clarke 1866	-73	213	296
Central America (NAD-27)	Clarke 1866	0	125	194
Bellevue (IGN)	Hayford	-127	-769	472
Campolnchauspe	Hayford	-148	136	90
Hong Kong 1963	Hayford	-156	-271	-189
Iran	Hayford	-117	-132	-164

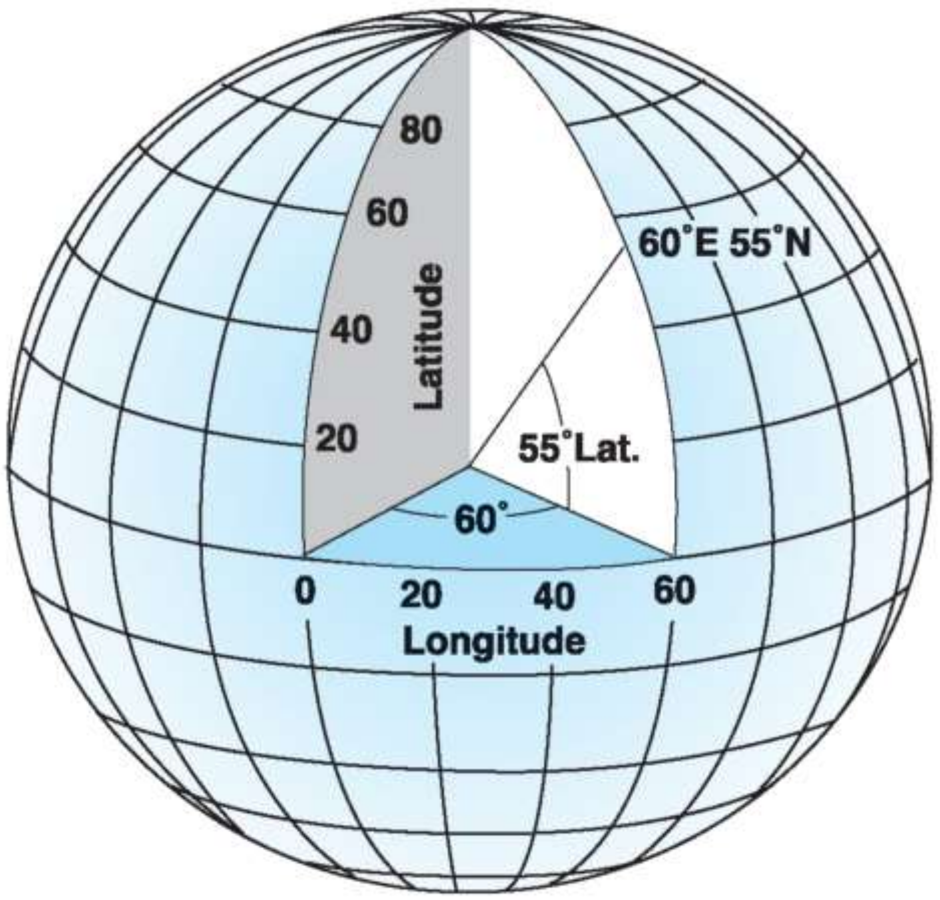
* positions compared to WGS84

Example local datums



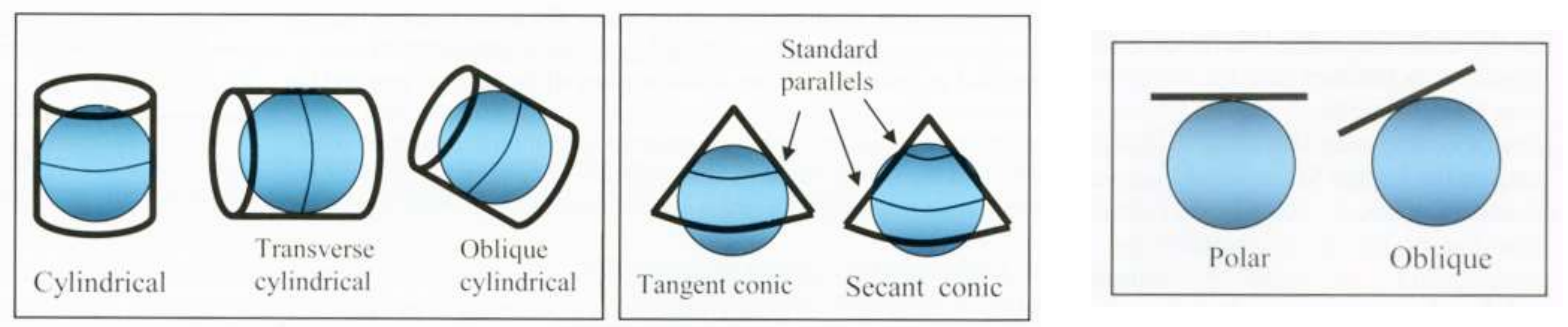
Geographic Coordinate Systems

- A geographic coordinate system (GCS) uses a 3-dimensional spherical surface to define locations on the earth.
- A GCS includes an angular unit of measure, a prime meridian, and a datum (based on a spheroid).
- A point is referenced by its longitude and latitude values. Longitude and latitude are angles measured from the earth’s center to a point on the earth’s surface.
- Latitude and longitude values are traditionally measured either in decimal degrees or in degrees, minutes, and seconds (DMS).
- Latitudes are measured relative to the equator and range from -90° (South Pole) to +90° (North Pole).
- Longitudes are relative to the prime meridian ranging from -180° when traveling west to 180° when traveling east.



Projection Coordinate Systems

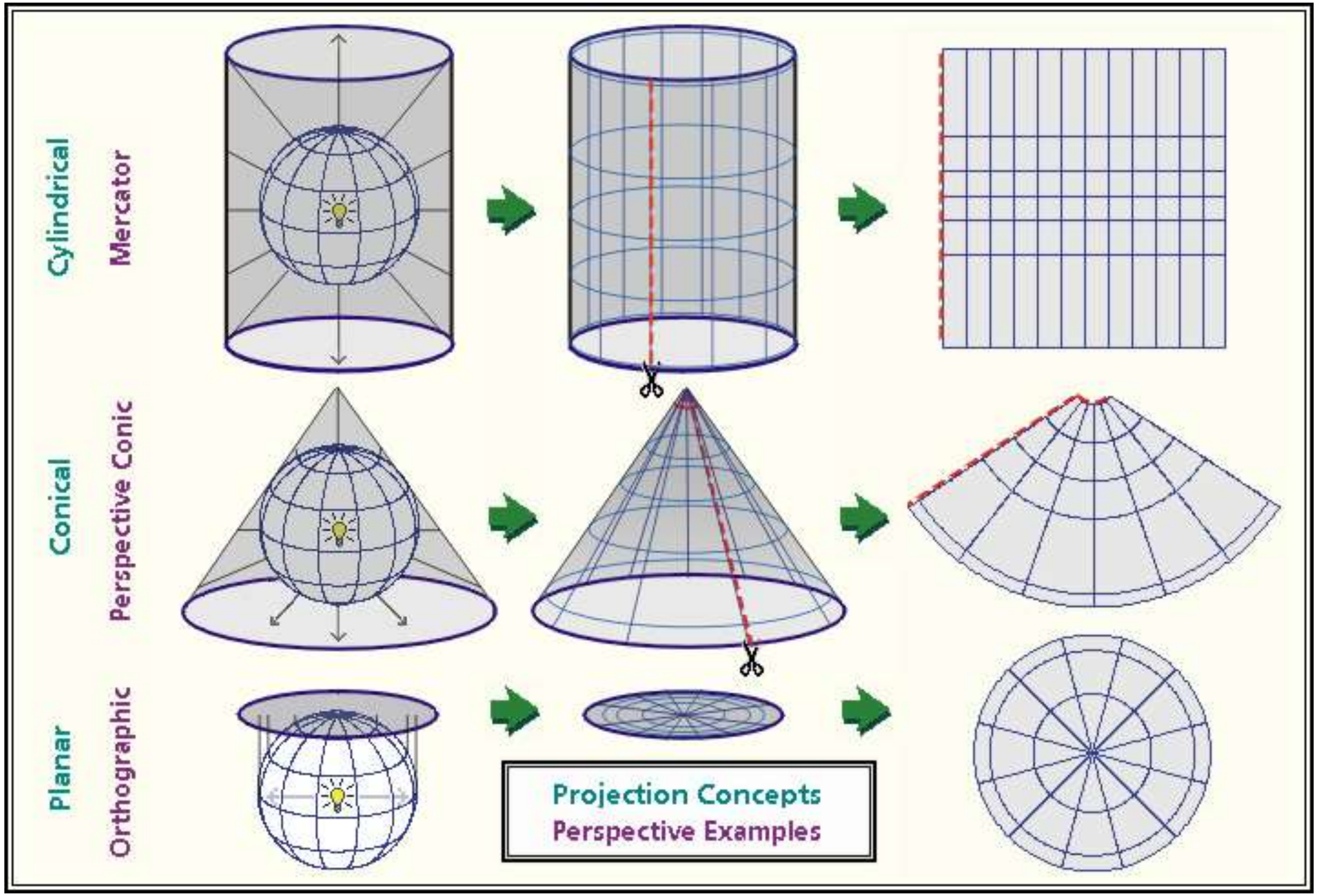
- Projected coordinate systems are defined on a flat, two-dimensional surface.
- Unlike a geographic coordinate system, a projected coordinate system has constant lengths, angles, and areas across the two dimensions.
- In a projected coordinate system, locations are identified by x,y coordinates on a grid, with the origin at the center of the grid.



Map Projection Types

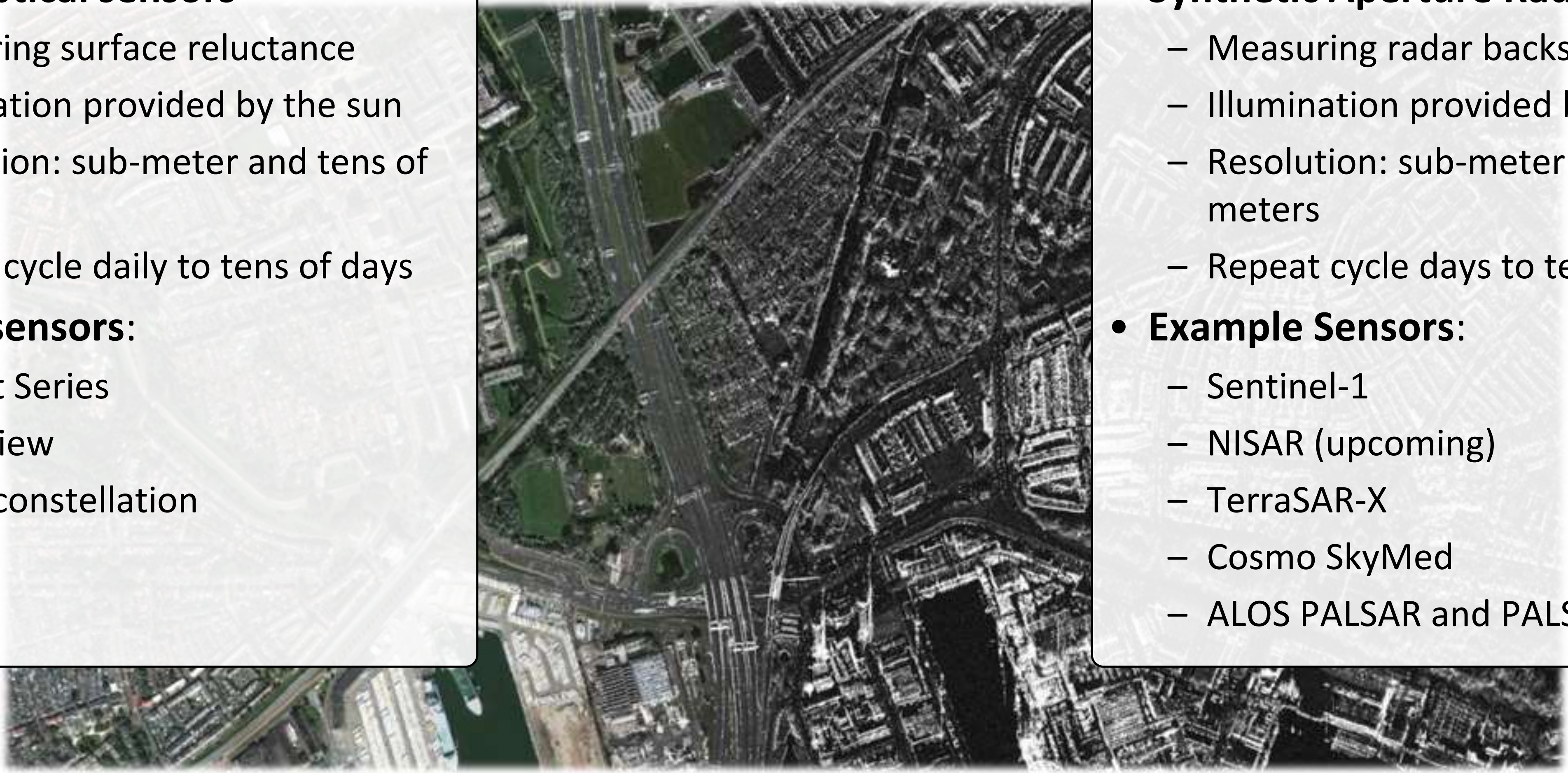
Map Projections

- The mathematical transformation of the 3-D surface into a flat map sheet is called map projection
- The visualizations on the right show how projections alter spatial properties leading to distortions.
  - **Conformal projections** preserve local shape (maintains all angles)
  - **Equal area projections** preserve the area of displayed features
  - **Equidistant maps** preserve the distances between certain points



SENSOR TYPES RELEVANT FOR THIS COURSE

Sensor Types Relevant for this Course



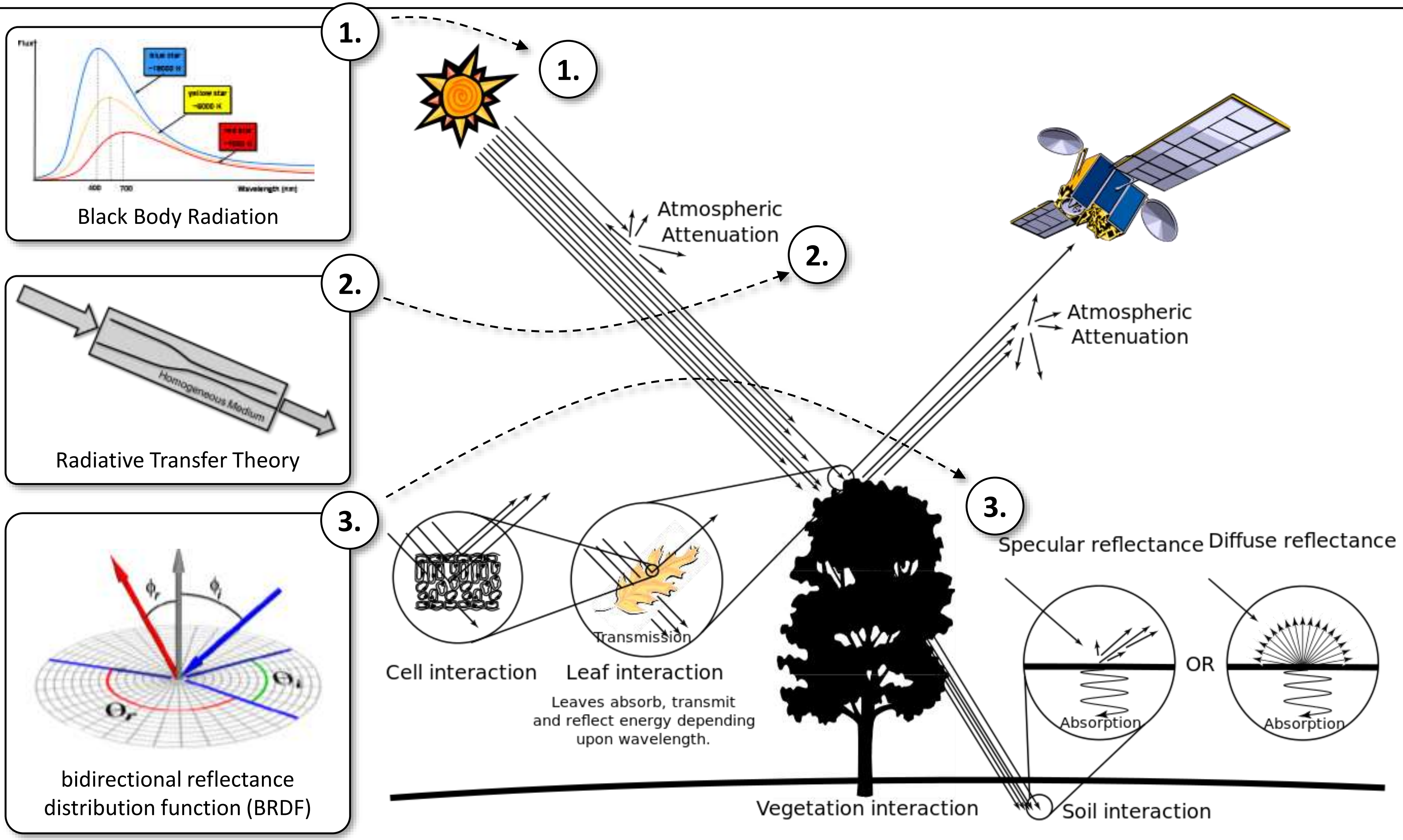
- **Electro Optical sensors**
  - Measuring surface reluctance
  - Illumination provided by the sun
  - Resolution: sub-meter and tens of meters
  - Repeat cycle daily to tens of days
- **Example sensors**:
  - Landsat Series
  - Worldview
  - Planet constellation

- **Synthetic Aperture Radar (SAR)**
  - Measuring radar backscatter
  - Illumination provided by sensor
  - Resolution: sub-meter to tens of meters
  - Repeat cycle days to tens of days
- **Example Sensors**:
  - Sentinel-1
  - NISAR (upcoming)
  - TerraSAR-X
  - Cosmo SkyMed
  - ALOS PALSAR and PALSAR-2

Sensor Types Relevant for this Course

1. Optical Remote Sensing Systems

The Genesis of an Electro Optical Image



Relevant Sensor Parameters

1. **Spatial resolution**
   – Ability to separate parts of targets or other properties pertinent to RS

2. **Spectral resolution**
   – location, width and sensitivity of chosen λ bands

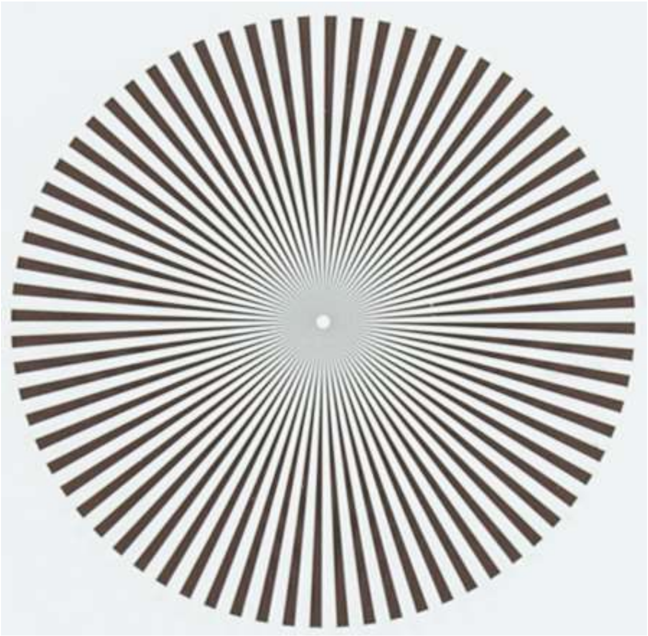
3. **Temporal sampling**
   – time between observations

4. **Radiometric resolution**
   – Sensitivity of the sensor to incoming radiance

1. Spatial Resolution

- **Minimum distance at which two objects can still be distinguished**
- The smallest quantity measurable in an image
- **Measuring spatial resolution of image data:**
  – Calibration targets:

Calibration Site in Sjökulla, Finland



Siemens Star Calibration Target

1. Spatial Resolution

Spatial Resolution vs. Pixel Size

Resolution vs. Pixel Size

Resolution: 10m
Pixel size: 10m

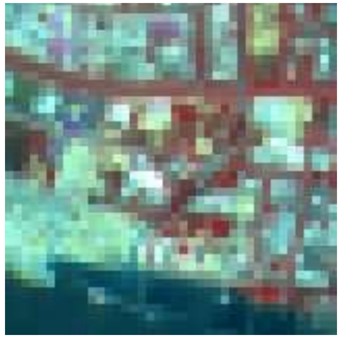
Resolution: **30m**
Pixel size: 10m

Resolution: **80m**
Pixel size: 10m

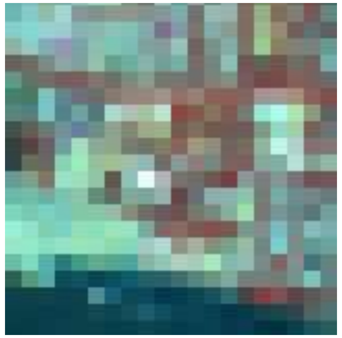
Resolution and visual appearance of images

Pixel size & res: 10m
160×160 pixels

Pixel size & res: **20m**
80×80 pixels



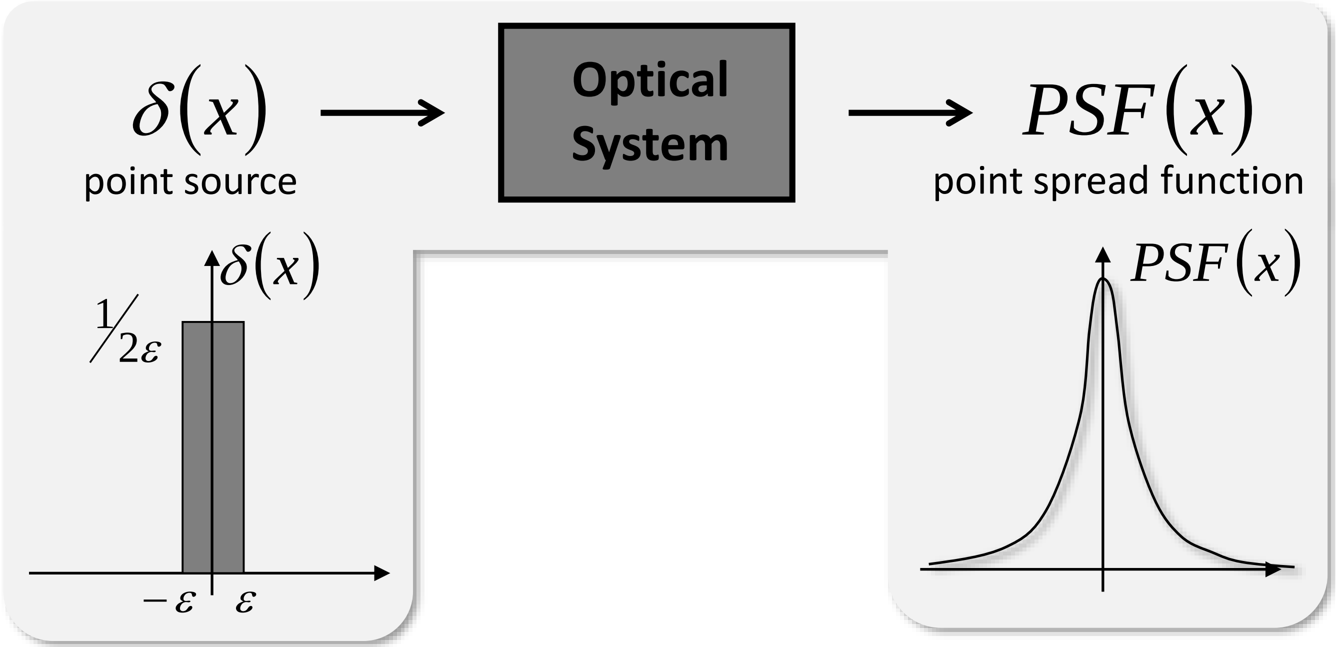
Pixel size & res: **40m**
40×40 pixels



Pixel size & res: **80m**
20×20 pixels

1. Spatial Resolution
Point Spread Function

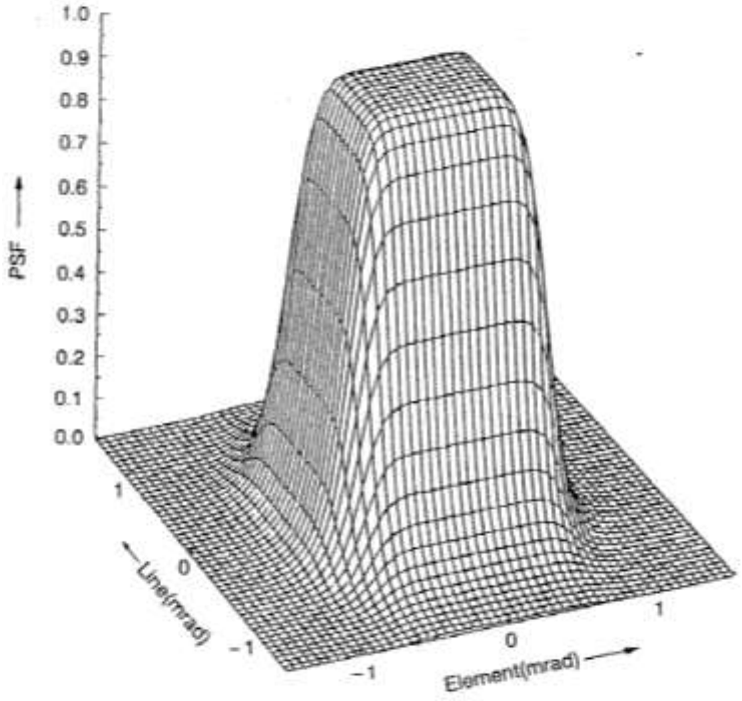
- **Point Spread Function**: Response of imaging system to a point source stimulant



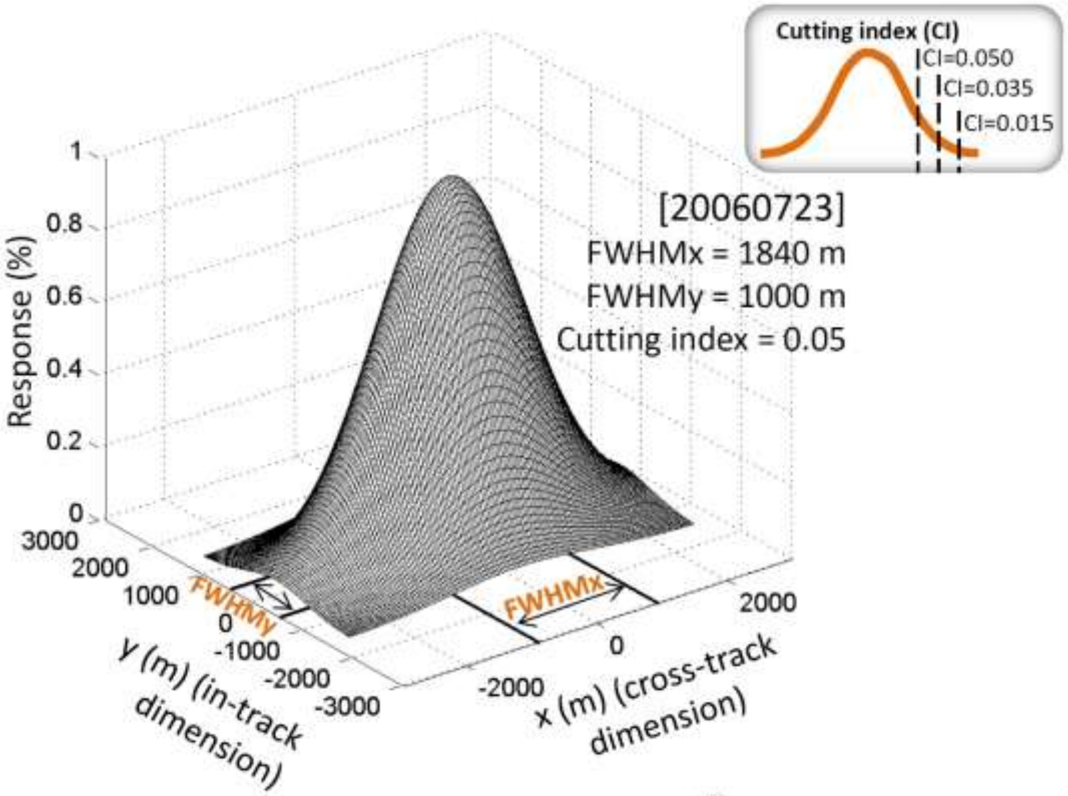
- **Idealized case**: pixel response is same as source impulse $\delta(x)$
- **In practice**: each pixel responds imperfectly to input signal (→ $\delta(x)$ deteriorates to a broader $PSF(x)$)

1. Spatial Resolution

Point Spread Function of Real Sensors



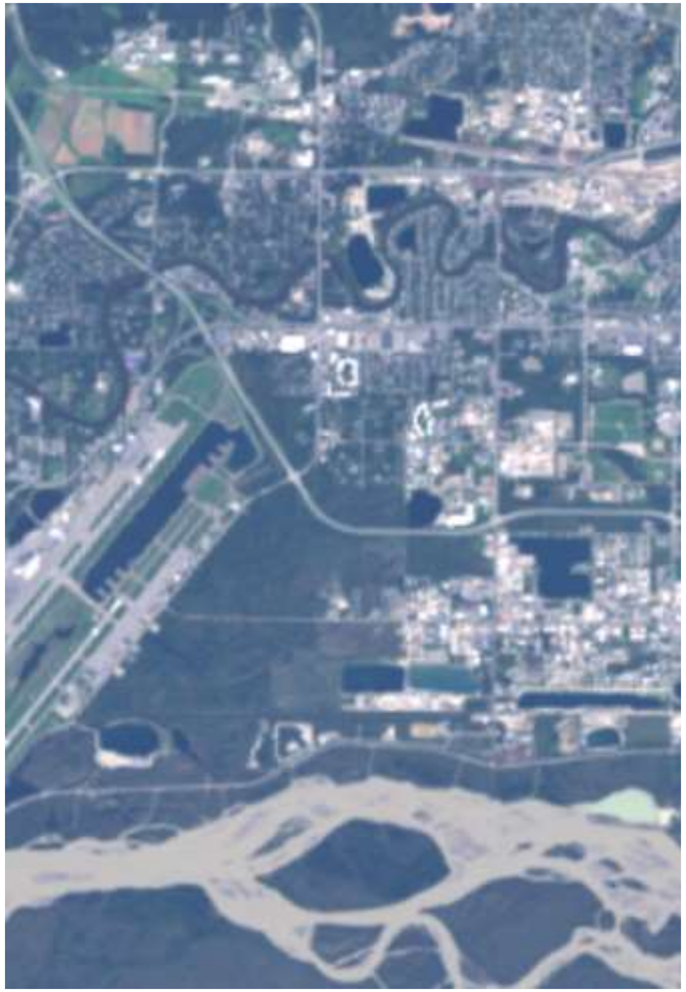
Example PSF of AVHRR Sensor



Average PSF of MODIS Bands 8 - 19

2. Spectral Resolution

panchromatic: 500-680 nm



Landsat 8

R: 640-670 nm G: 530-590 nm
B: 450-510 nm

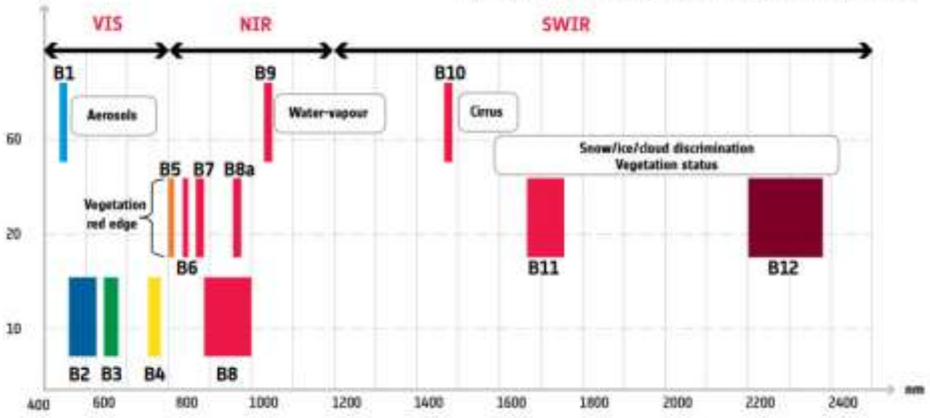
2. Spectral Resolution

- **Measure of wavelength discrimination:**
  - Smallest λ difference that can be detected
  - Width of the sensor spectral response

- Number & spacing of spectral bands also critical for discrimination

- **Typical spectral characteristics:**
  - Panchromatic – 1 band
  - Color – 3 bands (RGB)
  - **Multispectral** – 4+ bands
  - Hyperspectral – 100+ bands

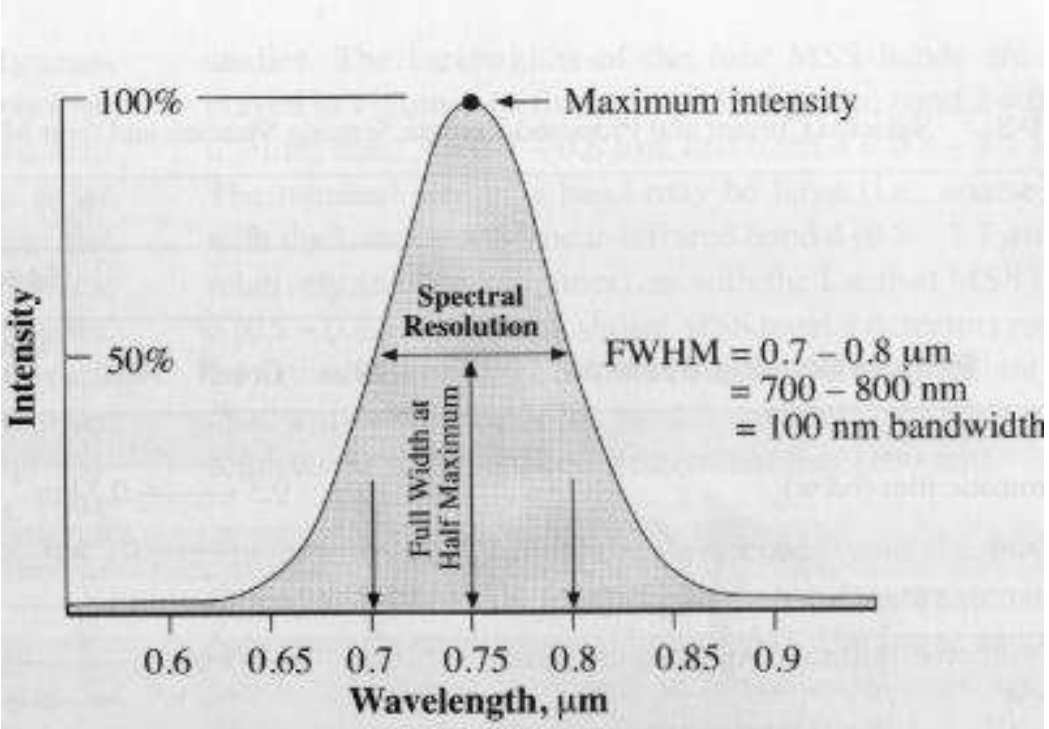
Source: http://esamultimedia.esa.int/docs/EarthObservation/Sentinel-2_ESA_Bulletin161.pdf



↑ Spatial resolution versus wavelength: Sentinel-2's span of 13 spectral bands, from the visible and the near-infrared to the shortwave infrared at different spatial resolutions ranging from 10 to 60 m on the ground, takes land monitoring to an unprecedented level

2. Spectral Resolution

- **Expressed by full width at half-maximum (FWHM) response**



b. Precise bandpass measurement of a detector based on Full Width at Half Maximum (FWHM) criteria

Wavelengths beyond the FWHM still contribute considerably to measurement

3. Temporal Sampling

Repeat period crucial for resolving dynamic processes

May 27, 2019

May 28, 2019

May 29, 2019

May 30, 2019

64.12N, 158.56 W

Ice break-up
Tanana River

planet.

Cubesat constellation: daily coverage

Think – Pair – Share

Temporal Sampling and Feature Tracking

- You want to develop an algorithm to measure the velocity of glacier flow using a time series of Landsat imagery such as the data to the right
  - **Q1**: What approach would you use to measure glacier flow from this time series
  - **Q2**: How may the temporal sampling provided by Landsat influence your algorithm design?

4. Radiometric Resolution

- Sensitivity of measurement

  Smallest change in intensity that can be distinguished

16 Values (4 bit)

- Digital images

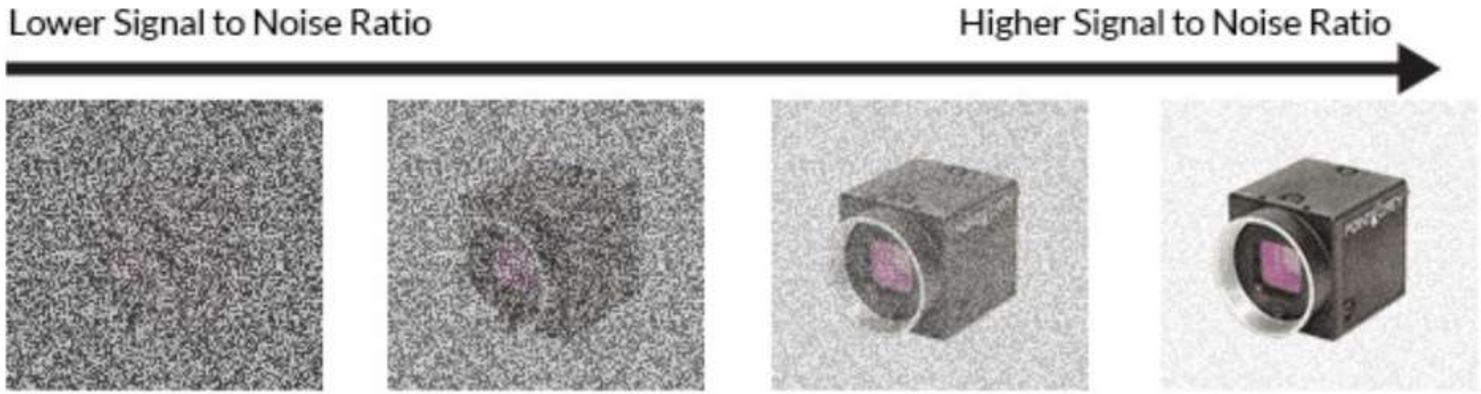
  # bits often referred to as radiometric resolution

4 Values (2 bit)

Signal to noise ratio

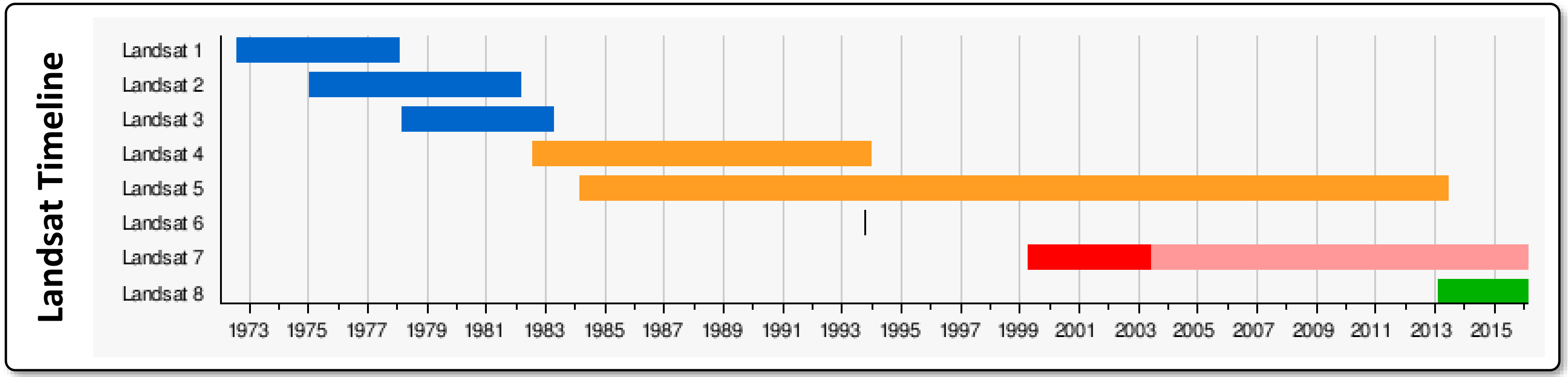
A complementary way of describing measurement fidelity

$$SNR\ [dB] = 10 \log_{10} \frac{P_{signal}}{P_{noise}}$$



The Landsat Program

- **Landsat 1**: 1972 – 1978
- **Landsat 2**: 1975 – 1981
- **Landsat 3**: 1978 – 1983
- **Landsat 4**: 1982 – 1993
- **Landsat 5**: 1984 – 2013
- **Landsat 6**: 1993, failed to reach orbit
- **Landsat 7**: 1999, still functioning, but with faulty scan line corrector (May 2003)
- **Landsat 8**: 2013, still active
- **Landsat 9:** Launched 2021



Key Features of the Landsat Program

- **Orbits are sun synchronous**: satellite crosses equator southbound on day side at about 10 AM local time
- **Orbits repeat ground track precisely every 14-18 days** (Revisit period)
- **All sensors in the series are compatible** (main bands were not changed just improved in resolution and new bands were added)

Spectral Bands of Landsat-7

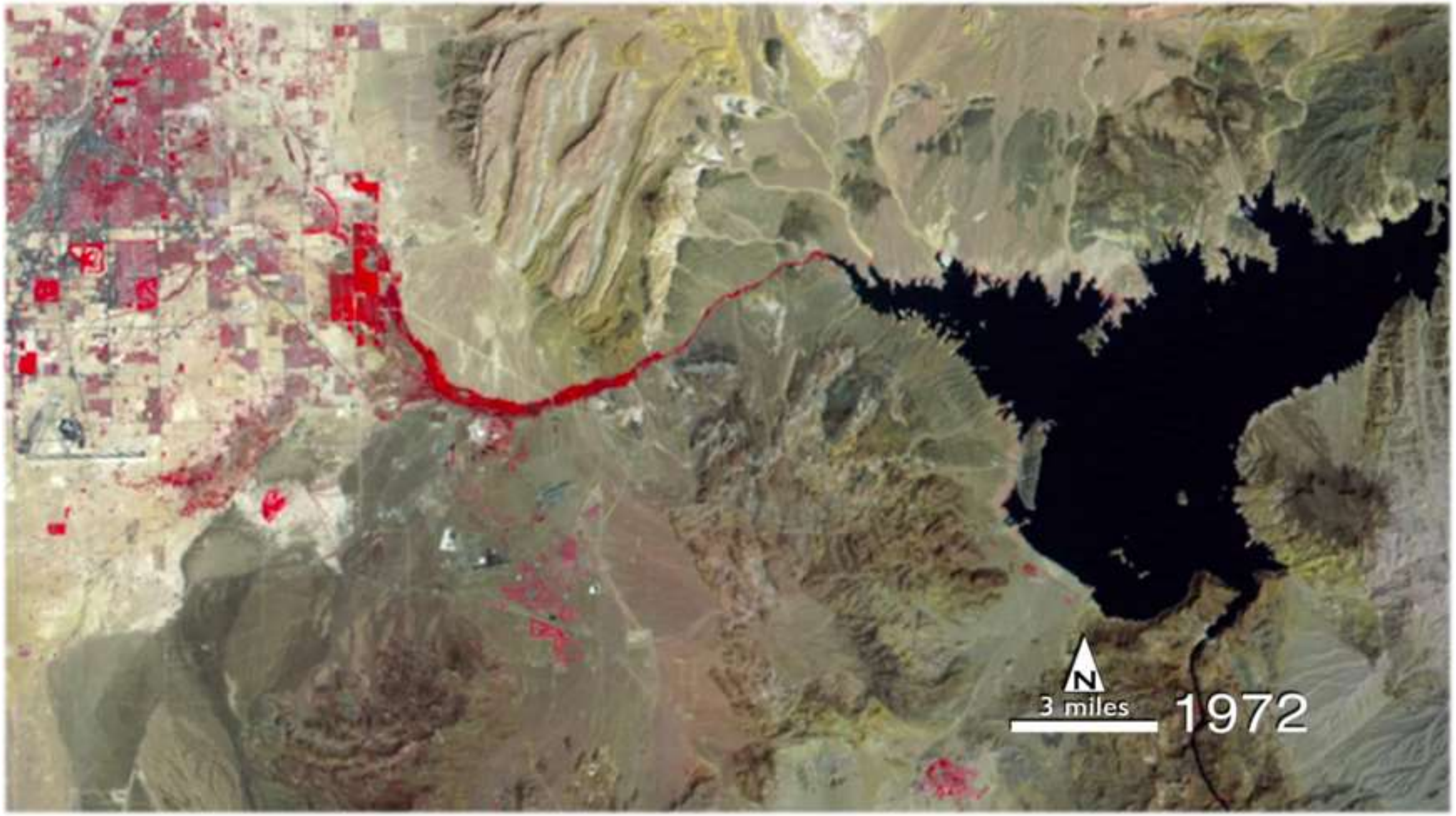
1	0.45-0.52µm	Blue-Green	30 m
2	0.52-0.60 µm	Green	30 m
3	0.63-0.69 µm	Red	30 m
4	0.76-0.90 µm	Near IR	30 m
5	1.55-1.75 µm	Mid-IR	30 m
6	10.40-12.50 µm	Thermal IR	60 m
7	2.08-2.35 µm	Mid-IR	30 m
	0,52-0.90 µm	Panchromatic	15 m

Uses of Landsat Bands

1. Coastal water mapping, soil/vegetation discrimination, forest classification, man-made feature identification
2. Vegetation discrimination and health monitoring, man-made feature identification
3. Plant species identification, man-made feature identification
4. Soil moisture monitoring, vegetation monitoring, water body discrimination
5. Vegetation moisture content monitoring
6. Surface temperature, vegetation stress monitoring, soil moisture monitoring, cloud differentiation, volcanic monitoring
7. Mineral and rock discrimination, vegetation moisture content

Benefit of the Long Landsat Time Series

- **Example:** Urban Growth of Las Vegas (and Effects on Lake Mead)



The DigitalGlobe High-Resolution Commercial Imaging Systems

- DigitalGlobe is the commercial vendor for the following high-res satellite systems:
  - EarlyBird-1
  - IKONOS
  - QuickBird
  - GeoEye-1
  - WordView-1 to -3

- All systems focus on high resolution (meter to sub-meter) and offer multispectral imaging capabilities with up to 8 bands between VIS and near IR.

WordView-3 Image

King Abdullah Petroleum Studies and Research Center

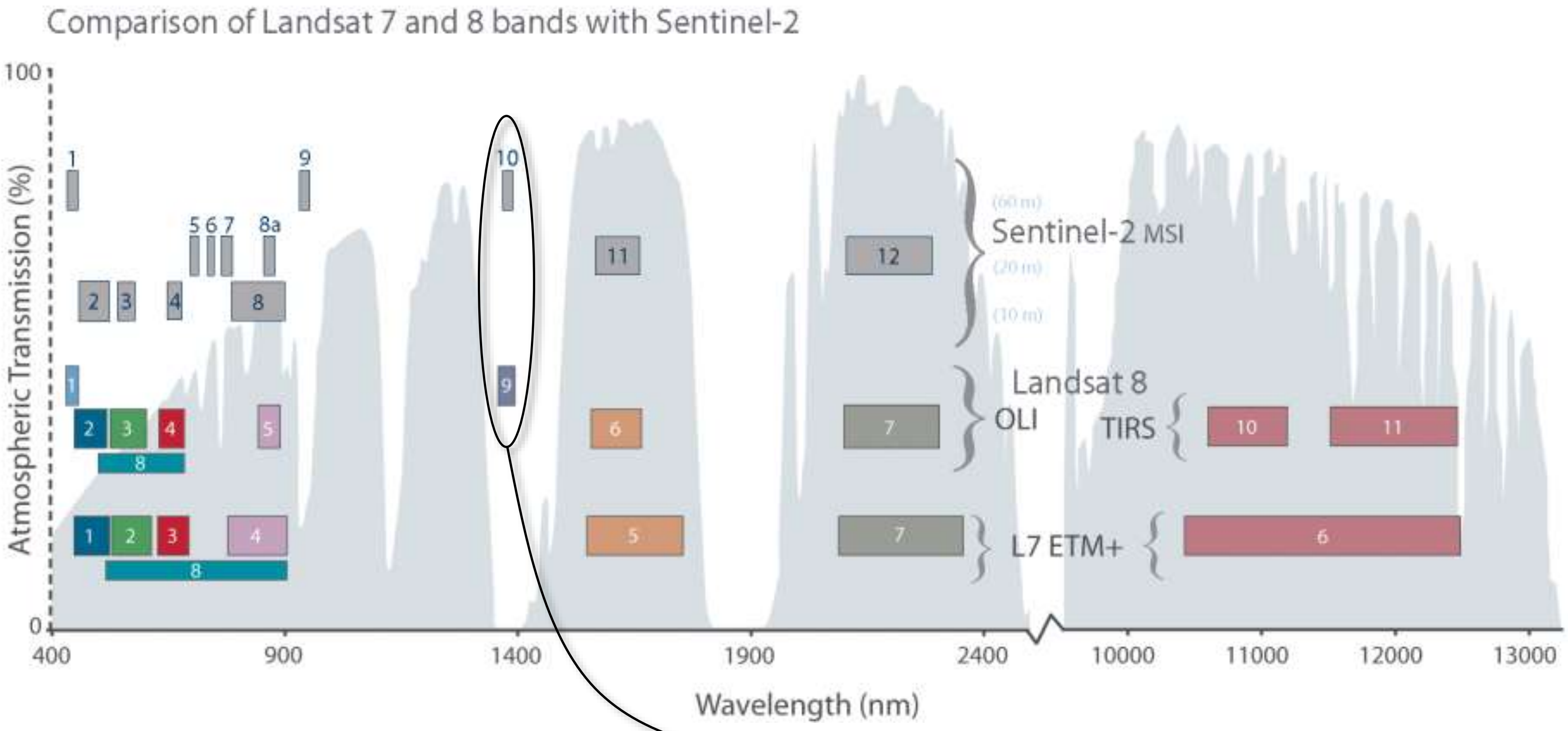
Sentinel-2

ESA’s new & freely available VIS and IR resource

Launch Date: 6/23/2015

Sentine-2 vs. Landsat-7 and -8

Spectral Bands



Question: What do you think Sentinel-2 Band 10 and Landsat-8 Band 9 are useful for?

Answer: They are used for mapping Cirrus clouds (high altitude clouds)

Want to Know More?

For a Deeper Dive Into Optical Remote Sensing:

Register for GEOS 654 Visual and Infrared Remote Sensing

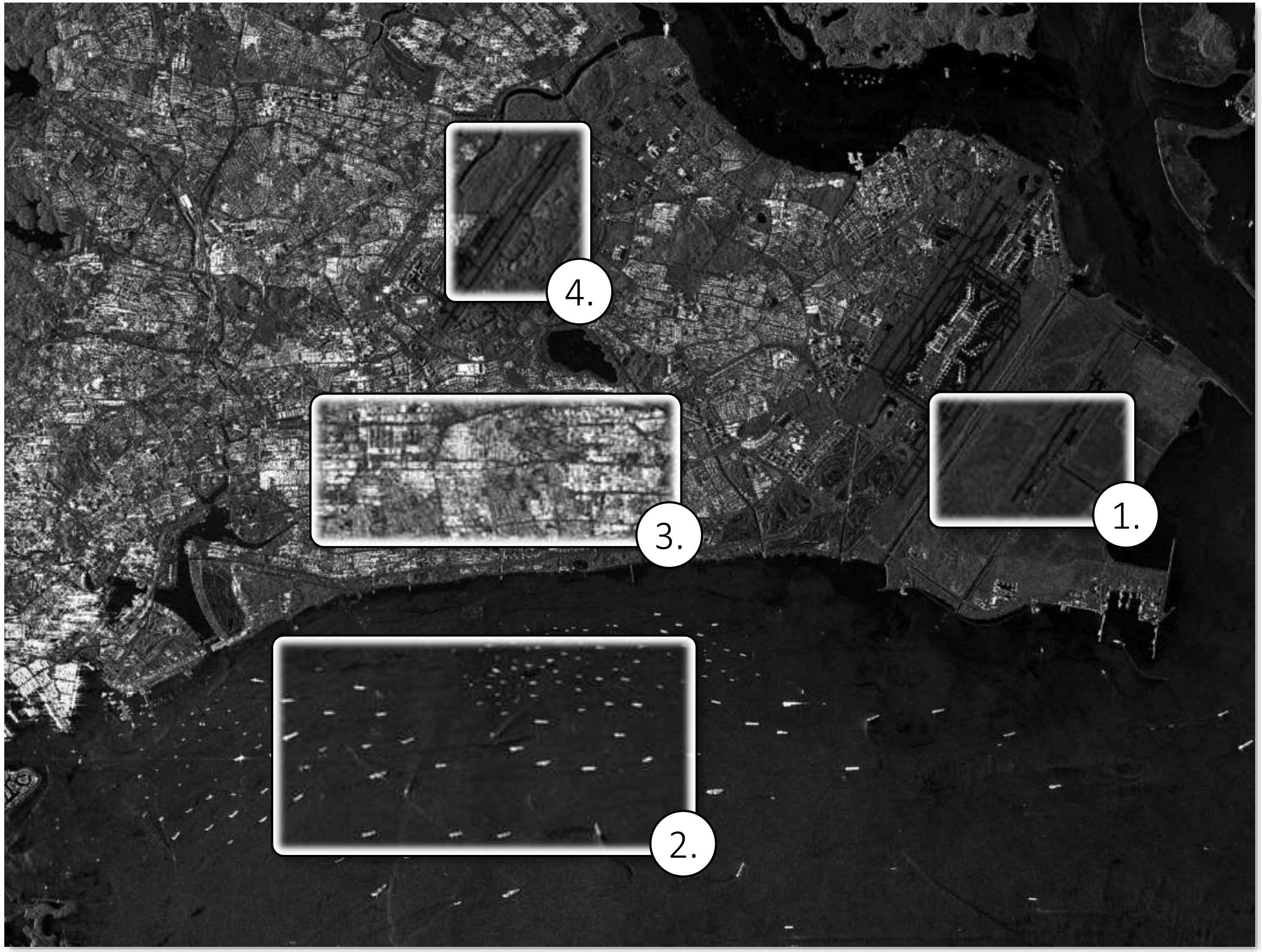
Sensor Types Relevant for this Course

1. Synthetic Aperture Radar Sensors

Think – Pair – Share

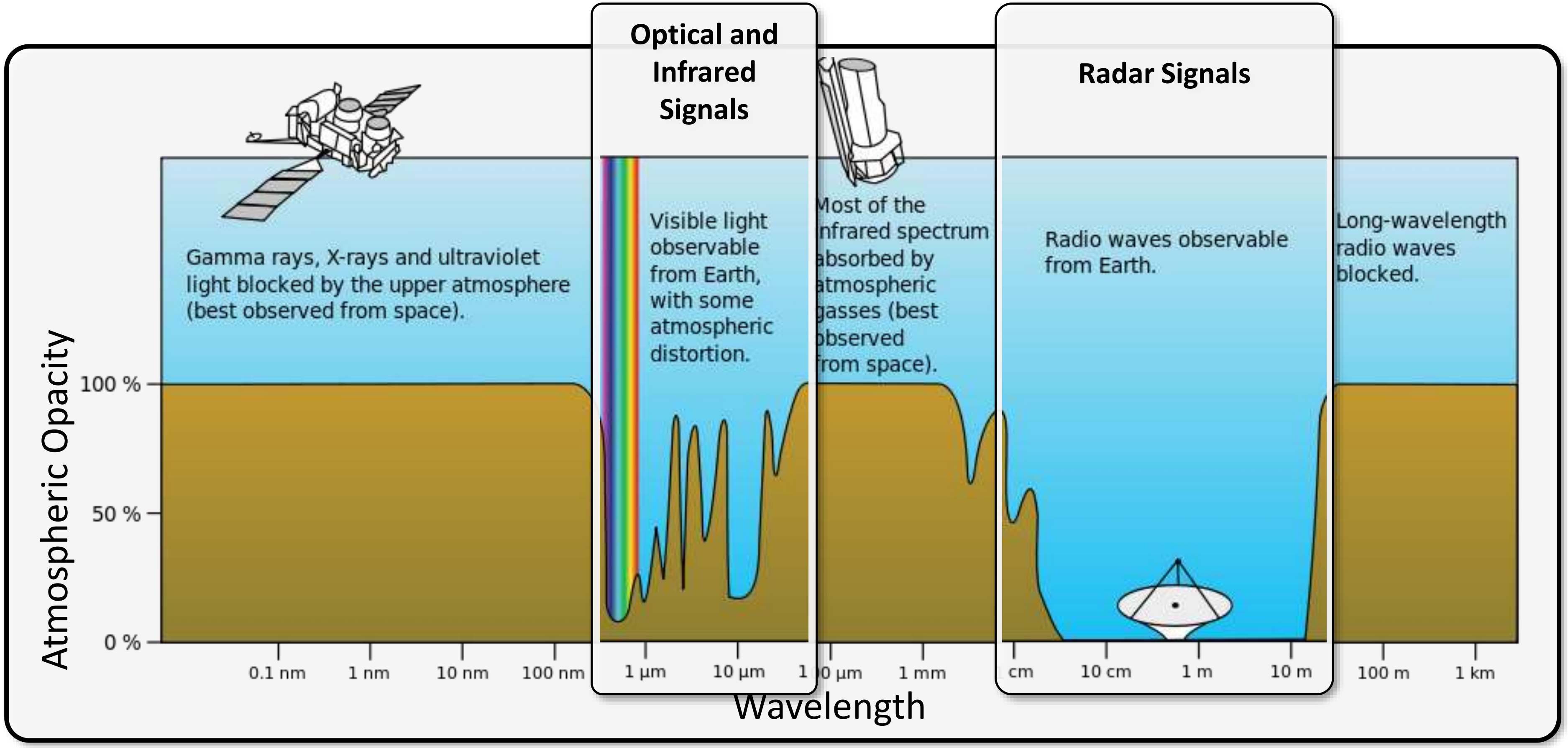
SAR Image Interpretation

- What do these five image areas show?



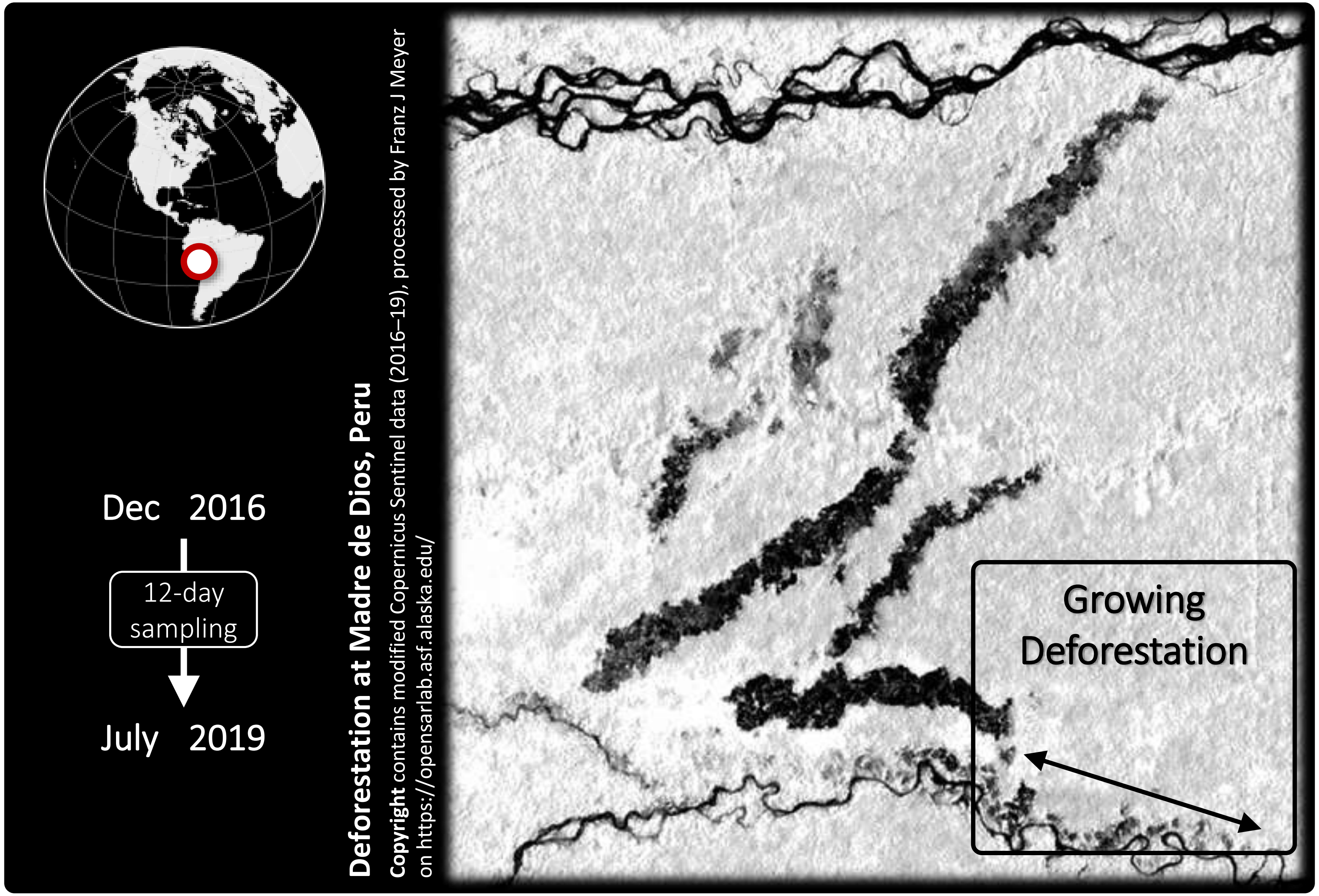
Wavelength Discriminates Radar from Optical Data

- **Radar has excellent capabilities for routine global change monitoring**
  - **24/7 imaging capabilities:** due to weather and illumination independence
  - **Advanced change detection performance**: due to stable image geometry and own signal source
  - **Complementary to optical sensors**: provides independent information about surface



NASA Earth Observatory images by Robert Simmon, using Suomi NPP VIIRS data from Chris Elvidge (NOAA National Geophysical Data Center)

Weather Independence Provides Advantages Especially For Cloud Affected Regions Such as the Rain Forest

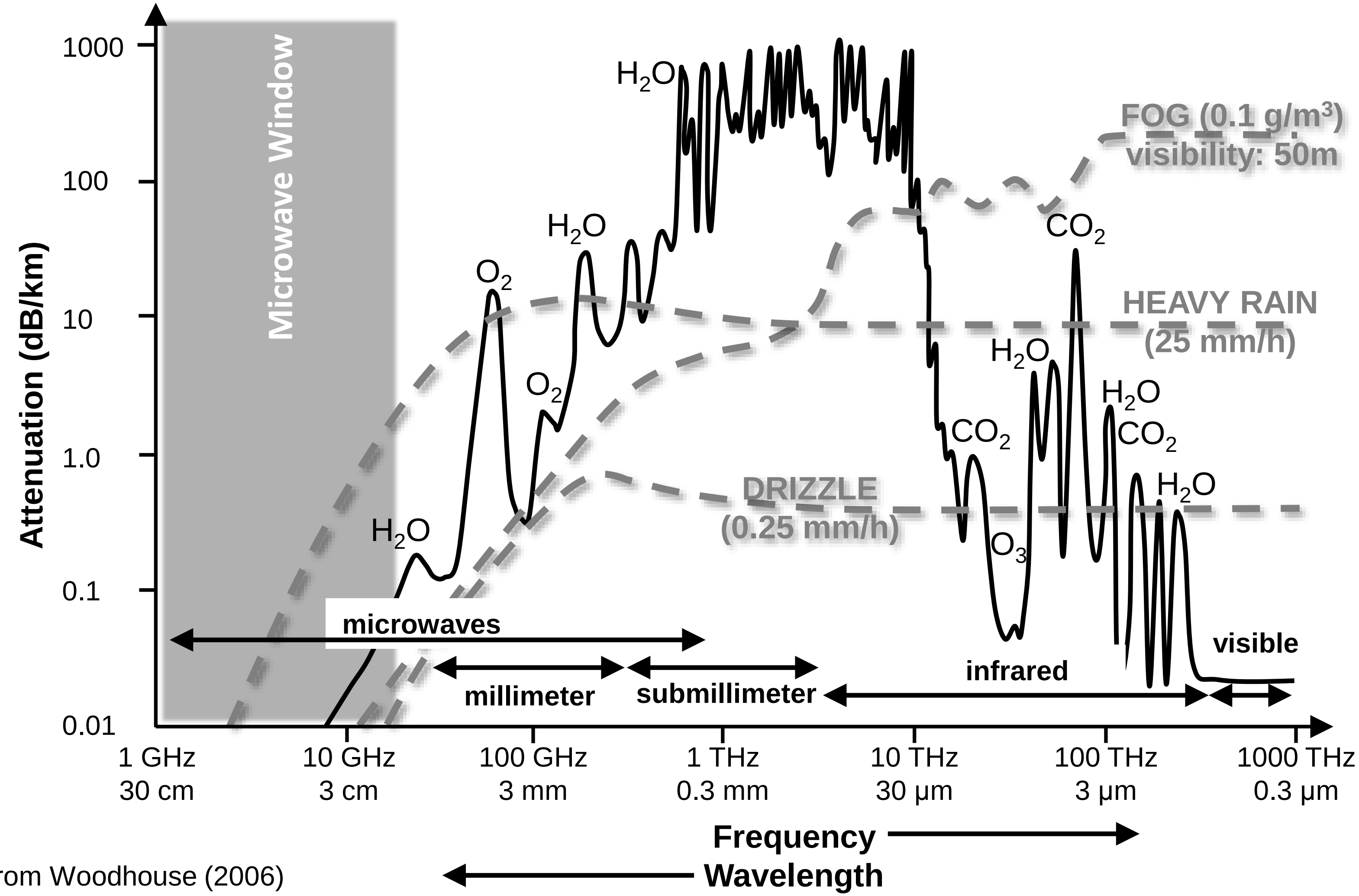


The Microwave Spectrum

(approximate)

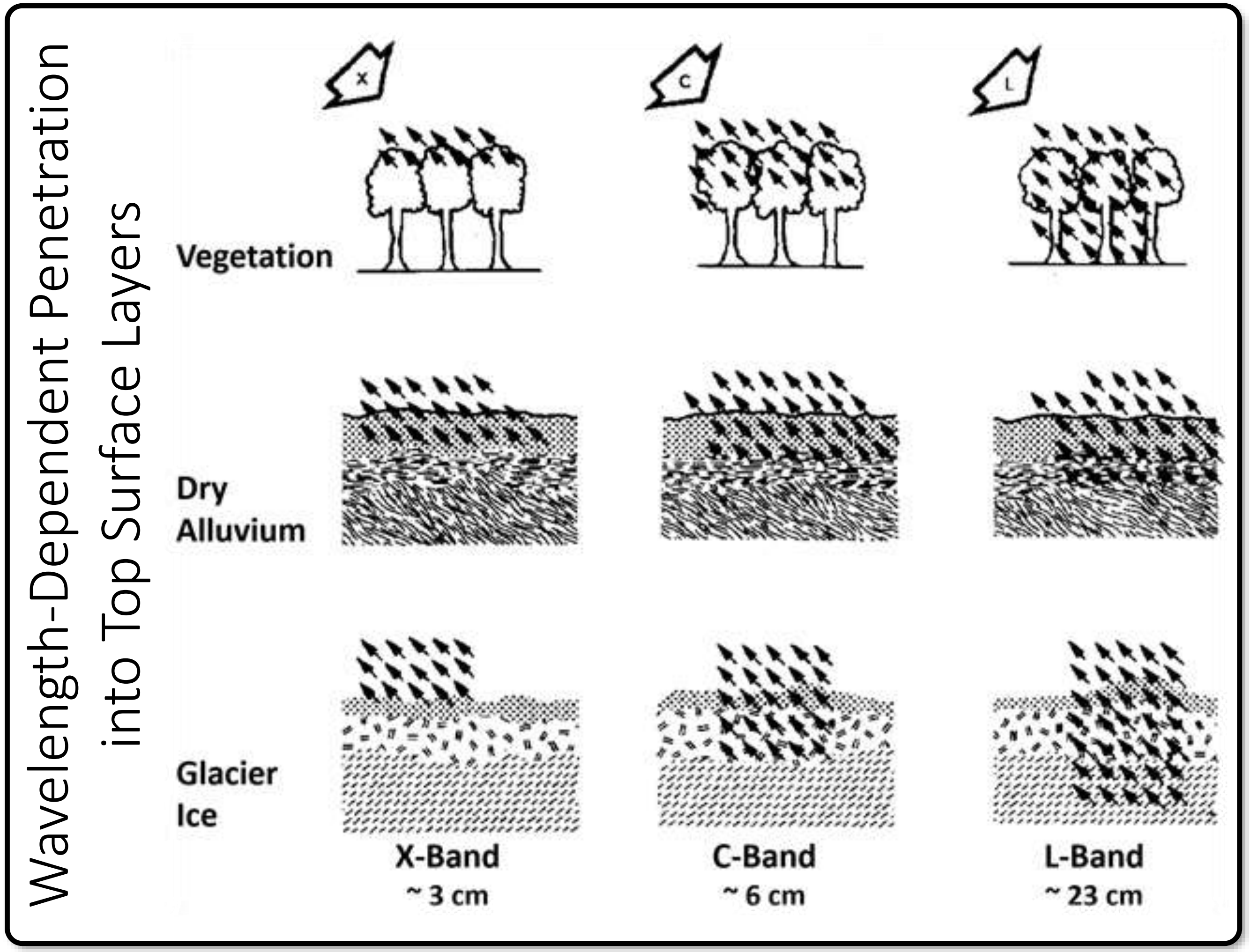
Band	Frequency f_0		Wavelength $\lambda = c/f_0$		Typical Application
Ka	27 – 40	GHz	1.1 – 0.8	cm	Rarely used for SAR (airport surveillance)
K	18 – 27	GHz	1.7 – 1.1	cm	Rarely used for SAR (H_2O absorption)
Ku	12 – 18	GHz	2.4 – 1.7	cm	Rarely used for SAR (satellite altimetry)
X	8 – 12	GHz	3.8 – 2.4	cm	**High-resolution SAR** (urban monitoring; ice and snow; little penetration into vegetation cover; fast coherence decay in vegetated areas)
C	4 – 8	GHz	7.5 – 3.8	cm	**SAR workhorse** (global mapping; change detection; monitoring areas with low to moderate vegetation; improved penetration; higher coherence)
S	2 – 4	GHz	15 – 7.5	cm	**Little but increasing use for SAR-based Earth obs.**; agriculture monitoring (NISAR will carry S-band; expands C-band applications to higher vegetation density)
L	1 – 2	GHz	30 – 15	cm	**Medium resolution SAR** (Geophysical monitoring; biomass and vegetation mapping; high penetration; InSAR)
P	0.3 – 1	GHz	100 – 30	cm	**Biomass estimation**. First P-band spaceborne SAR will be launched ~2020; vegetation mapping and assessment. Experimental SAR.

Atmosphere almost Transparent at Microwave Window

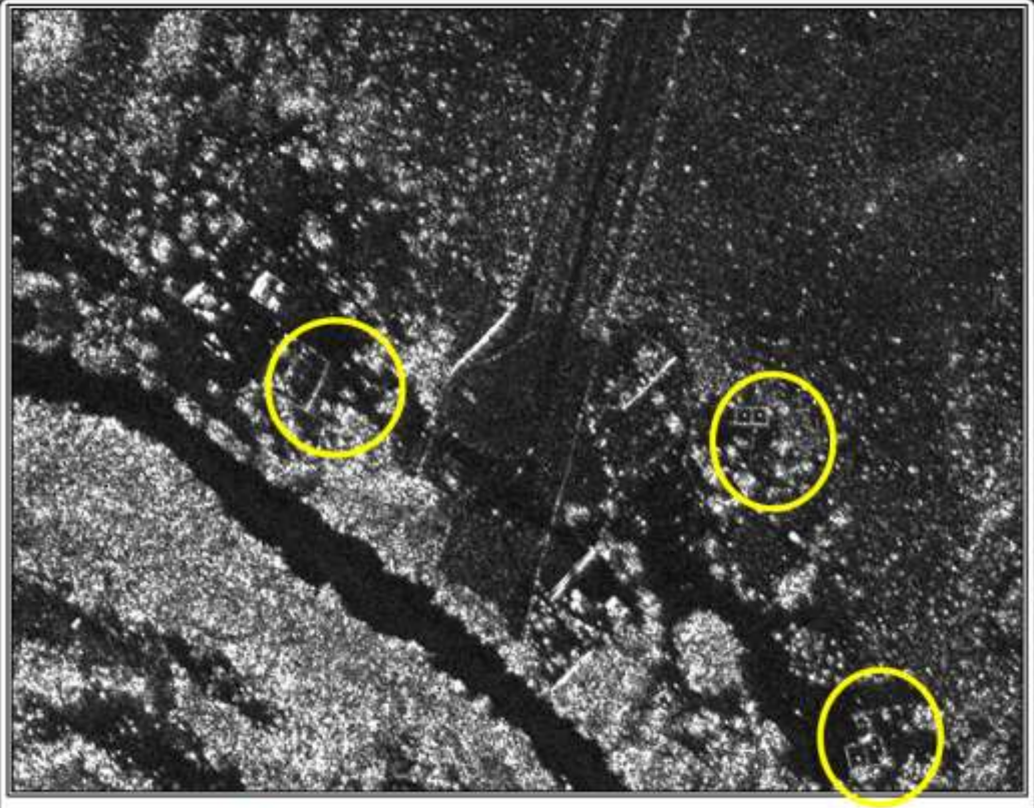


From Woodhouse (2006)

Depending on Signal Wavelength, SAR can Penetrate Into Vegetation and Soils



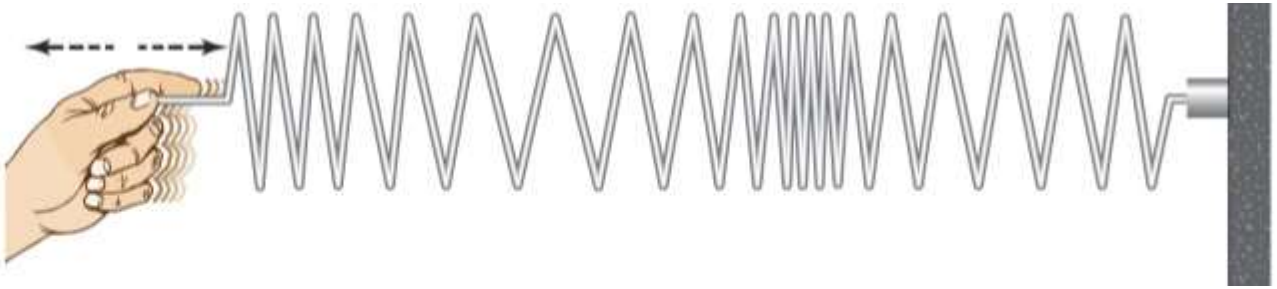
- **Example**: X-band vs P-band penetration into Forest Canopies



P-band radar image of forested area

Radar like Optical EM Signals are Transverse Oscillating Waves

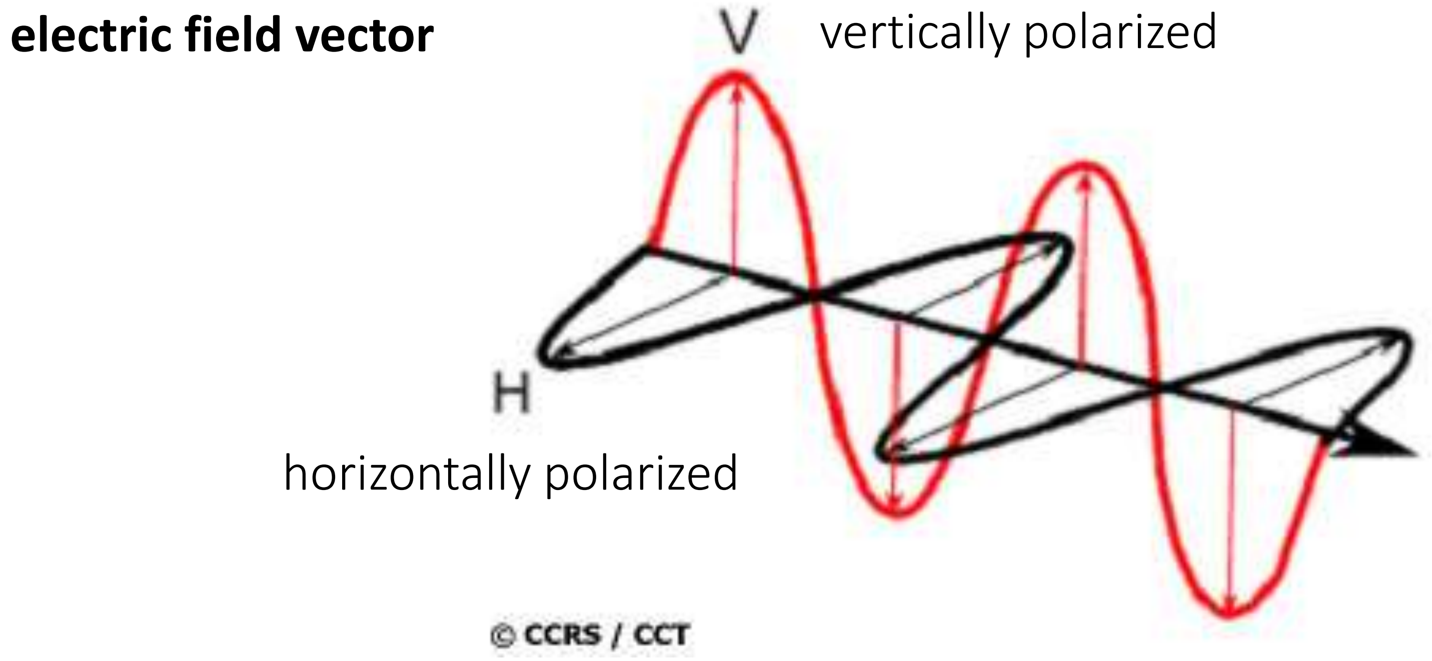
Longitudinal oscillating waves (sound waves, waves on oceans)



Transverse oscillating waves (e.g., EM waves)

Traverse oscillating waves (like EM waves) have one additional degree of freedom: Direction in which oscillation takes place, **called Polarization**

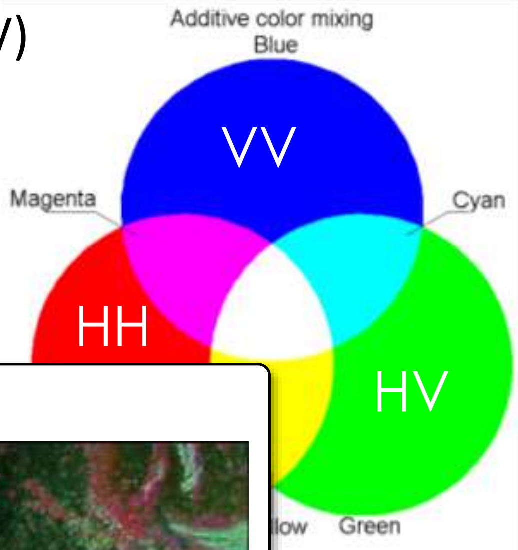
In Radar, we can Control the Polarization of the Transverse Oszillating Signal → Its Polarization



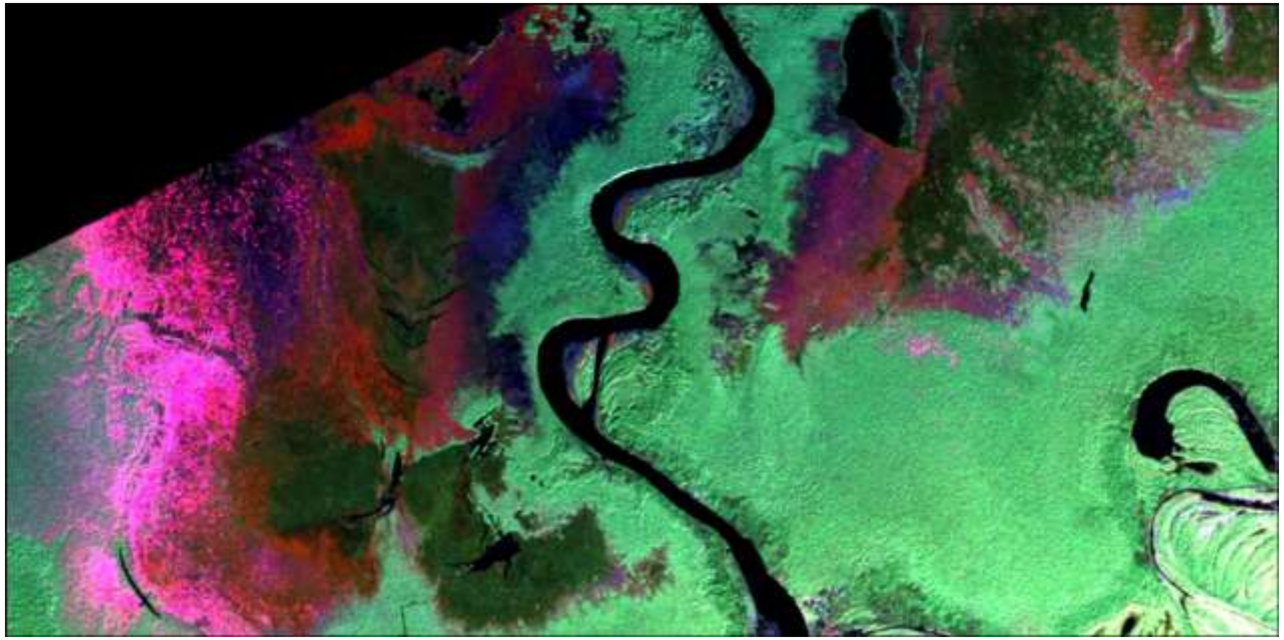
- Polarization planes are perpendicular – orientation technically arbitrary
- Usually, horizontal and vertical planes are chosen
- The terms horizontal and vertical then refer to either the earth or the antenna surface

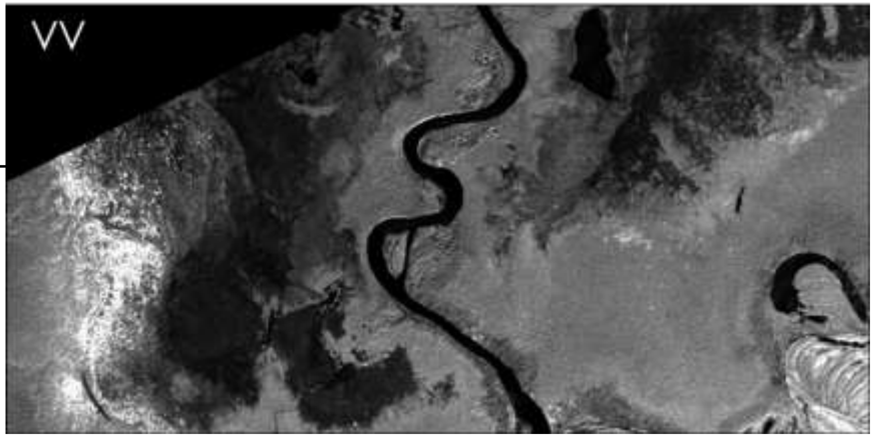
Example of Multiple Polarizations for Vegetation Studies - Pacaya-Samiria Forest Reserve in Peru

- L-band SAR images from UAVSAR (HH, HV, VV)



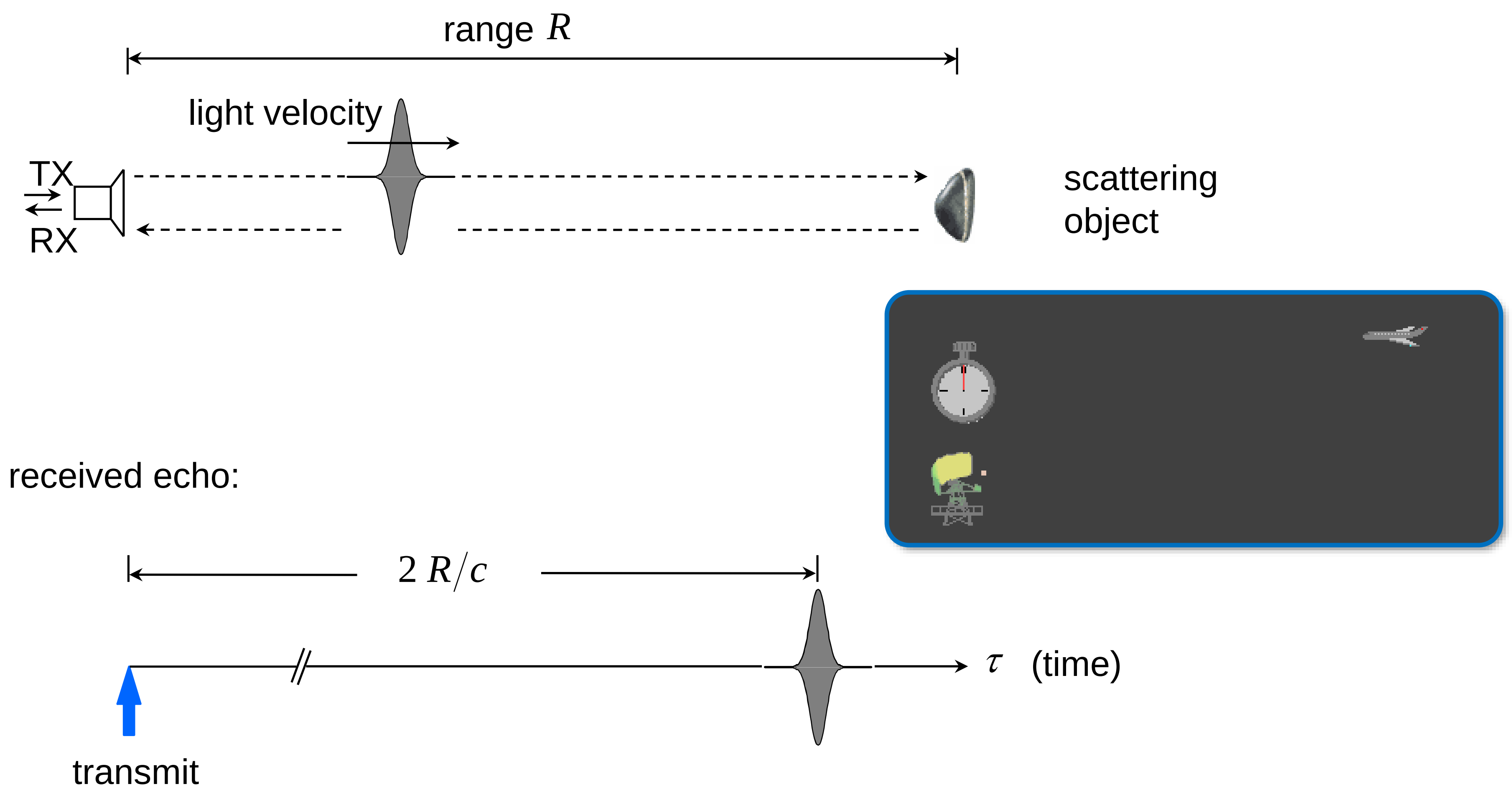
RGB Combination of Polarizations



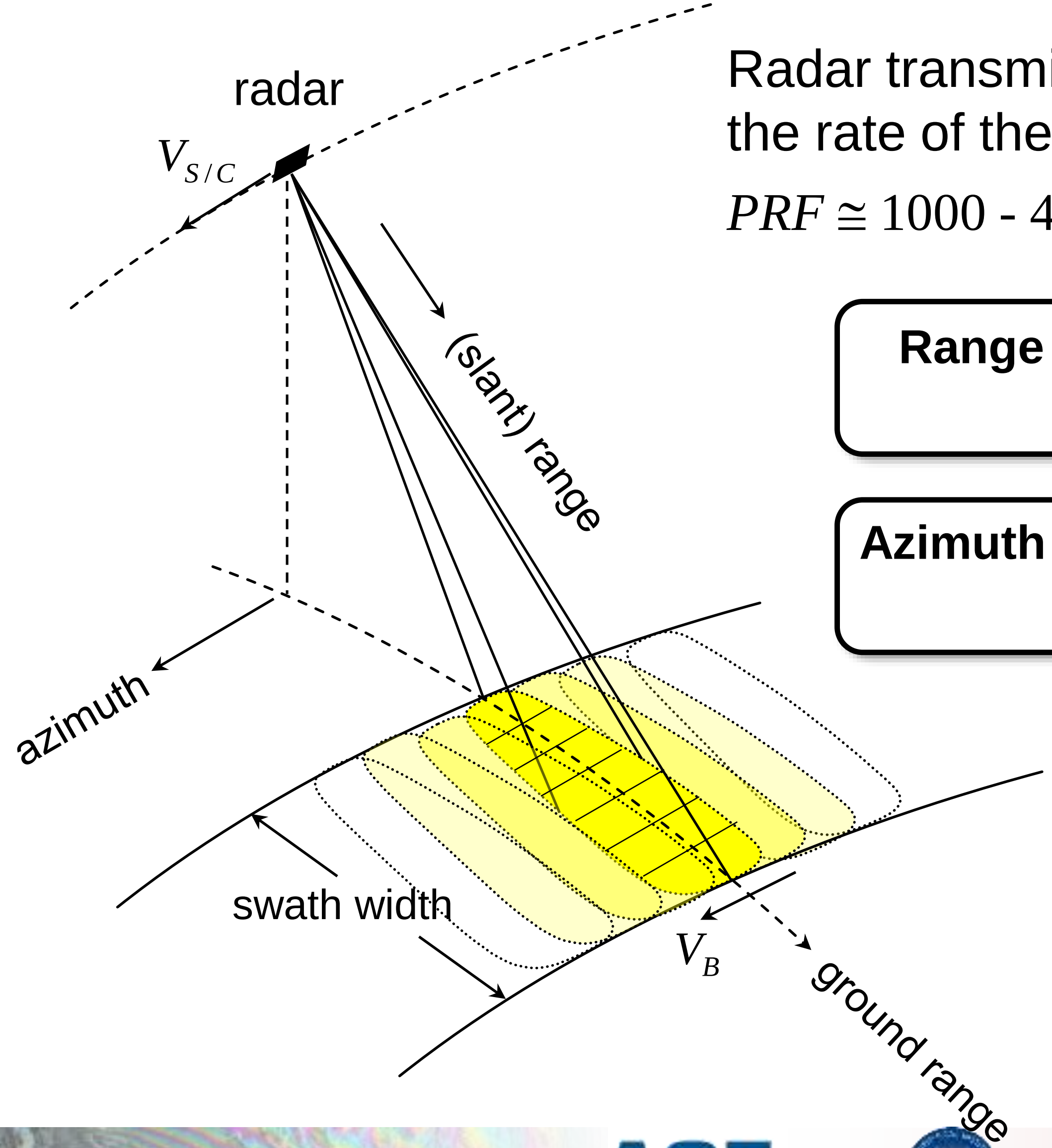


WHAT IS SYNTHETIC APERTURE RADAR (SAR)?

Radar Principle



How to Form a Radar Image



Radar transmits pulses and receives echoes at the rate of the pulse-repetition frequency (PRF):

$PRF \cong 1000 - 4000$ Hz

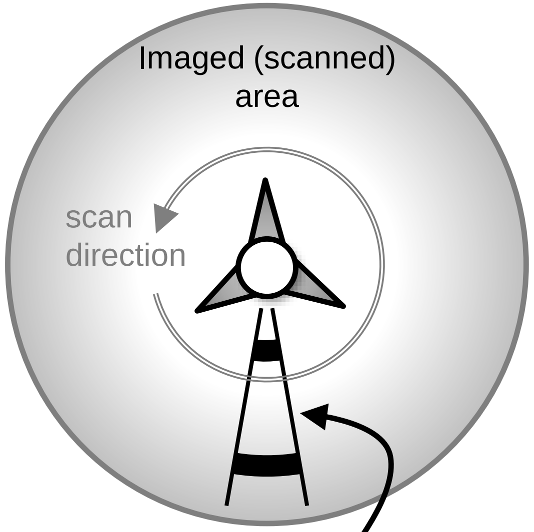
Range pixels:	pixel size defined by pulse width (radar principle)

Azimuth pixels:	scanning in flight direction at $V_{S/C}$

Imaging the Surface with SLARs

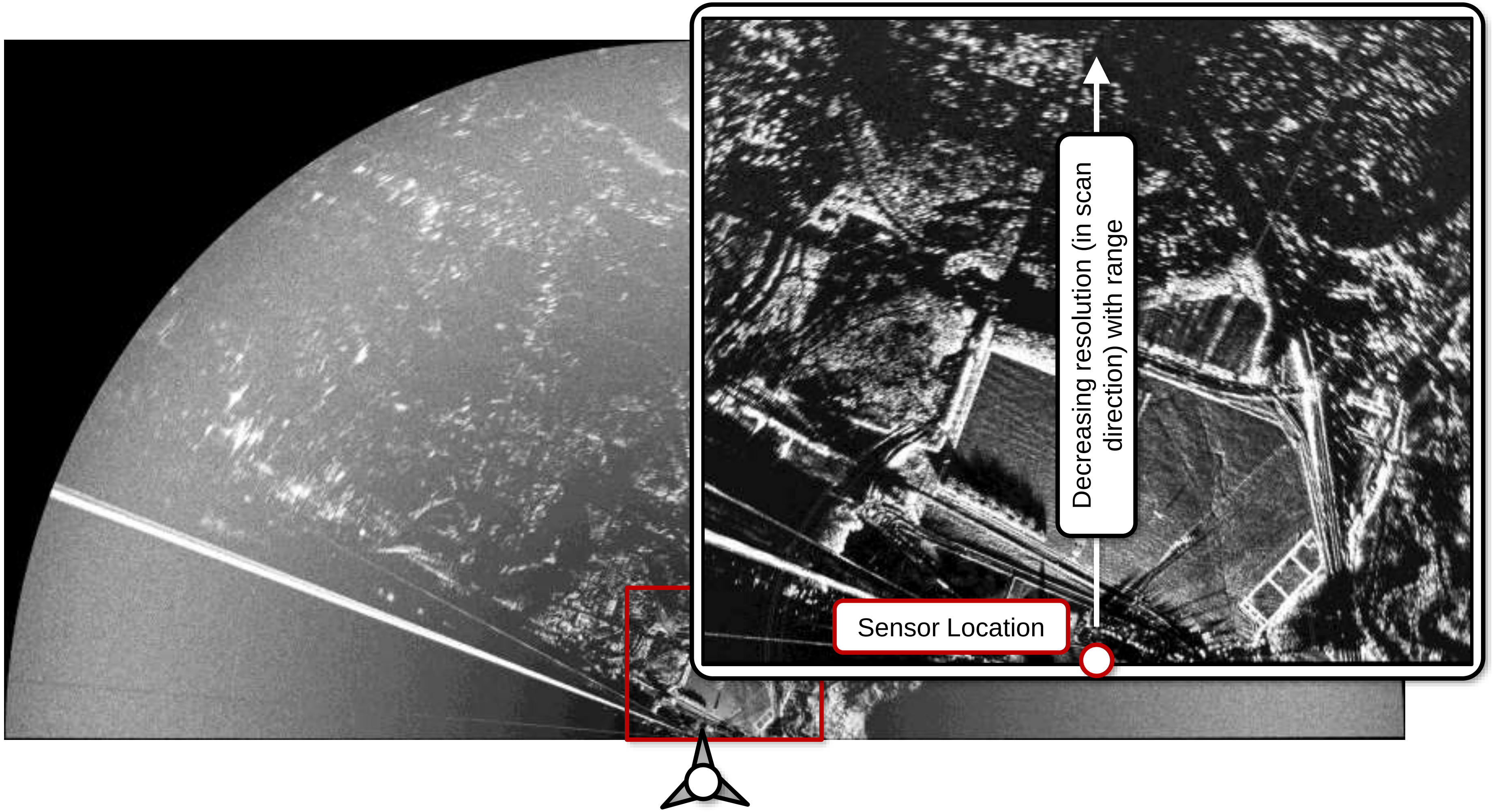
Scanning Ground-based Radar System as a SLAR Example

- Resolution defined by pulse length & length of antenna



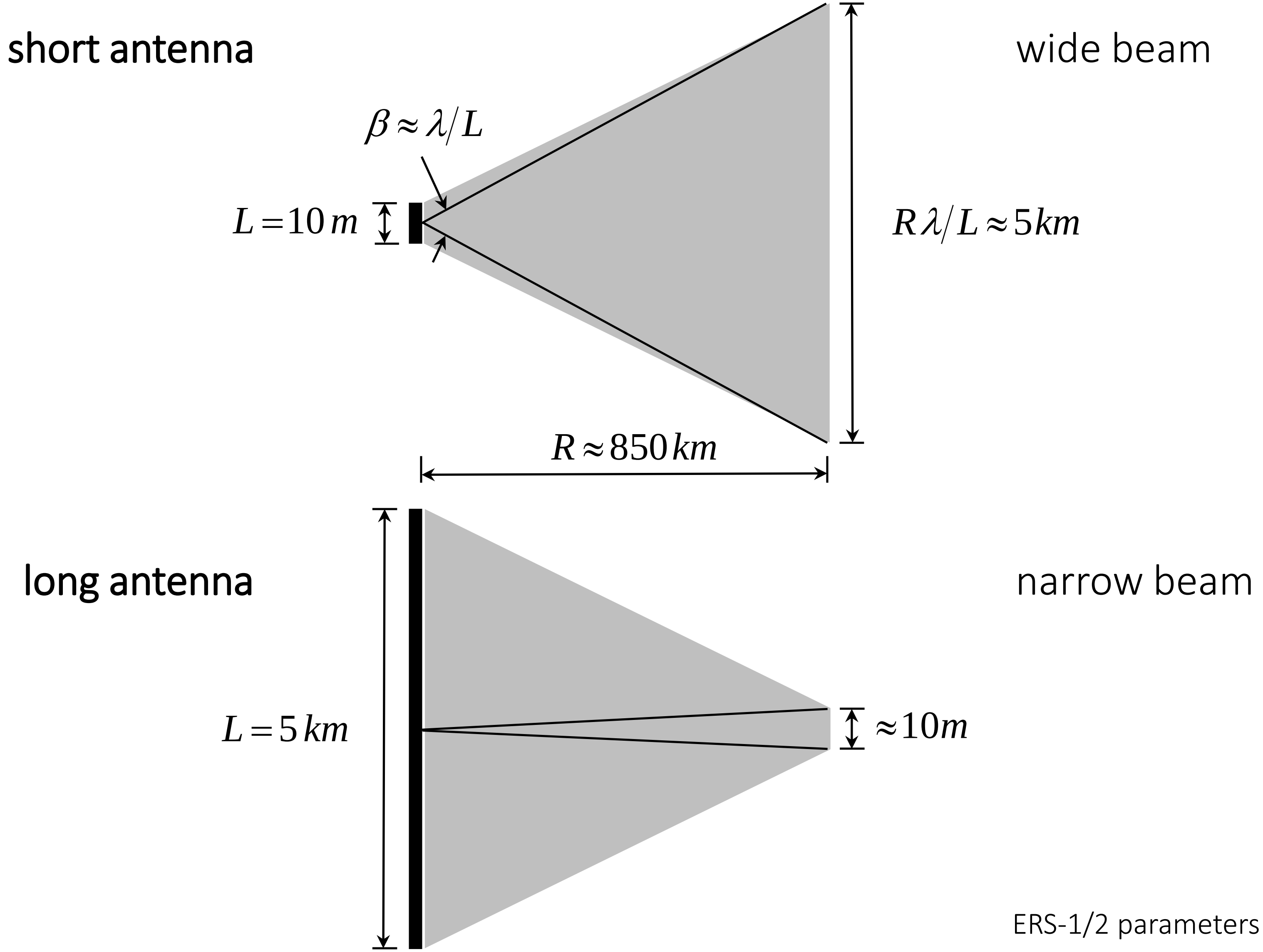
Example of Scanning Ground-Based Radar Acquisition

- 180 degrees scan angle – location: Fairbanks, Alaska



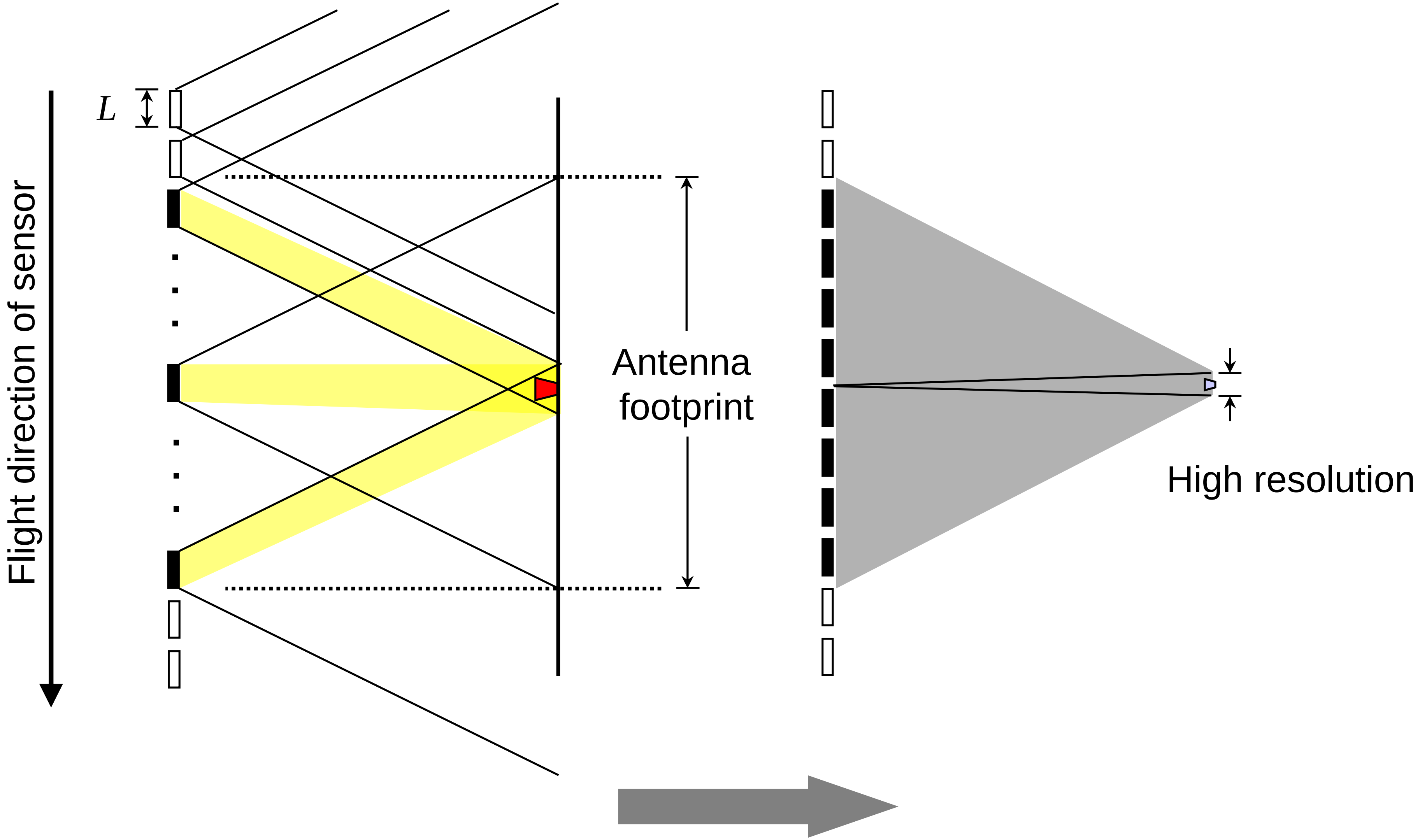
The Problem of SLARs – Azimuth Resolution Degrades with Distance

Antenna Size vs. Beam Width



ERS-1/2 parameters

Formation of a Synthetic Aperture — SAR Principle

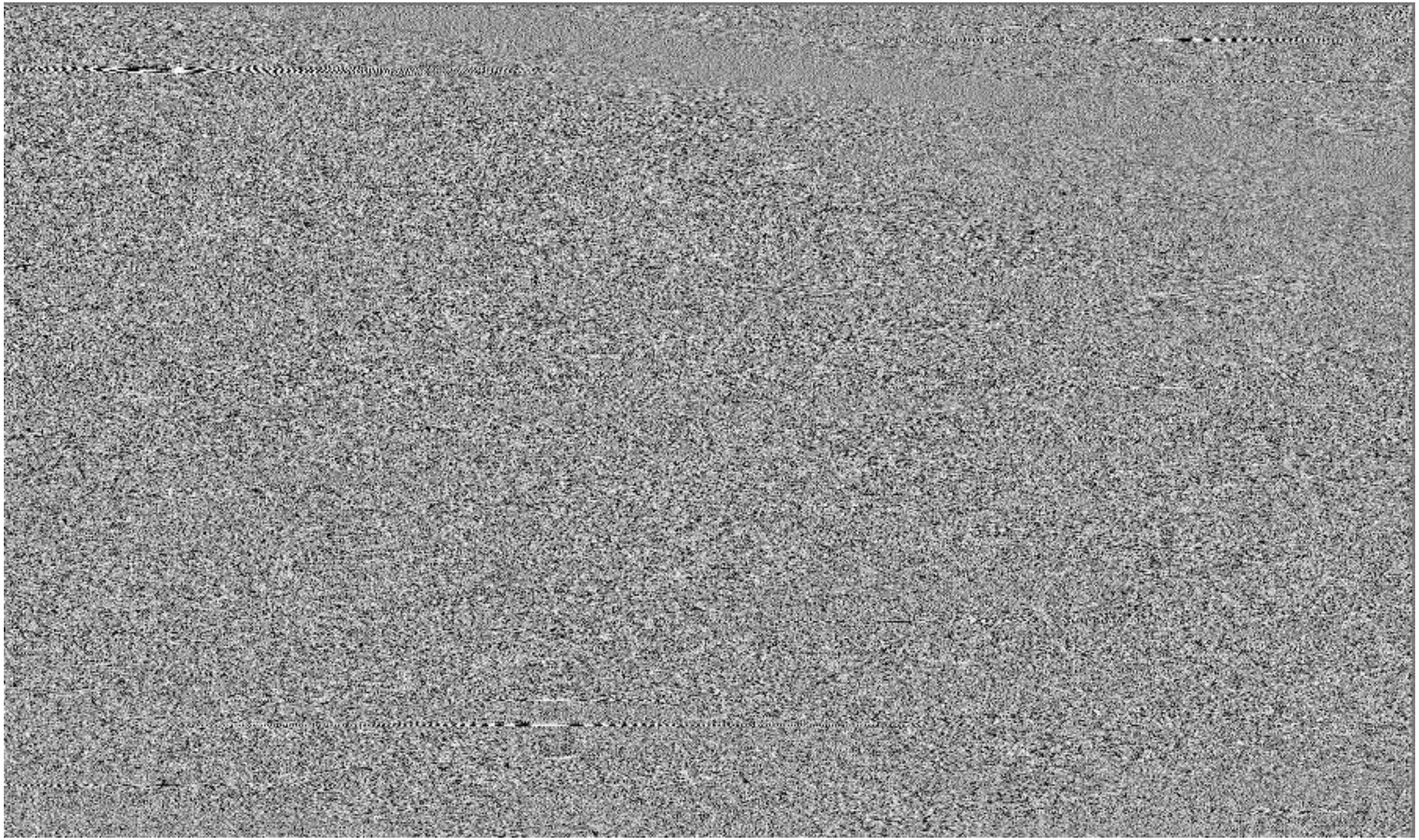


Combination of overlapping acquisitions

Original SAR Observations

→ azimuth

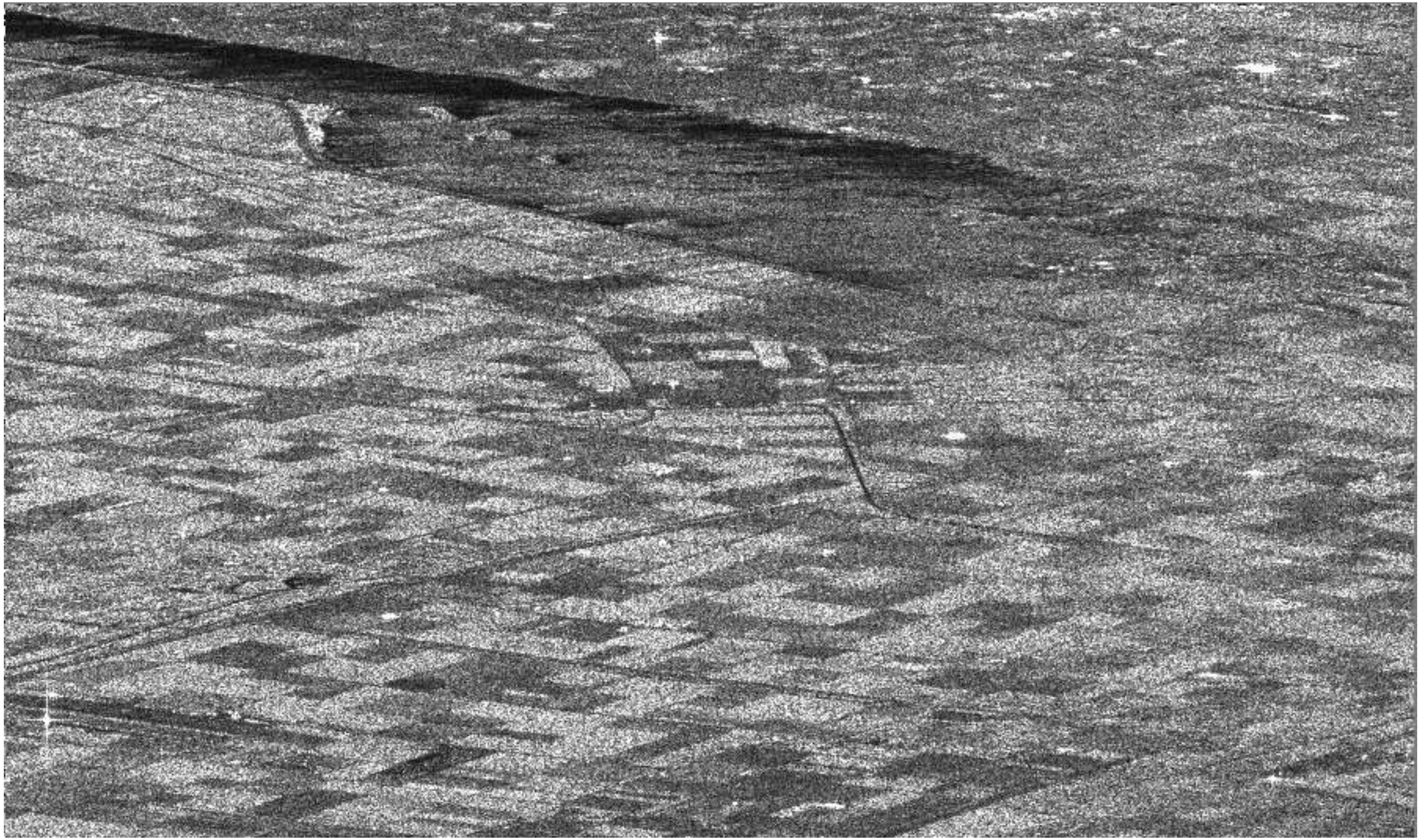
data ERS-1 © ESA



SAR Data After Image Formation

azimuth

data ERS-1 © ESA



SAR Data After Image Formation and Multi-Looking to Reduce Noise

azimuth

After azimuth pixel averaging by 4 to achieve approximately square pixels

data ERS-1 © ESA

Satellite SAR Sensors: L-Band

	SEASAT	JERS-1 Japan	ALOS PALSAR Japan	ALOS-2 PALSAR-2 Japan	ALOS-4 PALSAR-3 Japan	SAOCOM, 1A / 1B Argentina	NISAR USA/India
Operation Date	1978 (105 days)	1992-1998	1/2006 4/2011	2014	2020	2018/2019	2022
Frequency Band	L	L	L	L	L	L	L
Polarization	HH	HH	Polarimetric	Polarimetric	Polarimetric	Dual	Dual
Spatial Resolution [m]	20	18	10, 20, 100	3 - 100	3 - 100	10-100	10
Repeat Cycle [days]	17	44	46	14	14	16/8	12

Satellite SAR Sensors: C-Band

	RADARSAT-1 Canada	RADARSAT-2 Canada	RADARSAT Constellation Mission Canada	ERS-1/2 Europe	Envisat Europe	Sentinel-1 ESA
Launch/ Operation Date	1995	2007	2018	1991-2011	2002-2012	2014 (A) 2016 (B)
Frequency Band	C	C	C	C	C	C
Polarization	HH	Quad-pol	Quad-pol	VV	HH, VV, HV	Dual-Pol Interferometric
Spatial Resolution [m]	10-100	3-100	3-100	30	10-100	5-100
Repeat Cycle [days]	24	24	1	3/75/176	35	12/6

Sentinel-1 C/D approved for operations until 2030

Satellite SAR Sensors: X-Band

	TerraSAR-X Tandem-X DLR/InfoTerra	Cosmo SKYMED Constallation, ASI, eGeos
Operation Date	4/2007 2009 Tandem-X	2007
Frequency Band	X	X
Polarization	Polarimetric Interferometric	Polarimetric Interferometric
Spatial Resolution [m]	Up to 1	Up to 1
Repeat Cycle [days]	11	16

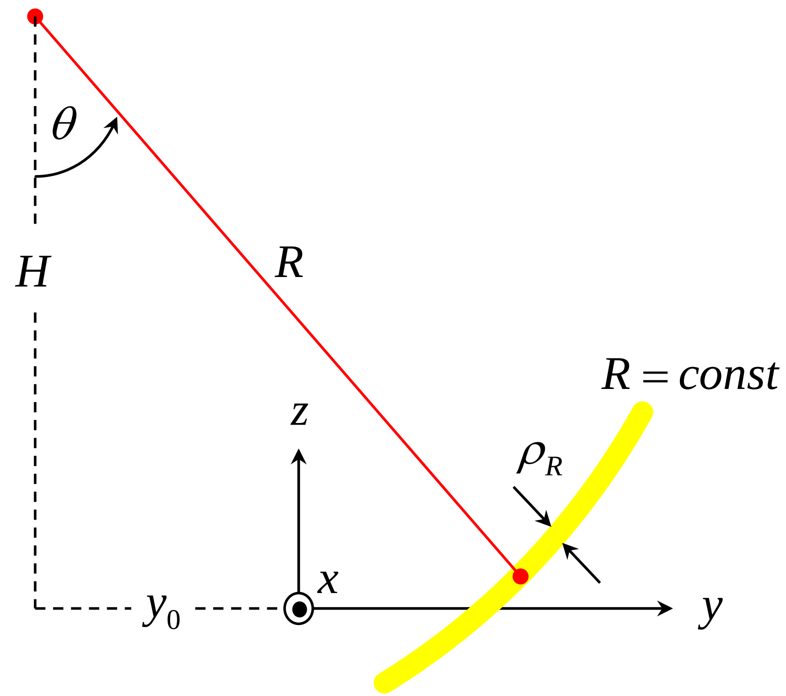
Satellite SAR Sensors: Other Bands

	ESA Biomass Mission Europe	NISAR USA/India
Operation Date	2018	2020
Frequency Band	P	S
Polarization	Polarimetric Interferometric	Polarimetric Interferometric
Spatial Resolution [m]	50-200	~3
Repeat Cycle [days]	25	12

GEOMETRIC PROPERTIES OF SAR

Geometric Distortions are Caused by the Slant Observation Geometry of SAR Systems

For SAR images processed to 'zero-Doppler' geometry: $\begin{pmatrix} x \\ y \\ z \end{pmatrix} \Rightarrow \begin{pmatrix} x \\ R \end{pmatrix}$

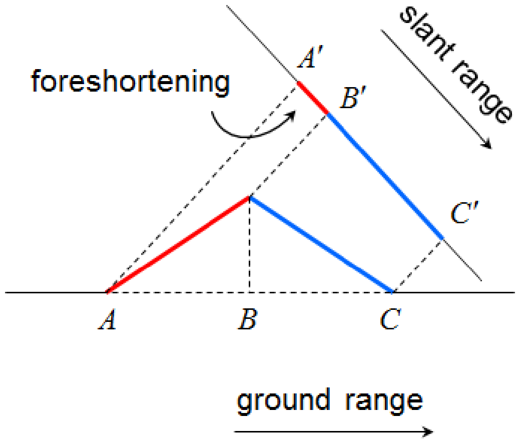


where $R = \sqrt{(y_0 + y)^2 + (H - z)^2}$

Three Types of Geometric Distortions Occur As a Consequence of Oblique Look Angle

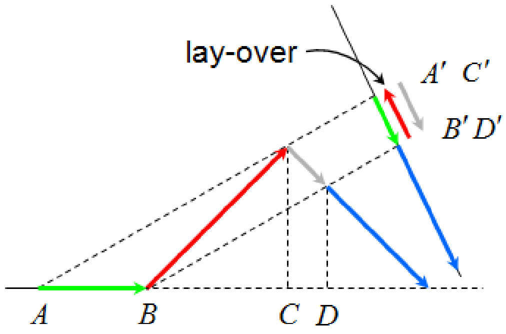
Foreshortening

- Sensor-facing slope forshortened in image
- Foreshortening effects *decrease* with increasing look angle



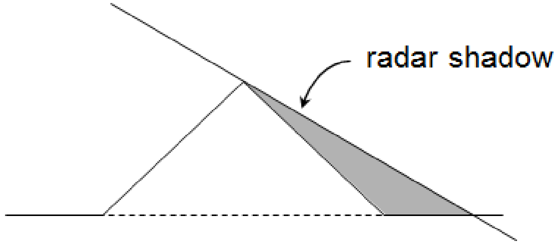
Layover

- Mountain top overlain on ground ahead of mountain
- Layover effects *decrease* with increasing look angle



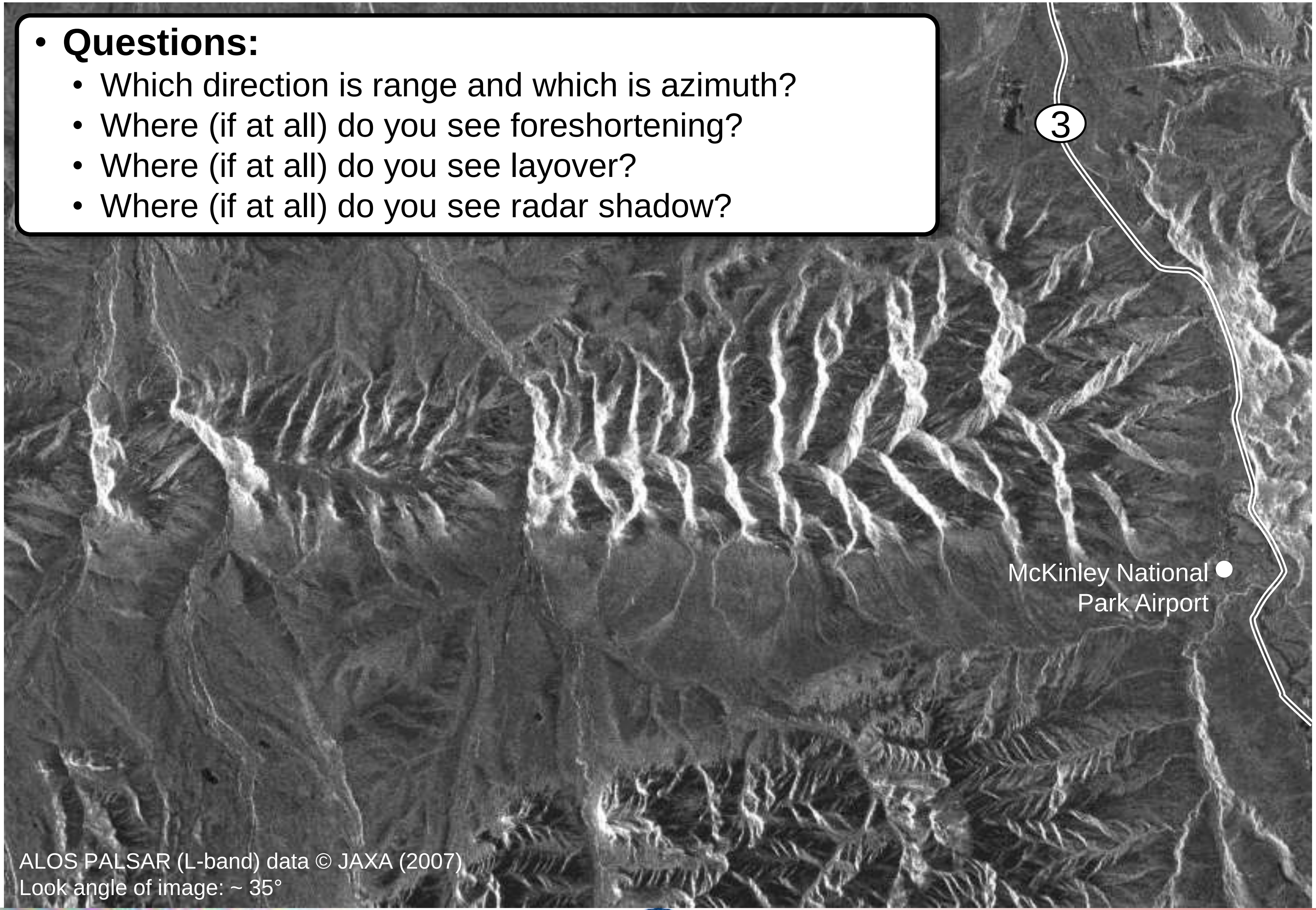
Shadow

- Area behind mountain cannot be seen by sensor
- Shadow effects *increase* with increasing look angle



Examples of Geometric and Radiometric Distortions in SAR Imagery

- **Questions:**
  - Which direction is range and which is azimuth?
  - Where (if at all) do you see foreshortening?
  - Where (if at all) do you see layover?
  - Where (if at all) do you see radar shadow?



CORRECTING GEOMETRIC PROPERTIES OF SAR

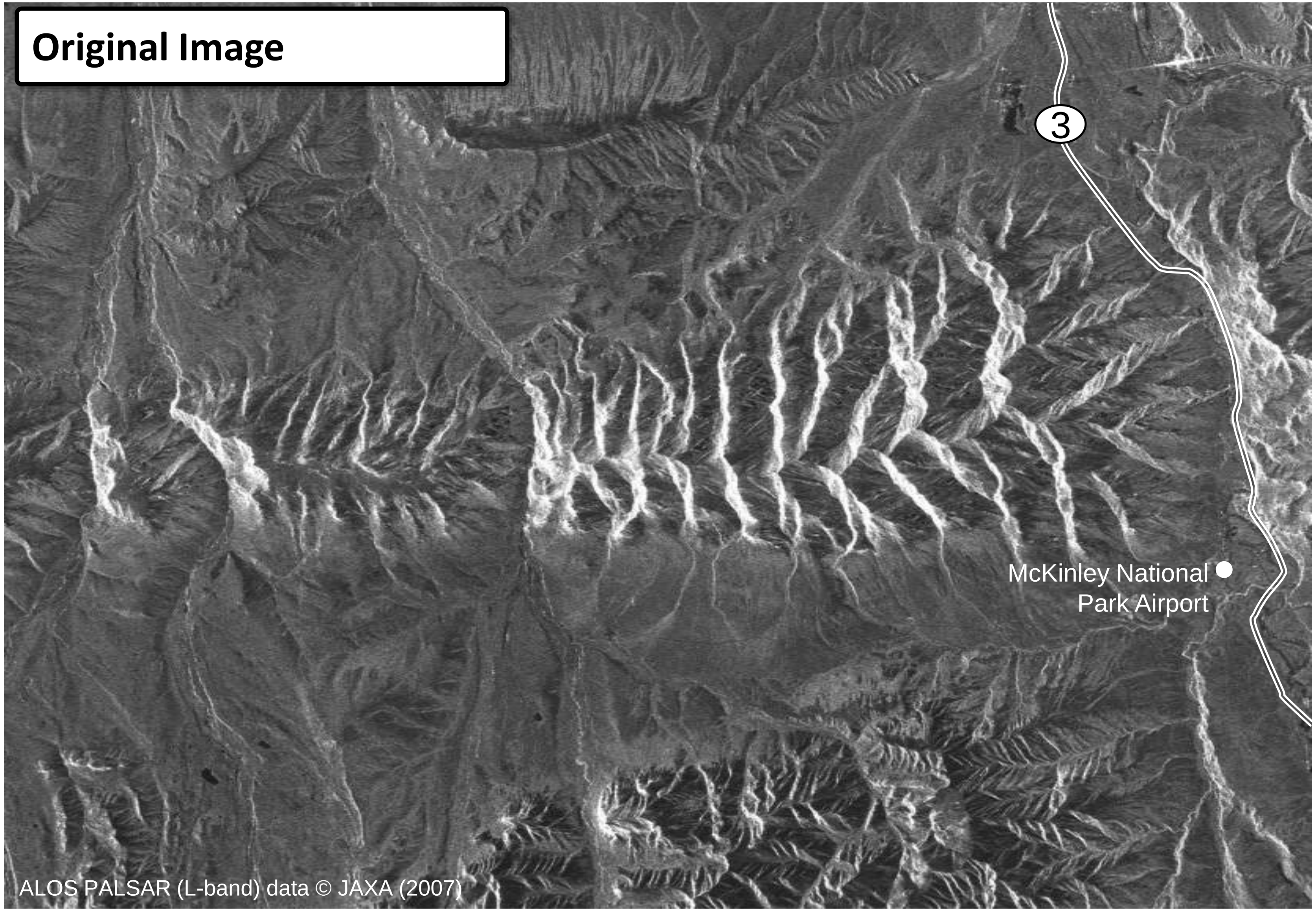
Geometric Terrain Correction

- **Geometric terrain correction (GTC) describes how to remove geometric distortions by using a DEM in the geocoding process:**
  - To make sure that ALL pixels appear at their proper geographic location
  - To allow for overlaying SAR data onto remote-sensing data from different sensors

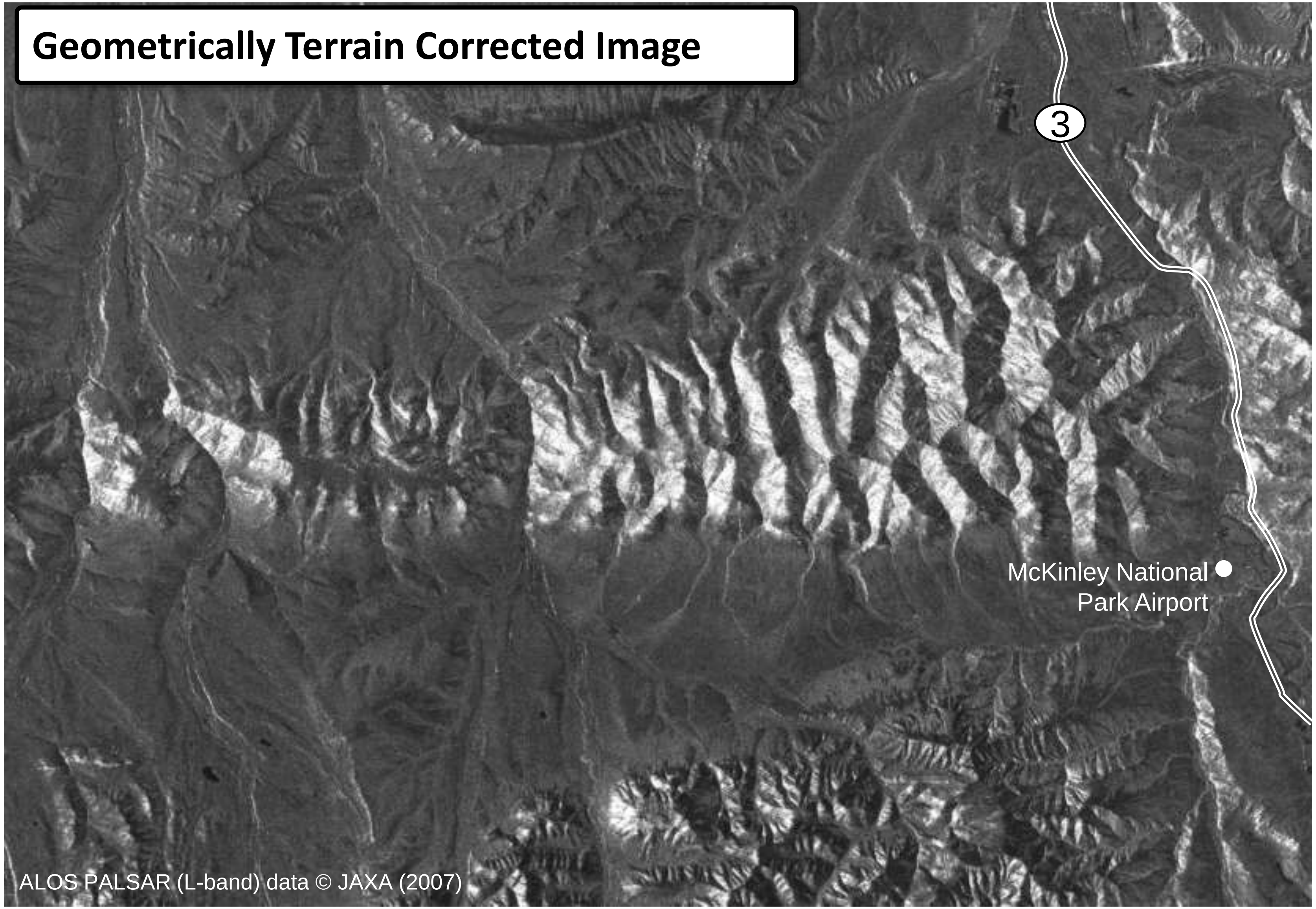
- **GTC problem:** What are the image gray values in every pixel of the output (geocoded) image given the input image and the DEM?

- **Two main approaches for geocoding *including GTC* are shown in the following:**
  - Backward Geocoding
  - Forward Geocoding

Geometric Terrain Correction Example (I)



Geometric Terrain Correction Example (II)

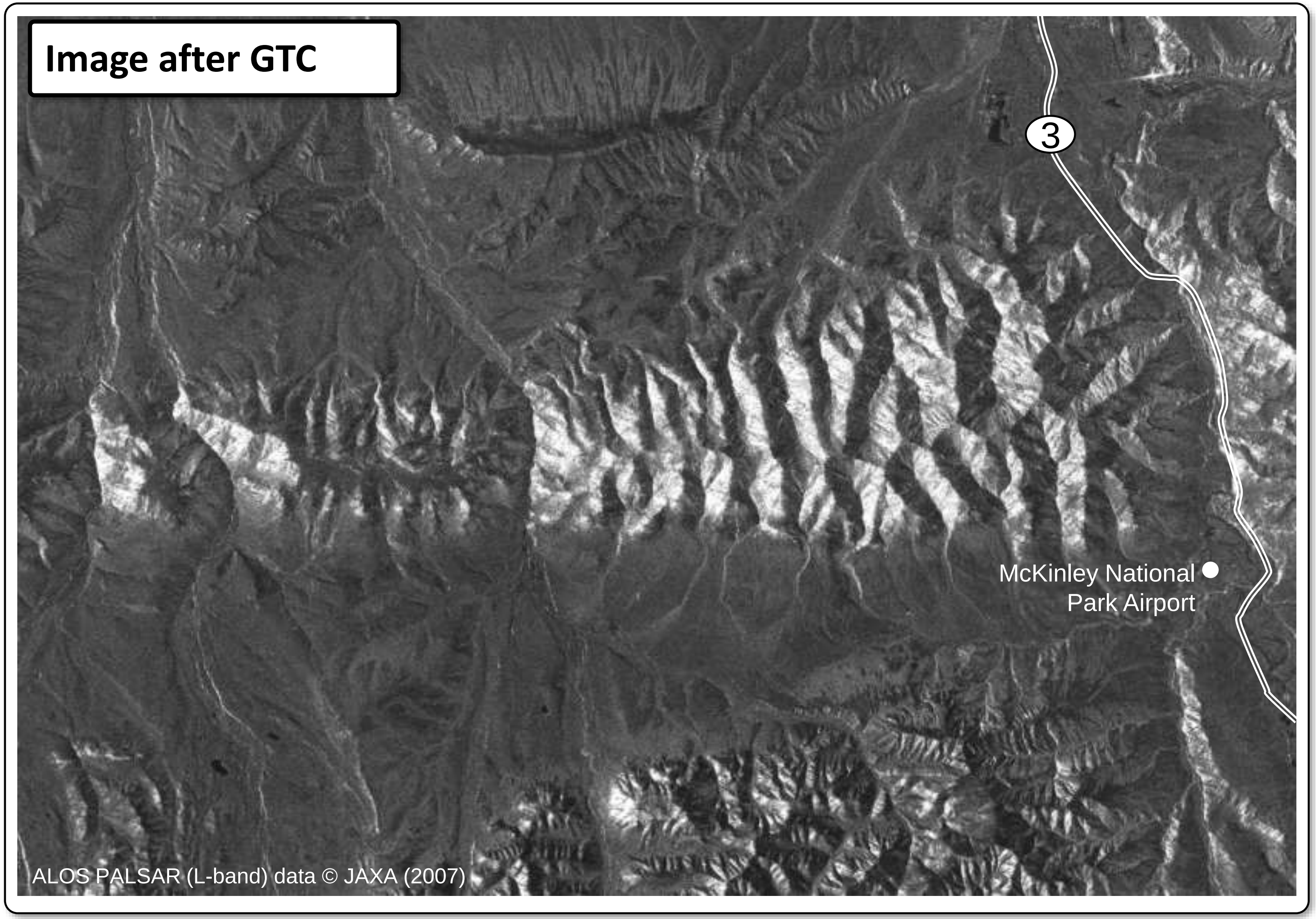


Radiometric Terrain Correction

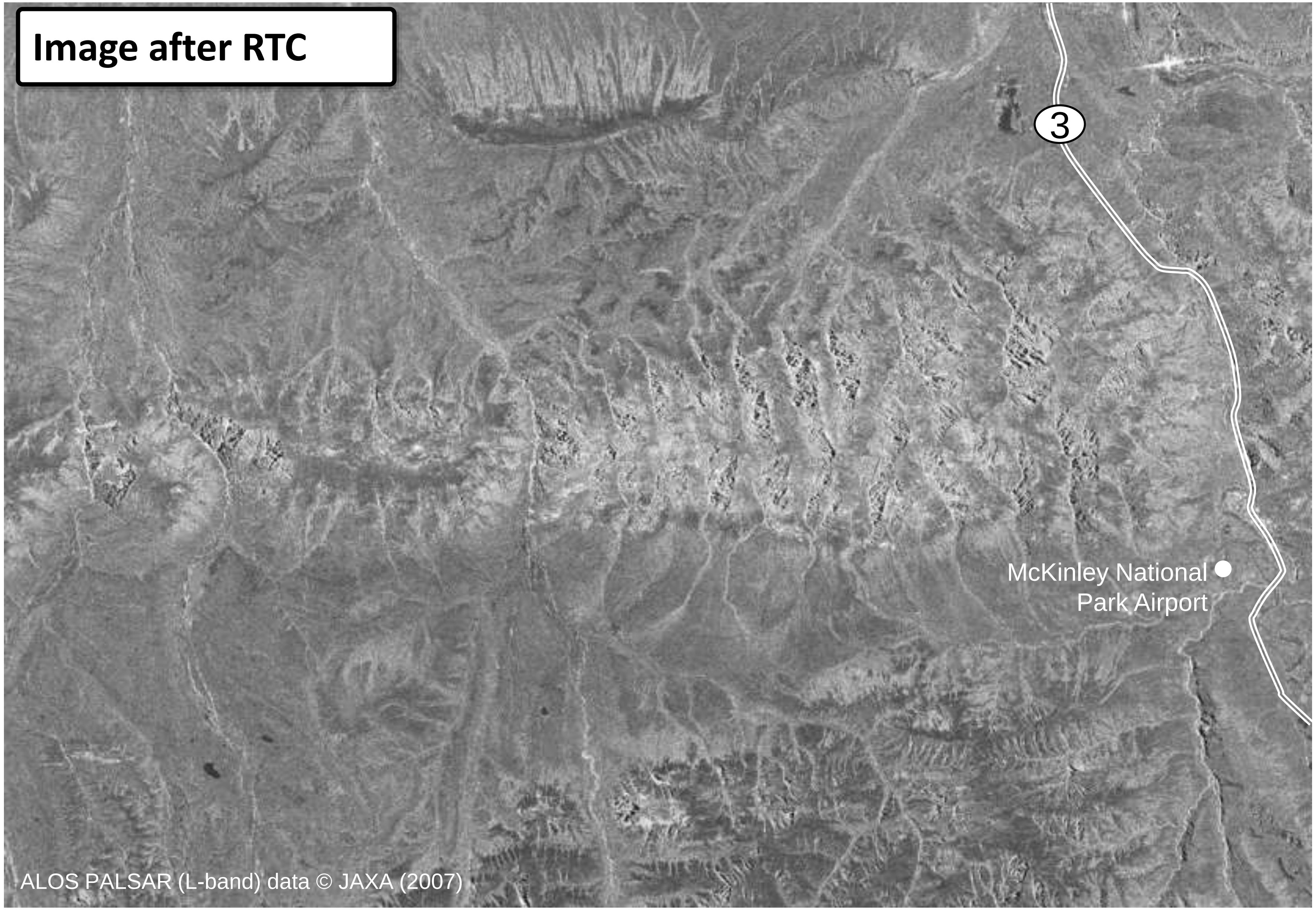
- **Problem:** Sensor facing slopes appear overly bright in radar images.
- **Cause:** Pixel Size on sensor-facing slopes is larger → more ground is integrated into pixel → brightness goes up

- **Solution:** **Radiometric Terrain Correction (RTC)**
  1. Using DEM and observation geometry, calculate *exact equivalent area* A_σ covered by each pixel
  2. Normalize radar cross section by A_σ to arrive at terrain normalized data σ_T^0

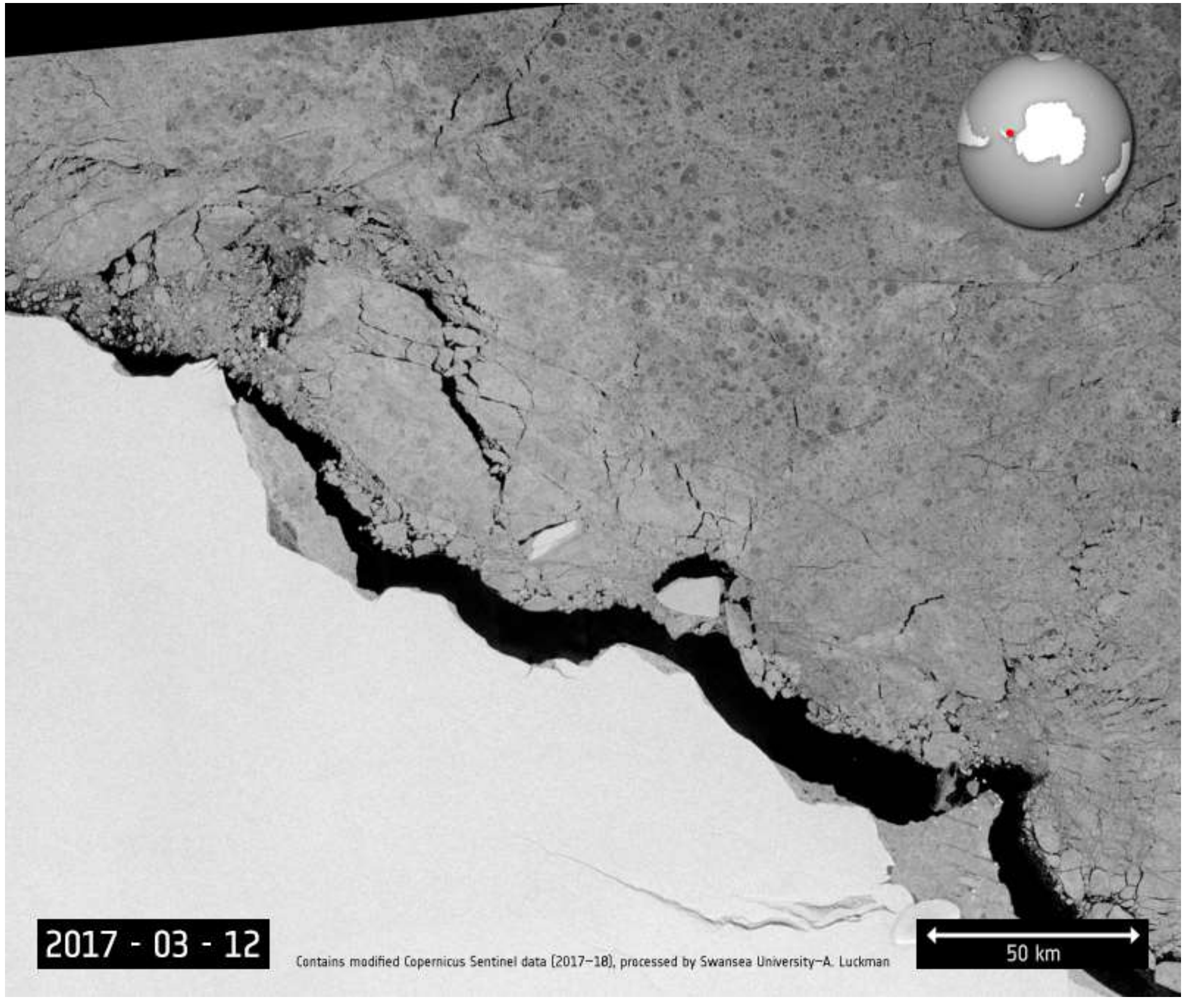
Radiometric Terrain Correction Example (I)



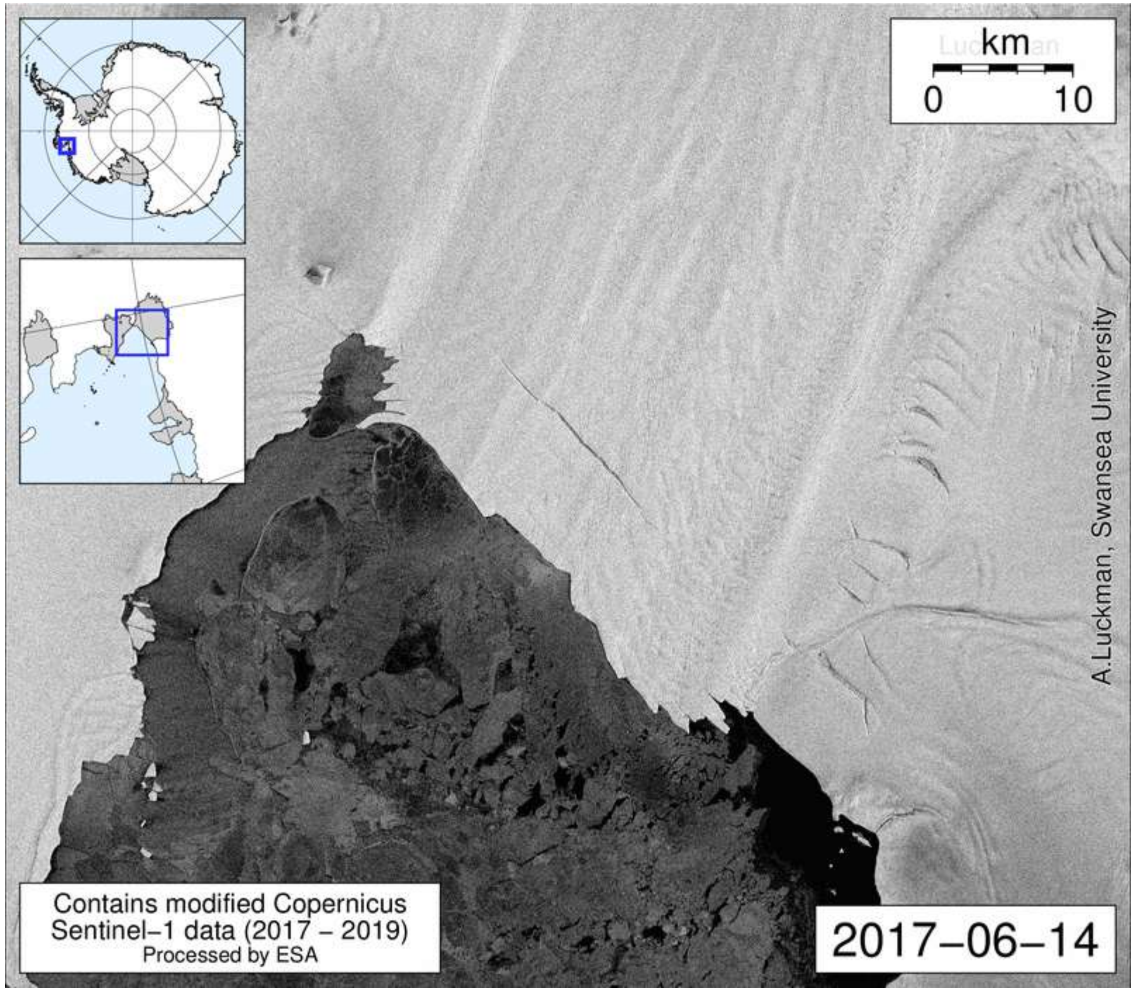
Radiometric Terrain Correction Example (II)



Sentinel-1 RTC Image Time Series In Antarctica



Iceberg A68 Breaking off the Larsen C Ice Shelf



Pine Island Glacier: Satellite animation mid-2017 to Feb-2020

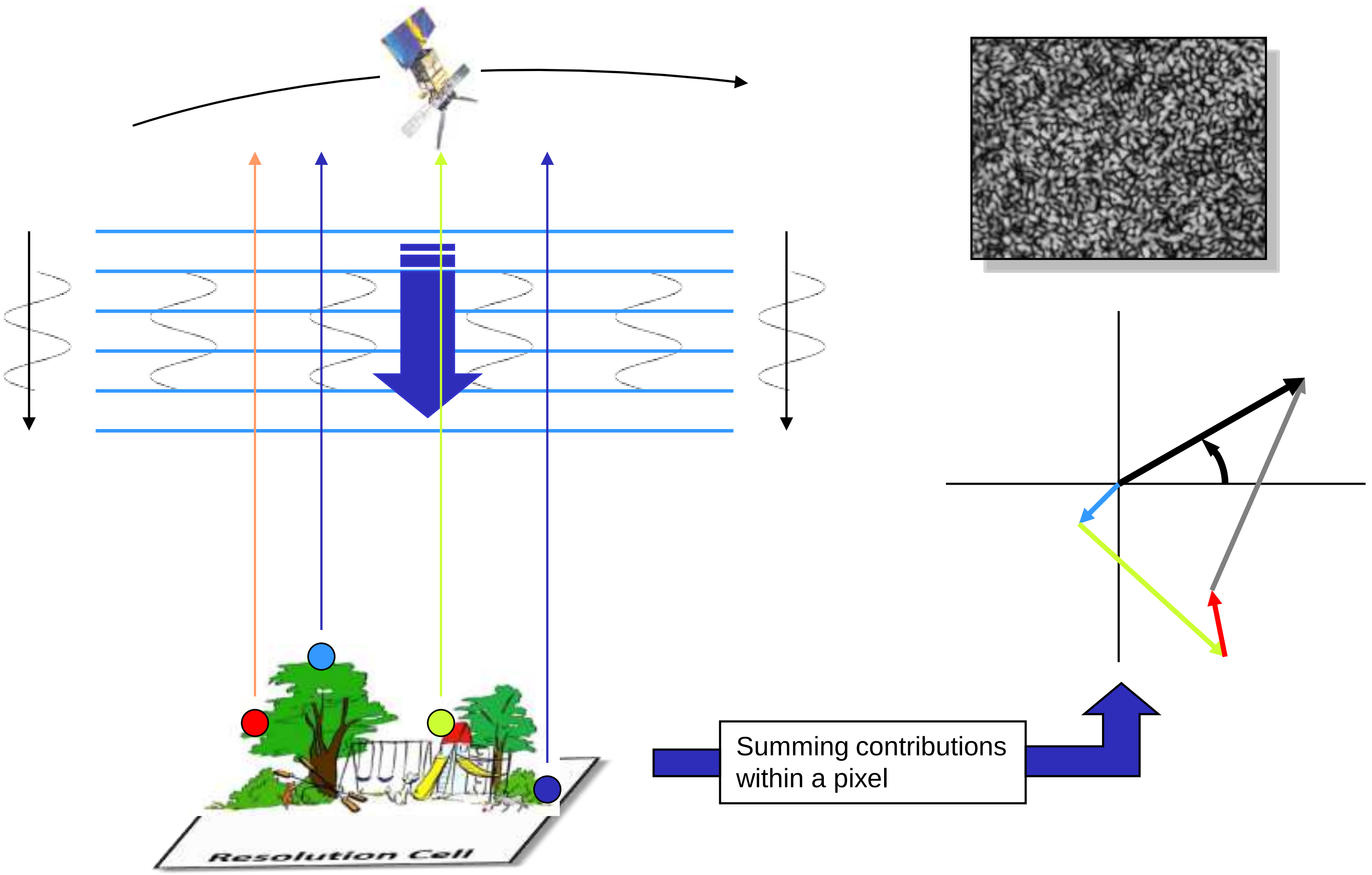
RADIOMETRIC DISTORTIONS – THE SPECKLE NOISE

SAR Images Often Appear a Bit Noisy

- **Do you see the noise?**
- **This noise is caused "Speckle" and is an inherent property of all coherent imaging systems**
- **Technically speaking, it is not noise but an interference pattern**

http://www.astronomy.com/news/2015/02/a-new-way-to-view-titan-despeckle-it

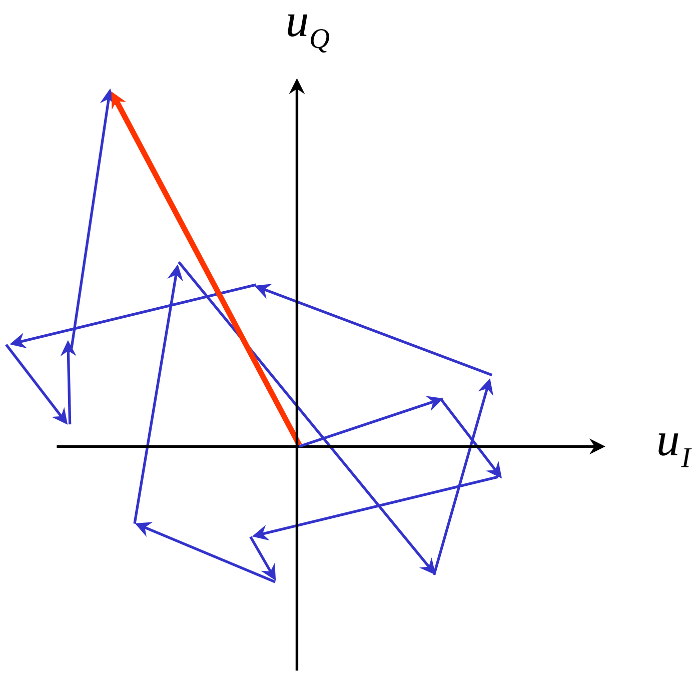
Coherent Waves and Speckle

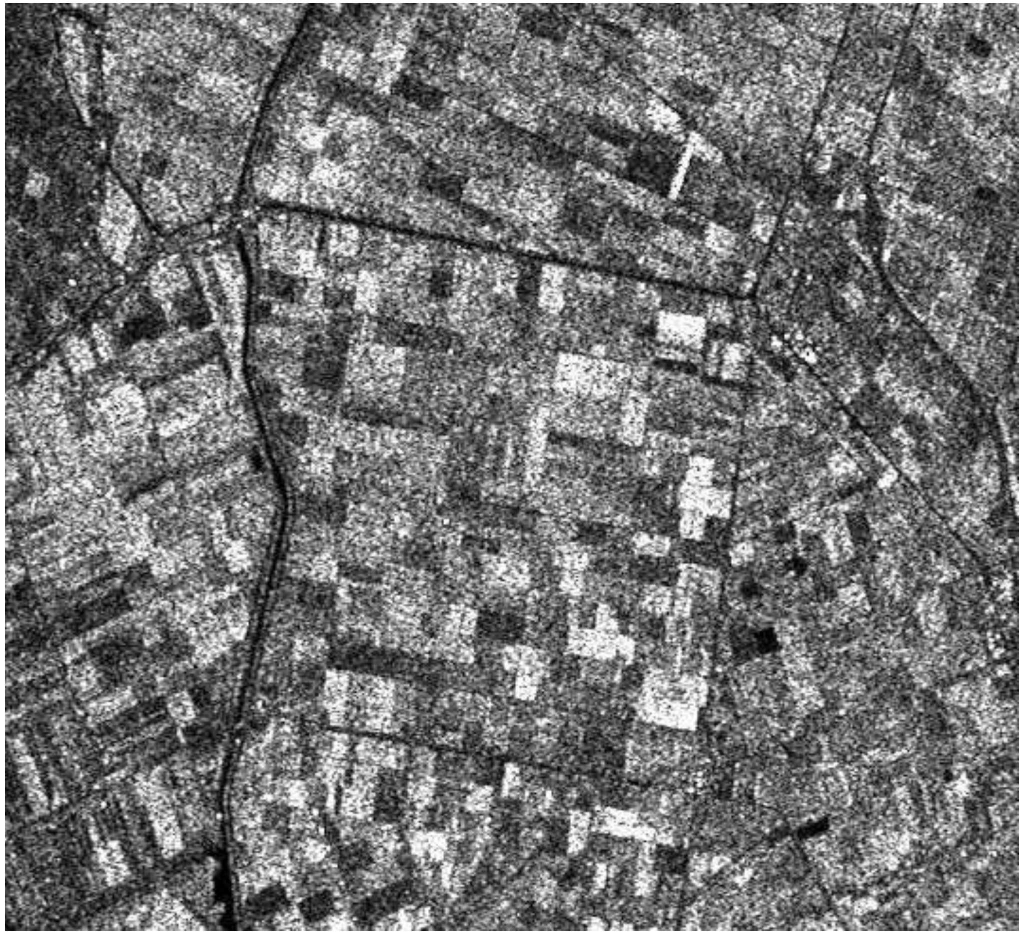


Speckle

Random positive and negative interference of wave contributions from the many individual scatterers within one resolution cell

- → varying brightness from pixel to pixel even for constant σ^0
- → granular appearance

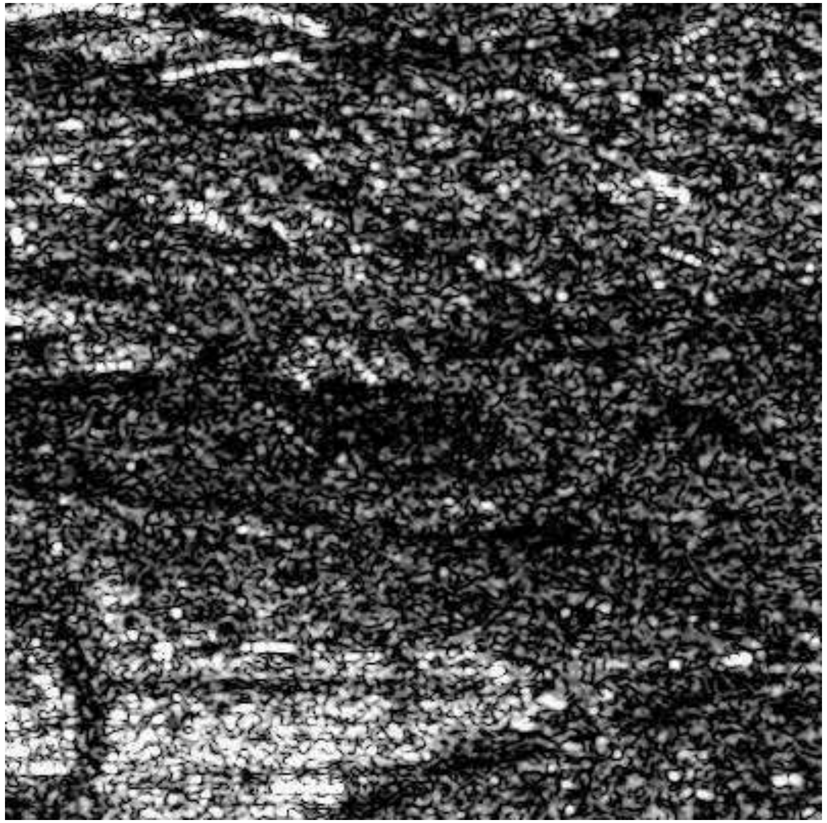




Speckle Example

Time Series of SAR Images

incoherent average of 70 ERS SAR images



individual images (9 years)

- **Right image** shows how speckle can vary over time and in space
- **Left image** shows that *on average*, the backscatter from an area is equal to its radar cross section σ^0

Speckle Reduction

- ***SPECKLE is a scattering phenomenon and not noise. However, speckle can be modeled as multiplicative noise for distributed targets (Lee, IGARSS-98)***

- Speckle "masks" underlying image

- **Speckle filtering:**
  - **GOAL: Reduction of the speckle noise without sacrificing information content (including the spatial resolution)**
  - **PRINCIPLE:** ***Select homogeneous neighboring pixels and then average***

- **Simplest form of speckle reduction:** averaging of adjacent pixels (box filter) or **multi-looking → loss of resolution**

- More complex models (try to limit resolution degradation)

Selected Speckle Filters

SPECKLE FILTERS	DESCRIPTION	RELATED PUBLICATION(S)
Change-preserving multi-temporal Speckle filter	Filter for stacks of SAR images; reduces speckle while preserving changes in the time series (e.g., related to deforestation)	Quegan and Yu, 2001
Lee filter	Standard deviation-based (sigma) filter, filtering data based on statistics calculated from the data. Unlike a Gaussian or boxcar filter, the Lee filter and other similar sigma filters preserve image sharpness and detail while suppressing noise.	Lee, 1980
Enhanced Lee filter	The enhanced Lee filter is an adaptation of the Lee filter. Each pixel is put into one of three classes, which are treated as follows: Homogeneous: The pixel value is replaced by the average of the filter window. Heterogeneous: The pixel value is replaced by a weighted average. Point target: The pixel value is not changed.	Lopes et al., 1990
Frost and enhanced Frost filters	The Frost filter is an exponentially damped circularly symmetric filter that uses local statistics. The Enhanced Frost filter is an adaptation of the Frost filter. It classifies and filters pixels according to the logic explained in the row above.	Frost et al., 1982; Lopes et al., 1990
Non-local means filters	The basic idea behind non-local means filters is to provide an estimate of the clean image via a proper averaging of similar pixels or patches, found in the image. Essentially, the algorithm searches for image patches that resemble the area around the pixel to be filtered. Using some similarity criterion, these patches are found and averaged together to de-noise the image without losing resolution.	Buades et al., 2005; Chen et al., 2014; Di Martino et al., 2016; Martino et al., 2015

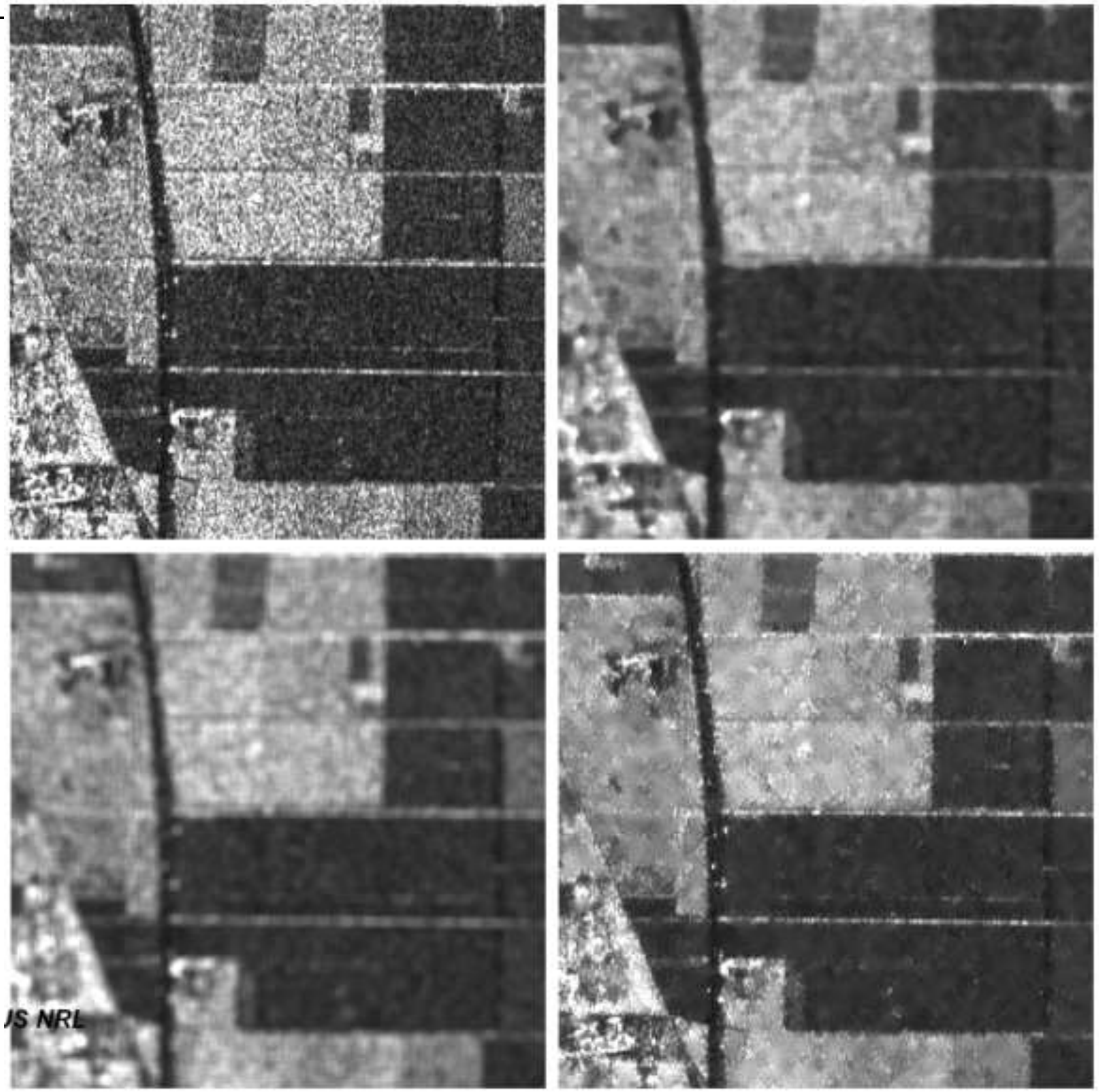
SAR Handbook: Comprehensive Methodologies for Forest Monitoring and Biomass Estimation. Eds. Flores, A., Herndon, K., Thapa, R., Cherrington, E. NASA. 2019. DOI: 10.25966/hbm1-ej07

Speckle Reduction

Example

Original
4-look
amplitude

5x5 Median



5x5 Boxcar

Lee refined
(7x7)

QUESTIONS?