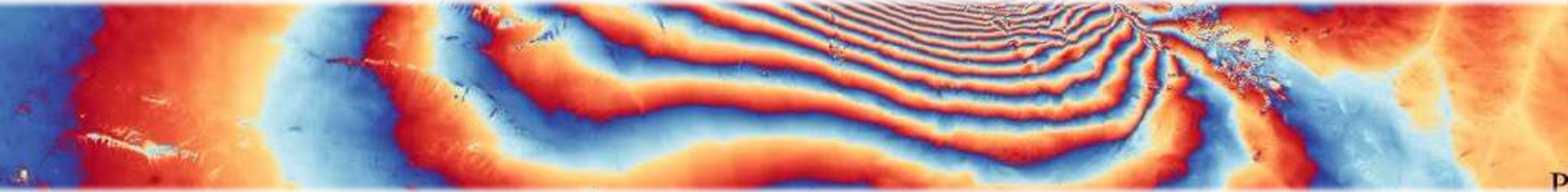
GEOS 639 – INSAR AND ITS APPLICATIONS

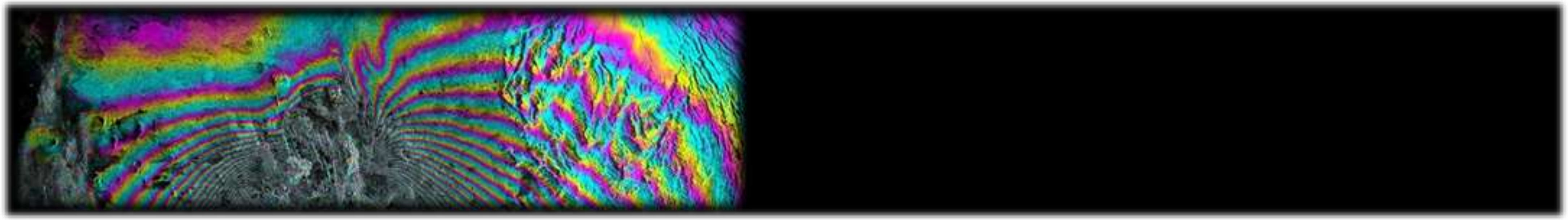
GEODETIC IMAGING AND ITS APPLICATIONS IN THE GEOSCIENCES

Lecturer:

Franz J Meyer, Geophysical Institute, University of Alaska Fairbanks, Fairbanks; fjmeyer@alaska.edu

Lecture 6: Interferometric SAR Techniques – Topographic Mapping



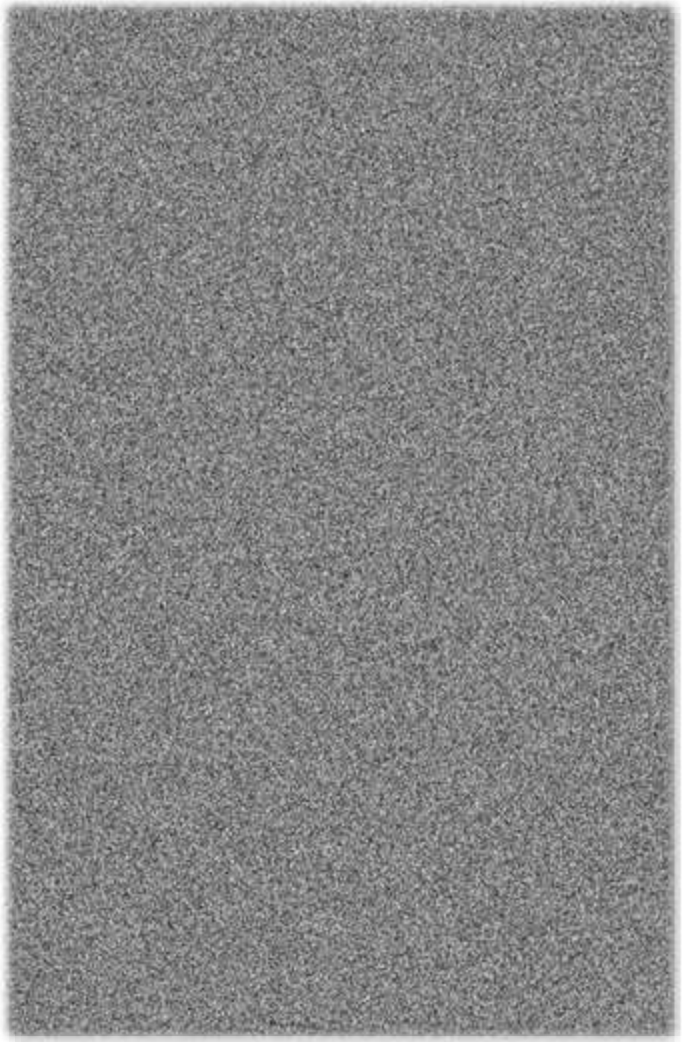


INSAR FOR TOPOGRAPHIC MAPPING: CONCEPT

Think – Pair – Share

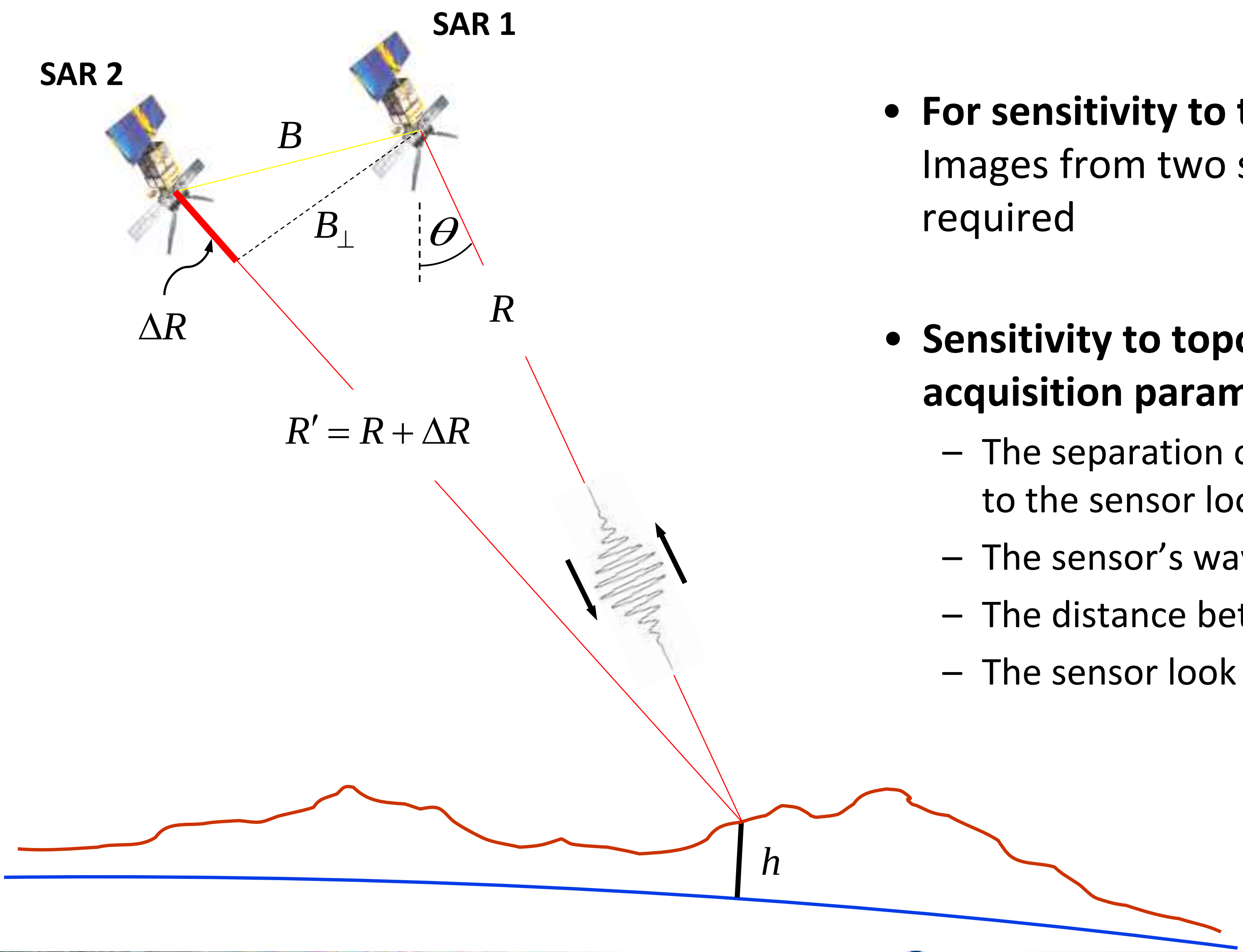
For InSAR to Work, we Require Accuracte Co-Registration between the InSAR Image Partners:

- **Q1**: Using the image to your right as a visual clue, why is highly accurate co-registration required?
- **Q2**: How accurate do you think the co-registration needs to be?
  - Within 10s of pixels
  - At about the pixel level
  - At 1/100 of a pixel or better



Phase signature of a single SAR image

Across-Track InSAR Geometry To Enable Topographic Mapping



- **For sensitivity to topography:**
  Images from two slightly different vantage points are required

- **Sensitivity to topography depends on these acquisition parameters:**
  - The separation of the acquisition locations perpendicular to the sensor look direction $B_\perp$
  - The sensor's wavelength λ
  - The distance between satellite and ground R
  - The sensor look angle θ

Measuring Topography using InSAR

How to measure topographic height from the InSAR phase: $$\phi_{topo} = \frac{4\pi}{\lambda} \frac{B_\perp}{R \sin\theta} h$$

How well can we measure height: $$\sigma_h = \frac{\lambda}{4\pi} \frac{R \sin\theta}{B_\perp} \cdot \sigma_\phi$$

example ALOS PALSAR: $\lambda \approx 25\,\mathrm{cm}$

$R \approx 800\,\mathrm{km}$

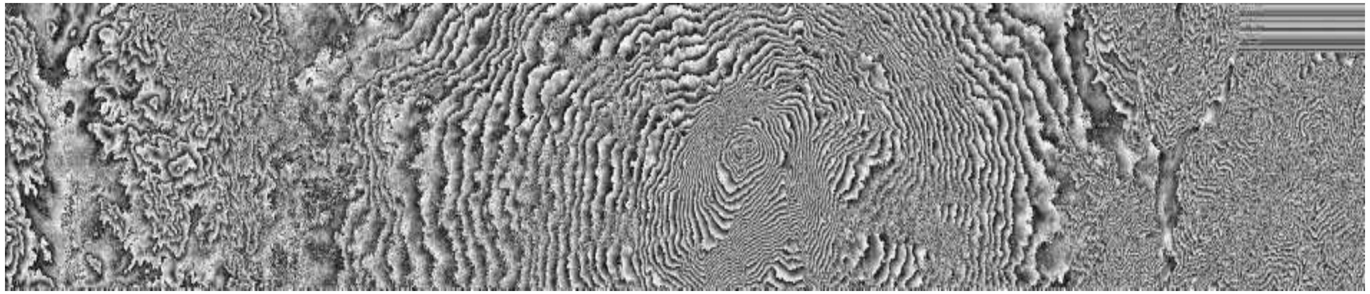
$\theta = 30^\circ \rightarrow \sin\theta = 0.5$

baseline	height for 1 phase cycle (2π)
50 m	≈ 1000 m
100 m	≈ 500 m
200 m	≈ 250 m

Interferometric Sensitivity as a Function of Wavelength

Three simultaneously acquired Interferograms with identical $B_\perp$, R, and θ but varying λ

X-band
$\lambda \approx 3.1cm$



C-band
$\lambda \approx 5.6cm$

L-band
$\lambda \approx 24.0cm$

Mt. Etna
data: SRL-2

Think – Pair – Share

Try to answer the following questions:

- **Q1:** What is the Height difference between Points 1 and 2?

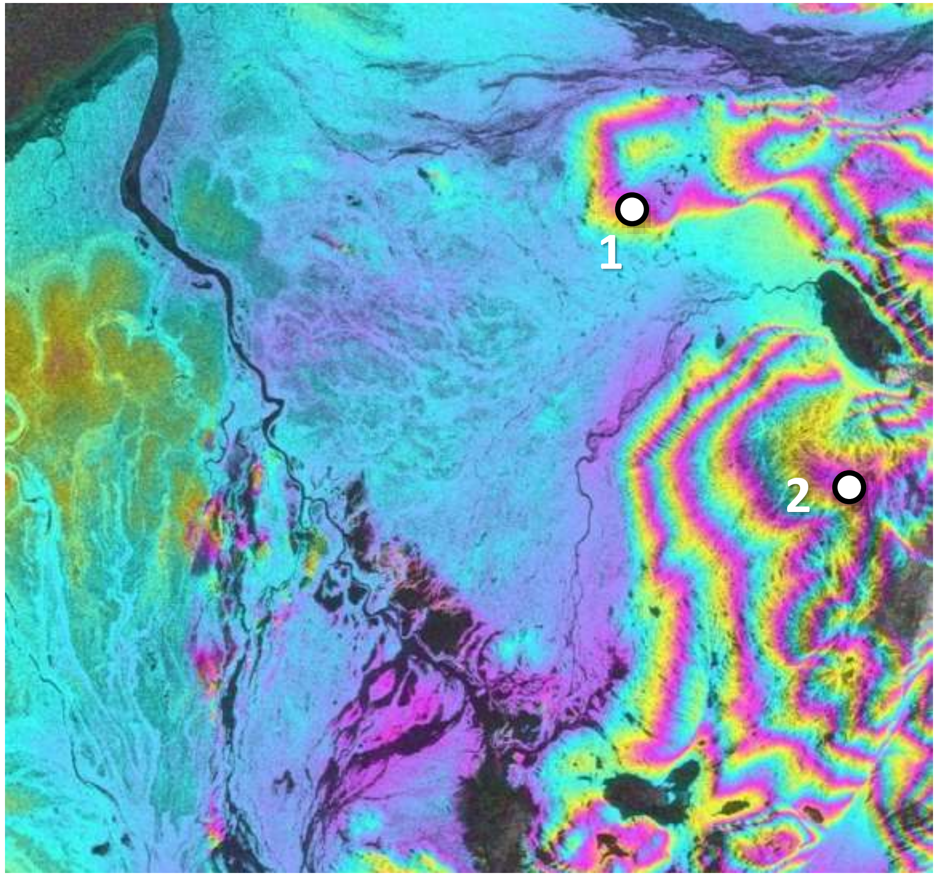
Height per phase cycle (fringe): $h_{2\pi} = \frac{\lambda}{2} \frac{R \sin\theta}{B_{\perp}}$

Parameters:

$$
\begin{aligned}
B &= 400m \\
R &= 800{,}000m \\
\sin\theta &= 0.5 \\
\lambda &= 0.25m
\end{aligned}
$$

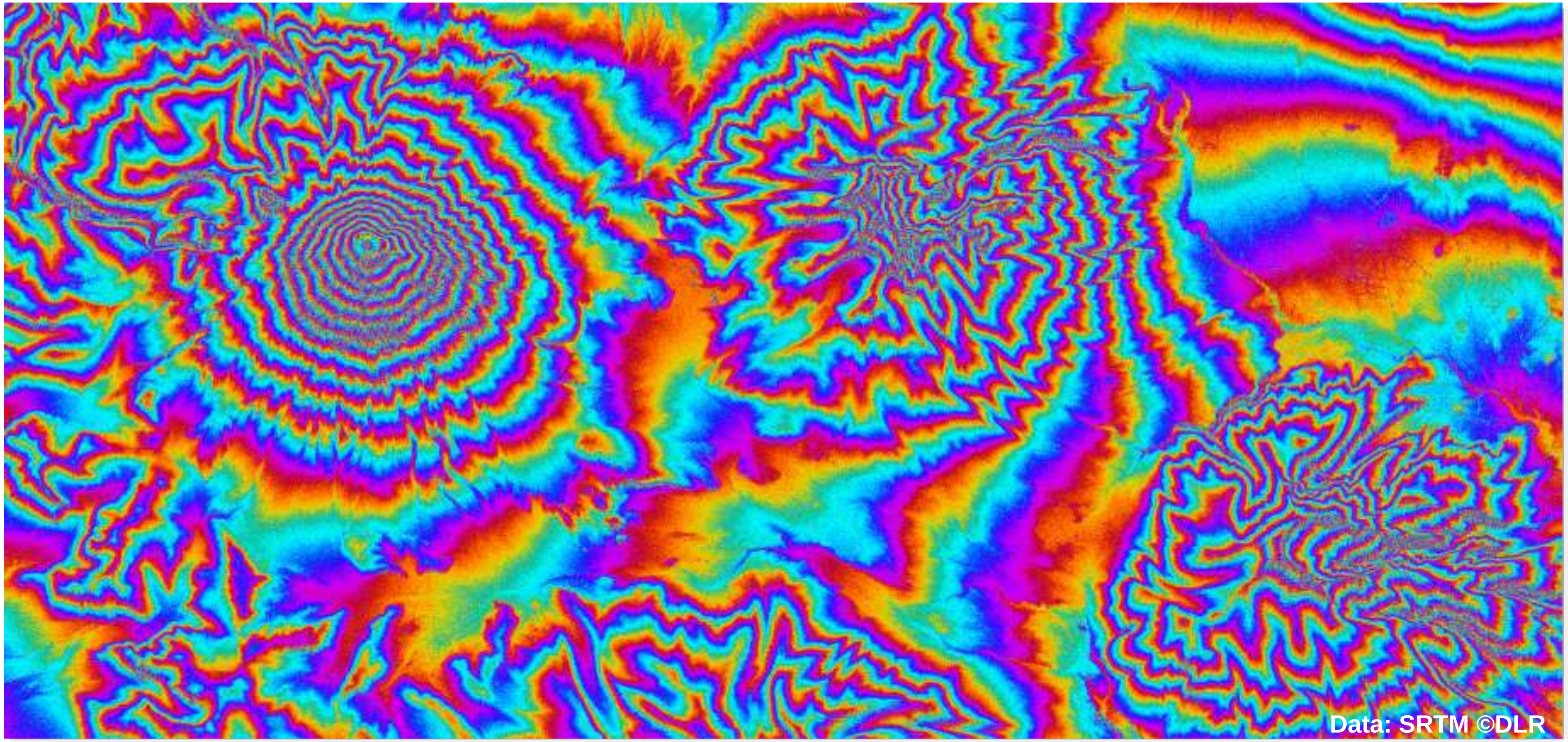
Height per fringe: $h_{2\pi} =$

About 4 fringes → $\Delta h_{1-2} =$



- **Q2:** What is the absolute Height at Point 2?

Problem of InSAR: Interferometric Phase is Ambiguous

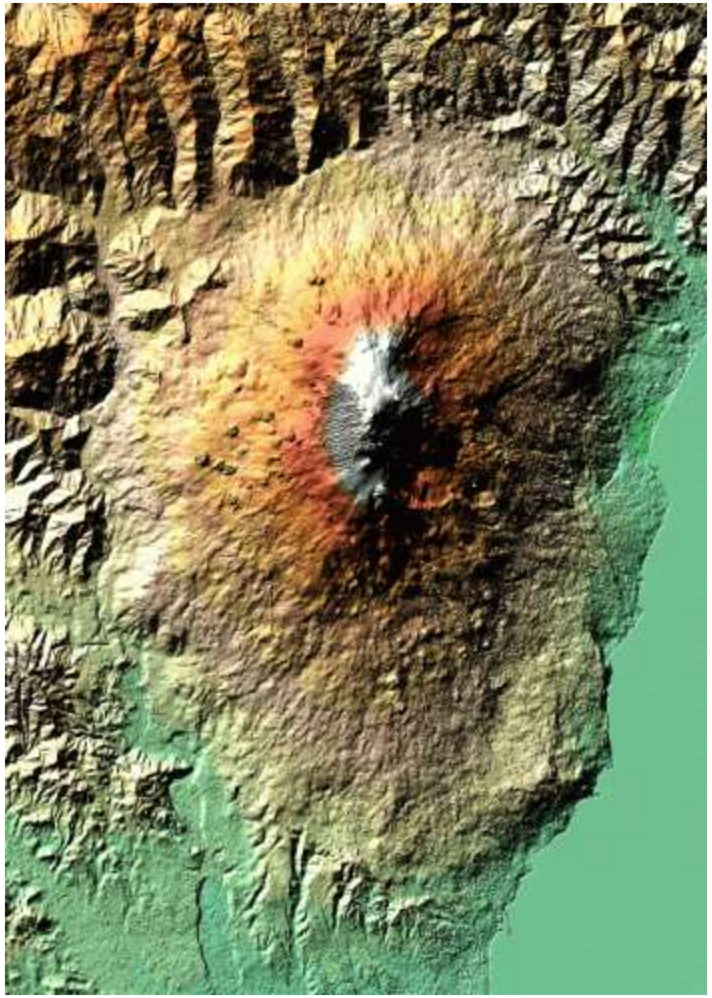


A specific interferometric phase value matches several topographic height values!

Phase Unwrapping: Find "Most Likely" Absolute Phase Given Measured Ambiguous Phase

- **Phase Unwrapping algorithms find mathematical ways of describing that …**

this is much more likely …



… than this

A Typical InSAR Processing Workflow

1. **Select and order InSAR-capable SAR data** from a data server

2. **Import SAR data into an InSAR processing system**

3. **Calculate spatial baseline & apply spectral (wavenumber) shift filtering** (not discussed in the lectures – applied automatically by most available tools)

4. **Determine co-registration parameters**:
   - cross-correlate >100 image chips spread over image
   - use over-sampling and interpolation to locate correlation peaks
   - apply regression to parameterize co-registration (e.g. affine transform)

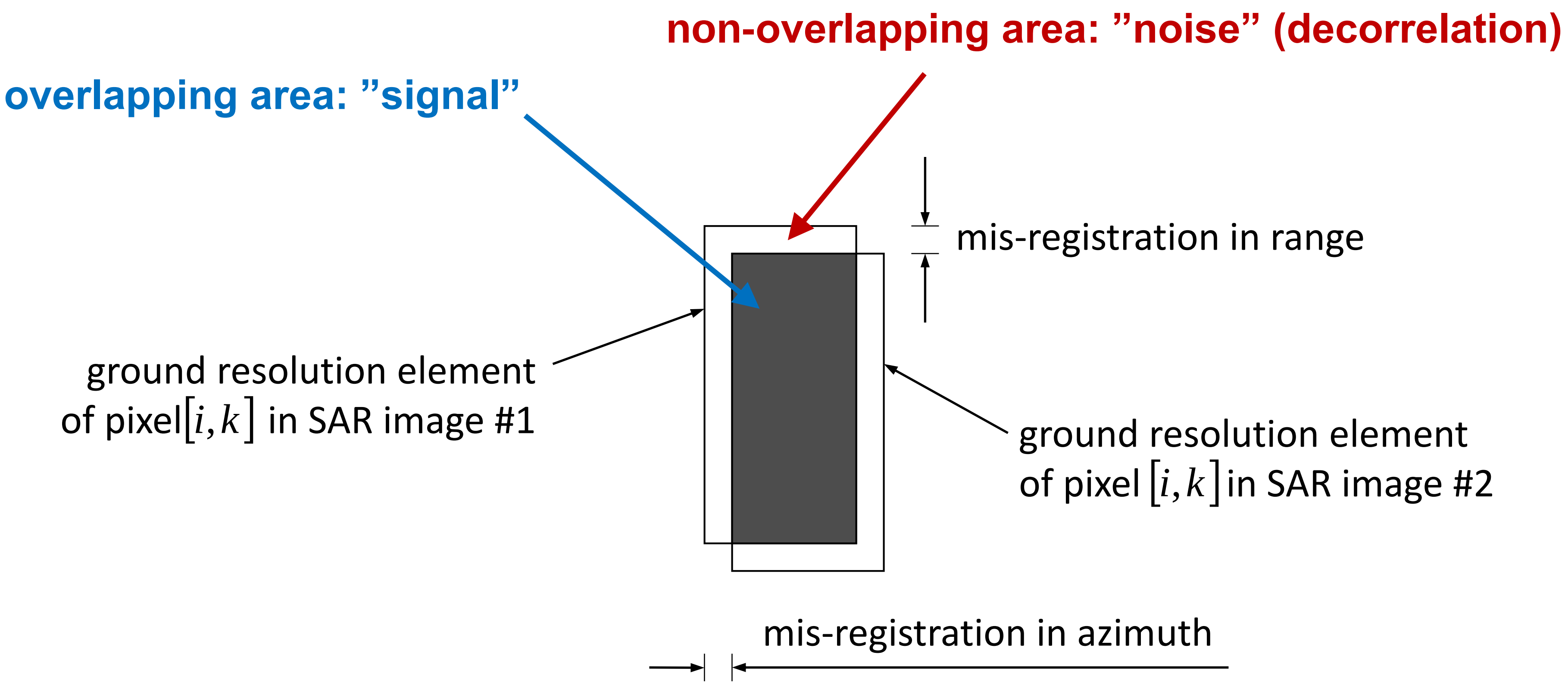
5. **Co-register images:**
   - Resample slave image(s) to match master image
   - Required accuracy: << 1/10 resolution element
   - More on required co-registration accuracy on Slides 20 & 21

A Typical InSAR Processing Workflow

6. **[Optional Orbit improvement:** If precise orbit information is available.]
7. **Interferogram formation:** $I = u_1 \cdot u_2^*$; optional multi-looking may be applied.
8. **Flat Earth phase removal:** Simulate and subtract phase trend due to the geometry changes from near range to far range.
9. **Coherence Calculation:** Coherence is calculated as described in Lecture 12.
10. **For differential InSAR (d-InSAR):** Using a DEM, simulate and subtract interferogram replicating topography-related phase.
11. **Apply phase filter:** A phase filter is applied to reduce InSAR phase noise and reduce phase unwrapping complexity (see next section).
12. **Phase Unwrapping:** Turns originally ambiguous interferometric phase into unambiguous absolute phase.
13. **Geocoding and Terrain Correction:** Note that flat earth phase needs to be added before geocoding to obtain absolute phase.

Effects of Coregistration Errors on Coherence

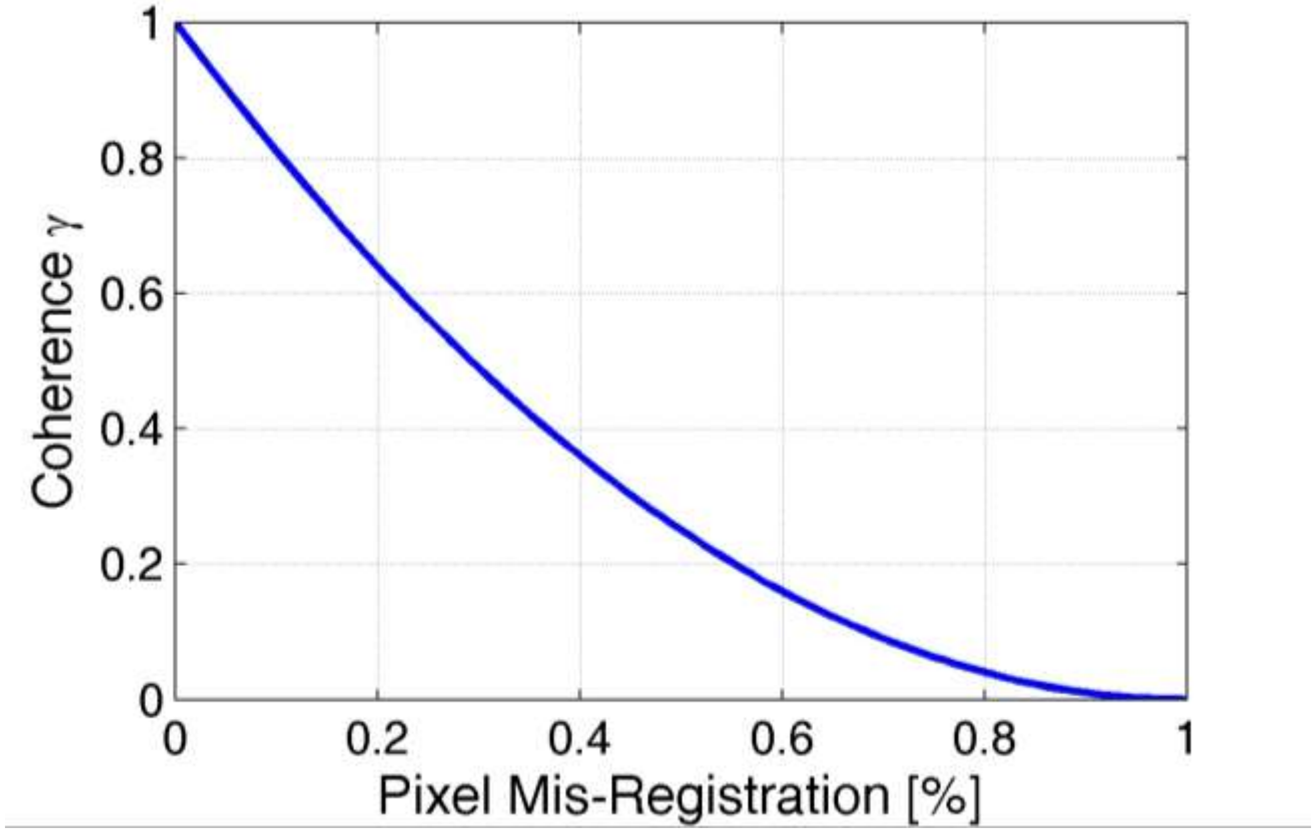
- **How accurately must the two SAR images be co-registered before interferogram formation?**



Stripmap rule-of-thumb: 1/10 of a resolution element mis-registration is usually acceptable

Coherence Reduction Caused by Image Mis-Registration

- **Here a plot how coherence drops with pixel misregistration:**
  - **Assumption:** Mis-registration is only cause of de-correlation
  - Mis-registration expressed in fractions of pixels

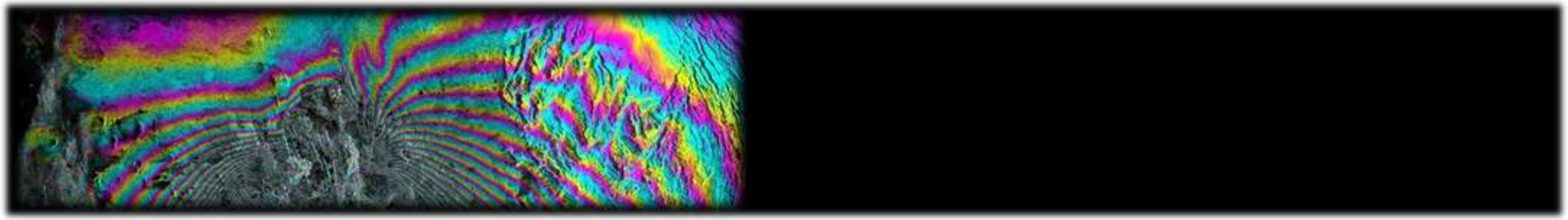


Tips for Selecting Suitable Images for InSAR

<u>**How to select a suitable image pair for successful InSAR processing**</u>

- **Required conditions:**
  - Images from identical orbit direction (both ascending or both descending)
  - Images with identical incidence angle and beam mode
  - Images with identical resolution and wavelength (usually: same sensor)
  - Images with same viewing geometry (same track/frame combination)

- **Recommended conditions:**
  - For topographic mapping: Limited time separation between images (temporal baseline)
  - For topographic mapping: Image pairs with sufficient spatial baseline
  - Images from similar seasons / growth / weather conditions

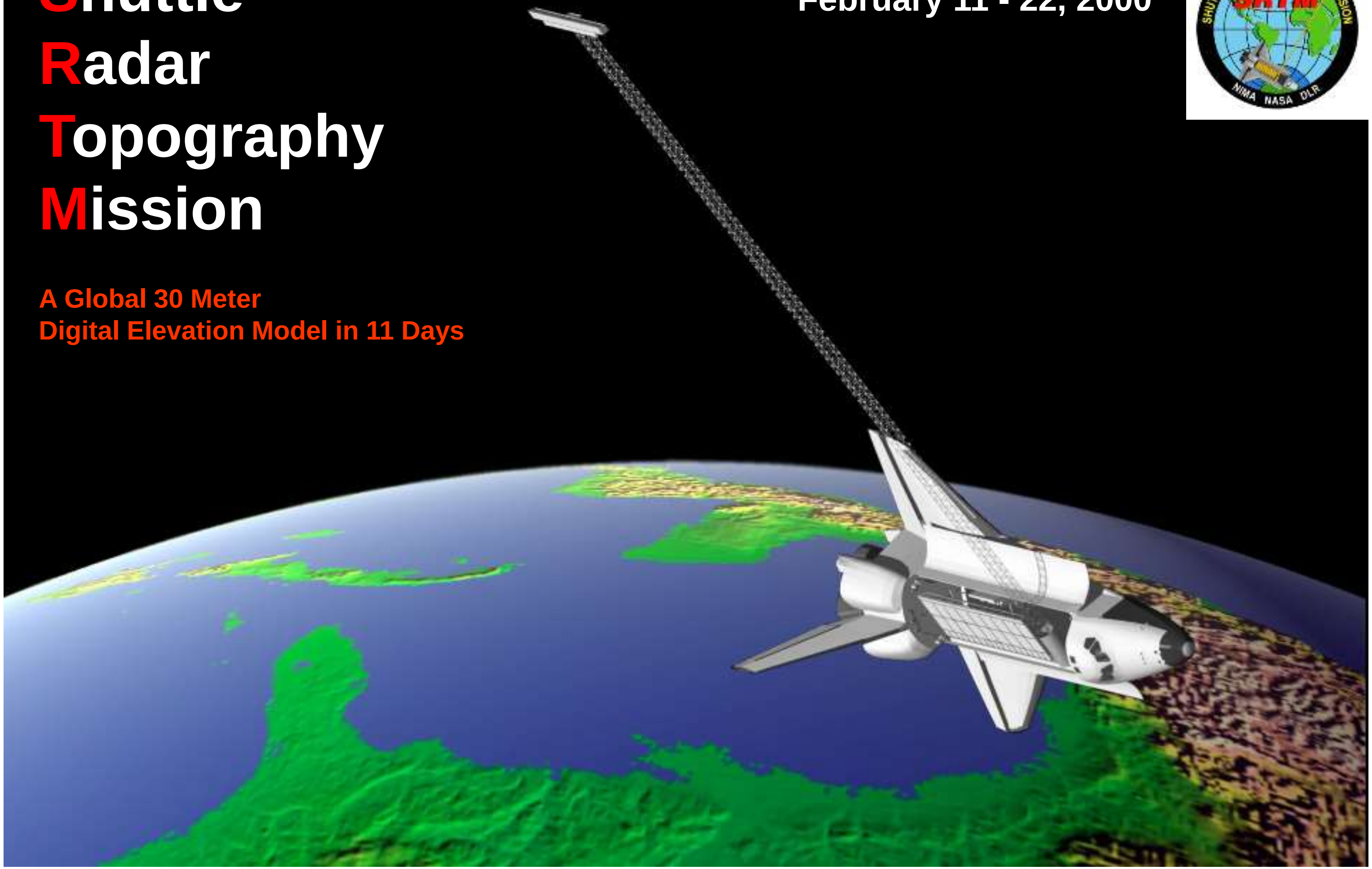


INSAR FOR TOPOGRAPHIC MAPPING: MISSIONS

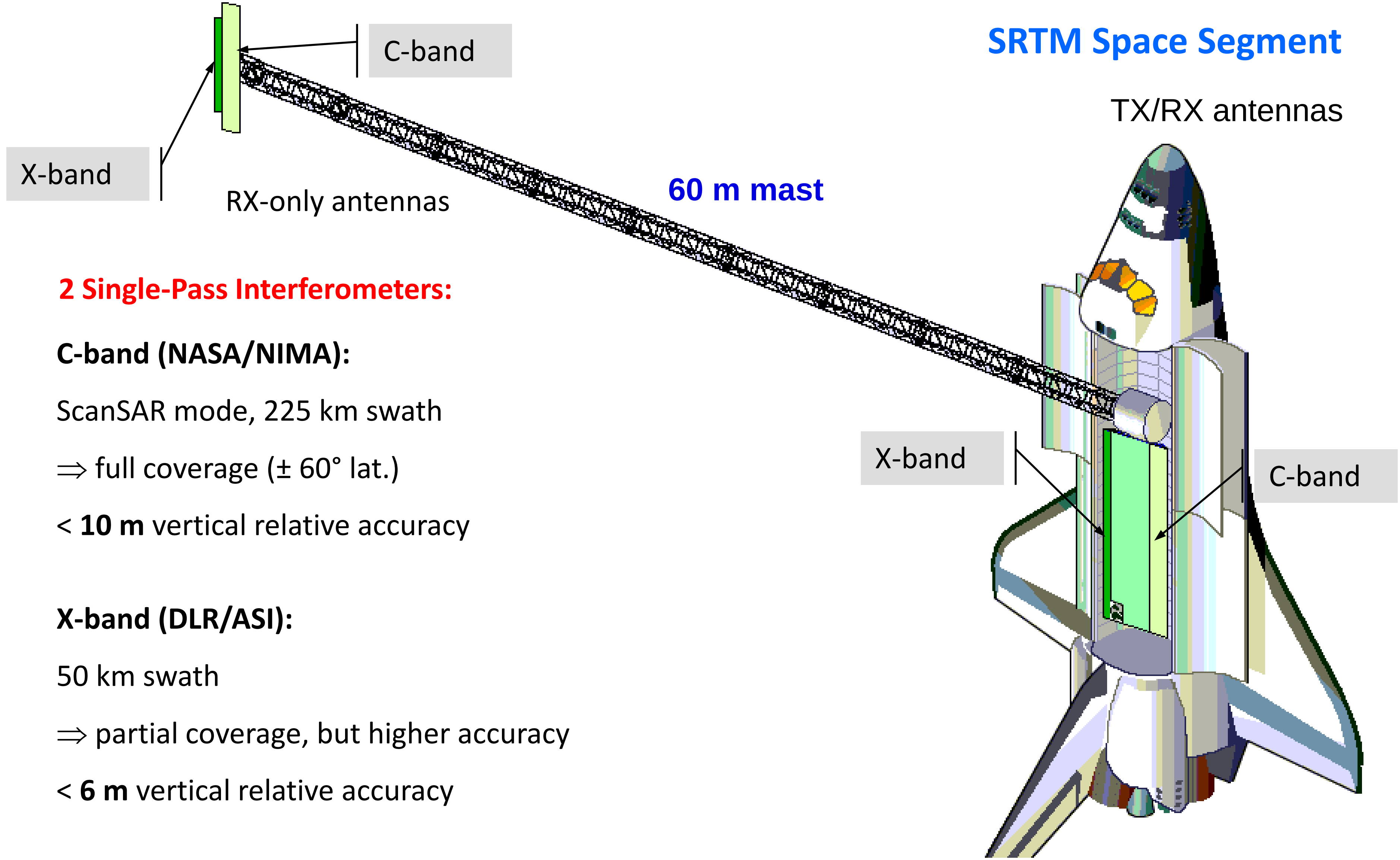
Shuttle
Radar
Topography
Mission

February 11 - 22, 2000

A Global 30 Meter
Digital Elevation Model in 11 Days



SRTM – A Dedicated Topographic Mapping Mission



2 Single-Pass Interferometers:

C-band (NASA/NIMA):

ScanSAR mode, 225 km swath

$\Rightarrow$ full coverage (± 60° lat.)

< **10 m** vertical relative accuracy

X-band (DLR/ASI):

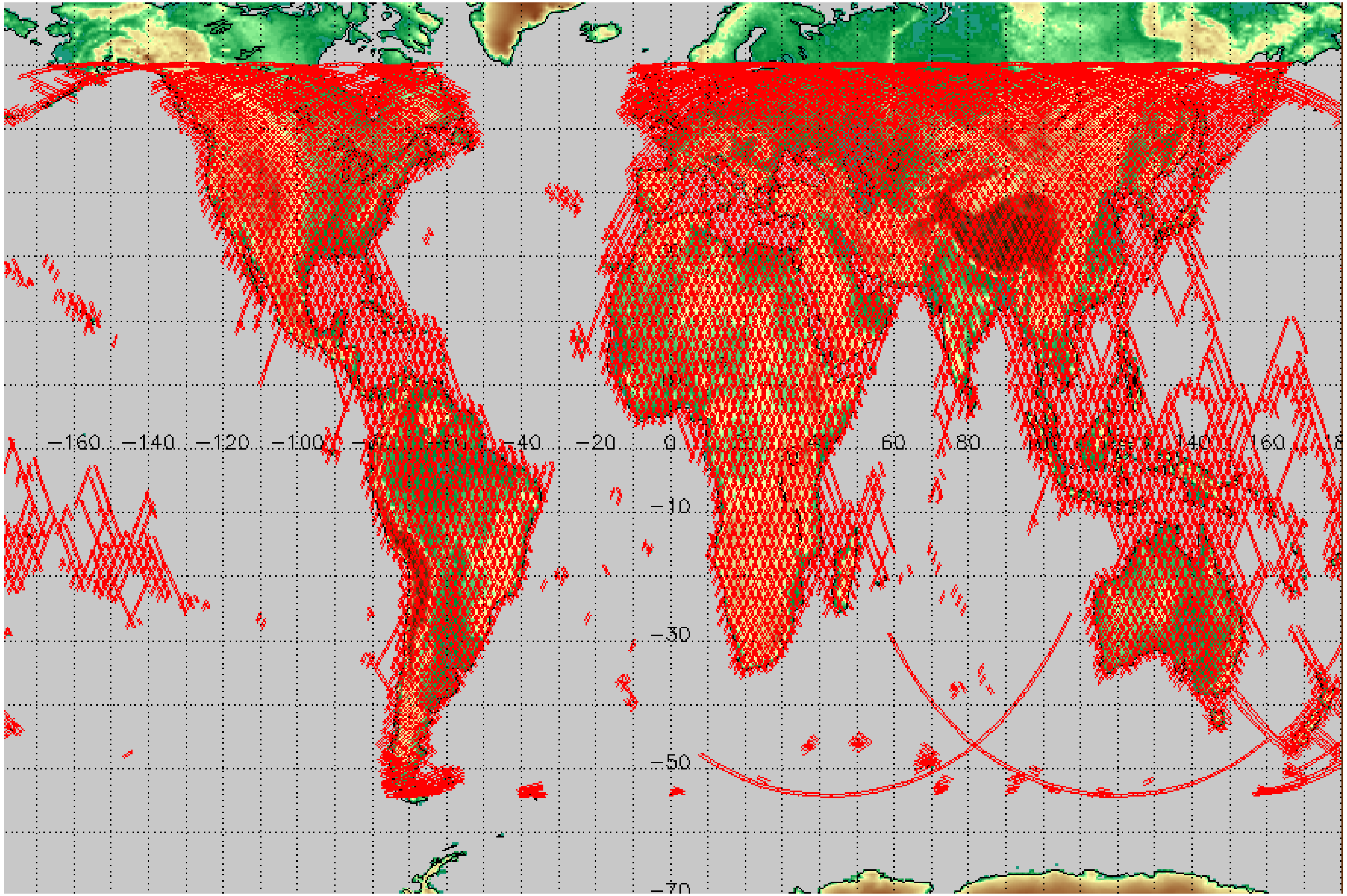
50 km swath

$\Rightarrow$ partial coverage, but higher accuracy

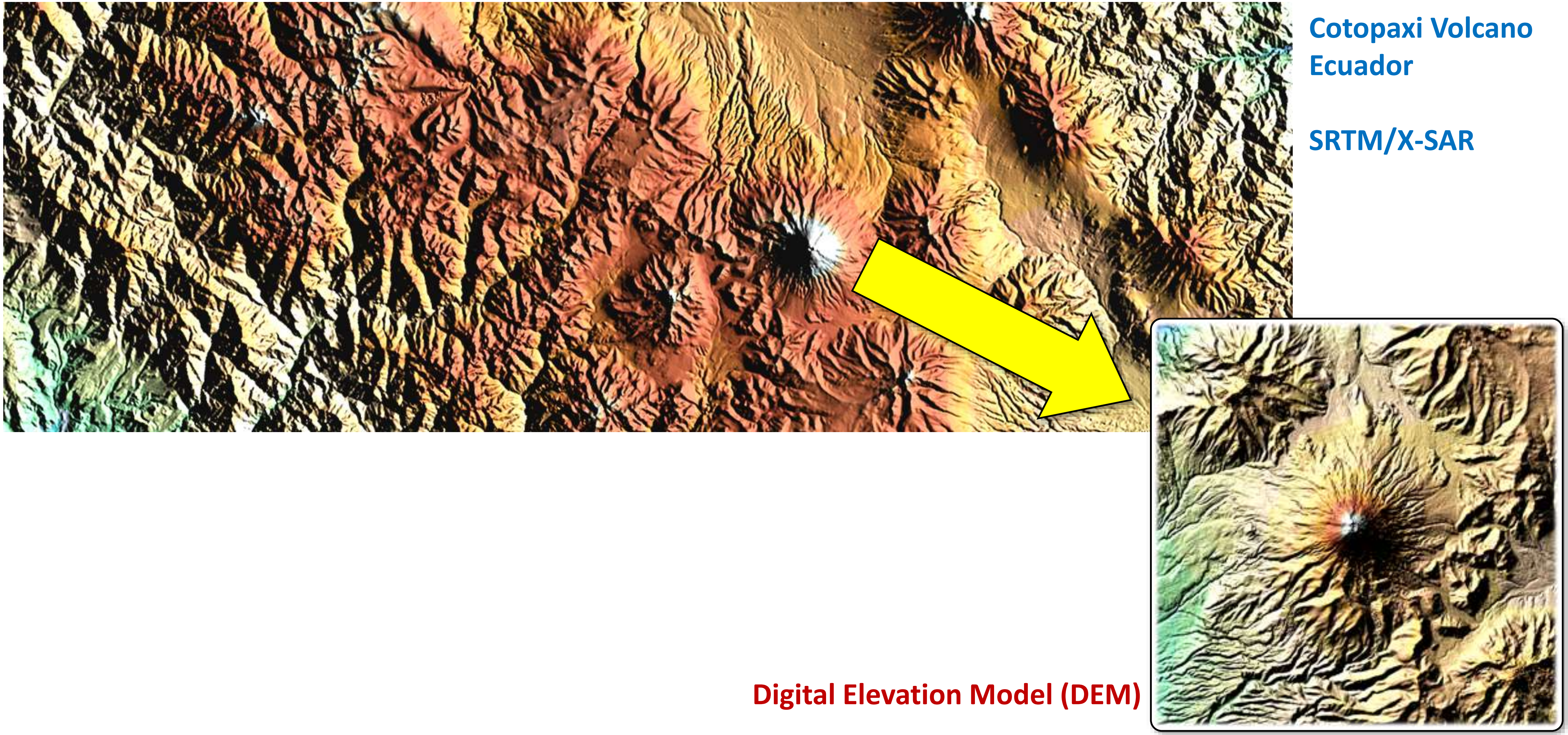
< **6 m** vertical relative accuracy

SRTM – Deployment of Mast

SRTM Coverage



SRTM Example, Cotopaxi Volcano, Ecuador



Cotopaxi Volcano
Ecuador

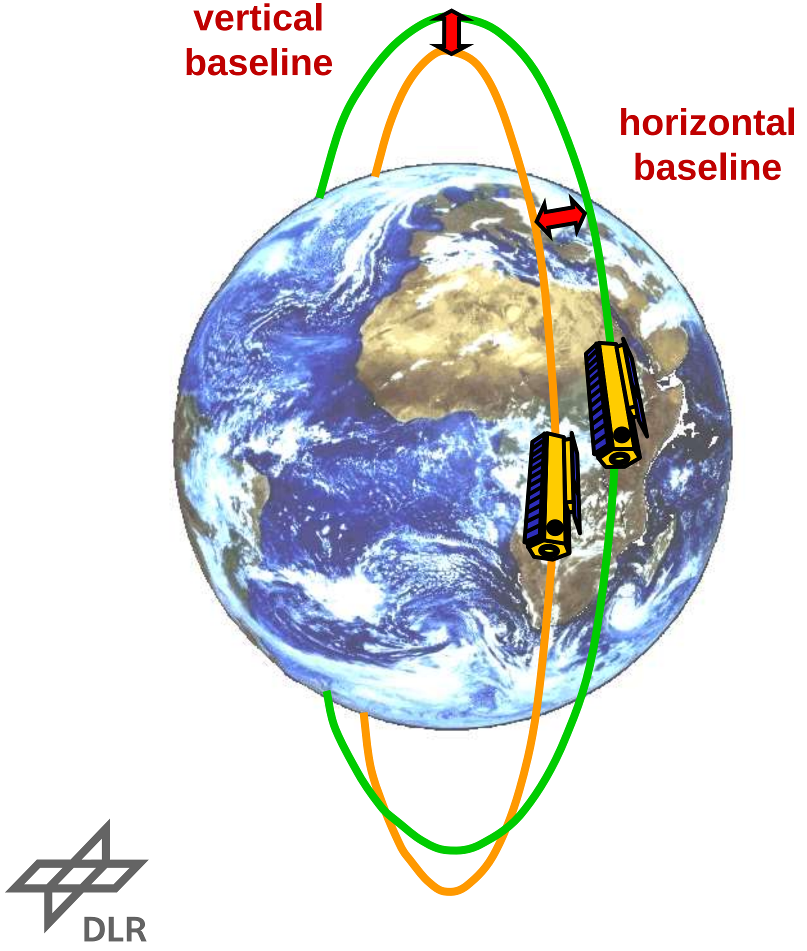
SRTM/X-SAR

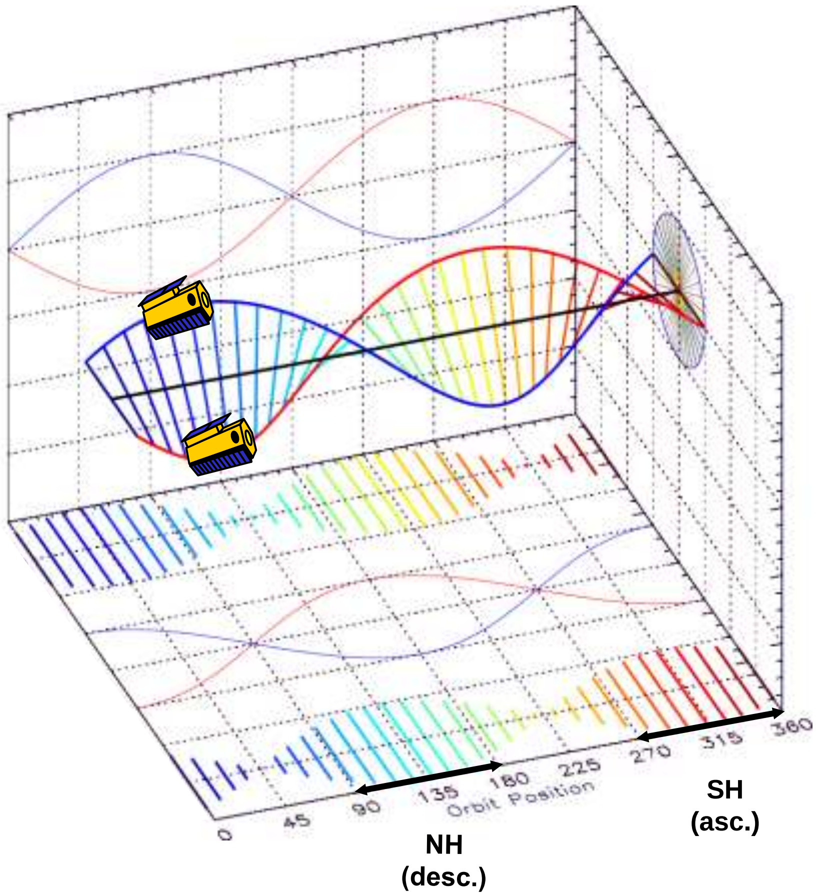
Digital Elevation Model (DEM)

TanDEM-X - An X-Band Mission for Global Topographic Mapping

- **Mission Goals:**
  - Acquisition of a global DEM according to HRTI-3 standard
  - Generation of Local DEMs with HRTI-4 quality
  - Demonstration of innovative bistatic imaging techniques and applications

Helix Orbit of TanDEM-X





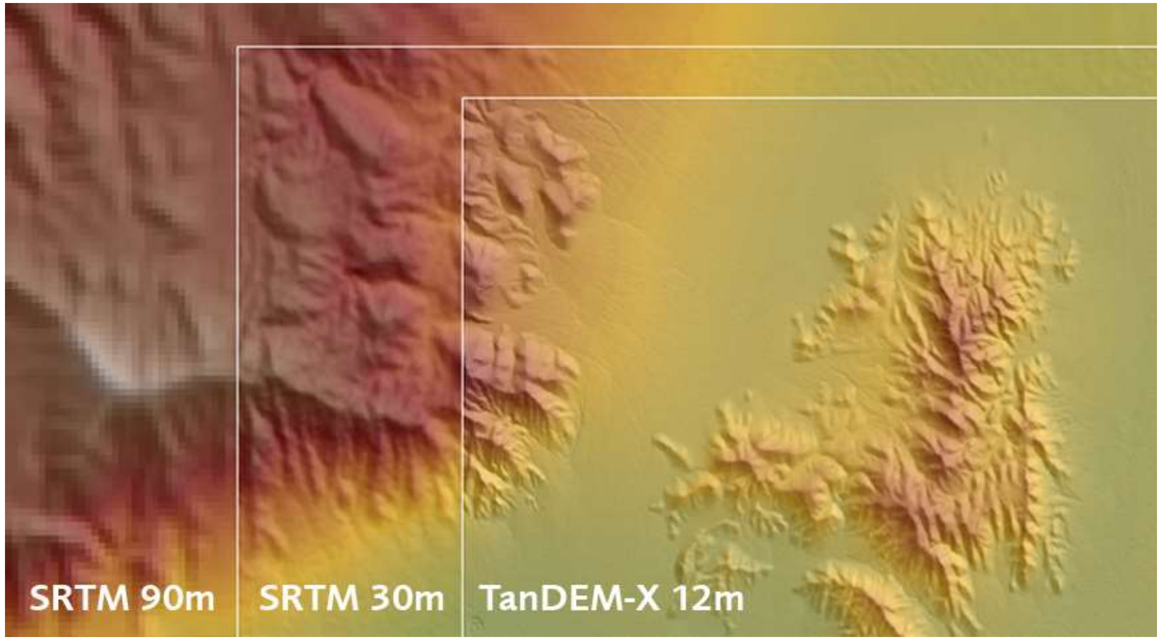
TanDEM-X

DEM Vertical Accuracy

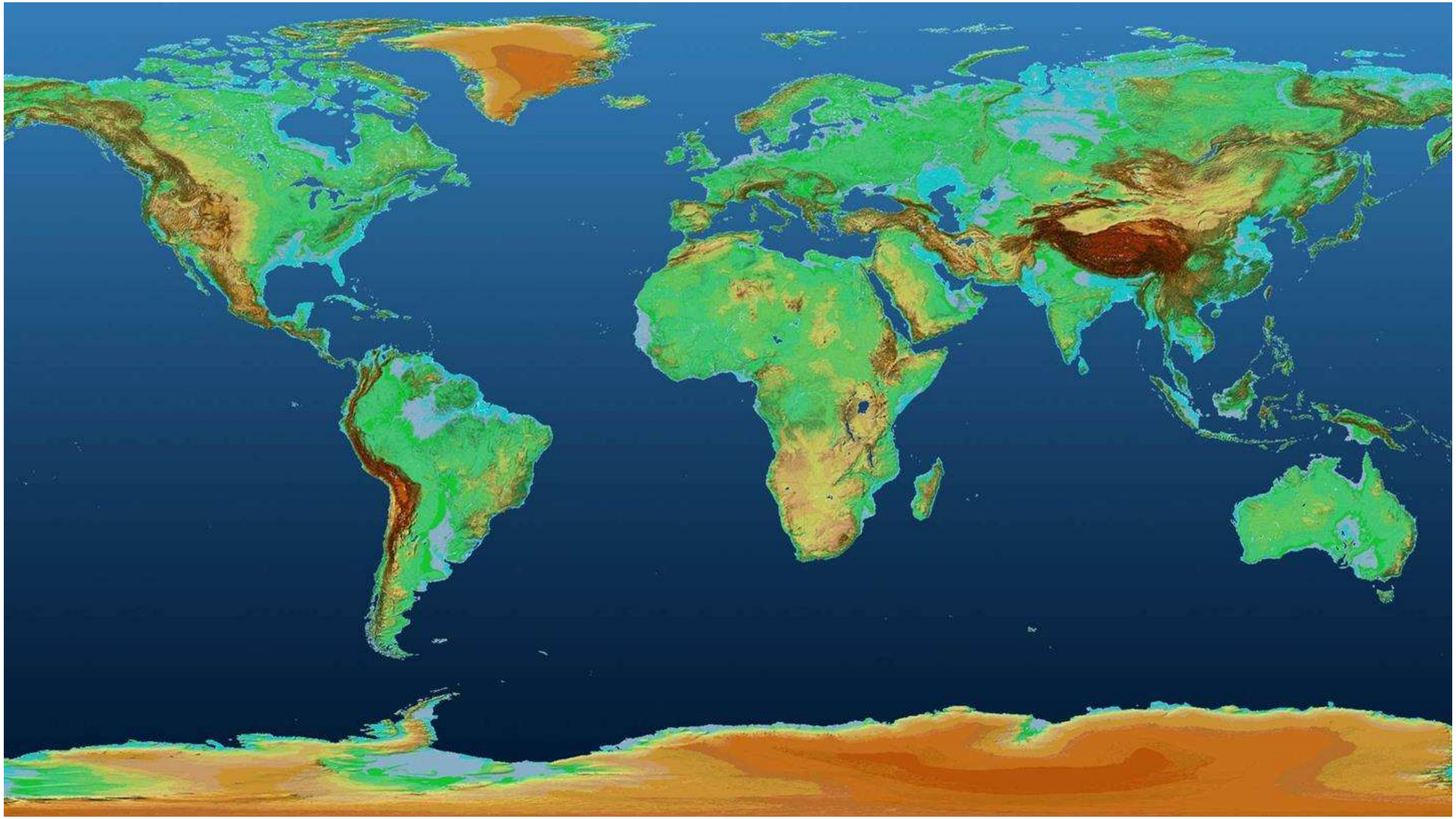
	Spatial Resolution	Absolute Vertical Accuracy (90%)	Relative Vertical Accuracy (point-to-point in 1° cell, 90%)
DTED-1	90 m x 90 m	< 30 m	< 20 m
DTED-2	30 m x 30 m	< 18 m	< 12 m
TanDEM-X	12 m x 12 m	< 10 m	< 2 m
Level-4	6 m x 6 m	< 5 m	< 0.8 m

Visualization of improved DEM quality:

TanDEM-X vs. SRTM DEMs

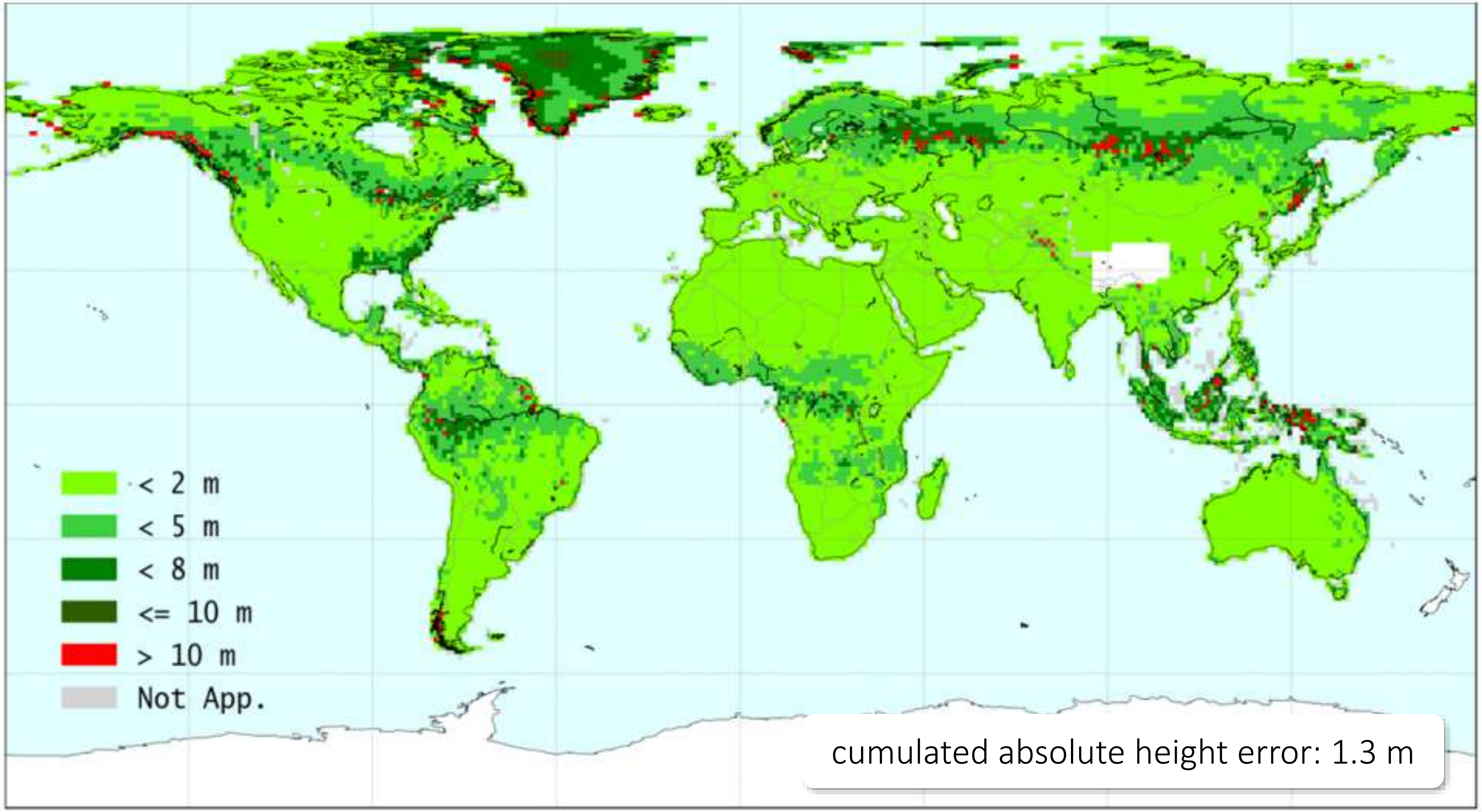


Global TanDEM-X DEM



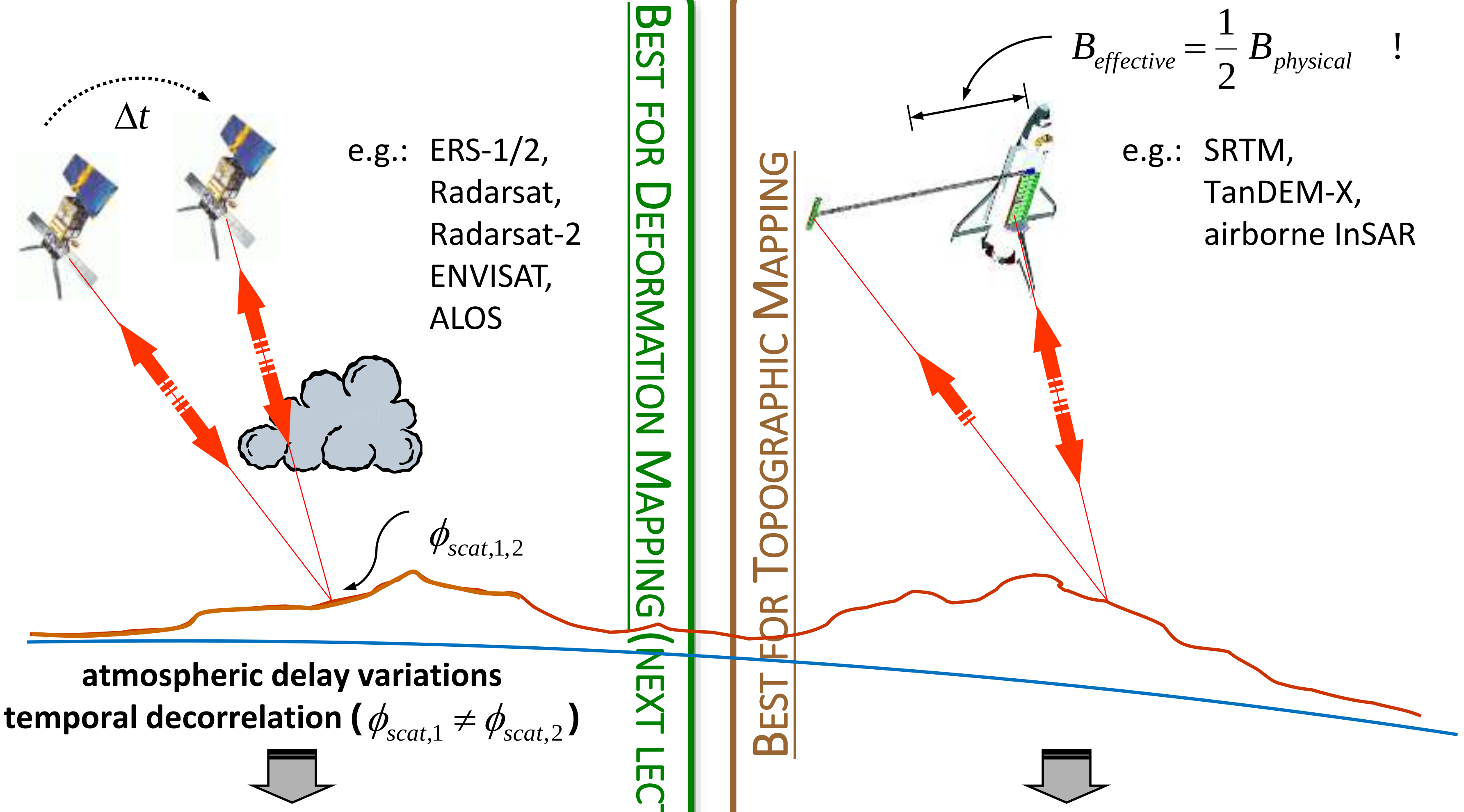
Global TanDEM-X DEM

Absolute Height Error



Zink, Manfred, et al. "TanDEM-X mission status: the complete new topography of the Earth." *2016 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*. IEEE, 2016.

Repeat-Pass vs. Single-Pass Interferometry



BEST FOR DEFORMATION MAPPING (NEXT LECTURE)

e.g.: ERS-1/2, Radarsat, Radarsat-2 ENVISAT, ALOS

atmospheric delay variations
temporal decorrelation ($\phi_{scat,1} \neq \phi_{scat,2}$)

- **reduced & variable quality**
- **sensitive to surface deformation**

BEST FOR TOPOGRAPHIC MAPPING

e.g.: SRTM, TanDEM-X, airborne InSAR

- **high and constant quality DEMs**
- **not sensitive to surface deformation**

What's Next?

- This is what awaits next:
  - Lab on DEM generation using InSAR