InSAR

CE 603 Photogrammetry II

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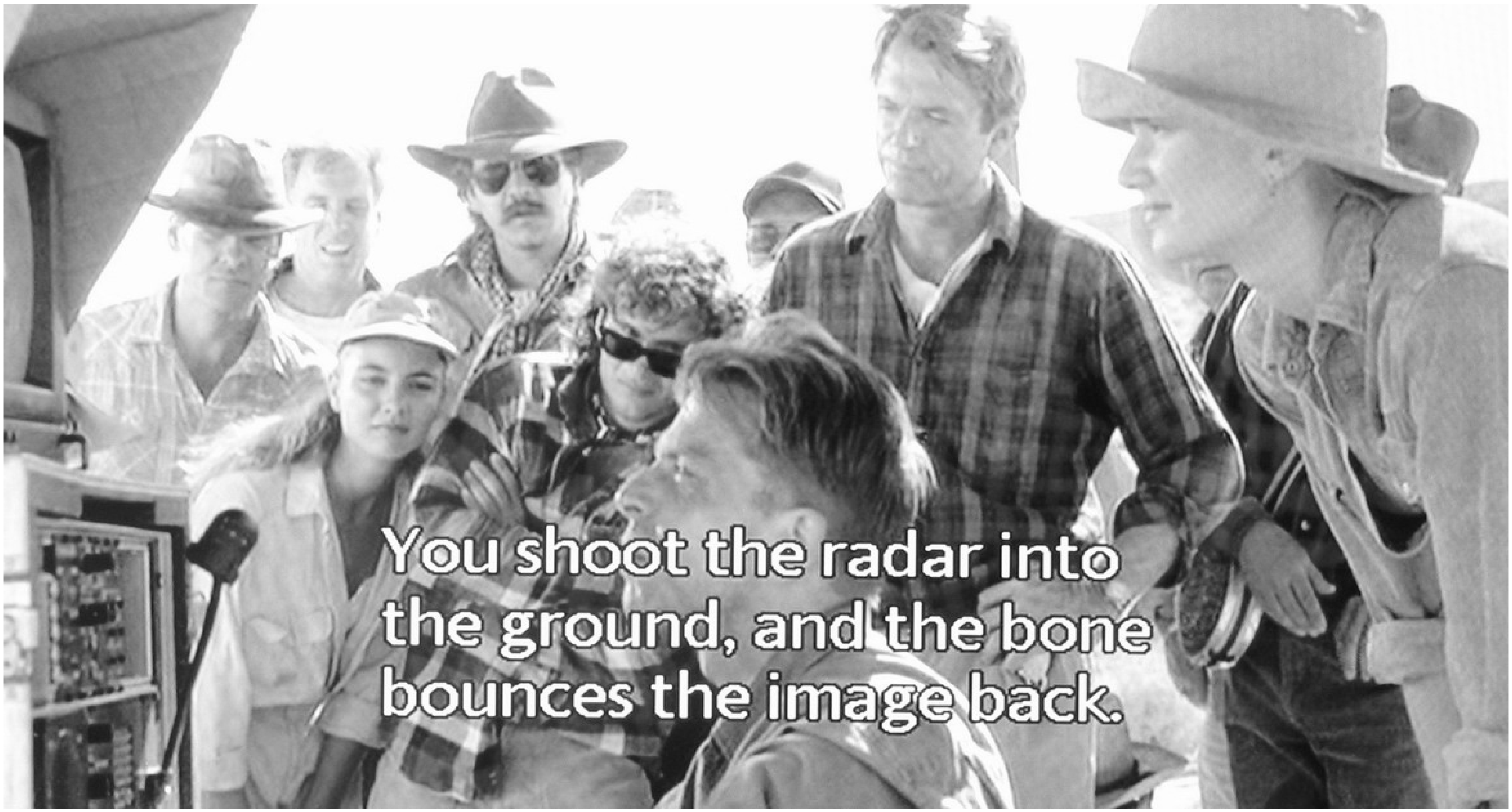
Imaging Radar



Review of SAR

- Mode: active
  Imaging radar works day and night
- Sensor: antenna
- Spectrum: microwave (1 millimeter to 1 meter)
  Sees through clouds and dry soil
- Computer processing

Outline for InSAR

- Introduction
- SAR Imagery
- Principles of InSAR: Phase → Elevation
- InSAR Processing
- InSAR Applications

Introduction to InSAR

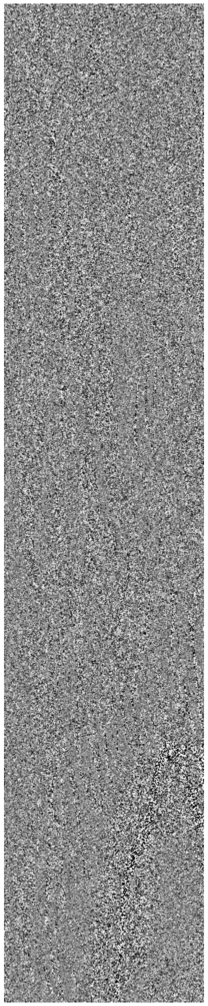
- InSAR ---- Interferometric SAR
  - A process of using interference of microwave to determine length (distances) or changes in length very accurately
  - The phase difference between pair of SAR images→ topographic information
- Interferometric SAR vs. Stereo SAR
  - Phase (mainly) vs. brightness
  - Small baseline (same angles) vs. large baseline (different angles)
  - DEM Accuracy: higher vs. lower
  - Processing complex: more vs. less

InSAR Modes

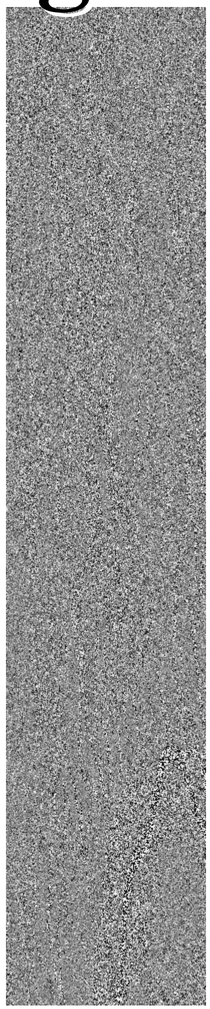
- Two-pass: repeat-track
  - Two slightly displaced tracks (aircraft) or orbits
  - Purpose: topographic mapping
  - Systems: ERS-1and ERS-2 tandem mode; 1 day apart
- One-pass: across-track
  - Two antennas displaced in the across-track direction
  - Purpose: topographic mapping
  - Systems: SRTM
- One-pass: along-track
  - Two receive antennas displaced in the along-track direction
  - Purpose: the velocity of targets moving towards or away from the radar
  - Systems: RADARSAT-2's experimental Moving Object Detection (MODEX)

SRTM

SAR Imagery
---- Single-Look Complex Image

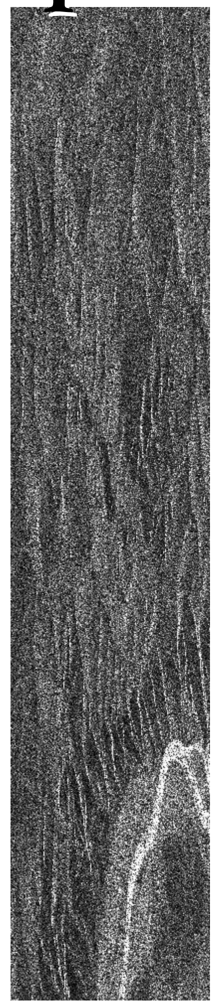


Real

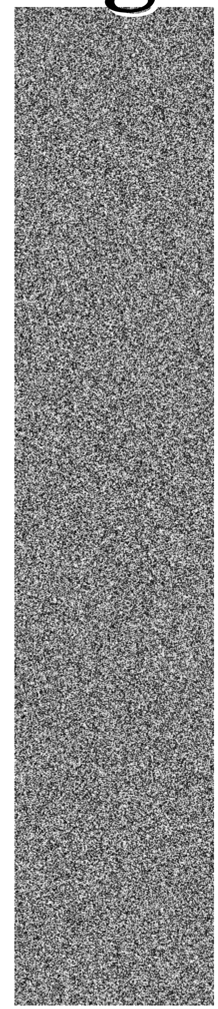


Imaginary

→



Magnitude

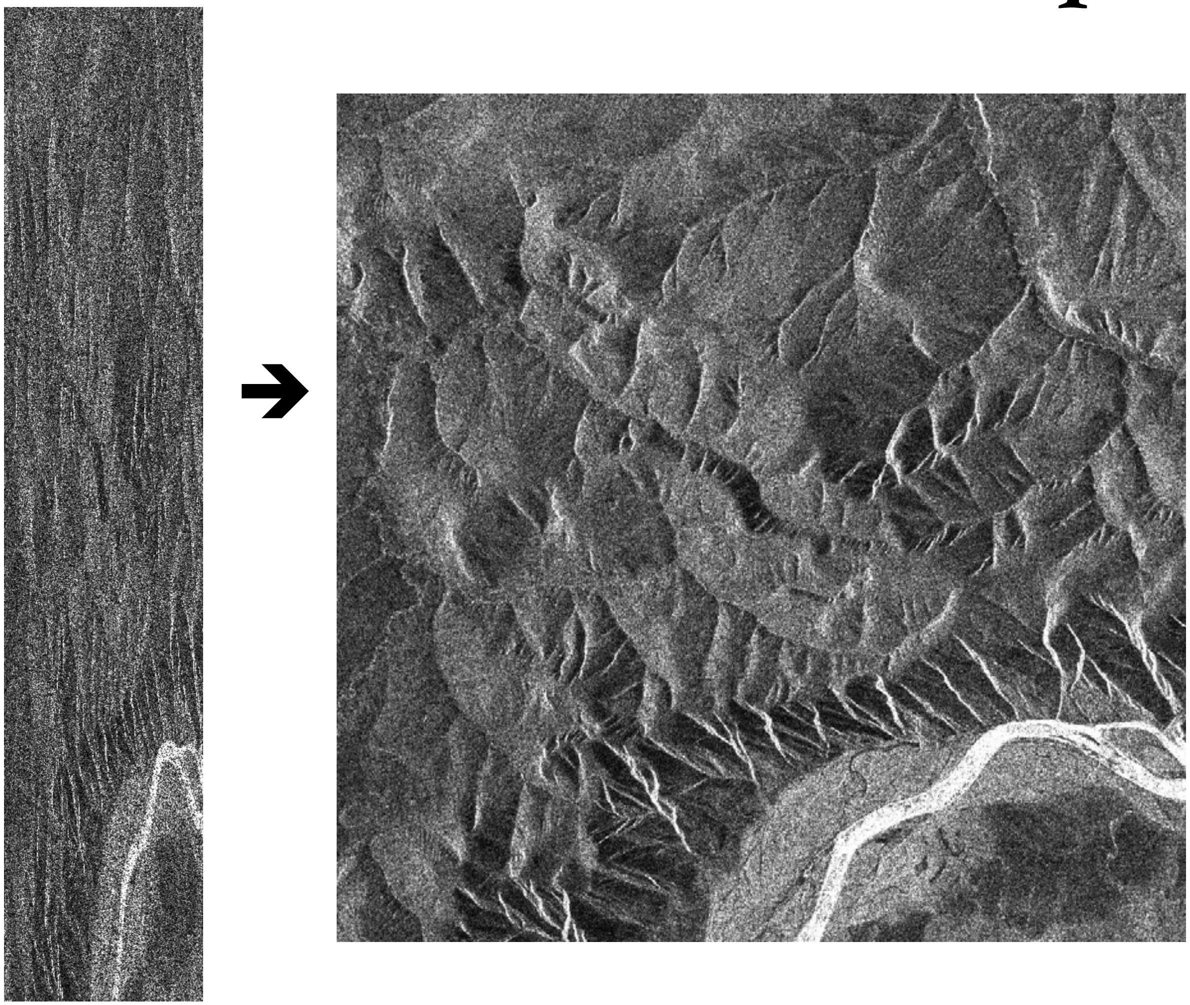


Phase

SAR Imagery
---- SAR Complex Data (I)

- I (Real) and Q (Imaginary): signal's cosine and sine components
- Magnitude
  - sqrt(I^2 + Q^2)
  - Like other medium resolution remote sensing images
  - Used for traditional remote sensing application
- Phase
  - atan(Q/I) or atan2(Q, I)
  - Wavelength = 5.66 cm
  - used for interferometry
- 8 Bytes (4 for I and 4 for Q) per pixel

SAR Imagery
---- Multi-look Complex Image

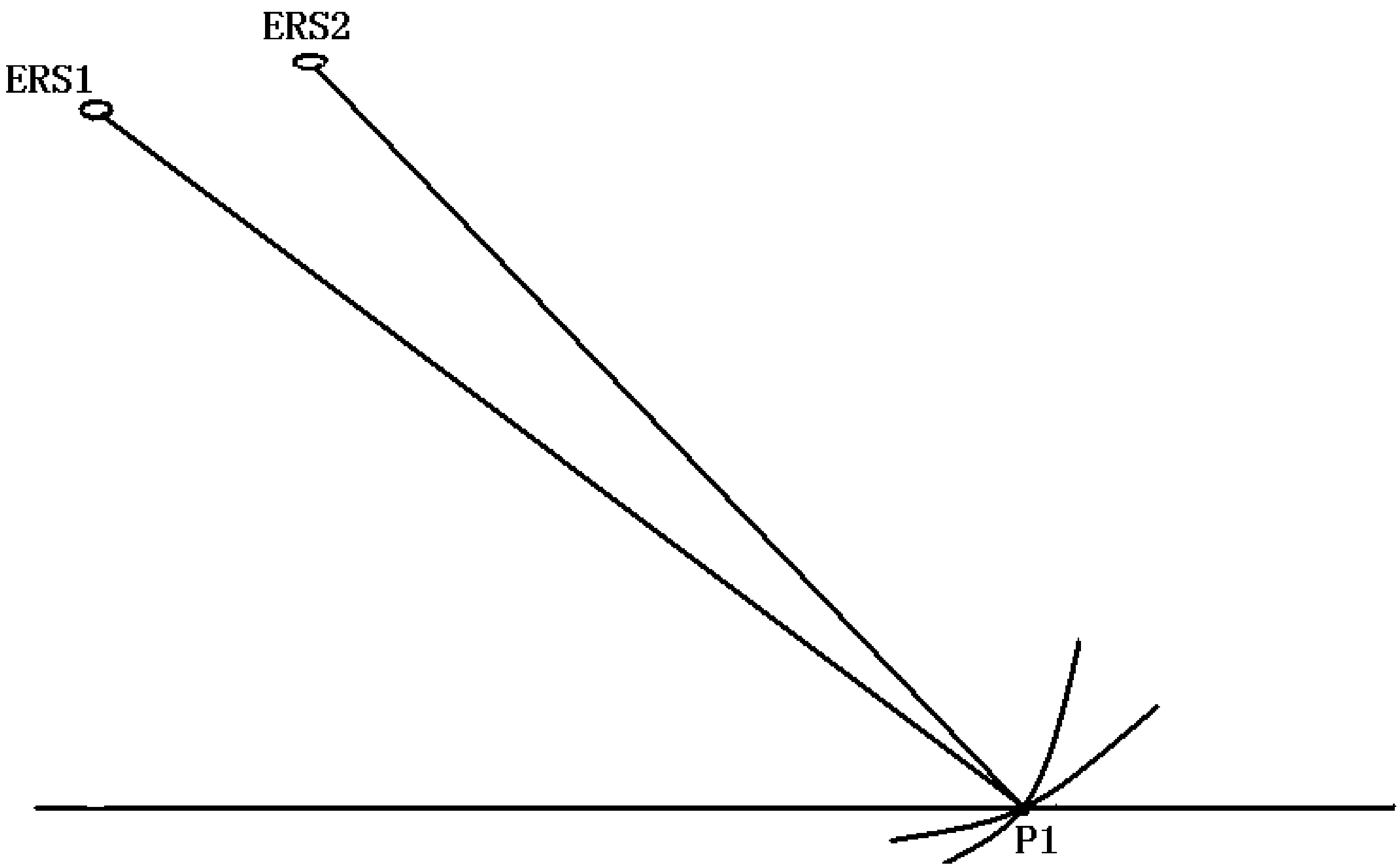


- Location: Fairbanks, Alaska
- Stretch ratio: 1/5 along azimuth direction

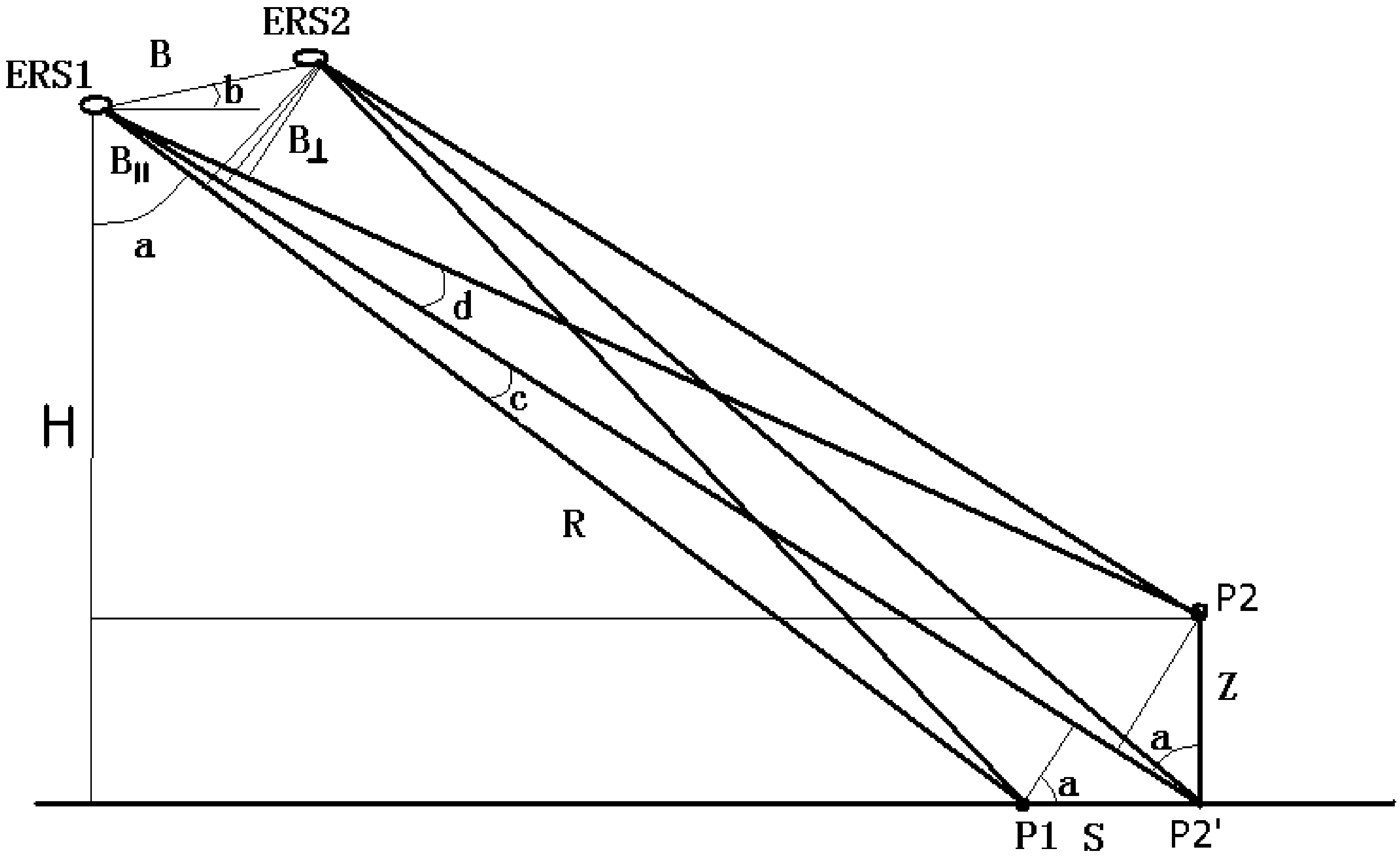
SAR Imagery
---- SAR Complex Data (II)

- Resolution
  - Range spacing: 8 m in slant range → 8 m/sin(23^o) = 20 m on the ground
  - Azimuth spacing: 4 m
  - Azimuth : Range = 1 : 5 (SLC: single-look complex images)
  - Multi-look complex images: stretching along azimuth
- Full swath complex products
  - 100 km x 100 km
  - About 25,000 lines (azimuth)
  - About 5,000 samples (range)

From Phase to Elevation
---- Two Pulses Fixing A Point



From Phase to Elevation
---- Range to Phase



From Phase to Elevation
---- Symbols

- P1 and P2 are adjacent pixels
- H is the altitude of ERS1 = 785 km
- a is the look angle = 23 degrees
- B is the baseline between ERS1 and ERS2
  - b is the angle between B and horizontal plane
  - B parallel (Bp) = B*cos(π /2-a+b) = B*sin(a-b)
  - B normal (Bn) = B*sin(π /2-a+b) = B*cos(a-b)
- Z is the elevation of P2
- S is the pixel resolution on the ground (=20 m)
- Assumptions
  - c << a → cos(c) = 1 and sin(c) = c
  - d << a → cos(d) = 1 and sin(d) = d
  - Z << H → Z/(H-Z) = Z/H

From Phase to Elevation
---- Equations for Phase Differences

$$\phi_1 = \frac{2B_{\|}}{\lambda} \cdot 2\pi = \frac{4\pi}{\lambda} B_{\|} = \frac{4\pi}{\lambda} B \cdot \cos\left(\frac{\pi}{2} - a + b\right)$$

$$= \frac{4\pi}{\lambda} B \cdot \sin(a-b)$$

$$\phi_2 = \frac{4\pi}{\lambda} B \cdot \sin(a+c-b) = \frac{4\pi}{\lambda} B \cdot \sin[(a-b)+c]$$

$$= \frac{4\pi}{\lambda} B \cdot \sin(a-b) \cdot \cos(c) + \frac{4\pi}{\lambda} B \cdot \cos(a-b) \cdot \sin(c)$$

$$\approx \frac{4\pi}{\lambda} B \cdot \sin(a-b) + \frac{4\pi}{\lambda} B \cdot \cos(a-b) \cdot c$$

$$\phi_3 = \frac{4\pi}{\lambda} B \cdot \sin[(a-b)+(c+d)]$$

$$\approx \frac{4\pi}{\lambda} B \cdot \sin(a-b) + \frac{4\pi}{\lambda} B \cdot \cos(a-b) \cdot (c+d)$$

$$\sin(c) \approx c; \cos(c) \approx 1; \sin(d) \approx c; \cos(d) \approx 1$$

- Equations for Phase differences Φ_1, Φ_2, and Φ_3 between two images (ERS1 and ERS2) for P1, P2', and P2

From Phase to Elevation ---- Equations for the Changes of Phase Differences

$$\phi_2 - \phi_1 = \frac{4\pi}{\lambda} B \cdot \cos(a-b) \cdot c$$

$$\approx \frac{4\pi}{\lambda} B \cdot \cos(a-b) \cdot \frac{S \cdot \cos(a)}{R}$$

$$= \frac{4\pi}{\lambda} B \cdot \cos(a-b) \cdot \frac{S \cdot \cos(a)}{\frac{H}{\cos(a)}}$$

$$= \frac{4\pi}{\lambda} B \cdot \cos(a-b) \cdot \frac{\cos^2(a)}{H} \cdot S$$

$$= \frac{4\pi}{\lambda} B_\perp \cdot \frac{\cos^2(a)}{H} \cdot S$$

$$Set: k = \frac{4\pi}{\lambda} B_\perp \cdot \frac{\cos^2(a)}{H}$$

$$\Rightarrow \phi_2 - \phi_1 = k \cdot S$$

$$\phi_3 - \phi_2 = \frac{4\pi}{\lambda} B \cdot \cos(a-b) \cdot d$$

$$\approx \frac{4\pi}{\lambda} B \cdot \cos(a-b) \cdot \frac{Z \cdot \sin(a)}{\frac{H-Z}{\cos(a+c+d)}}$$

$$\approx \frac{4\pi}{\lambda} B \cdot \cos(a-b) \cdot \frac{\sin(a) \cdot \cos(a)}{H} \cdot Z$$

$$= \frac{4\pi}{\lambda} B_\perp \cdot \frac{\sin(a) \cdot \cos(a)}{H} \cdot Z$$

$$Set: k = \frac{4\pi}{\lambda} B_\perp \cdot \frac{\cos^2(a)}{H}$$

$$\Rightarrow \phi_3 - \phi_2 = k \cdot \tan(a) \cdot Z$$

From Phase to Elevation ---- Key Equations

$$k = \frac{4\pi}{\lambda} B_{\perp} \cdot \frac{\cos^2(a)}{H}$$

$$dP_f = \phi_2 - \phi_1 = k \cdot S \qquad (A)$$

$$dP_e = \phi_3 - \phi_2 = k \cdot \tan(a) \cdot Z \qquad (B)$$

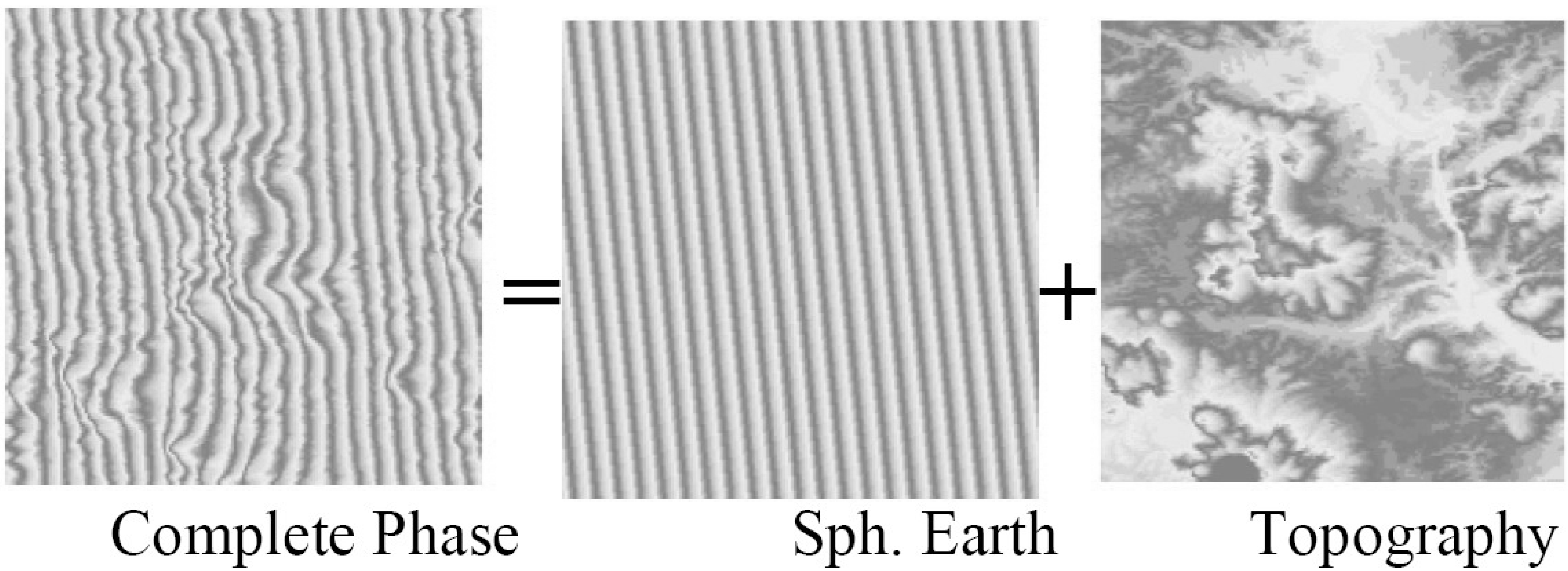
$$dP = \phi_3 - \phi_1 = dP_f + dP_e \qquad (C)$$

- Equation (A): Phase change due to the flat (spherical) earth: dP_f, proportional to the ground resolution in range direction
- Equation (B): Phase change due to the topography: dP_e, proportional to the elevation change
- Equation (C): Total phase change between the adjacent pixels: dP

From Phase to Elevation ---- Numeric Example

- Pick Bn = 200 m
- For a standard interferometric pair of SAR images, phase change between two adjacent pixels due to the flat (spherical) earth dP_f = 0.9586
- Assuming the total phase changes between two adjacent pixels dP are $\pi/4$, $\pi/2$, π, and 2π respectively
- The phase changes due to the topography will be $dP_e = dP - dP_f$ = -0.1732, 0.6122, 2.1830, and 6.2832
- The elevation change will be Z = dPe/k/tan(a) = -8.5 m, 30.1 m, 107.3 m, and 261.7 m
- If P1 is fixed to an elevation, the elevation of P2 will be known; then P3, P4, …

From Phase to Elevation
---- Phase Differences (Interferogram)



- Richard E. Carande, GEOS 695: SAR and InSAR: Principles and Applications, ASF

From Phase to Elevation ---- Phase Unwrapping

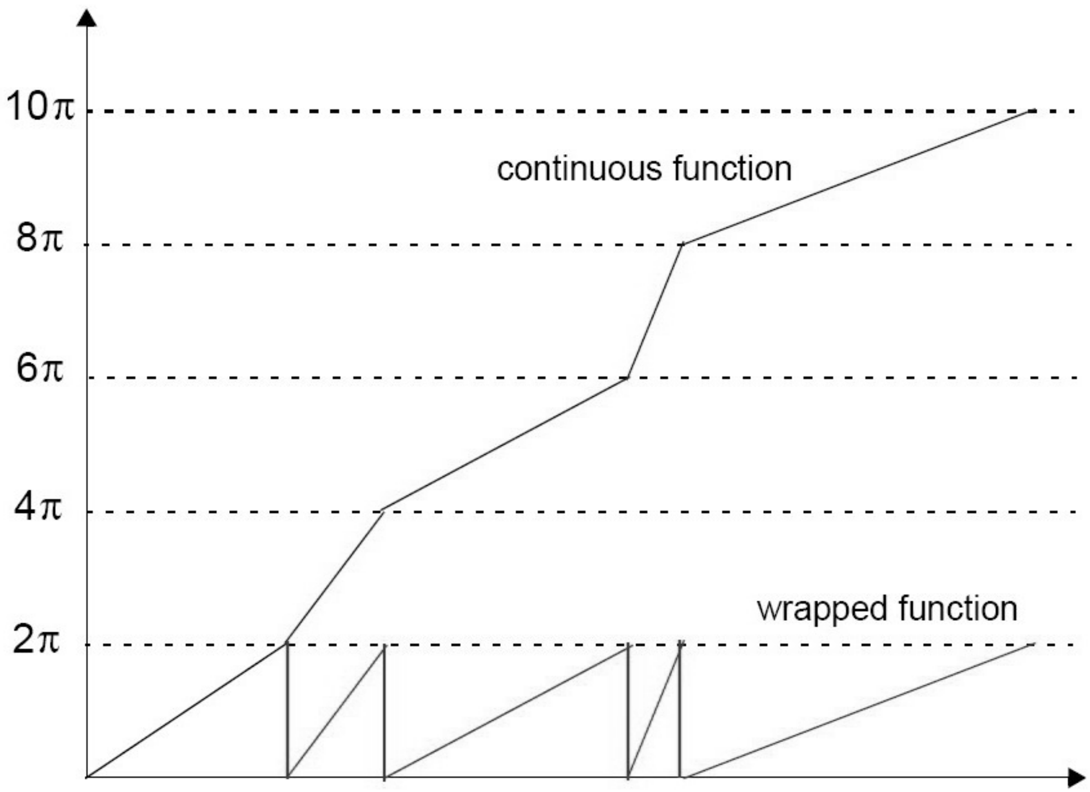
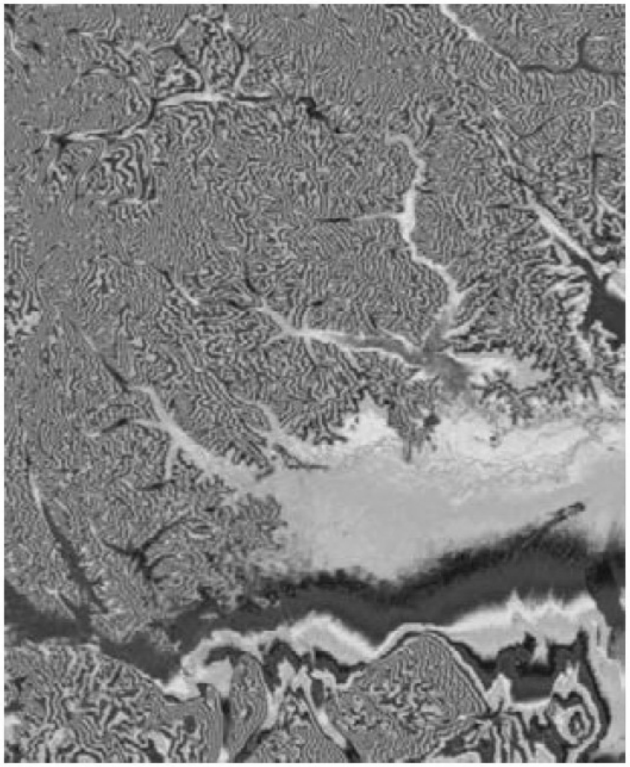
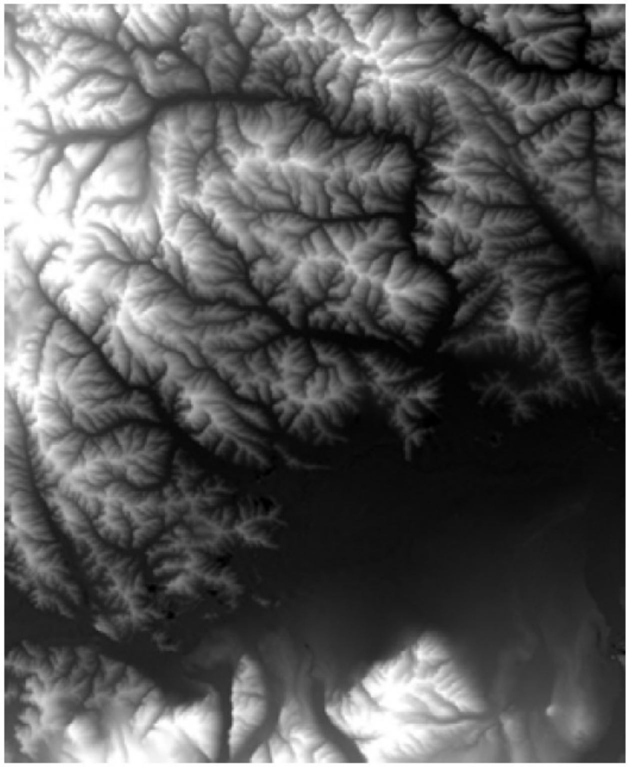


Figure 8-17: One-dimensional Continuous vs. Wrapped Phase Function

- Blue line is unwrapped phase
- Red line is wrapped phase in interferogram
- Elevation will be continuous by using unwrapped phase
- Source: ERDAS Fieldguide

From Phase to Elevation ---- Phase Unwrapping


wrapped phase

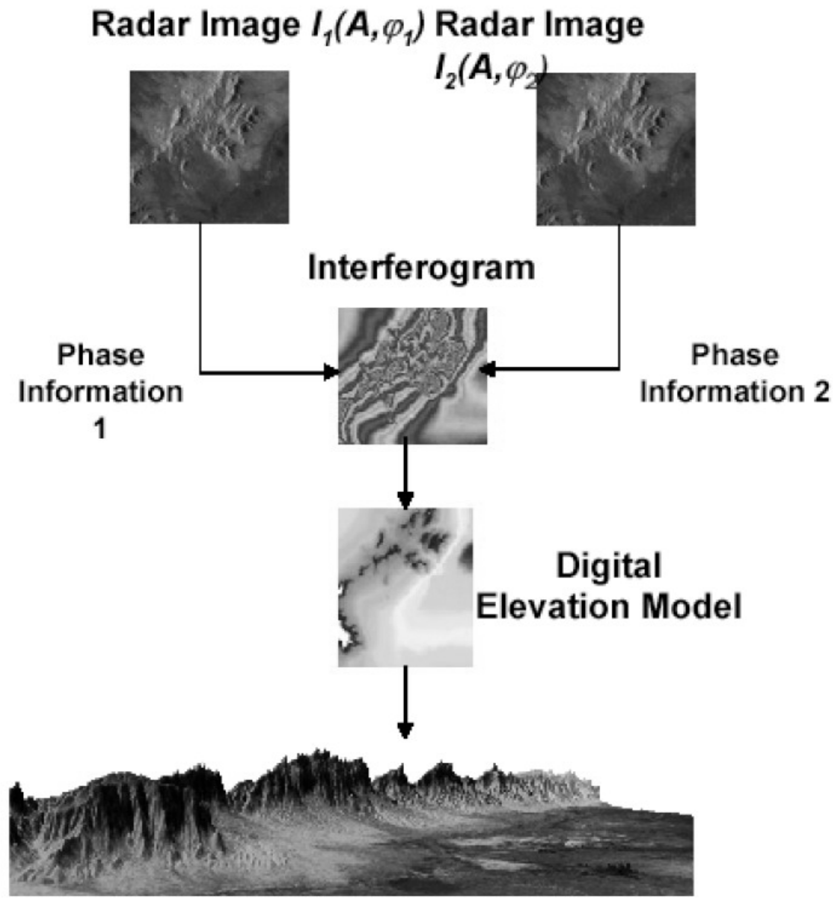

unwrapped phase

Source: Rüdiger Gens, DEM generation, ASF

From Phase to Elevation ---- Summary

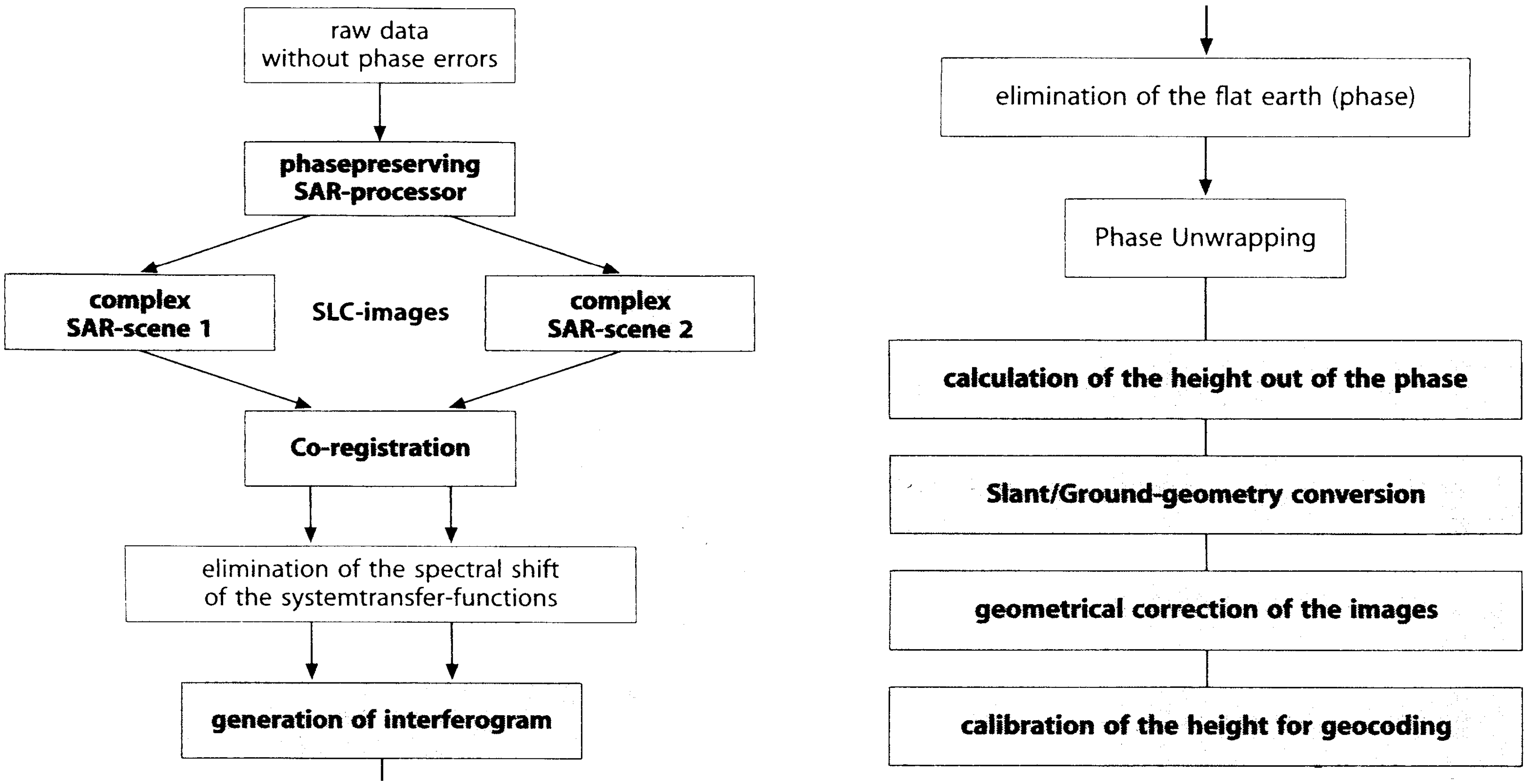
- Computation of phase difference between two SAR images for each pixel (same ground point)
- Computation of the total change of phase differences between pixels
- Subtracting the change of phase differences due to the flat (spherical) earth
- The change of phase differences due to the topography → The change of the elevation
- Phase unwrapping is needed for continuous elevation changes
- Only the relative elevation changes are computed; At least one fixed pixel is needed, in order to obtain the absolute elevation model

Interferometric SAR Processing ---- Overview



Wolfgang Keydel, DLR '04

Interferometric SAR Processing ---- Flow Chart



Source: A. Hein, Processing of SAR Data

Interferometric SAR Processing ---- Main Steps (I)

- Image Formation: Raw Data → Complex Images
  - Range Compression
  - Range Migration
  - Azimuth Compression
- Co-Registration of Interferometric Complex Image Pair
  - Image Matching
  - Image Re-sampling
  - Spectral Shift and Filtering
  - Coherence Computation

Interferometric SAR Processing ---- Main Steps (II)

- Interferogram Generation & Processing
  - Complex Conjugate Multiplication of SAR Image Pair
  - Noise Filtering
  - Flat Earth Correction
- Phase Unwrapping
- Elevation Calculation from Phase
  - Slant Geometry → Ground Geometry
  - Geometric Correction
  - Geocoding