# Spaceborne SAR

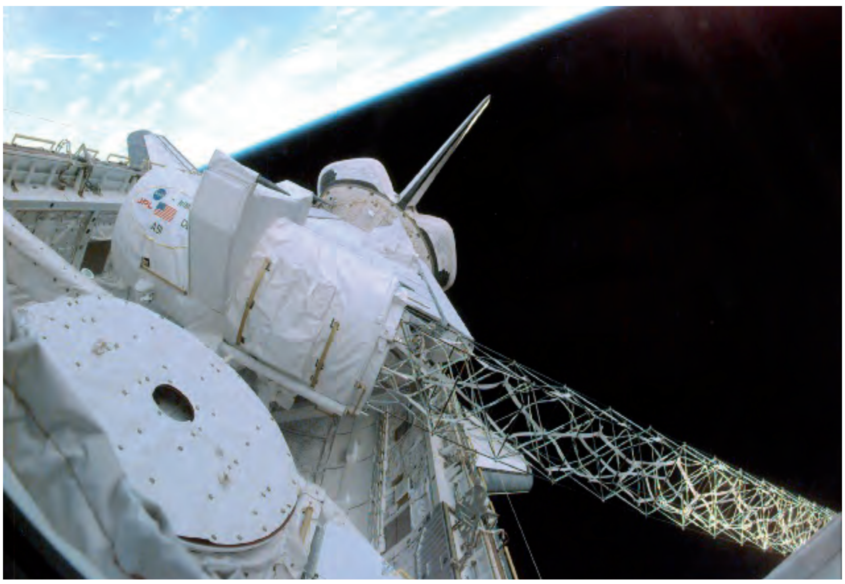



Figure 2-1: View into Endeavours cargo bay with the deployed 60 m SRTM mast (By courtesy of NASA).

## Shuttle Radar Topography Mission – SRTM

On February 22, 2000 one of the most complex space shuttle missions was successfully completed, the Shuttle Radar Topography Mission (SRTM). The main objective of this mission was to collect interferometric radar data for the generation of a near global Digital Elevation Model (DEM), covering the Earth's surface between -56° and +60° latitude.

The SRTM mission was a follow-on to the Shuttle Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR) missions that were successfully conducted twice in April and October 1994. For SRTM, the SIR-C (5.6 cm wavelength) and X-SAR (3 cm wavelength) radar instruments had each to be supplemented by a second receive channel, as well as a second receive only antenna at the end of a 60 m long deployable mast forming the first spaceborne single-pass interferometer.

SRTM was a cooperative project between NASA, NGA (National Geospacial-Intelligence Agency) and DLR. NASA's Jet Propulsion Laboratory (JPL) was responsible for the C-band radar system, the mast and the Attitude and Orbit Determination Avionics (AODA). DLR was responsible for the X-band radar system (X-SAR). The Institute had the project lead and was responsible for the specification, system engineering, mission operations (with support from DLR-GSOC), calibration and the scientific exploitation. Data processing, archiving and data distribution was the task of DLR-CAF. EADS Astrium GmbH was the main contractor for the X-SAR flight hardware development, integration and test.

### Single-Pass SAR Interferometry

Building a single-pass SAR interferometer requires at least one transmitter and two receivers with antennas separated by a so-called interferometric baseline. For SRTM, the baseline was formed by the 60 m long deployable mast structure reaching out of the orbiter cargo bay and carrying the secondary antennas at its end. The same reflected radar signal from points on the ground is received by both antennas, inboard and outboard, but at slightly different times, or as we call it with a phase difference, due to the tiny difference in distance. This phase difference can be accurately estimated, because single-pass interferometers do not suffer from problems with atmospheric disturbance and temporal decorrelation of the target backscatter encountered with repeat-pass interferometry.

With the precise knowledge of the shuttle's position and the baseline vector in space relative to the spot on the ground at any time, the height of the target can be processed. Orbit and baseline were measured with the AODA system: a set of GPS receivers, gyros, electronic distance meters, and star trackers. The position of the interferometer was measured by GPS with an accuracy of 1 m. The baseline angle was measured with an accuracy of about 2 arcseconds (short-time) and 7 arcseconds (mission). The baseline length was determined to millimetre accuracy.

**The Mission**

Seven hours after launch the mast had been successfully extracted and soon the first test data take was acquired over New Mexico / USA and processed by DLR. Figure 2-3 shows the first interferogram with the oscillations of the mast still uncompensated and without calibration.

The mapping of the continents was performed by operating the radar only over land with 5 to 15 seconds coverage over the ocean before and after the land. These acquisitions served as an absolute height reference using the well known ocean heights. More than 700 data takes were performed to map the earth in 11 days. Additionally, several long data takes only over ocean have been acquired to support the calibration and verification of the system.

The only problem during the mission was the malfunctioning of a cold gas valve. In consequence, the baseline orientation had to be maintained by corrective firings of the attitude control thrusters about every 90 seconds. These firings lead to increased oscillations of the mast and in consequence, to increased processing complexity and DEM errors. Nevertheless, after 159 orbital revolutions the C-band system with its 225 km wide swath had managed to cover the required surface. The X-band coverage, limited due to a swath width of 50 km, still comprises more than 60 million square kilometres.

**Data Analysis and Results**

The mission analysis revealed an excellent stability of the radar systems and a homogenous data quality with respect to the basic radar parameters, like received echo level, antenna azimuth beam alignment, interferometric coherence and Doppler centroid frequency. During

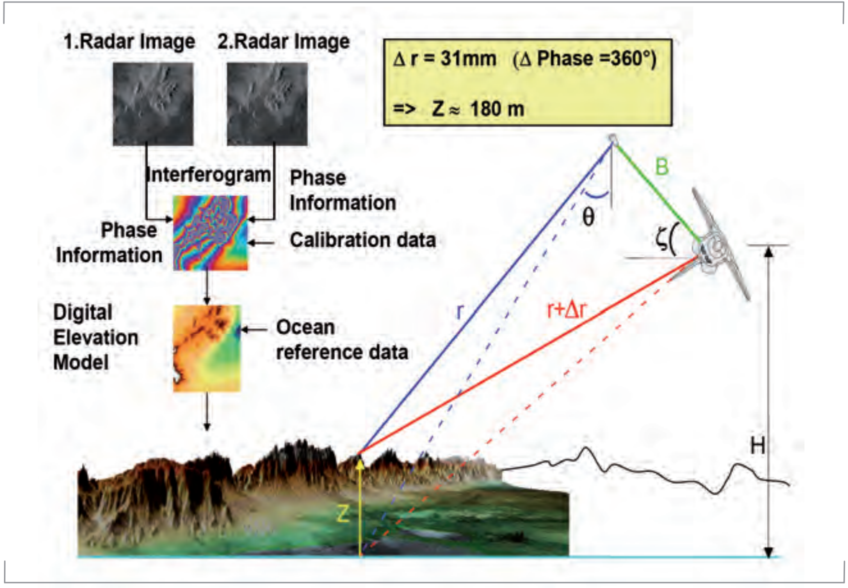



Figure 2-2: Single-pass SAR interferometry principle and baseline definition.

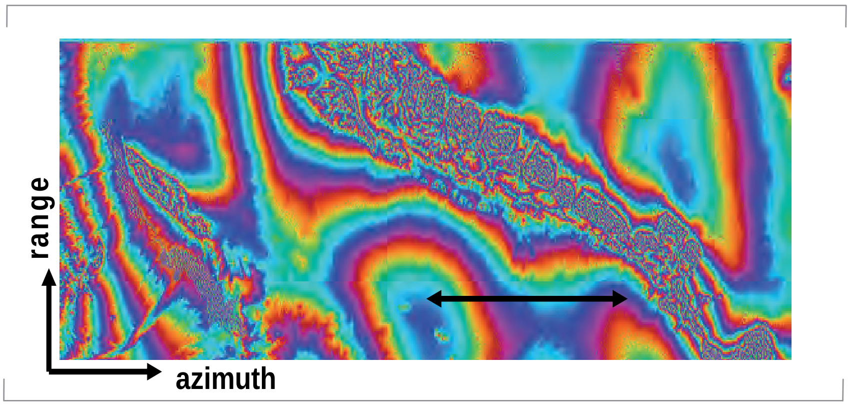



Figure 2-3: First X-SAR interferogram of the Shuttle Radar Topography Mission. The arrow shows the effects of uncompensated mast oscillations.

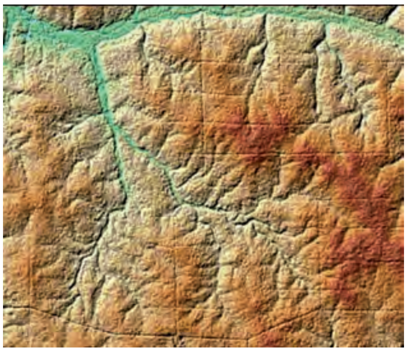
| Flat terrain | number | μ [m] | σ [m] |
|---|---|---|---|
| Forested areas | 2329 | -6.20 | 6.74 |
| Urban areas | 1683 | -2.63 | 4.10 |
| Open landscape | 20786 | -0.94 | 4.31 |
| Σ | 24798 | -1.55 | 4.84 |

| Moderate relief | number | μ [m] | σ [m] |
|---|---|---|---|
| Forested areas | 1970 | -1.98 | 7.60 |
| Urban areas | 725 | -1.14 | 4.86 |
| Open landscape | 8000 | +0.15 | 4.54 |
| Σ | 10695 | -0.33 | 5.33 |

| Highlands | number | μ [m] | σ [m] |
|---|---|---|---|
| Forested areas | 2272 | -4.43 | 8.62 |
| Urban areas | 766 | -1.04 | 5.29 |
| Open landscape | 7693 | -0.74 | 5.36 |
| Σ | 10731 | -1.54 | 6.37 |

**Table 2-1: SRTM DEM validation with navigation points in the western part of Germany.**

**Figure 2-4: SRTM X-band digital elevation model shows topography plus vegetation heights, rivers and clear cuts in the Kongo rain forest.**



a collaborative calibration phase after the mission that lasted more than one year, the processing teams calibrated all the timings, offsets and dynamic behaviour of the instruments.

The relative height error was specified to be 6 meters (90 %). This accuracy was generally confirmed by DLR investigations, e.g. by comparison with navigation points as shown in Table 2-1. Several other investigators confirmed this accuracy, e.g. an independent quality assessment at a 70 km by 70 km test site south of Hanover, Germany, using trigonometric points and the Digital Terrain Model ATKIS DGM5 concludes with a mean value of the height differences μ of 2.6 m and a standard deviation σ of 3.4 m.

The small height errors of ±2.5 m correspond to a line-of-sight mast motion compensation accuracy of 0.44 mm, which was an incredible achievement. Nevertheless, residual, uncompensated first order oscillations of the mast translate to this measurable error on an 8 km scale in flight direction.

The long term variations in the 10 to 20 minute scale are of little relevance for the user, as they represent only a small height offset within a DEM product. These slow drift errors are within specification and entirely handled by the ocean calibration and bundle adjustment approach.

With SAR interferometry, the location or height of a representative phase centre of the backscattering resolution cell is measured. In principle C-band radar waves should have a higher penetration into the vegetation than X-band waves leading to differences in the interferometric height measured in the two systems over forested areas. In order to compare the penetration between C- and X-band, for instance in rain forest, several areas in Brazil and Kongo (see Figure 2-4) have been investigated. A relatively flat terrain and visible clear-cuts along roads have been selected to remove any offset between C- and X-band not due to penetration effects.

The resulting height differences of about 1 m are not very significant and well within the height error boundaries of both systems.

In response to the announcement of opportunity (AO) 102 proposals have been accepted and more than 1200 DEM and radar products for scientific evaluation with regard to validation, calibration and geoscience applications have been ordered. Hundreds of papers have been written using SRTM data for their investigations.

Though the X-band data from SRTM have a better performance than the C-band data, the gaps in the coverage and the cost for the data access have reduced the worldwide use considerably.

For many applications, the 1 arcsec posting and the accuracy of the SRTM dataset is still not sufficient and the area north and south of 60 degrees latitude is still only available with 30 arcsec resolution. A satellite mission like TanDEM-X will provide DEM performance of the next higher quality level and fill the gaps.