

Status of the SRTM data processing: when will the world-wide 30m DTM data be available?

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ABSTRACT

DLR's X-band interferometric SAR system onboard the Shuttle Radar Topography Mission (SRTM) has been flown successfully in February 2000 and acquired 3660 G bytes of raw data to be processed to a near global Digital Elevation Model (DEM) of the earth with an absolute height accuracy of $\pm 16\text{m}$. Before starting the operational processing different kinds of calibration and motion compensation activities based on the attitude and position data and recorded instrument housekeeping data have to be performed. The preliminary results achieved over ocean test areas show the absolute height error and the relative error from the radar noise within specification. The processing and archiving facility is operational and the complete data set will be processed and available to the customers till mid 2003.

1. INTRODUCTION

On February 22nd, 2000, one of the most complex Space Shuttle missions ever attempted has been successfully completed, the Shuttle Radar Topography Mission (SRTM). 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 in between -56° and $+60^\circ$ latitude. [1]

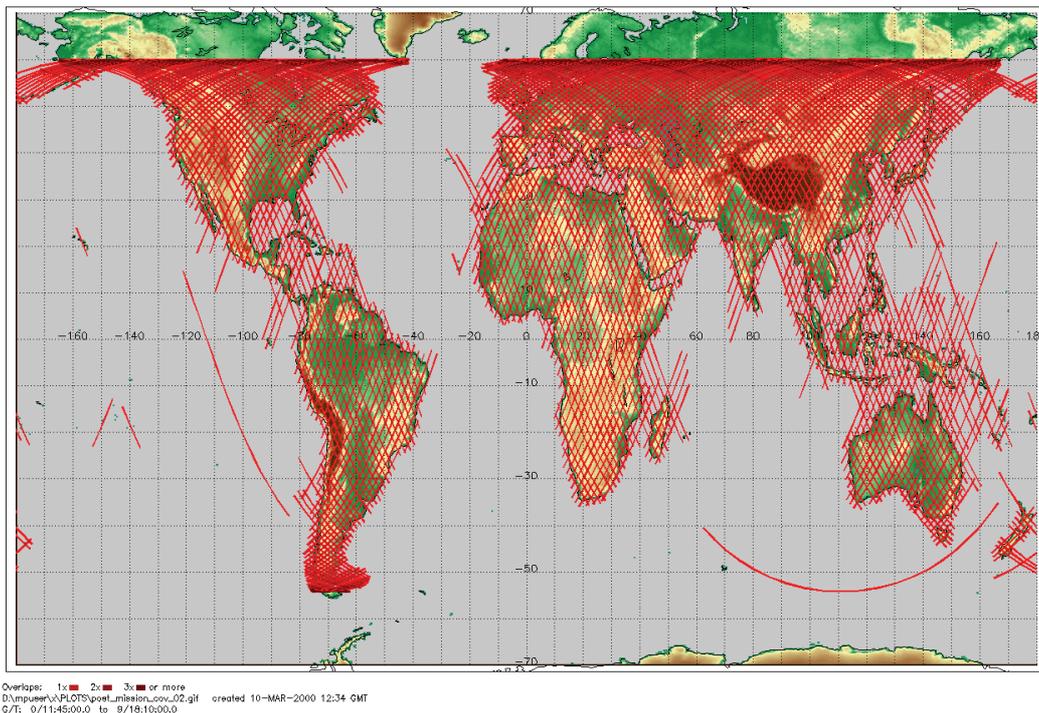


Fig. 1: X-SAR/SRTM Data Coverage

The mission was a complete success and the radar systems performed as expected. The DLR X-SAR system covered with its limited 50km wide swath in 367 data-takes a total area of land of 64 Mio. km² (Fig.1) and the C-band system of NASA/JPL with its Scan-SAR system covered the whole area without mayor gaps with a total of 119 Mio. km². The amount of raw radar data to be

archived and processed is 3660 G bytes for the X-SAR and 8590 G bytes for the C-band system. [2] All C-band data will be processed by NASA-JPL. DLR responsible for the X-SAR instrument, will process all X-SAR data. Data over Italy will be processed and made available only by ASI. The German Remote Sensing Data Center (DFD) of DLR developed a line of processors for the operational processing of the SRTM-X-band data.

2. THE CALIBRATION PHASE

After the duplication of all the flight tapes in April 2000 the X-SAR raw data have been sent to DLR's German Remote Sensing Data Center (DFD) for the processing. Approximately 100% of all tapes were screened and archived until end of May 2001. Preliminary coverage plots of all continents can be found in the project web page: <http://www.dfd.dlr.de/srtm>.

2.1. Motion Compensation

Without proper motion compensation the focussed SAR image of the secondary antenna would be shifted with respect to the primary image by an amount proportional to the momentary differential velocity of both antennas in the line of sight direction [3]. This differential shift together with the high Doppler frequencies of typically 3 kHz would lead to intolerable phase and height errors.

For the DEM geocoding we have to take into account the relatively fast moving baseline vector. The motion correction is performed by compensating the high frequency motion components in the SAR raw data and by using the remaining low frequency version of the baseline vector for InSAR processing and DEM geocoding.

The analysis of the attitude data post mission showed that the problem with the cold gas system, that was designed to support the attitude hold of the orbiter, caused much more frequent motion in the roll axis than expected because the orbiter attitudes control system had now also to correct for the gravity component. Figure 2 shows the baseline roll angle.

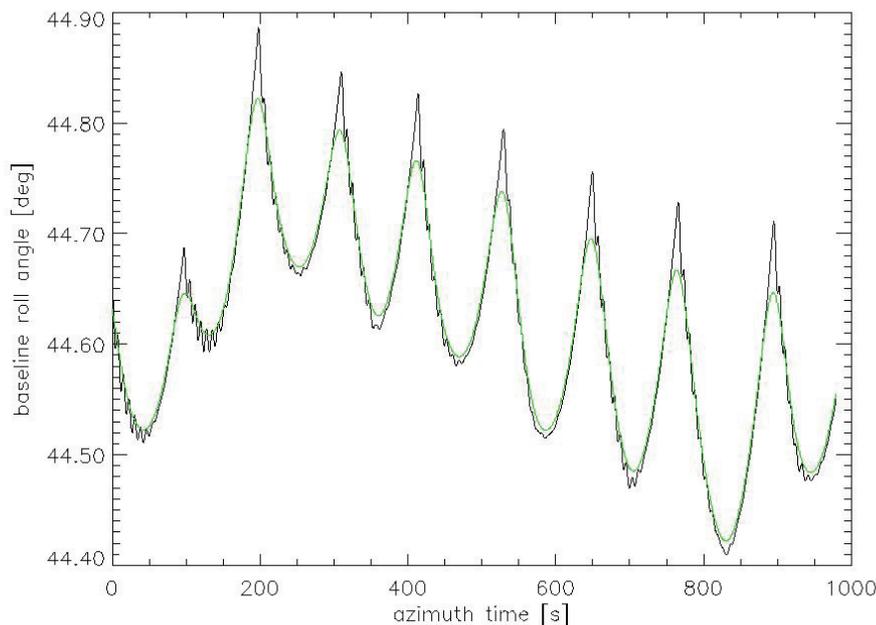


Figure 2: Baseline roll angle along track (black) with motion compensation effect (green)

The mast is pulled by gravity to get aligned with the vector towards the earth center. But the Shuttle attitude control system is set to a limit of plus minus 0.1° and later in the mission to 0.2° dead-band around the 57° roll angle causing the thrusters to fire whenever the upper boundary of the dead-band has been reached. The firing turned the orbiter and mast then again to the other direction and caused also a little oscillation of the mast, which has to be compensated in the phase of the radar signal during the motion compensation part of the data processing.

The principle of the motion compensation used for SRTM can be described as follows. A sensor trajectory, which considerably reduces the motion of the sensor in the line of sight, is calculated by smoothing the reference track. The phase corresponding to the distance in line of sight between the original and the calculated trajectory has then to be added to the single SAR scenes depending on range and azimuth. To do this, the sensor position for each of the image samples has to be known exactly. The Attitude and Orbit Determination Avionics (AODA) developed by JPL was part of the SRTM payload to provide the necessary baseline metrology. Within this system, the baseline is measured to 2 mm, the Shuttle attitude to 9 arc sec and the Shuttle position to 1 m as 1.6 sigma level accuracy.

The trajectory of the Space Shuttle can be considered very stable, i.e. the data acquisition of the primary antenna is not influenced by motion effects. Consequently, the motion compensation has only to be applied on the secondary antenna. In our case, only the mast oscillation causes relevant motion effects. Mast roll bending is the single essential effect on the SAR raw data. Consequently it is sufficient to determine and to smooth the motion in the roll axis of the outboard antenna with respect to the inboard antenna. The derived compensation phase is applied on the raw data. Figure 2 green line visualizes the effect of the motion compensation. The line of sight sensor velocity is reduced by a factor of 10. Furthermore the remaining motion is of good nature and can consequently be compensated by the interferometric coregistration in each scene.

The sensor motion in the line of sight caused by the mast oscillation considerably influences the radar observation. The AODA system supplied extremely accurate observation geometry data but the requirements are also extreme and it took one year to optimize this attitude data-set and to correct some errors. The motion compensation is now able to adjust the motion effects in the secondary scene and we can reach the required height accuracy.

2.2. Instrument Phase Errors

2.2.1. Phase variation from mast cables

Both the radar receive signal at IF-frequency (135MHz) and the 263MHz signal used for down-conversion at the outboard structure run over the 100m long mast cables connecting inboard and outboard electronics and experience phase variations corresponding to the temperature of the cables. A 1052 MHz stable oscillator signal generated in the RFE was distributed via a 10m cable to the RAE divided by four and sent at 263MHz via the up-link boom cable to the XDC. The 263MHz local oscillator frequency was then multiplied by 36 in the XDC, as was the corresponding phase variation over the boom cables.

The high temperature variations between -25°C and $+20^\circ\text{C}$ measured at the coax cables have been identified as the major error source within the instrument. A direct continuous precise measurement of the phase shift has been performed during the whole mission.

For that purpose the 263 MHz oscillator signal used for the down-conversion in the outboard XDC was reflected back via the down link cable and the two-way phase has been measured using a phase detector $\Delta\Phi$ in the RAE. The phase detector output phase resolution is 0.022° and the accuracy was

measured to be one resolution step, which corresponds to an one-way X-Band phase error of 0.4° , assuming identical phase variations on both the up link and down link boom cables.

Depending on the orbit position with its different sun and shadow conditions, the measured phase variation was up to 7° within one orbit. During the data processing this measured phase is divided by two (only one way for the radar signal), multiplied by a factor of 35.5 and subtracted from the radar signal phase. An uncompensated mast phase error would result in height errors of more than 27 meters over a 20 minute or 1500 km long data take.

2.2.2. Phase variation from PLL oscillator temperatures

Several phase lock loop (PLL) oscillators have been used in the radar instrument for up and down conversion of frequencies. All have been monitored, recording their tuning voltage and temperatures. Only one of them, responsible for the down-conversion of the X-Band signal to 1186 MHz (which is a factor of 32) showed an unstable tuning voltage whenever the sun got into the thermal control radiator window and the temperature started to rise over 30°C . This is due to a non optimum thermal design of that box for the northern part of the orbits. Post mission analysis indicated a correlation with phase variation in the secondary channel derived from the cal-tone phase. The inserted phase error of up to 50° has to be compensated.

2.3. Results so far

The results in applying the test versions of the attitude and orbit data file received from JPL to the motion compensation system showed still rather strong residual systematic height errors. The data file has been improved meanwhile by better understanding the difficult coupling between the various sensor data used and applying alignment corrections and a higher sampling rate. A twenty minutes long data take over an ocean area south of Australia was used to determine the height errors. The known height over the ocean was used as a reference, corrected by taking into account the geoid, height measurements from altimeters and tide tables, to correct the radar signal phase.

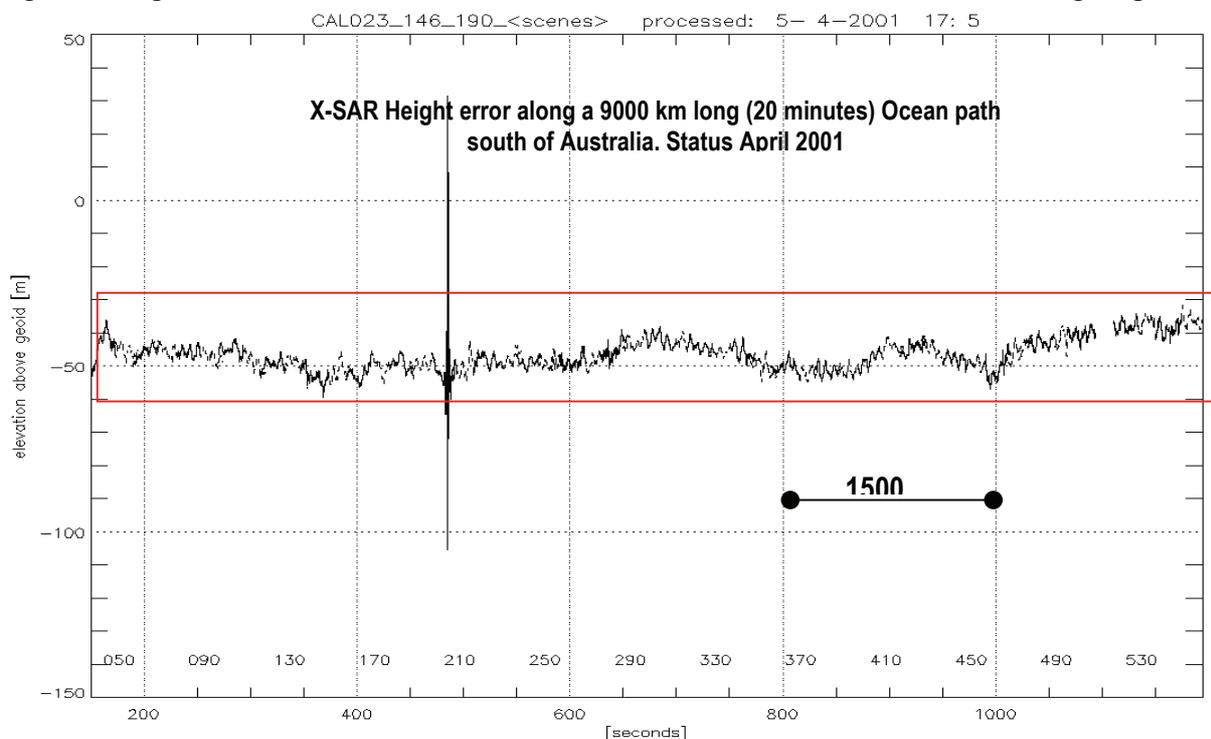


Fig.3: Residual X-SAR/SRTM height errors over a long ocean path. Red box indicates the specification of ± 16 m

The remaining height error is due to insufficient motion compensation, minor not yet corrected systematic instrument phase errors and the expected radar phase noise, which has been averaged out in the graph. Figure 6 shows the resulting height error over the geoid. The long-term error over the 20 minutes is only about ± 10 meters but there are short-term variations every 7,1 seconds and every 100 seconds with errors of the same amount, which seem to be correlated with the mast motion. Two of these long ocean data-takes have been performed during the mission to derive the systematic error [4].

3. THE VALIDATION PHASE

During the validation phase the SRTM products will be compared to high precision digital terrain models available over selected test areas and along kinematic GPS tracks. Several investigators have applied for experiments and investigations in the frame of the announcement of opportunities and will contribute to the quality assessment and validation. The first sample product delivered to the principal investigators in May 2001 is an area in Gujarat in India Figure 4.

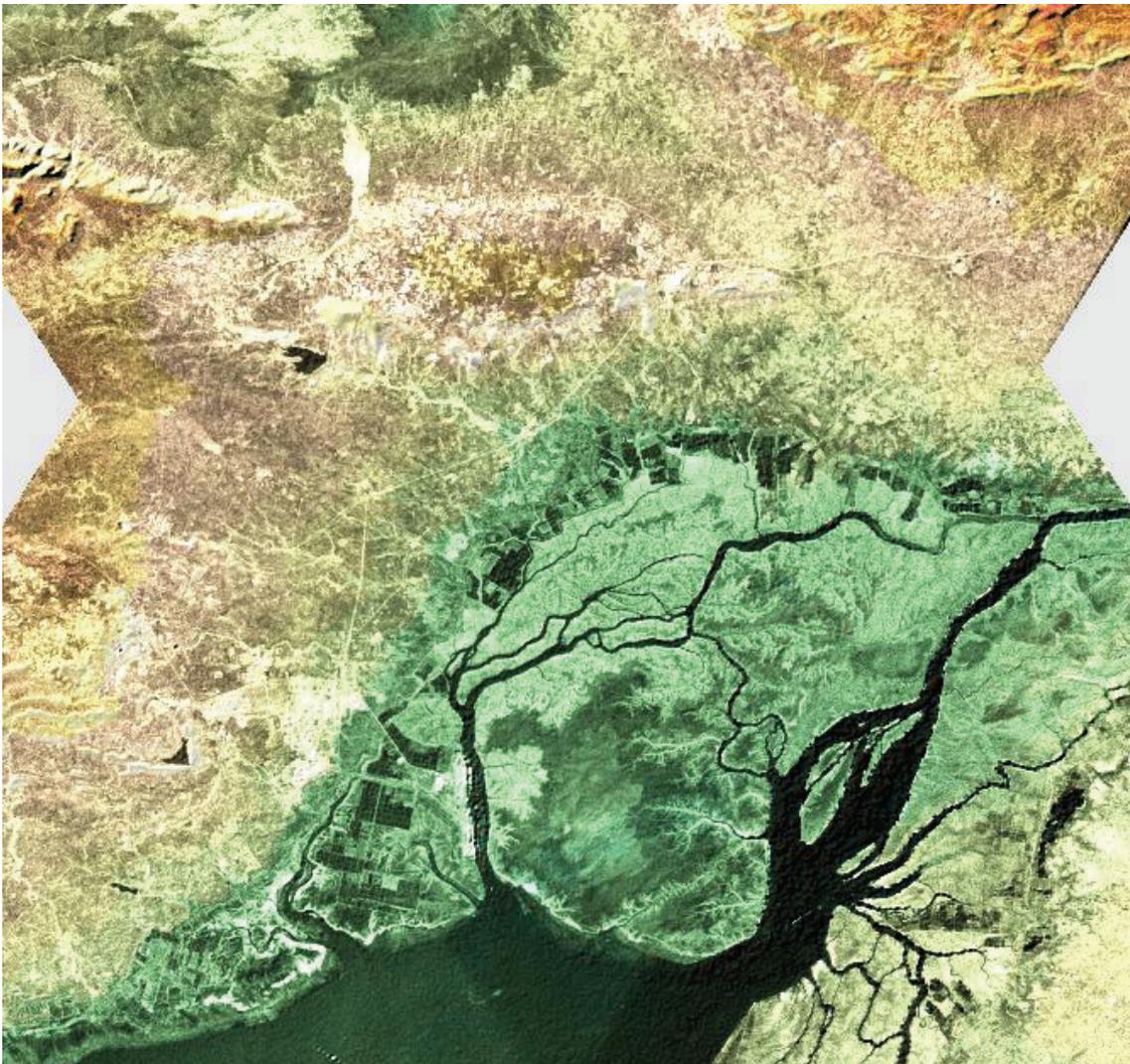


Figure 4. X-SAR/SRTM DEM and radar image Gujarat India.

4. OPERATIONAL PROCESSING

The X-SAR/SRTM processing facility [5] consists of the screening and transcription system, the InSAR processor and the Geocoding and Mosaicking System (GeMoS). The subsystems are independently operated processors controlled by DFD's Data Information and Management System (DIMS) [6]. The intermediate data as well as the final products are stored and exchanged via a central robot archive. The interferometric processor transforms on a pair by pair basis the raw data into the complex products. Then the interferogram of the unwrapped phase, the coherence map and the intensity image are generated. Motion compensation will correct effects caused by oscillations of the boom.

The Geocoding and Mosaicking System converts the phase values to elevation information taking into account the shuttle's orbit and the exact relative location of out-board and in-board antenna. The geocoding step comprises the exact determination of the 3-dimensional ground coordinates of each 30m x 30m image pixel. This geometric transformation is applied to the elevation as well as to the image data and the coherence map.

Up to this step only single scenes are considered. The mosaicking process takes into account adjacent and overlapping scenes. Its task is the combination of individual elevation models to a continuous large area DEM. Finally the DEM mosaic is split into the 15'x15' tiles, transformed into the DTED format and transferred to the archive. The terrain corrected image data remain in the internal format and will be CEOS formatted before delivery.

In October 2001 we plan to start the operational processing over Europe because here we have the best available DEMs to verify the quality of the product and to make final adjustments before starting to process the data from areas with no or bad quality DEMs. Till mid 2003 all X-SAR data shall be processed to DEMs and radar images.

5. DATA DISTRIBUTION

The SRTM/X-SAR data will be archived and distributed using DFD's Data Information and Management System (DIMS) [6]. It is a multi-mission ground system and consists of four major components, the product library (data catalogue), the ordering and production control, the robot archive and the user information service including product delivery. The product library provides a complete and consistent reference to the configured products. Based on the product library, ordering control manages the business process ordering throughout the system. An operating tool provides interactive access to the above components. The robot archive provides an extendable capacity of 300 T bytes. The product delivery supports both on media (CD-R) and via Internet. A user information system based on Java/www technology enables querying and ordering.

DFD's web gate is Eoweb (<http://www.eoweb.dlr.de>). A map browser supports the definition of the search criteria and the inspection of the query results.

Two different product categories will be generated from the radar data provided by the in- and outboard antennas which are the digital elevation model and SAR image products.

The 3-dimensional ground coordinates are derived from the different range distances of the earth surface point to the antennas. Beside the DEM a so-called height error mask will describe the precision. Radar image products will be available only from the primary (inboard) antenna.

Meanwhile DLR has developed a data policy for SRTM, which will allow distributing the data with minor restriction to everybody. The cost for one km² DEM will be 1 Euro, which only covers the archiving and cost of fulfilling the user request.

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