EE/Ae 157 b

Interferometric Synthetic Aperture Radar

PRINCIPLES OF IMAGING RADAR
CHARACTERISTICS OF RADAR WAVES

- The propagation of radar waves are governed by Maxwell's equations. From these equations, one can derive the so-called free-space wave equation:

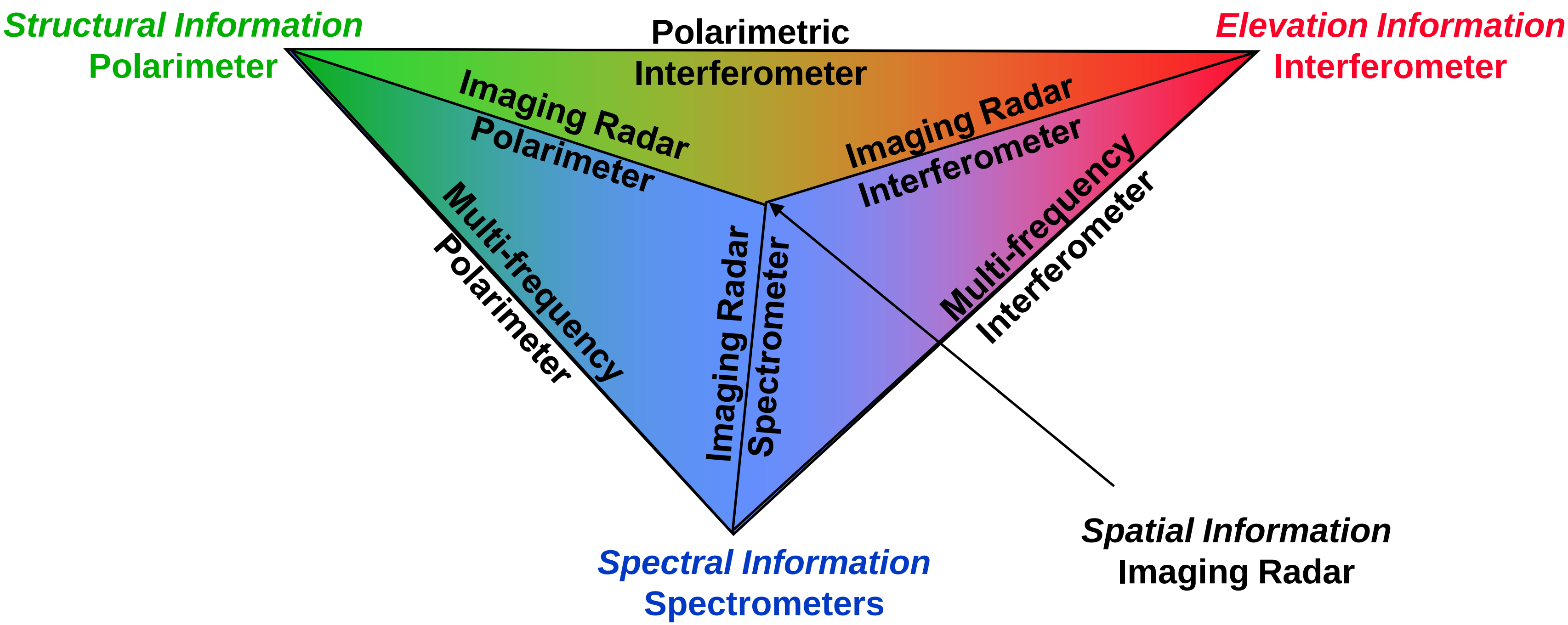
$$\nabla^2 \mathbf{E} + \frac{\omega^2}{c_r^2} \mathbf{E} = 0$$

- The solution to this free-space wave equation is of the form:

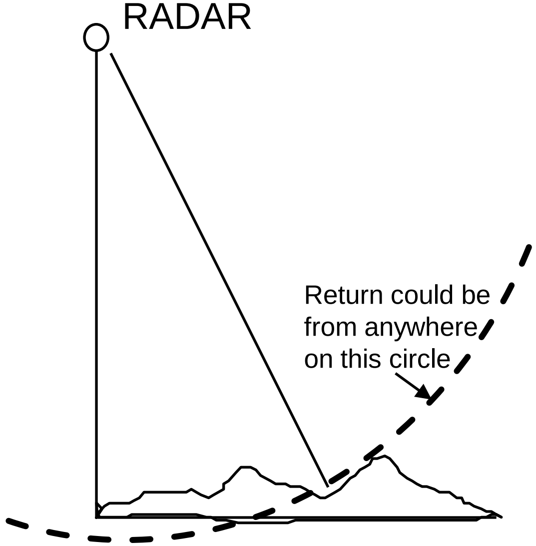
$$\mathbf{E} = \mathbf{A} e^{i(kr - \omega t + \phi)}$$

- There are three parameters in this wave solution that we commonly exploit in radar remote sensing:
  - Amplitude and polarization provides information about scattering properties and structure
  - Frequency diversity allows us to learn more about the size of scatterers
  - Phase information is used in interferometry to reconstruct three-dimensional topography, as well as small changes to topography

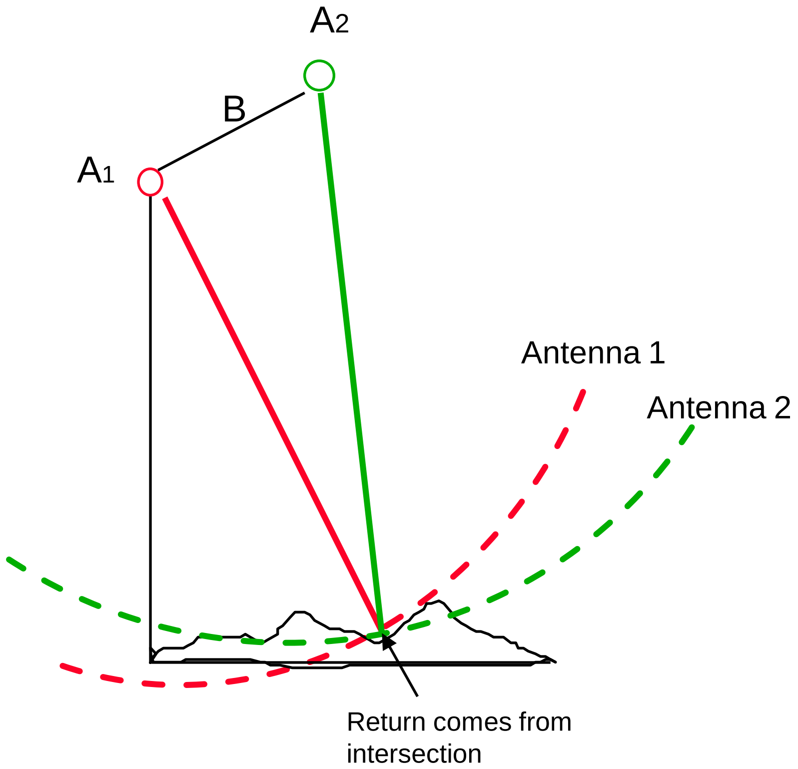
PRINCIPLES OF IMAGING RADAR
TYPES OF IMAGING RADARS



RADAR INTERFEROMETRY
HOW DOES IT WORK?



SINGLE ANTENNA SAR



INTERFEROMETRIC SAR

RADAR INTERFEROMETRY
TRIGONOMETRY

- The radar phase difference for a common transmitter is

$$\phi_1 = \frac{4\pi}{\lambda}\rho ; \phi_2 = \frac{2\pi}{\lambda}(2\rho + \delta\rho)$$

$$\Rightarrow \Delta\phi = \frac{2\pi}{\lambda}\delta\rho$$

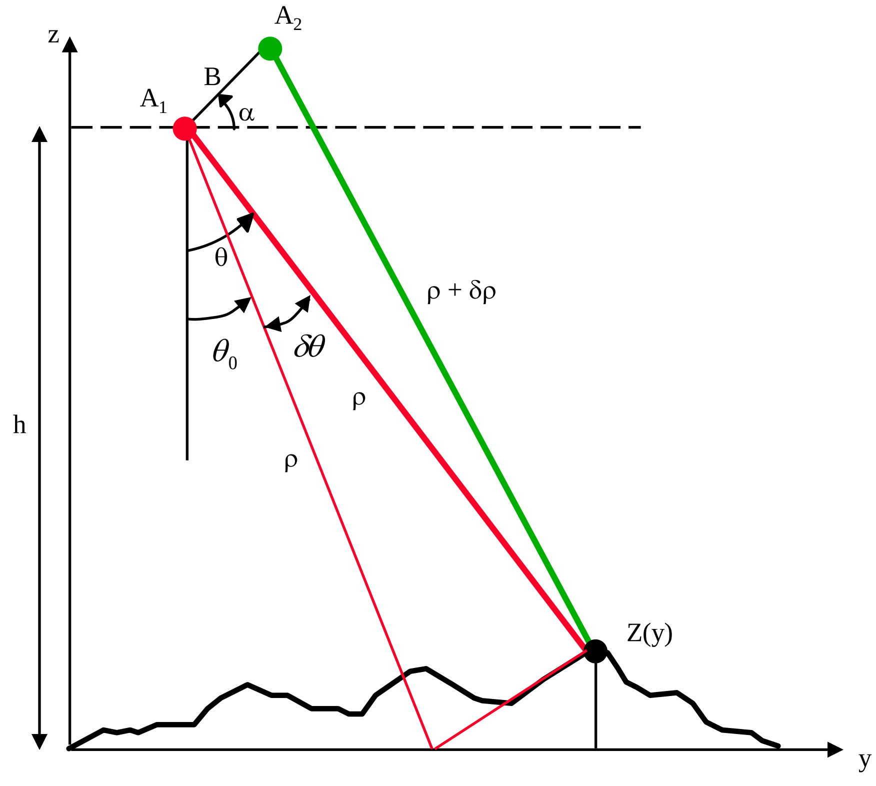
- For the spaceborne case, $B << \rho$ From the law of cosines, we find that

$$(\rho + \delta\rho)^2 = \rho^2 + B^2 - 2\rho B \cos\left(\frac{\pi}{2} - \theta + \alpha\right)$$

$$\Rightarrow \delta\rho \approx -B\sin(\theta - \alpha)$$

$$\Rightarrow \Delta\phi = -\frac{2\pi}{\lambda}B\sin(\theta - \alpha)$$

- The phase difference is directly proportional to the *electrical* length of the interferometer baseline



SIMULTANEOUS BASELINE

RADAR INTERFEROMETRY

Phase Difference in the Absence of Topography

(B=60m, alpha=45,wavelength=5.66 cm, altitude = 234 km)

RADAR INTERFEROMETRY

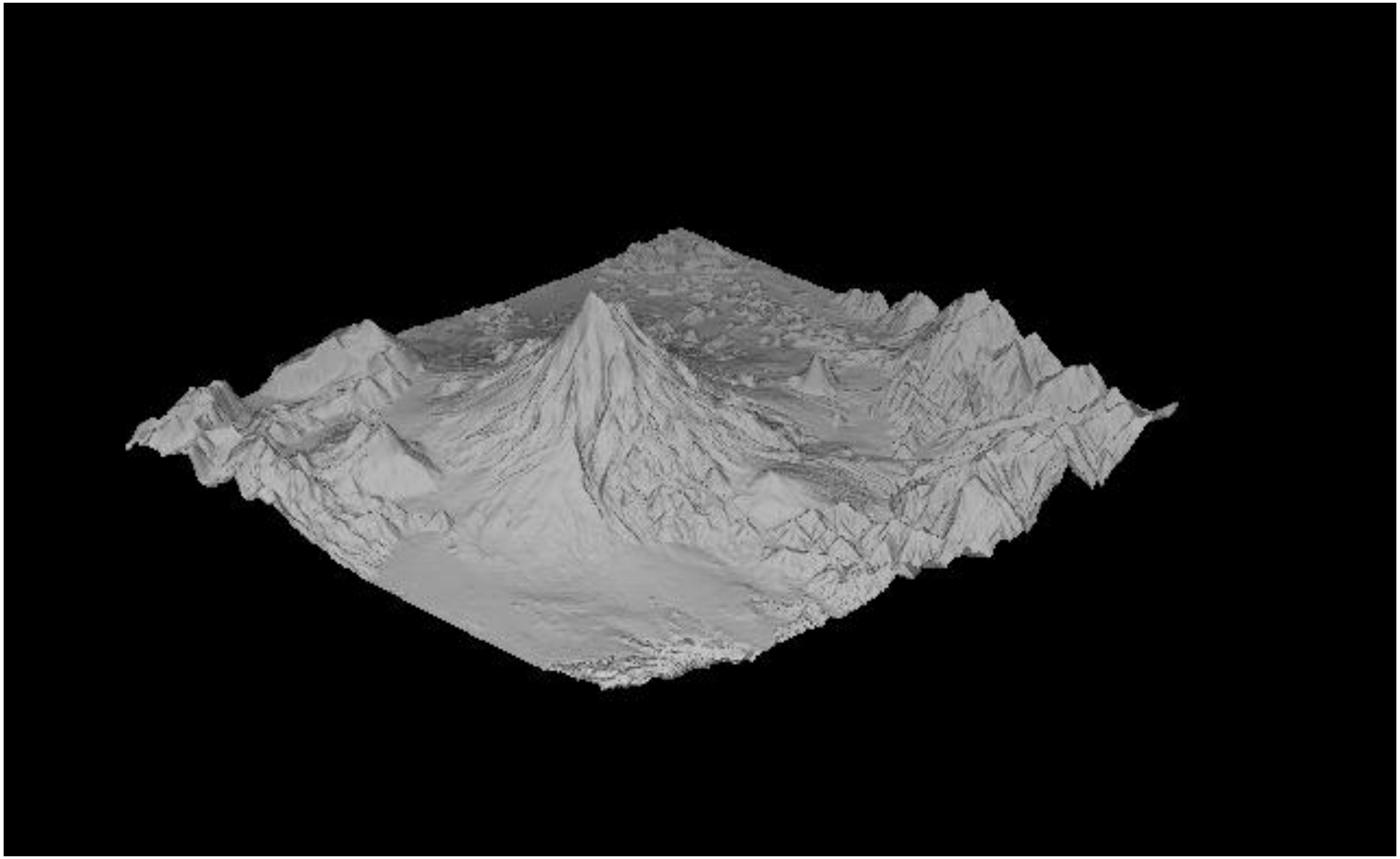
Phase Difference is a function of the ELECTRICAL Length of the Baseline

(B=60m, alpha=45, altitude = 234 km)

Wavelength = 5.66 cm

Wavelength = 24 cm

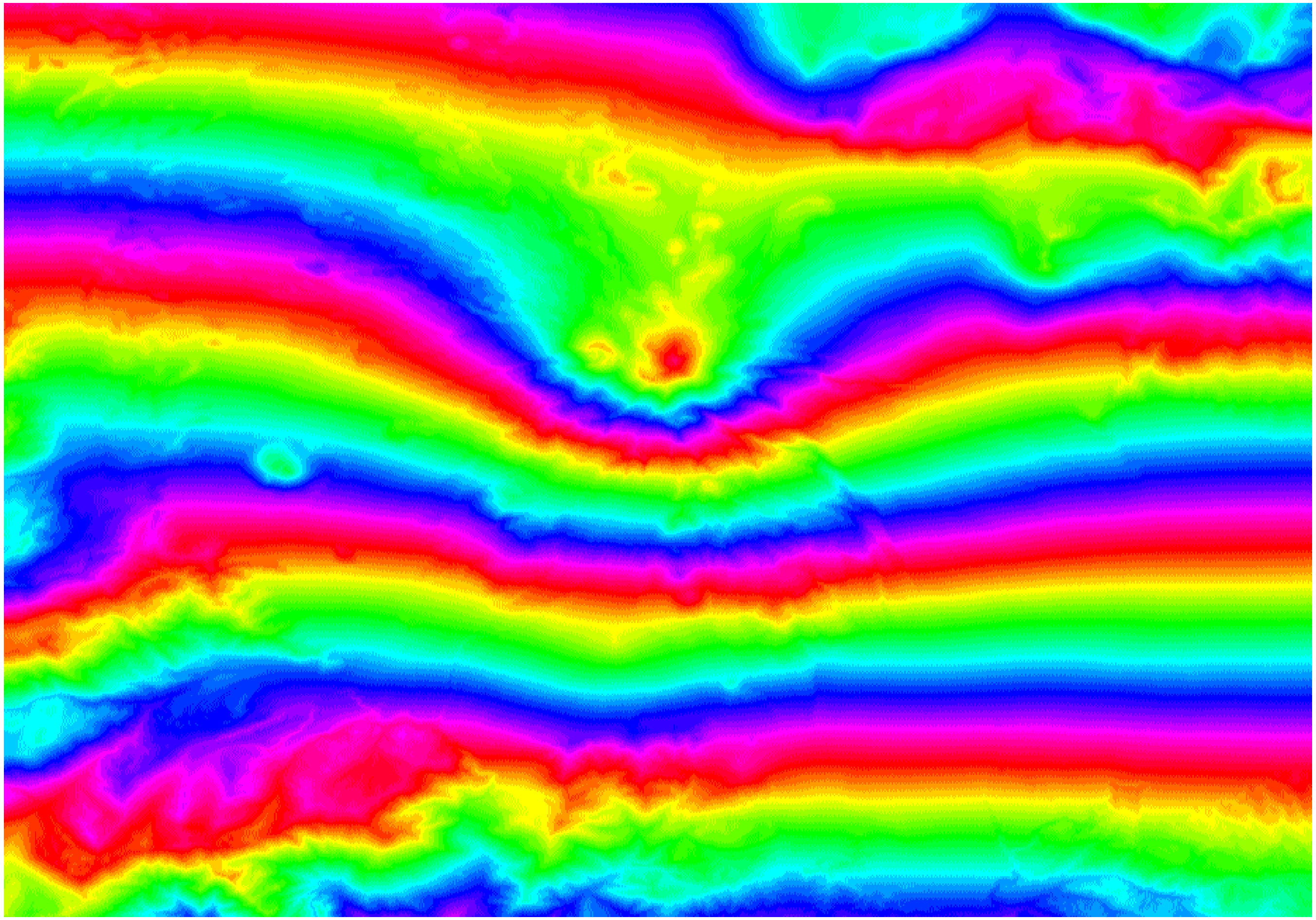
RADAR INTERFEROMETRY
Example: Mt. Shasta, California



RADAR INTERFEROMETRY

Mt Shasta Phase Difference

(B=60m, alpha=45,wavelength=5.66 cm, altitude = 234 km)



Radar Look Direction

Radar Movement

RADAR INTERFEROMETRY
TRIGONOMETRY (continued)

- Now let θ_0 represent the look angle to a point on a "flat earth" as shown in the figure. Then

$$\sin(\theta - \alpha) = \sin(\theta_0 + \delta\theta - \alpha)$$
$$\approx \sin(\theta_0 - \alpha) + \cos(\theta_0 - \alpha)\delta\theta$$

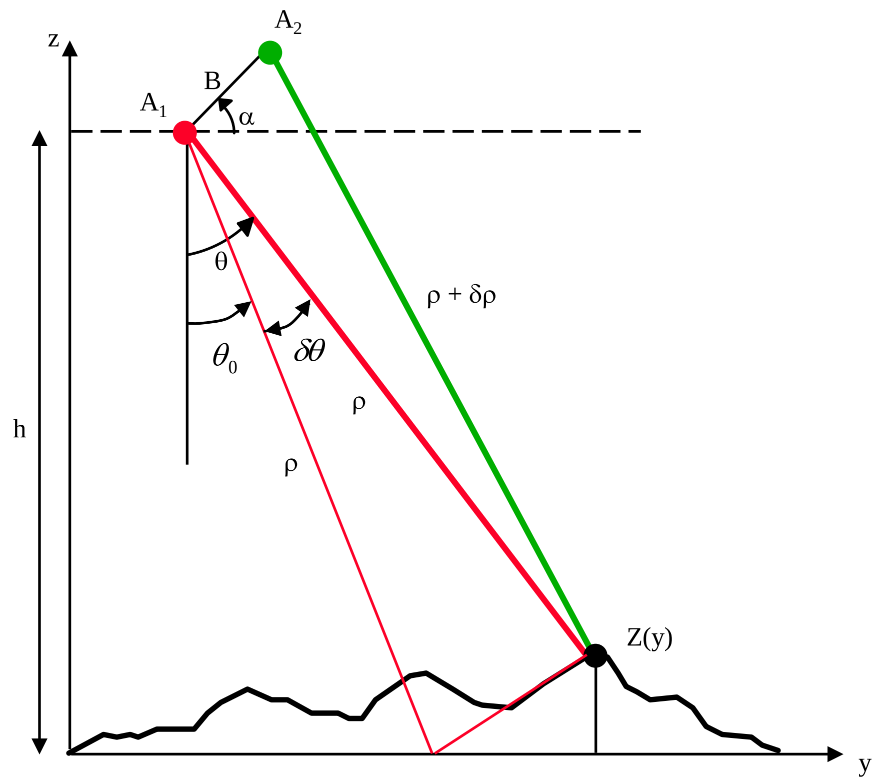
- In terms of the interferometric phase, it means we can write

$$\Delta\phi \approx -\frac{2\pi}{\lambda} B \sin(\theta_0 - \alpha) - \frac{2\pi}{\lambda} B \cos(\theta_0 - \alpha)\delta\theta$$

- The first term represents the phase difference measured for the "flat earth," *i.e.* in the absence of any topography. If we remove the so-called "flat earth phase," we are left with

$$\Delta\phi_{flat} = -\frac{2\pi}{\lambda} B \cos(\theta_0 - \alpha)\delta\theta$$

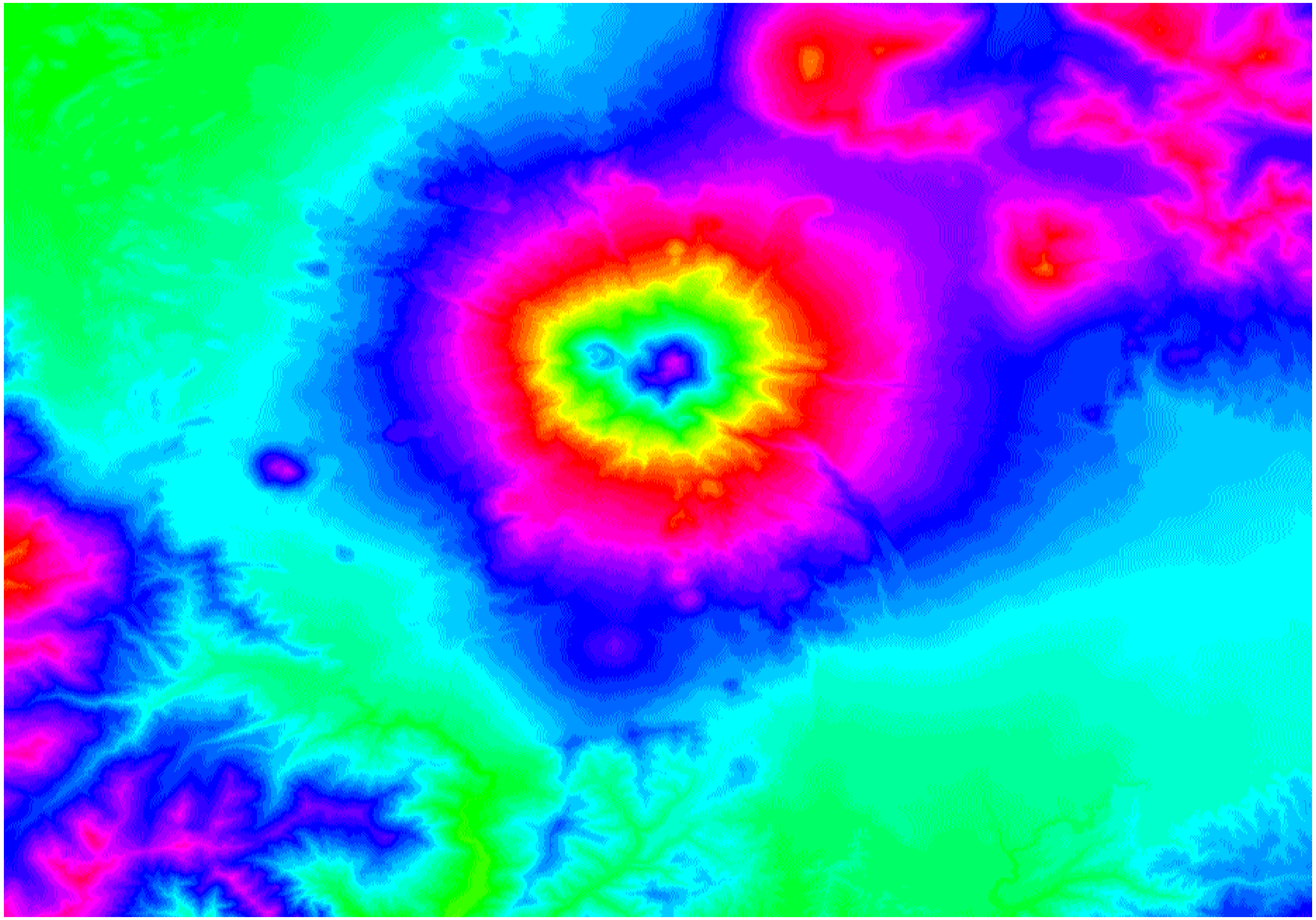
- This is the so-called "flattened interferogram"



RADAR INTERFEROMETRY

Mt Shasta Flattened Interferogram

(B=60m, alpha=45,wavelength=5.66 cm, altitude = 234 km)



RADAR INTERFEROMETRY
SENSITIVITY TO TOPOGRAPHY

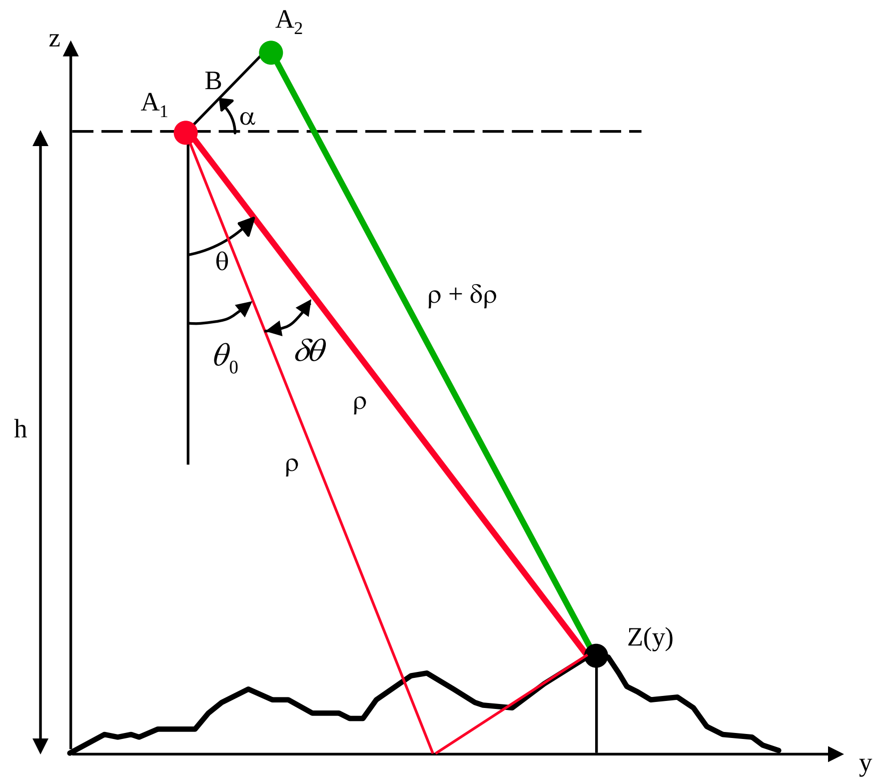
- The elevation of the image point is found from

$$\delta\theta \approx \frac{z(y)}{\rho \sin\theta_0}$$

- The so-called *ambiguity height* is the elevation change required to change the flattened phase difference by one cycle

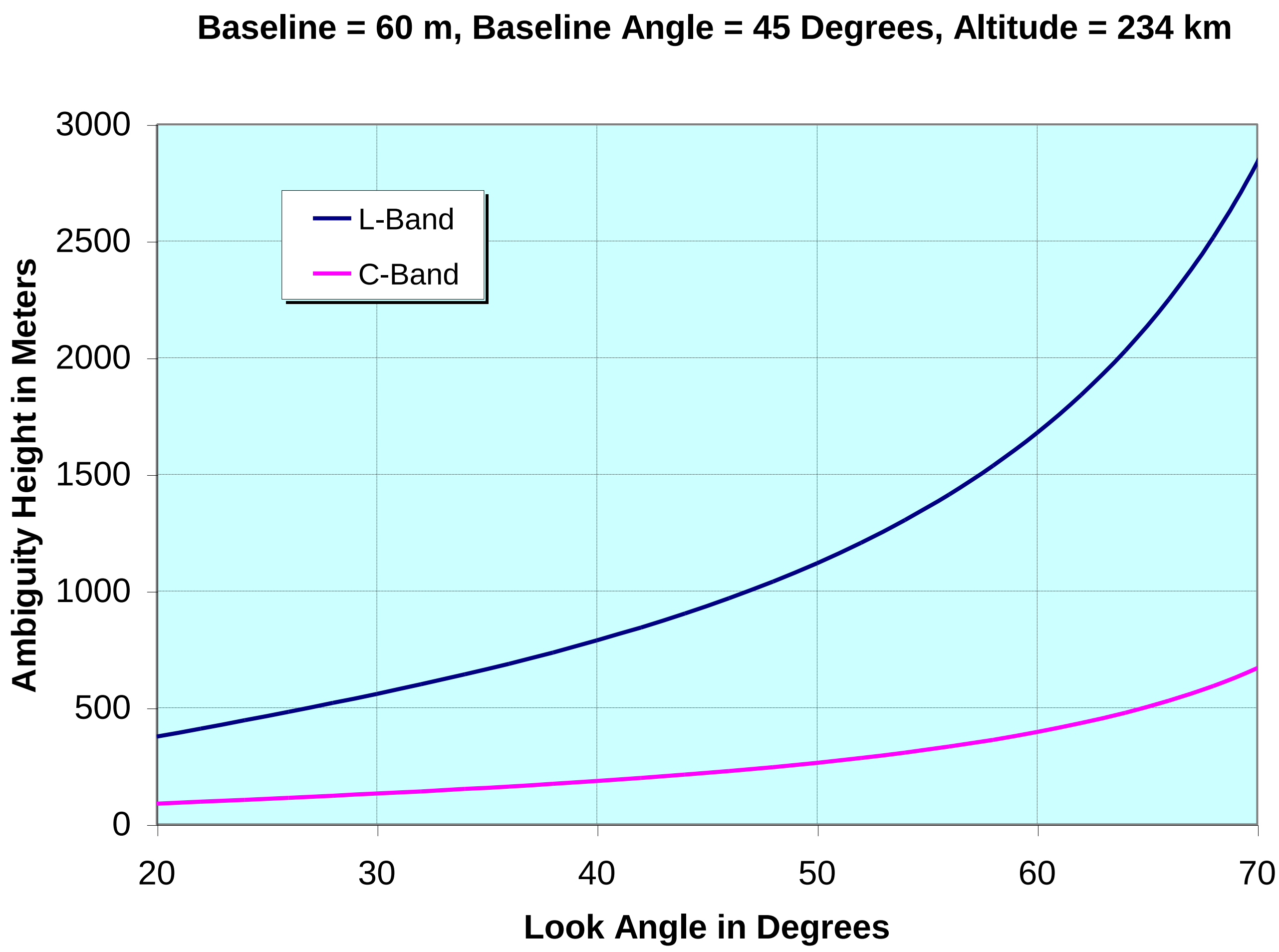
$$h_a = \frac{\lambda \rho \sin\theta_0}{B\cos(\theta_0 - \alpha)}$$

- A small ambiguity height means good sensitivity to topography
- If the elevation is the scene varies by more than the ambiguity height, the phase will be "wrapped", since we only measure phase modulo 360 degrees.

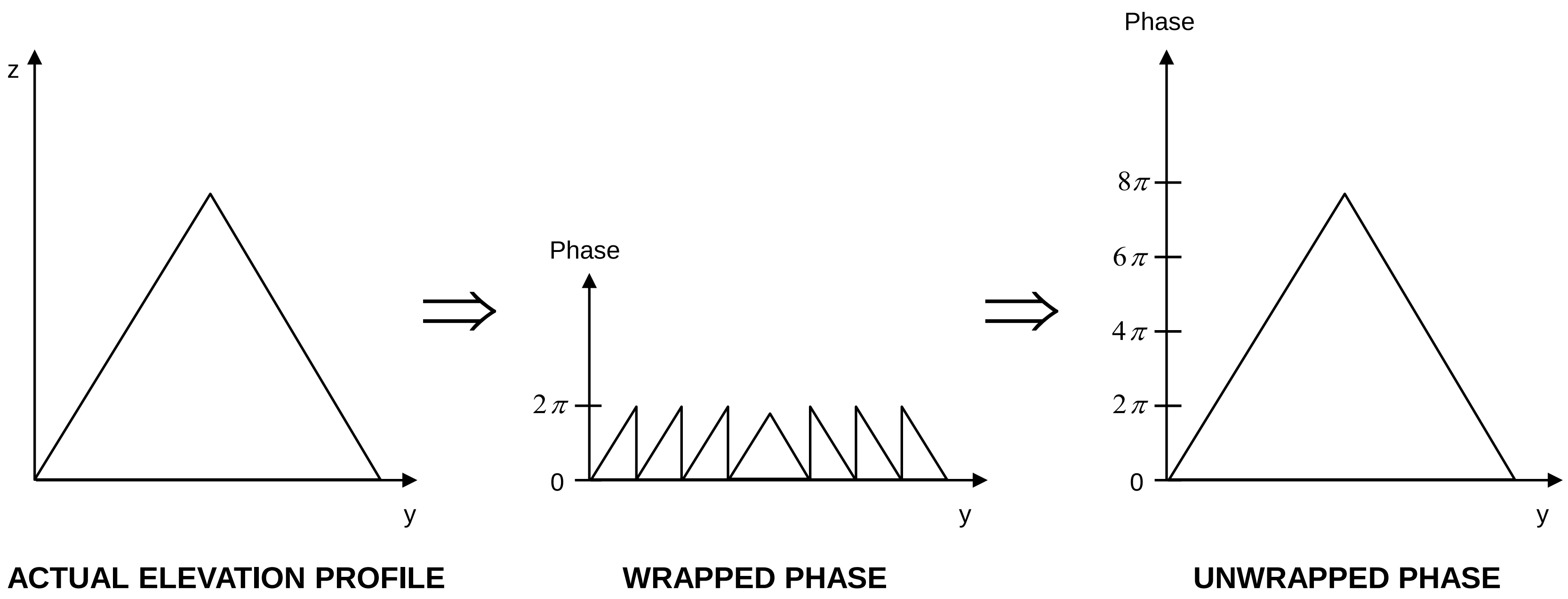


RADAR INTERFEROMETRY

Ambiguity Height

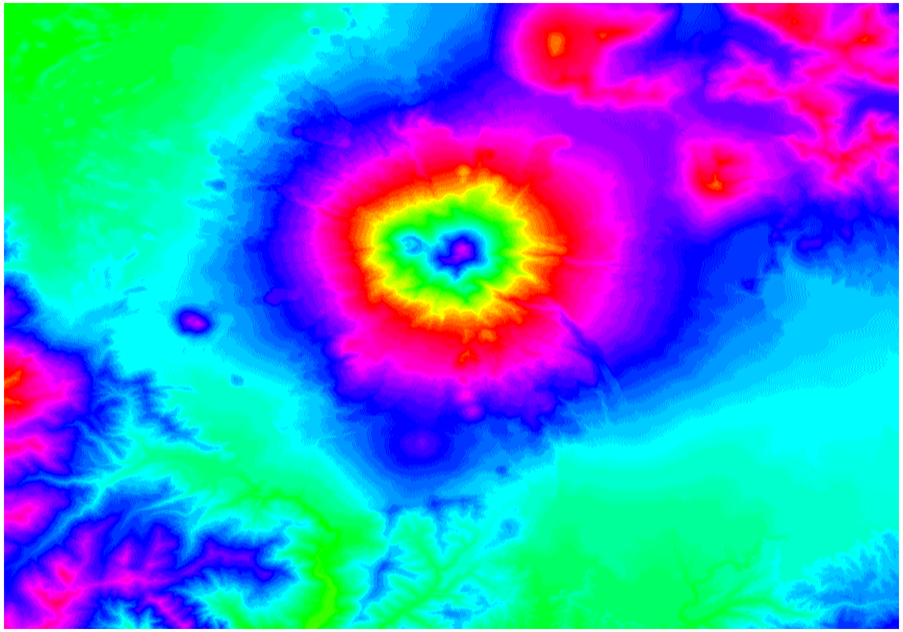


RADAR INTERFEROMETRY
PHASE UNWRAPPING



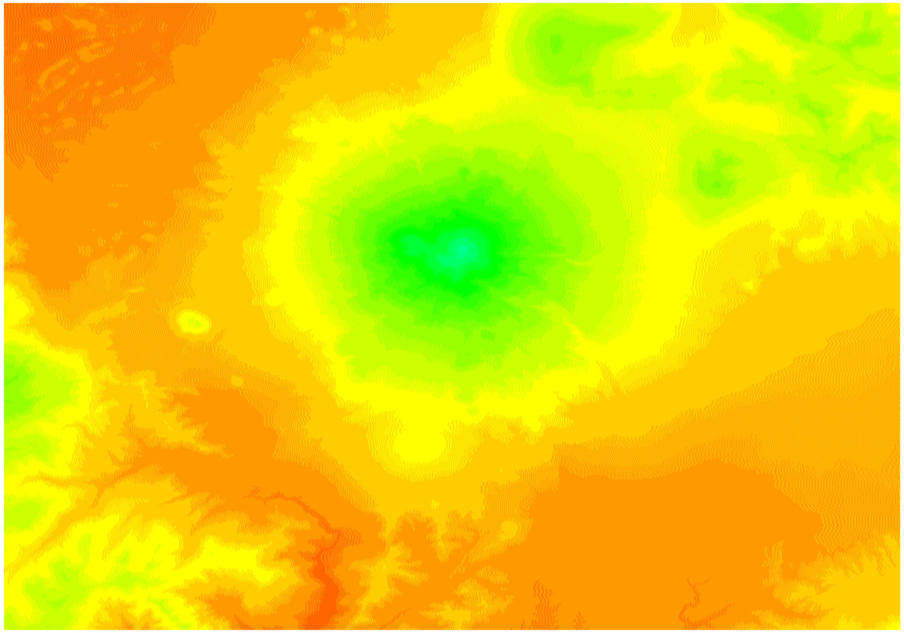
RADAR INTERFEROMETRY
Ambiguity Height & Phase Wrapping

Relief exceeds ambiguity height, resulting in wrapped phases



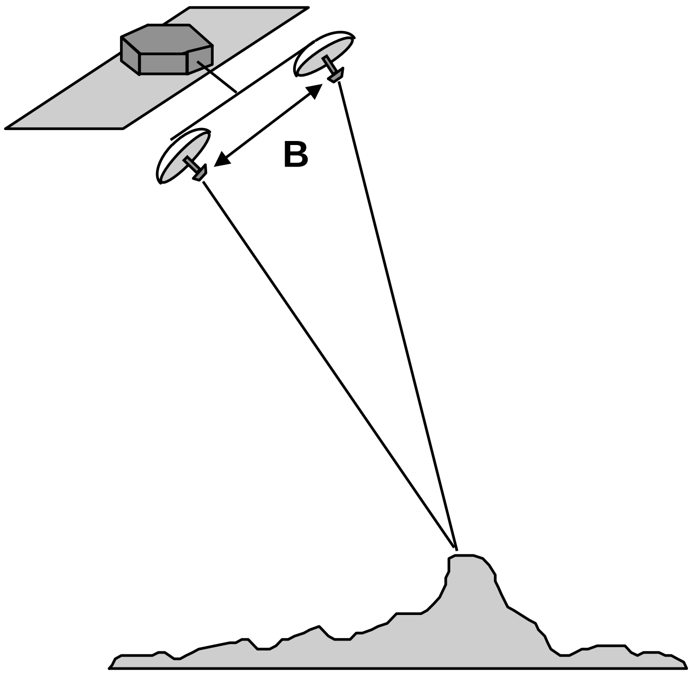
Wavelength = 5.66 cm

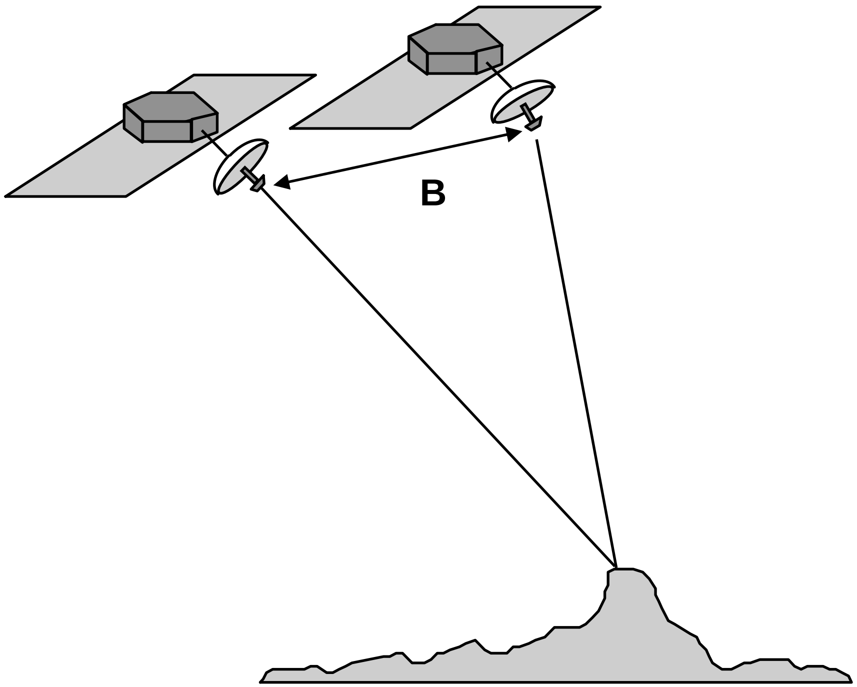
Relief does not exceed ambiguity height; Phase is not wrapped



Wavelength = 24 cm

RADAR INTERFEROMETRY
HOW IS IT IMPLEMENTED?





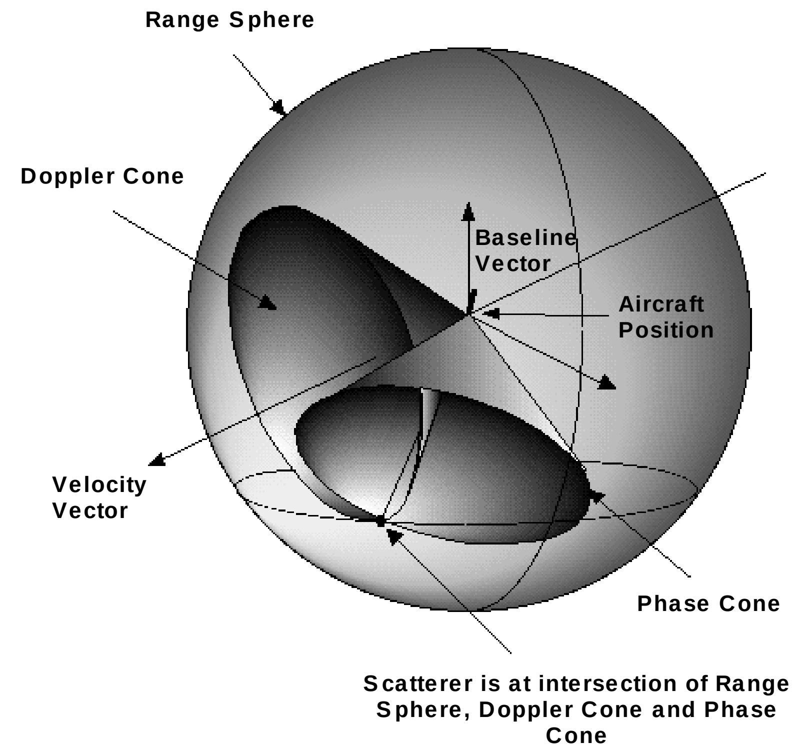
SIMULTANEOUS BASELINE
Two radars acquire data at the same time

REPEAT TRACK
Two radars acquire data from different vantage points at different times

RADAR INTERFEROMETRY
COMPARISON OF TECHNIQUES

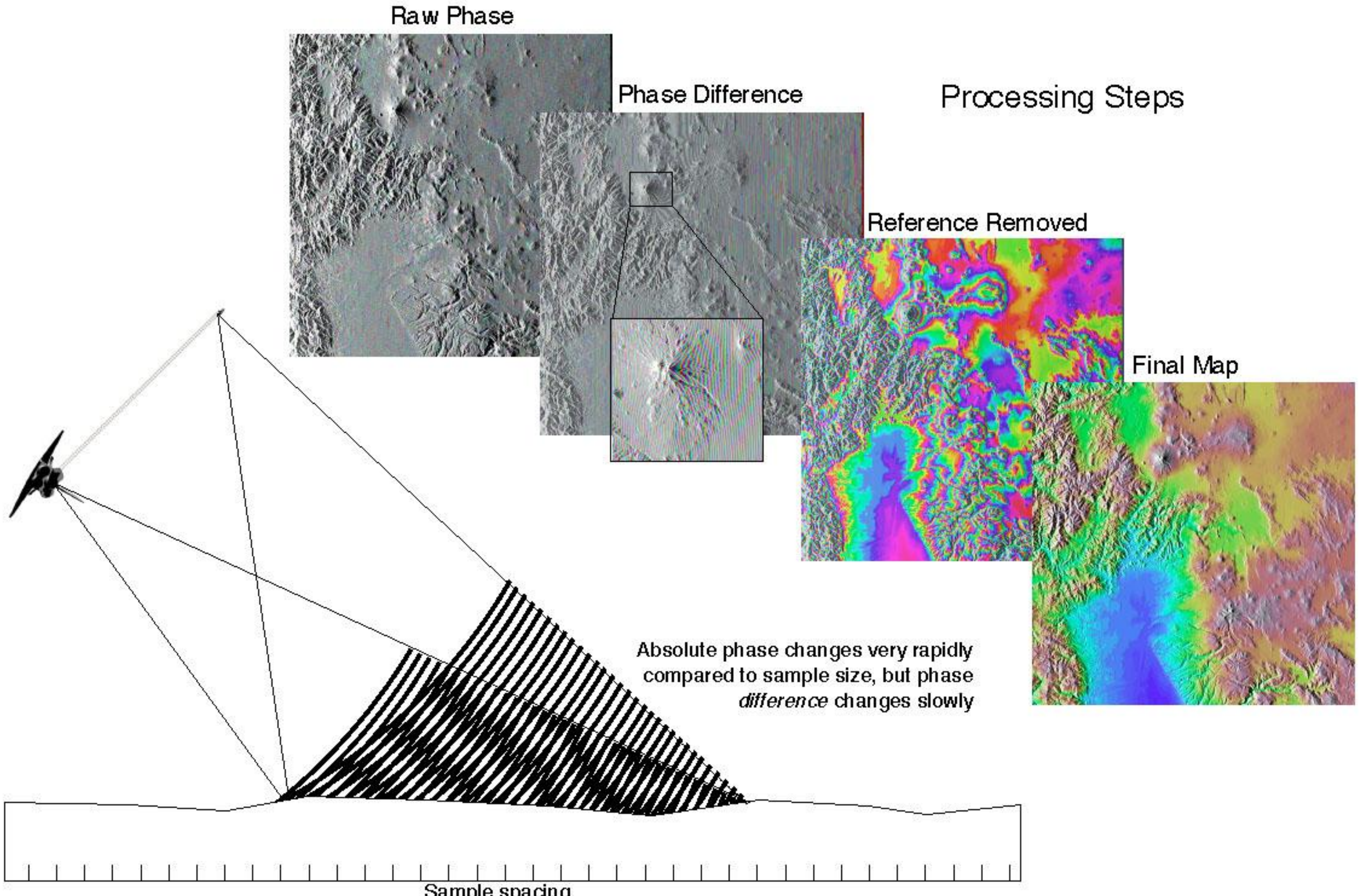
IMPLEMENTATION	ADVANTAGES	DISADVANTAGES
Simultaneous Baseline	• Known baseline	• Difficult to get adequate baseline in space
	• No temporal decorrelation	• High data rate from two radars
	• Typically better performance	• Typically higher cost
Repeat Track	• Lower data rate from one radar	• Temporal decorrelation
	• Lower cost	• Baseline not well known and may be changing
	• Depending on orbit, any baseline can be realized	

INTERFEROMETRIC SAR PROCESSING GEOMETRY



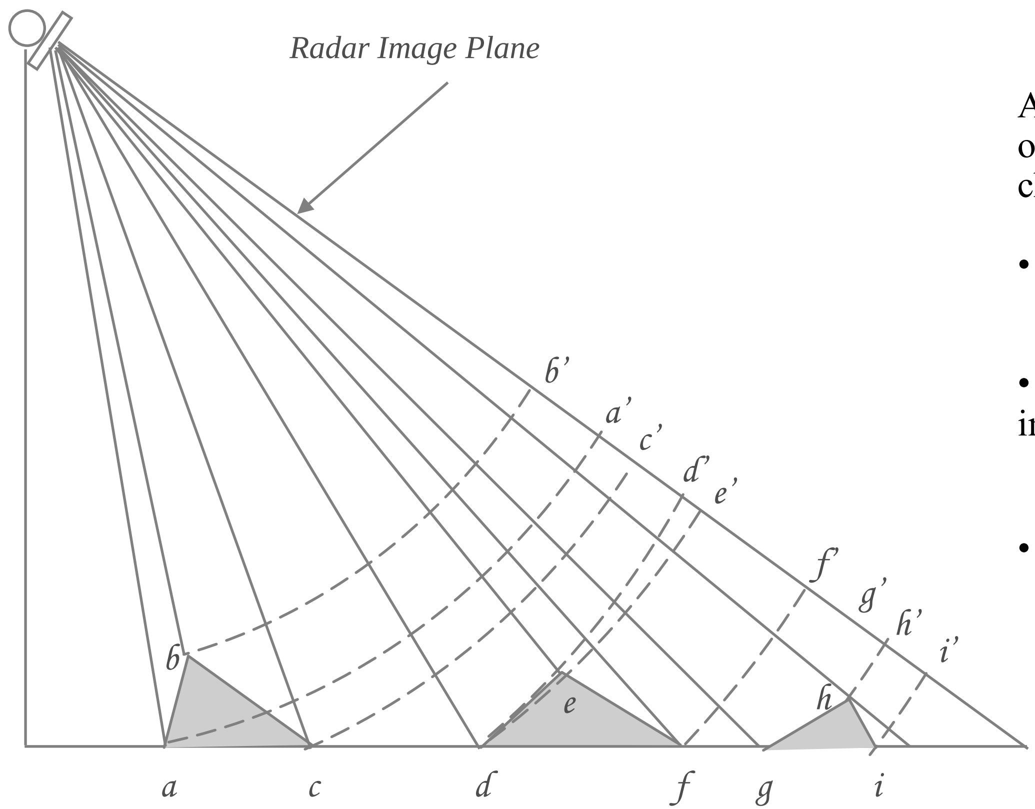
JPL

Shuttle Radar Topography Mission



PRINCIPLES OF IMAGING RADAR

SAR IMAGE PROJECTION



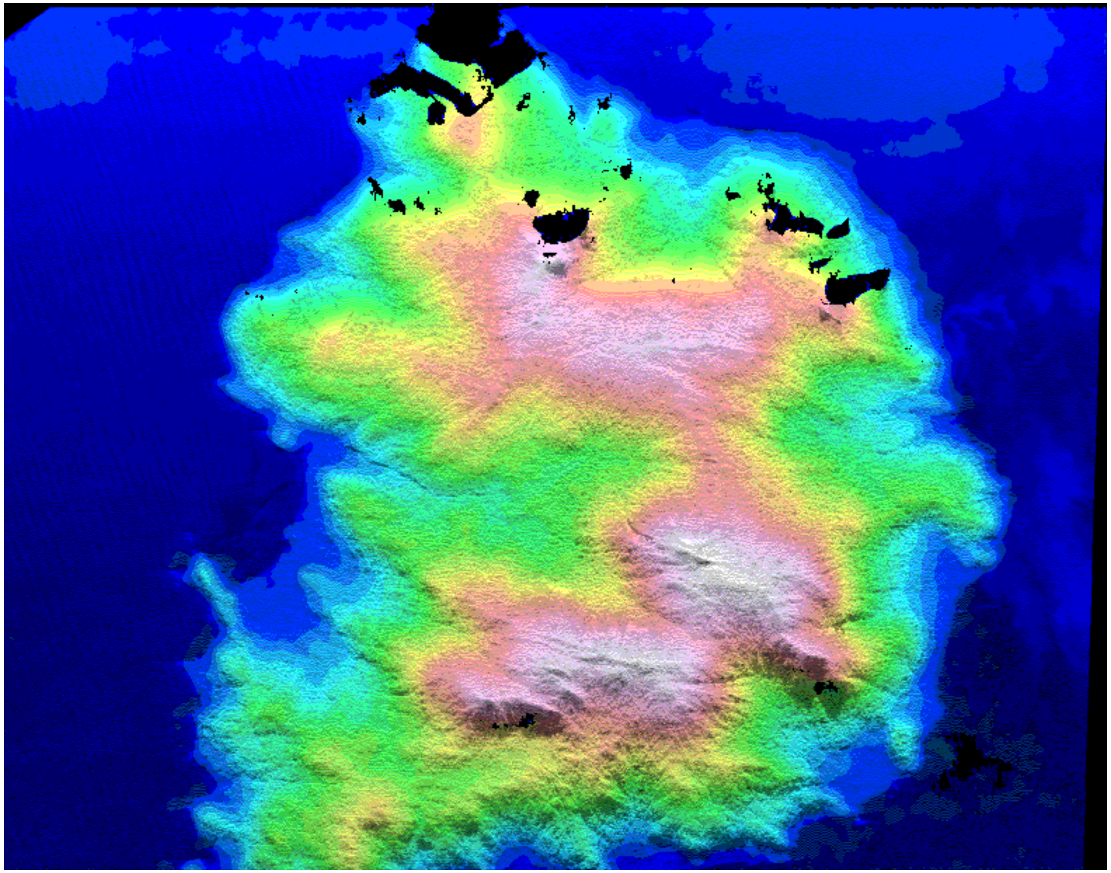
A three-dimensional image is projected onto a two-dimensional plane, causing characteristic image distortions:

- b' appears closer than a' in radar image
  ⇒ **LAYOVER**

- d' and e' are closer together in radar image
  ⇒ **FORESHORTENING**

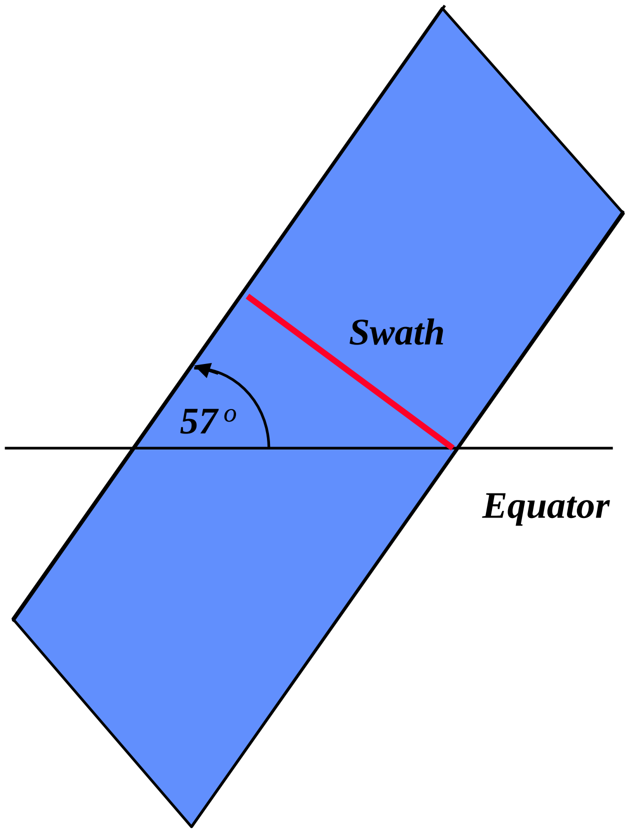
- h to i not illuminated by the radar
  ⇒ **RADAR SHADOW**

RADAR INTERFEROMETRY
EXAMPLE: TOPSAR DATA



RADAR INTERFEROMETRY
IS IT POSSIBLE TO USE THE SPACE SHUTTLE TO MAP THE EARTH? (1994)

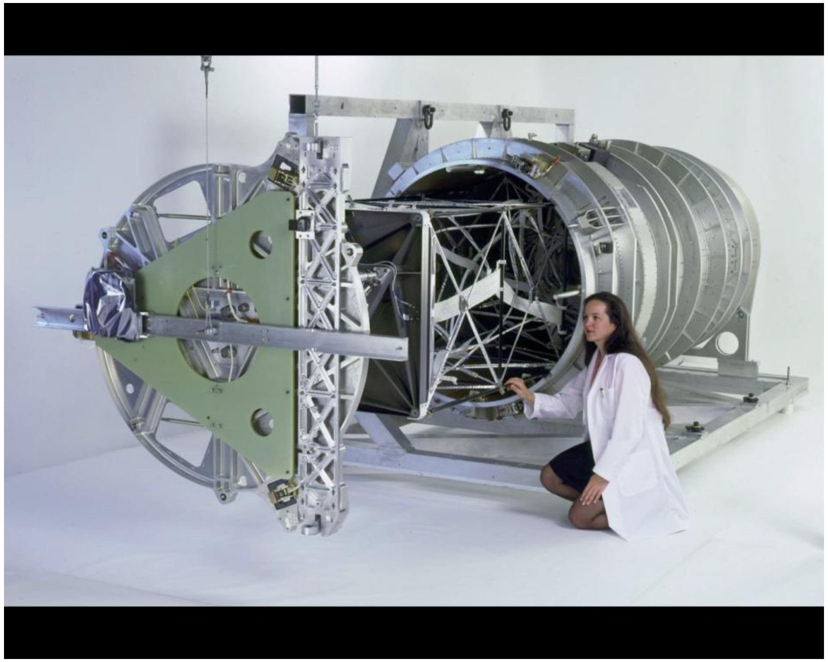
- With the weight of a typical radar payload, the shuttle can be launched into an orbit with 57 degrees inclination, and altitude <= 250 km. The typical time available for mapping is <= 10 days
- There is a 10 day repeat orbit with altitude 234 km, giving 159 orbits in 10 days
- The required swath width at 57 degrees inclination would be 211 km
- Using the SIR-C hardware in a "scanSAR" mode, we can record a 225 km swath, providing 7 km overlap at each side



Shuttle Radar Topography Mission Objectives

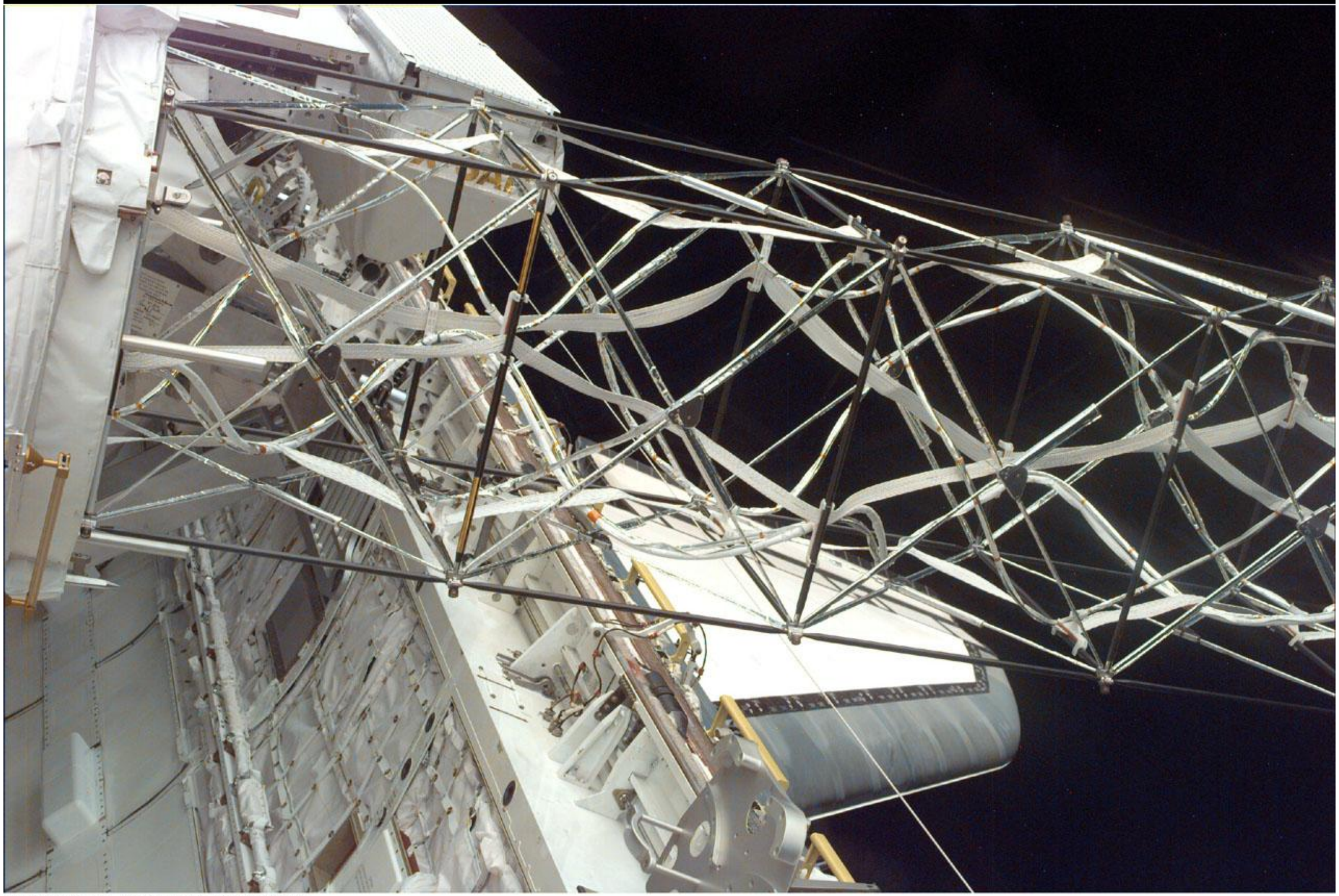
- Acquire a C-band radar interferometric data set sufficient for the production of digital topographic of the Earth's landmass accessible from a 57° inclination orbit.
- Acquire ancillary data (position, attitude, radar performance and calibration) sufficient to allow processing the C-band data set into data products meeting the following specifications
  - 1 arcsecond posting (~ 30 m)
  - 16 m absolute height accuracy
  - 10 m relative height accuracy
- Generate terrain-corrected georeferenced image products coincident with the acquired digital elevation data set.
- SRTM is a cooperative project of the NASA and NIMA in the U.S.A., and the DLR in Germany. The Italian Space Agency is cooperating with DLR by contributing flight hardware previously flown in 1994, and by participating in data processing.

The Mast



SRTM Hardware lowered into Payload Bay

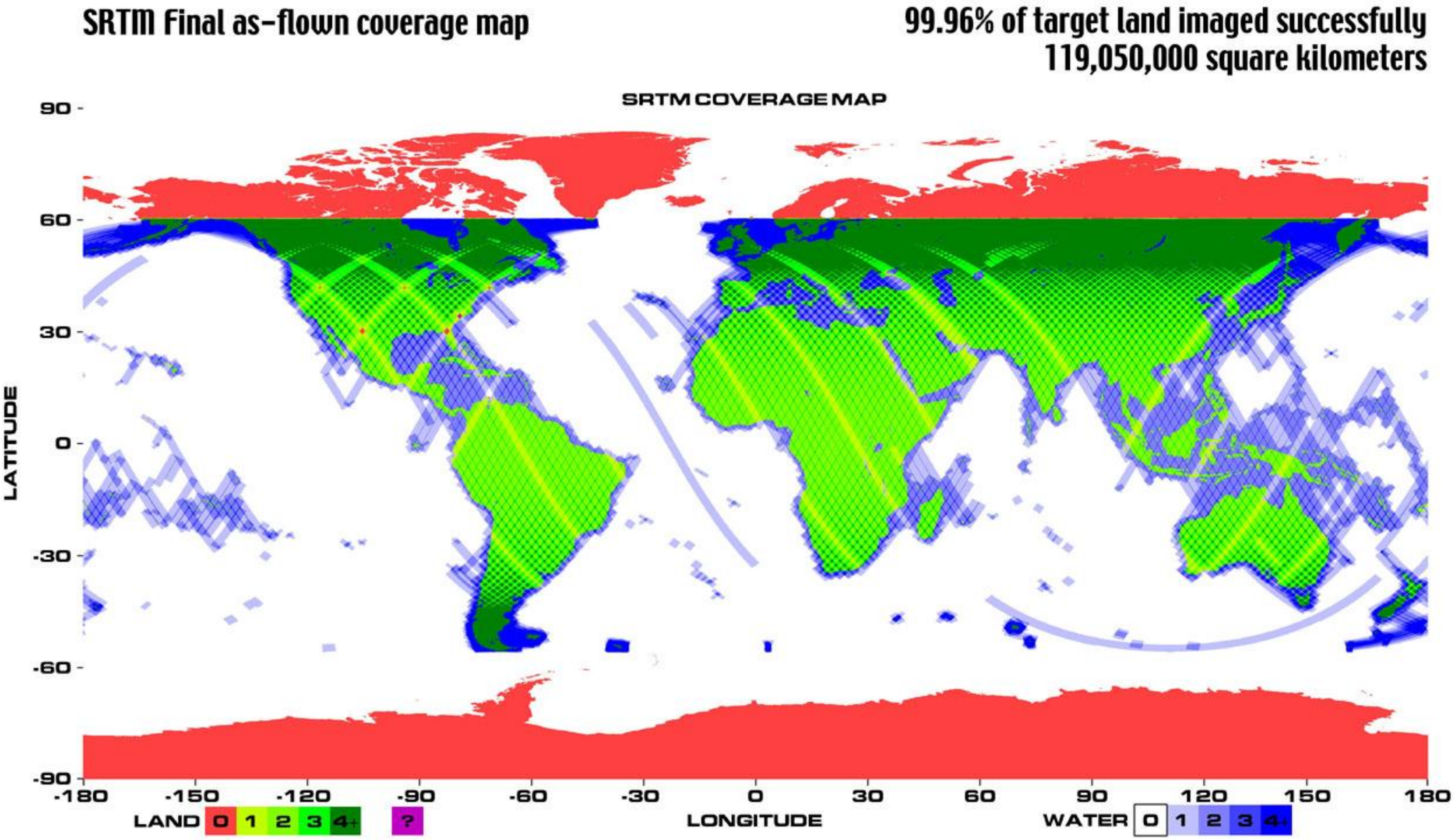
The Mast on Orbit



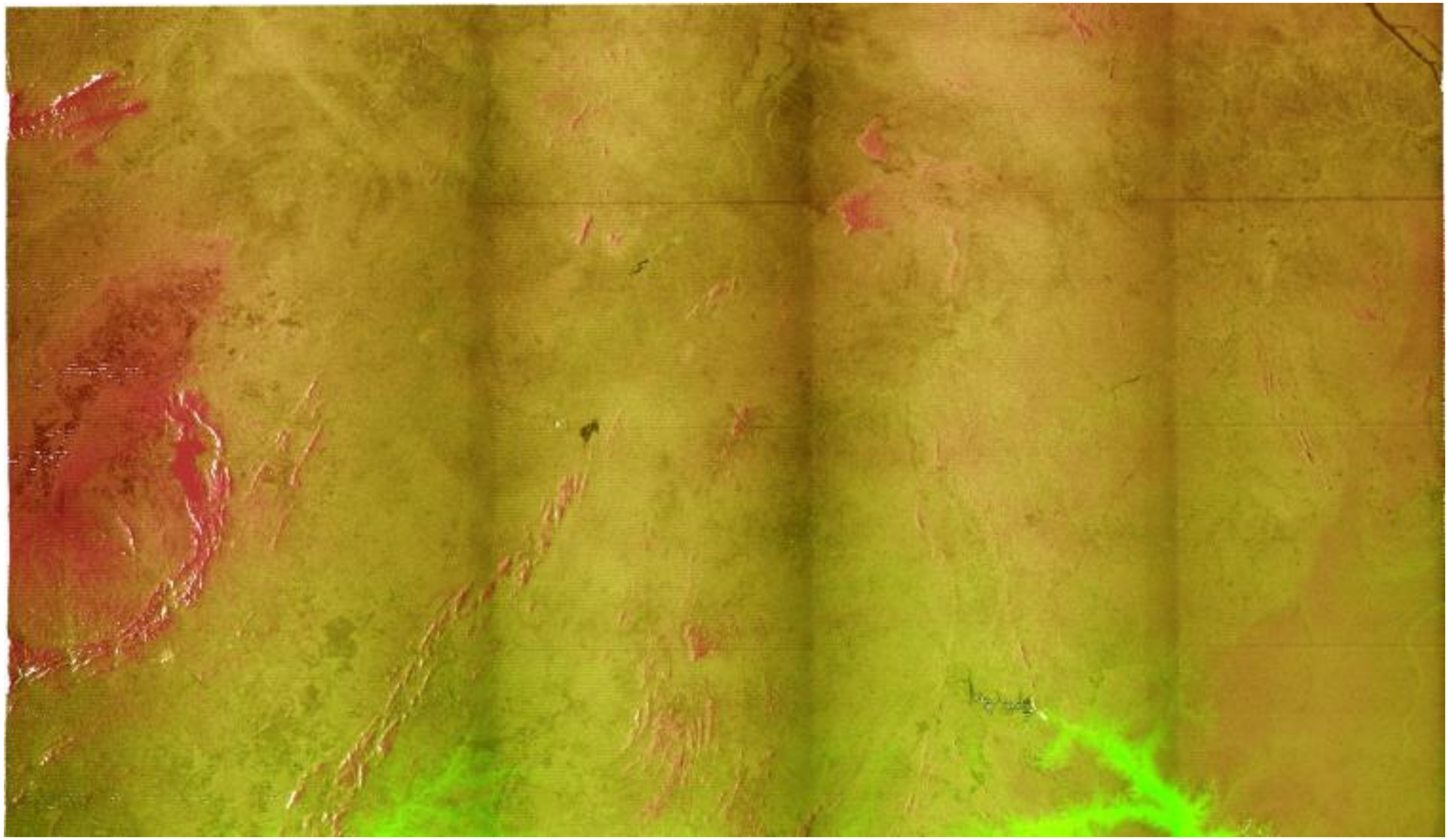
S99E5475 2000:02:16 06:07:15

The Mast on Orbit

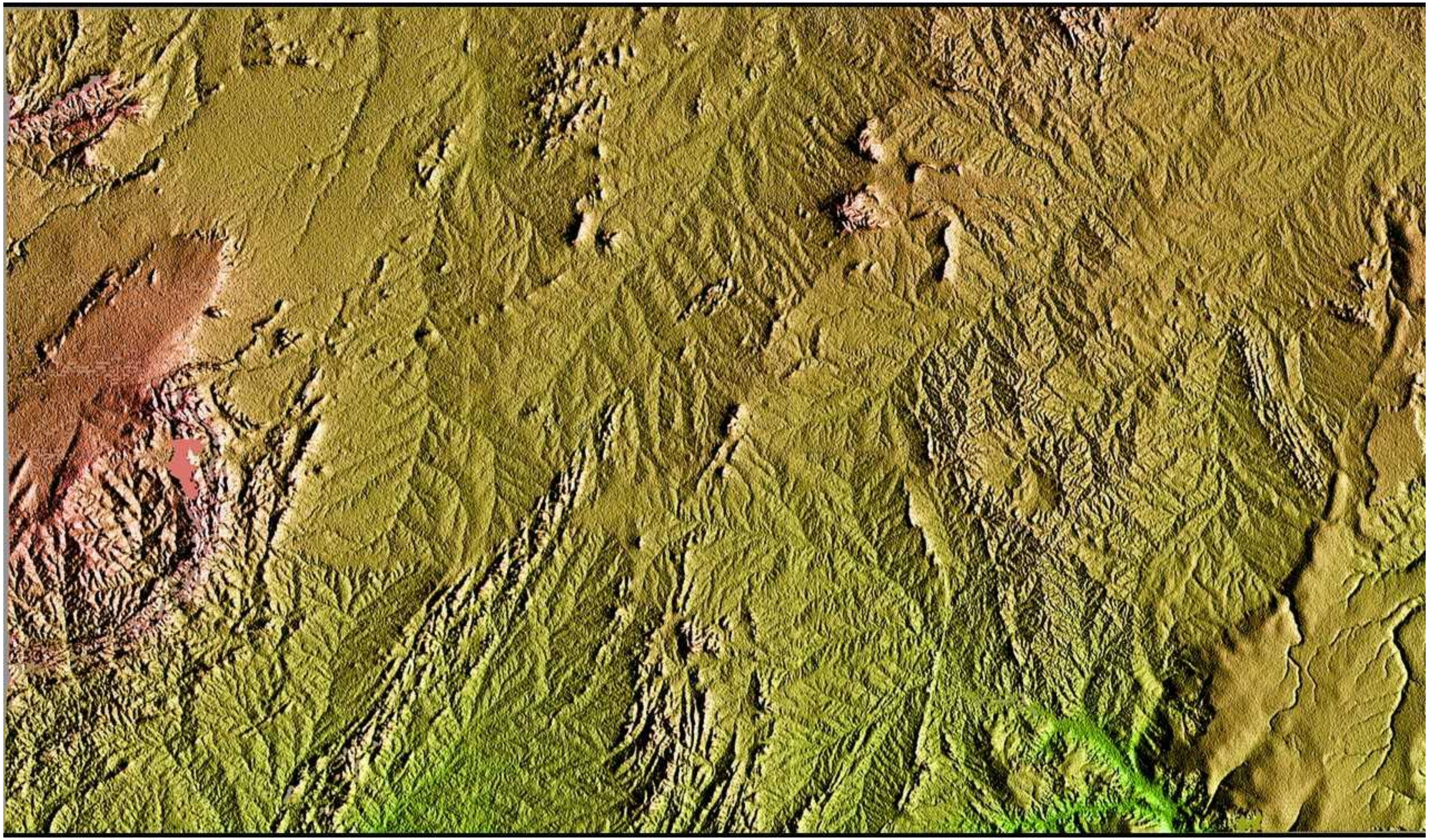
Final Coverage



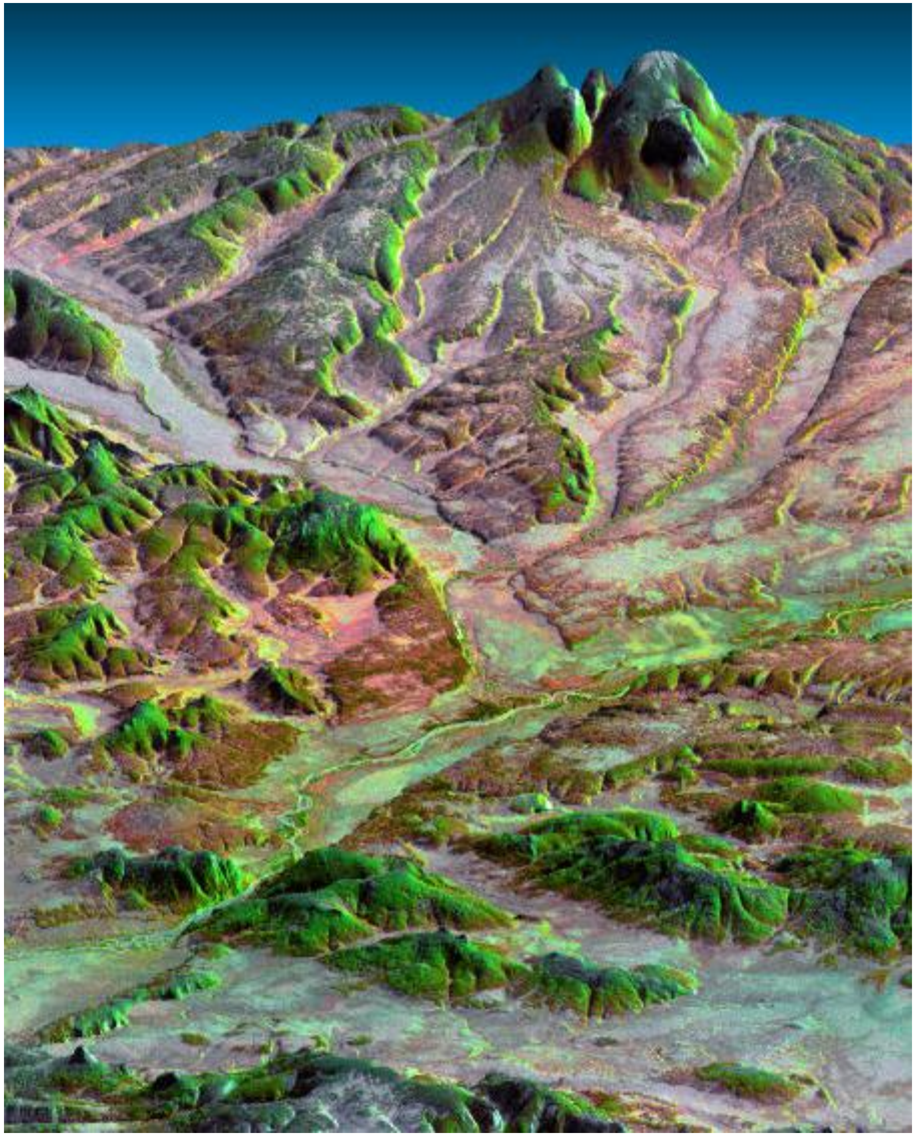
Radar Image: Bahia, Brazil



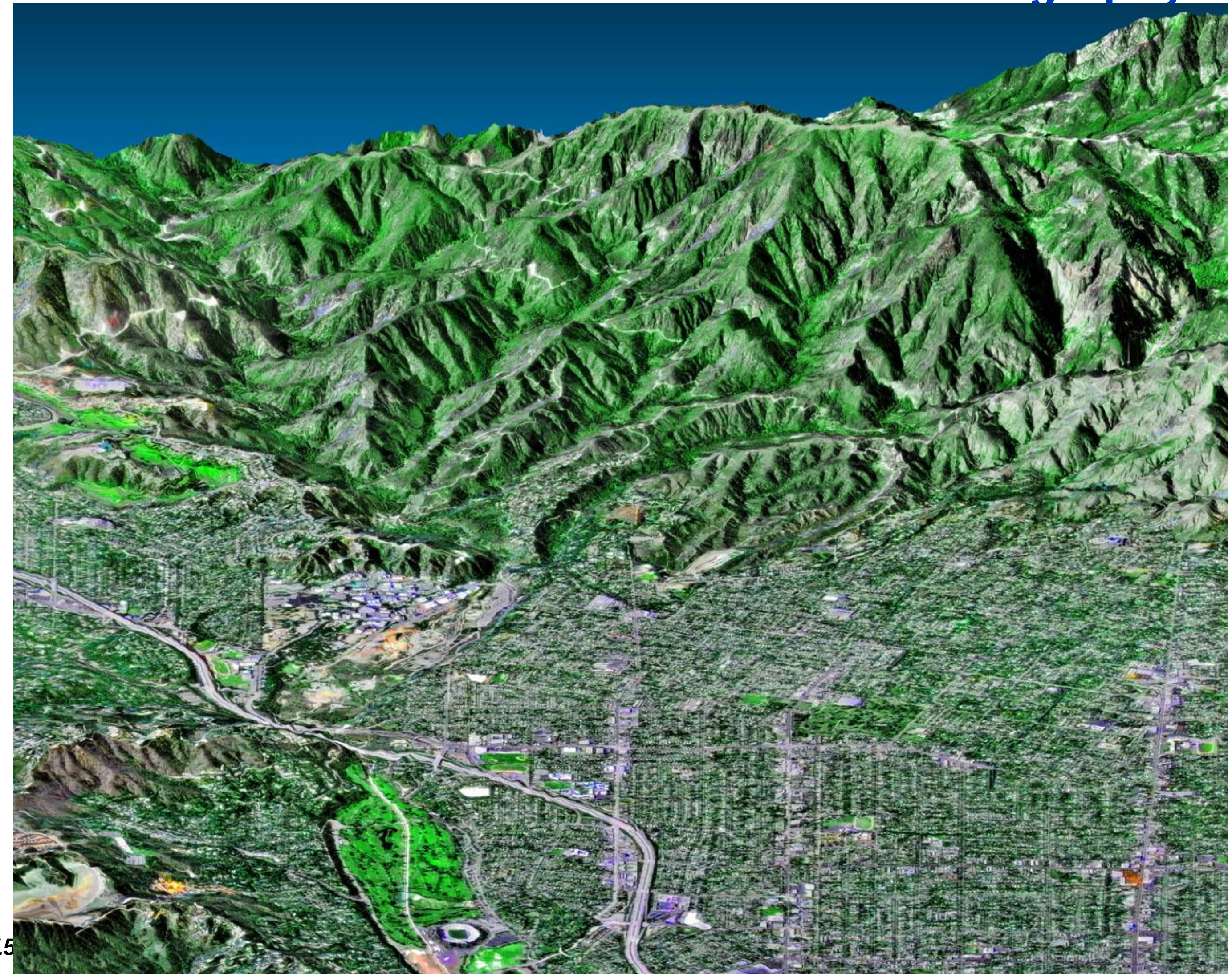
Shaded Relief: Bahia, Brazil



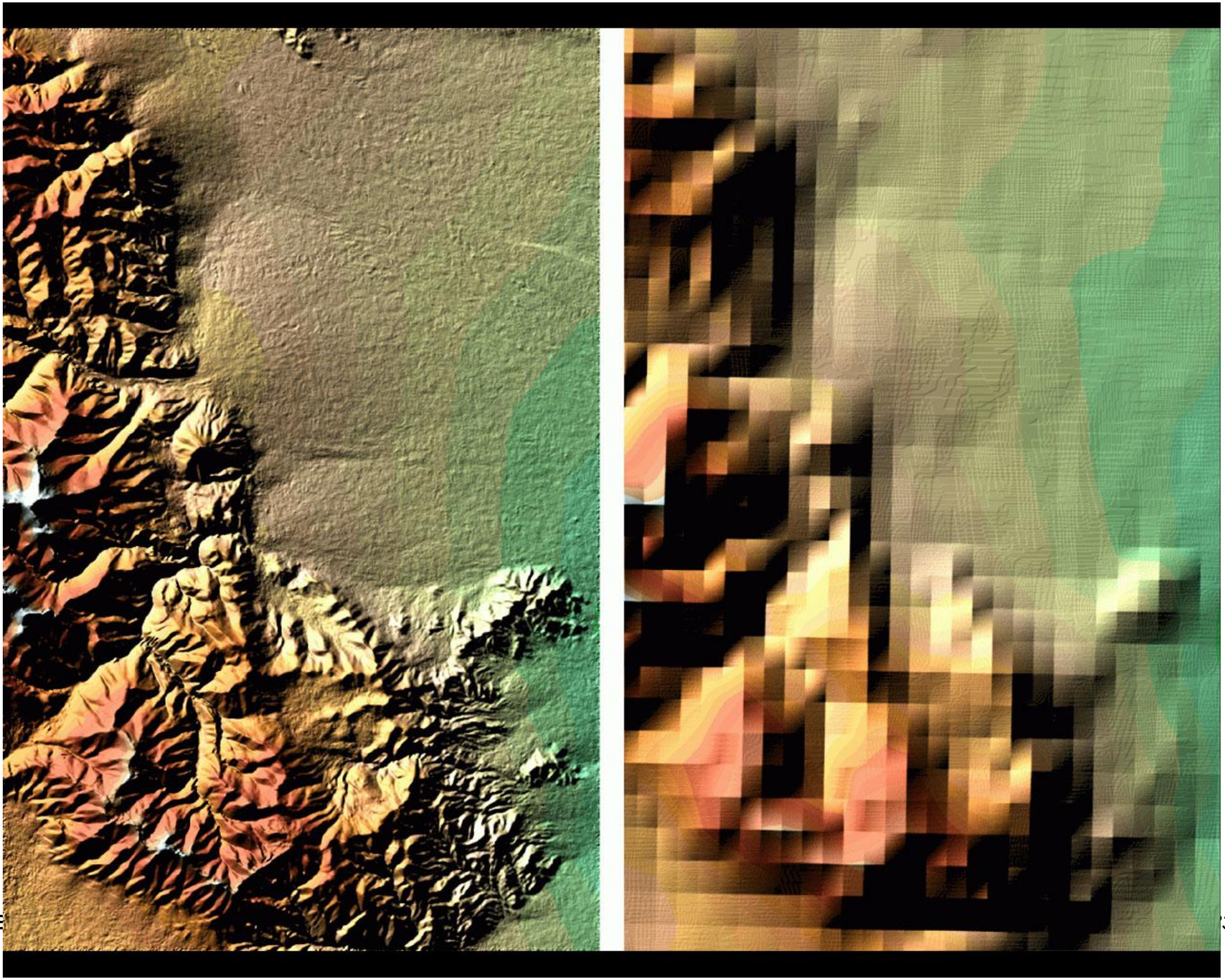
Combination with LandSat Data



Combination with LandSat and Aerial Photography



Data Resolution



INTERFEROMETRY
Error Sources

- From the trigonometry, we see that the elevation of the point is given by

$$z(y) = h - \rho \cos\theta$$

- The accuracy with which we can measure the elevation depends on how well we measure the position of the radar platform (*h*), the radar slant range (ρ) and the angle θ.
- The angle θ is derived from the measurement of the interferometric radar phase. Therefore, the accuracy of the elevation is also influenced by how accurately we measure the interferometric radar phase ($\Delta\phi$), the baseline length *(B*) and orientation angle (α), and the radar wavelength (λ).
- The general expression for the elevation error is derived by adding the errors

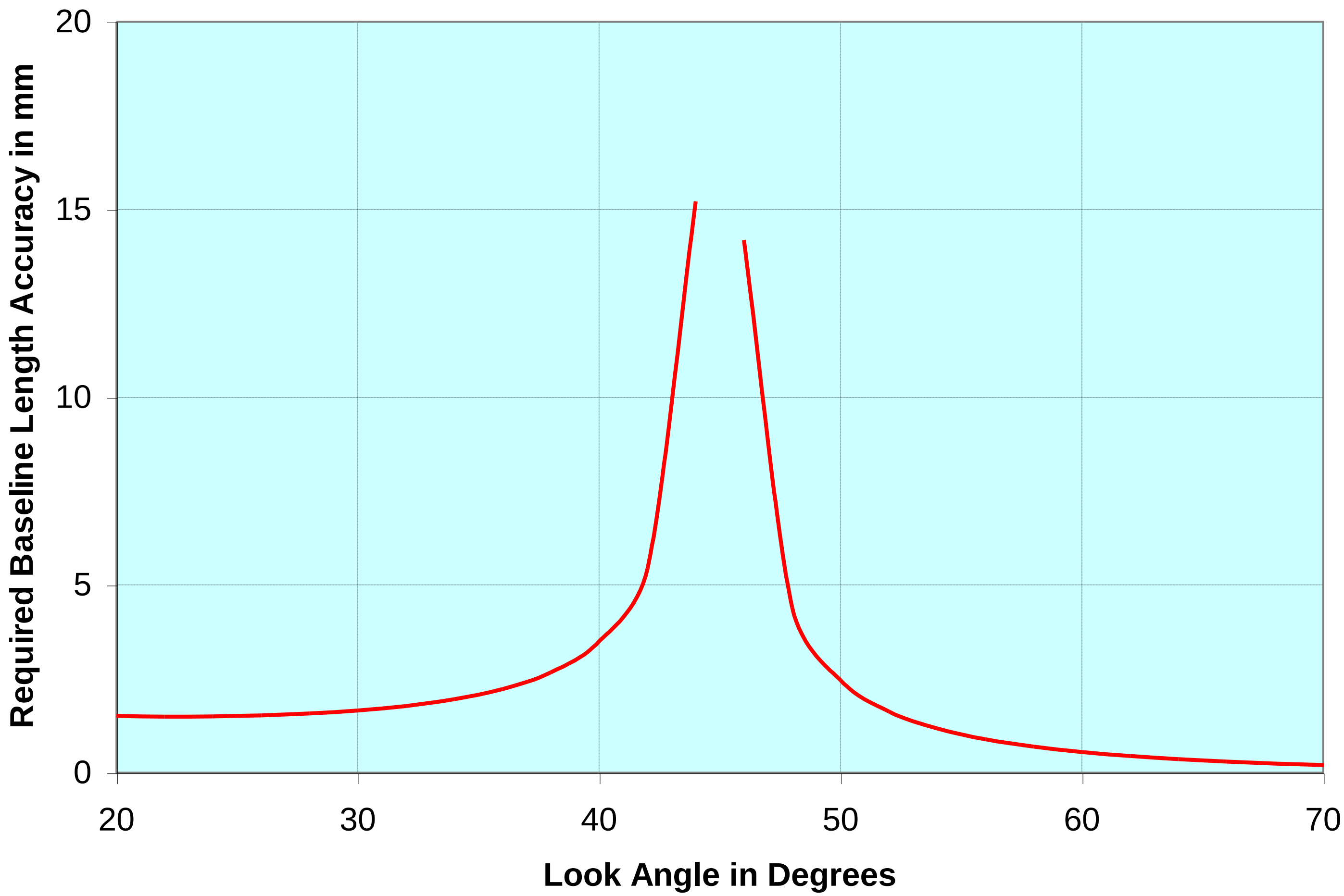
$$\sigma_z^2 = \left(\frac{\partial z}{\partial h}\right)^2 \sigma_h^2 + \left(\frac{\partial z}{\partial \rho}\right)^2 \sigma_\rho^2 + \left(\frac{\partial z}{\partial \alpha}\right)^2 \sigma_\alpha^2 + \left(\frac{\partial z}{\partial \lambda}\right)^2 \sigma_\lambda^2 + \left(\frac{\partial z}{\partial \phi}\right)^2 \sigma_\phi^2 + \left(\frac{\partial z}{\partial B}\right)^2 \sigma_B^2$$

- The measurement uncertainty is taken into account through the σ_i terms $\left(\sigma_\phi = \sqrt{\frac{1}{SNR}}\right)$

INTERFEROMETRY

Error Sources (Continued - Baseline Length)

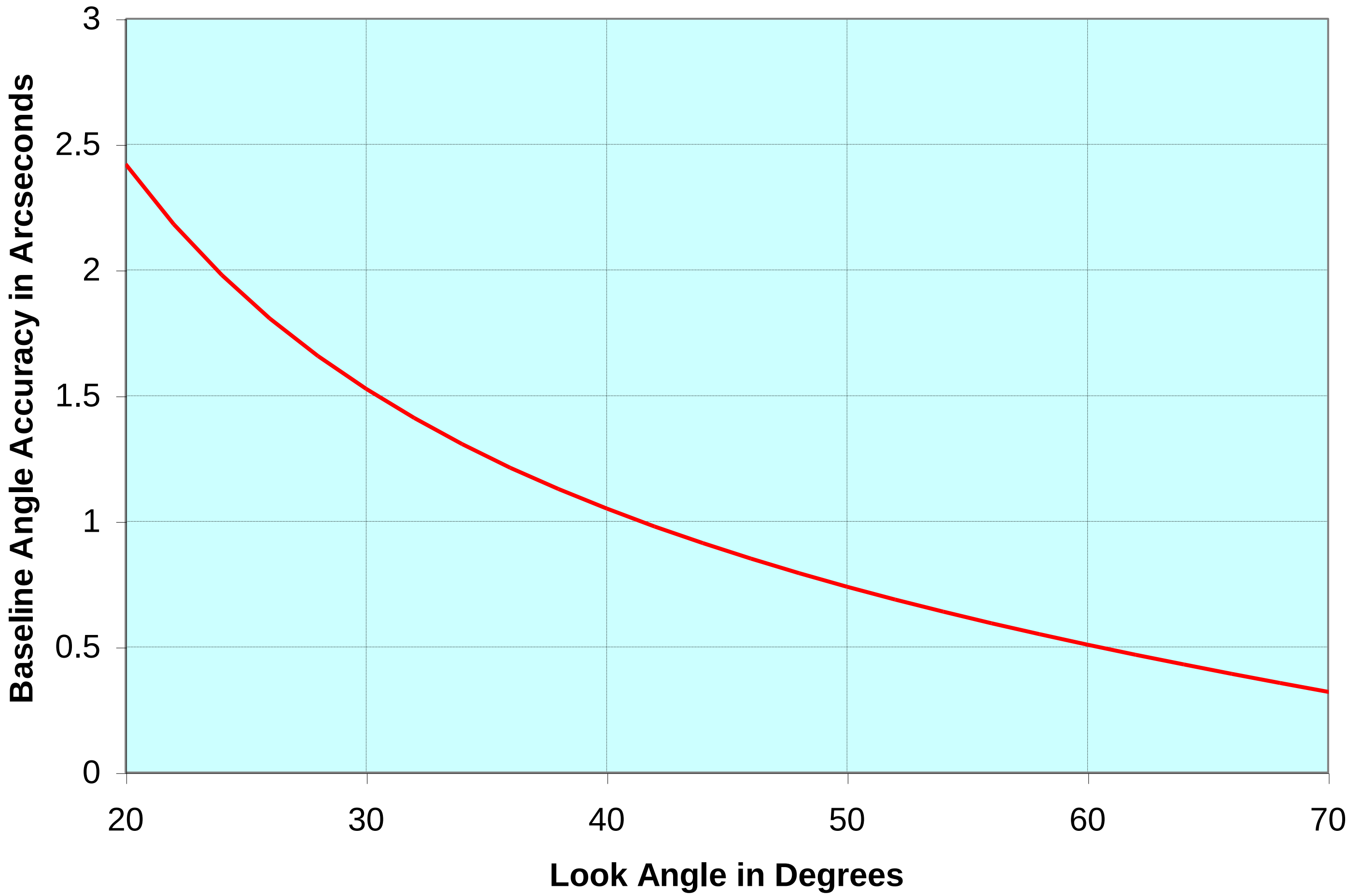
Baseline = 60m, Baseline Angle = 45 Degrees, Altitude = 234 km, Wavelength = 5.66 cm



INTERFEROMETRY

Error Sources (Continued - Baseline Angle)

Baseline = 60m, Baseline Angle = 45 Degrees, Altitude = 234 km, Wavelength = 5.66 cm



INTERFEROMETRY

Error Sources (Continued - Signal-to-noise ratio)

Baseline = 60m, Baseline Angle = 45 Degrees, Altitude = 234 km, Wavelength = 5.66 cm