Tandem-X: A Global Mapping Mission

Johannes BOEER, Hauke FIEDLER, Gerhard KRIEGER, Manfred ZINK, Markus BACHMANN and Jaime HUESO GONZALEZ, Germany

Key words: cartography, geoinformation, remote sensing, mapping, HRTI-3

SUMMARY

TanDEM-X (TerraSAR-X Add-on for Digital Elevation Measurements) is an innovative spaceborne Earth observation mission based on two synthetic aperture radar satellites operating in close formation as a single-pass interferometer and allowing flexible baseline selection. The mission is currently prepared and implemented in the frame of a public-private partnership between the German Aerospace Center (DLR) and EADS Astrium GmbH. The first satellite, TerraSAR-X, is already injected successfully into a sun synchronous orbit. The launch of the second satellite is planned for September 2009.

Focus of this paper is the mission's primary goal, the derivation of a global, consistent digital elevation model (DEM) in accordance with the HRTI-3 quality standard.

First of all, the mission scenario and data acquisition strategy is presented which shall ensure global mapping within the limited mission time. The mission scenario is based on a large number of bi-static radar image acquisitions in stripmap mode with all land surface being covered at least twice with different heights of ambiguity (baselines) to facilitate phase unwrapping.

To meet the stringent requirements of vertical accuracy a comprehensive calibration concept has been developed. As the interferometric height of the terrain is derived from the phase difference between two bi-static images, all phase errors and drifts of the SAR instruments will directly lead to degraded height information. In addition to internal and external calibration of the radar instruments inter-satellite synchronization is required to reduce this type of errors.

Apart from instrument phase, the precision of height measurements also depends on signal noise and the precision of baseline determination, i.e. relative orbit as well as attitudes of the two satellites. Some of these inaccuracies can be reduced in the process of assembling the single raw DEMs (mosaicking) by exploitation of available height reference data and by combining multiple image acquisitions and image overlaps.

Tandem-X: A Global Mapping Mission

Johannes BOEER, Hauke FIEDLER, Gerhard KRIEGER, Manfred ZINK, Markus BACHMANN and Jaime HUESO GONZALEZ, Germany

1. INTRODUCTION

TanDEM-X (TerraSAR-X Add-on for Digital Elevation Measurements) is a bistatic SAR interferometry mission which is currently implemented as a national Earth observation mission by the German Aerospace Center (DLR) and EADS Astrium GmbH. It is a synchronized SAR satellite formation consisting of the TerraSAR-X satellite (TSX) and another new TerraSAR-X like add-on satellite (TDX) to enable single-pass SAR interferometry with variable across-track baselines of typically 250–500 m. The basic system parameters for the TanDEM-X system are given in (Table 1).

The instruments on both satellites are advanced high resolution X-band synthetic aperture radars based on active phased array technology, which can be operated in Spotlight, Stripmap, and ScanSAR mode with full polarization capability (Stangl et al, 2006). The center frequency of the instruments is 9.65 GHz with a selectable SAR chirp bandwidth of up to 300 MHz. The active phased array antenna, which has an overall aperture size of 4.8 m x 0.7 m, is fixed mounted to the spacecraft body and incorporates 12 panels with 32 dual-pol waveguide sub-arrays each. This enables agile beam pointing and flexible beam shaping.

Parameter	Value	Parameter	Value
Orbit Height (equator)	511.5 km	Antenna Length	4.8 m
Carrier Frequency	9.65 GHz	Antenna Width	0.7 m
Chirp Bandwidth	100 MHz	Antenna T/R Elements	32 x 12
Sampling Frequency	110 MHz	Antenna Tapering	linear phase
Mutual Swath Overlap	~ 4 km	Antenna Mounting	33.8°
Peak Tx Power	2260 W	Raw Data Quantization	3 bits/sample
Duty Cycle	18 %	Image Pair Misregistration	< 0.1 pixel
Noise Figure T/R Module	4.3 dB	Along-Track Baseline	< 1 km
Losses (atmosphere, radiator, …)	3.1 dB	Sigma Nought Model, 90%, (Ulaby et al, 1989)	Soil & Rock, VV
Azimuth Processing Losses	< 1.5 dB	Indep. Post Spacing	12 m x 12 m

Table 0-1: TanDEM-X System Parameters

Primary mission goal is the production of a global digital elevation model (DEM) with an accuracy which is currently available only on a local scale. Secondary mission goals are along-track interferometry (ATI) for measuring the velocity of moving objects with a high accuracy, digital beam-forming, bi-static experiments and local DEMs with increased accurracy for suitable terrain (local areas with high reflectivity, low noise, high correlation, suitable observation conditions).
The launch of TDX, which is designed for a nominal lifetime of 5½ years, is planned for September 2009. It will therefore have a nominal overlap of 3 years with TSX, which is

already in space since June 2007. A prolongation of the mission overlap might be possible by means of an extension of TSX operation which is compatible with the TSX consumables and resources.

In addition to the primary payload (a SAR instrument in combination with a 2-frequency GPS receiver for precise baseline determination) the satellites are also equipped with a Laser Communication Terminal (LCT) for optical data communication.

2. MISSION CONCEPT

2.1 Satellite Formation

The TanDEM-X operational scenario requires the coordinated operation of two satellites flying in close formation. The adjustment parameters for the formation are the orbits node line angle, the angle between the perigees, the orbit eccentricities and the phasing between the satellites. With these parameters, several options have been investigated during the phase A study, and the HELIX satellite formation shown in Figure 1 has finally been selected for operational DEM generation.

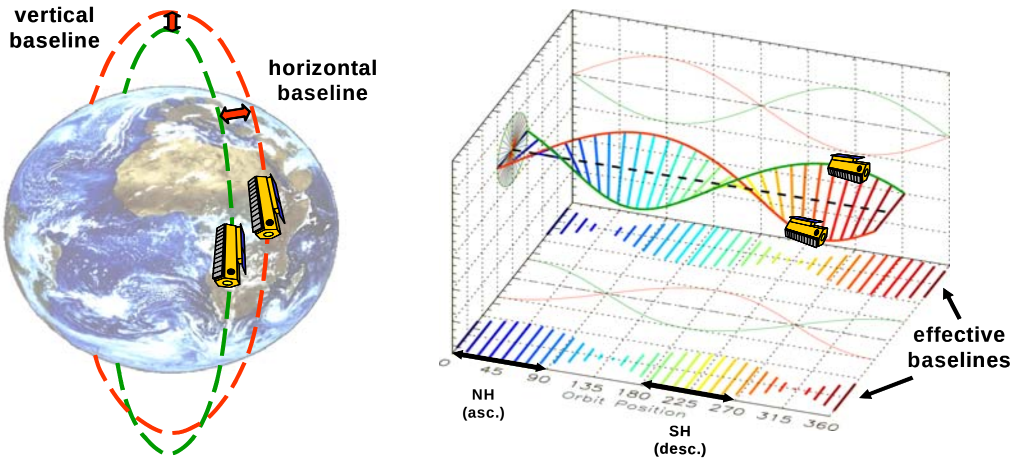

Figure 0-1: HELIX satellite formation for TanDEM-X. Left: orbital arrangement. Right: cross-track baselines as function of the orbit position. The positions correspond to one complete orbit cycle**.**

This formation combines an out-of-plane (horizontal) orbital displacement by different ascending nodes with a radial (vertical) separation by different eccentricity vectors resulting in a helix like relative movement of the satellites along the orbit. Since there exists no crossing of the satellite orbits, arbitrary shifts of the satellites along their orbits are allowed. This enables a safe spacecraft operation without the necessity for autonomous control.

It is furthermore possible to optimize the along-track displacement at predefined latitudes for different applications: cross-track interferometry will aim at along-track baselines which are as short as possible to ensure an optimum overlap of the Doppler spectra and to avoid temporal decorrelation in vegetated areas, while other applications like along-track interferometry or super resolution require selectable along-track baselines in the range from hundred meters up to several kilometers.

The HELIX formation enables a complete mapping of the Earth with a stable height of ambiguity by using a small number of formation settings (Krieger07). Southern and northern latitudes can be mapped with the same formation setting by using ascending orbits for one and descending orbits for the other hemisphere, as illustrated in Figure 1 on the right. A fine tuning of the cross-track baselines can be achieved by taking advantage of the natural rotation of the eccentricity vectors due to secular disturbances, also called motion of libration. The phases of this libration can be kept in a fixed relative position by scheduling small manoeuvres using the cold gas thrusters on a daily basis, while major formation changes as well as a duplication of the orbit keeping manoeuvres required by TSX will be performed by the hot gas thrusters.

2.2 TanDEM-X Acquisition Modes

Interferometric data acquisition with the TanDEM-X satellite formation can be achieved in different operational modes: Examples are bistatic, monostatic, and alternating bistatic operation, which are illustrated in Figure 2.

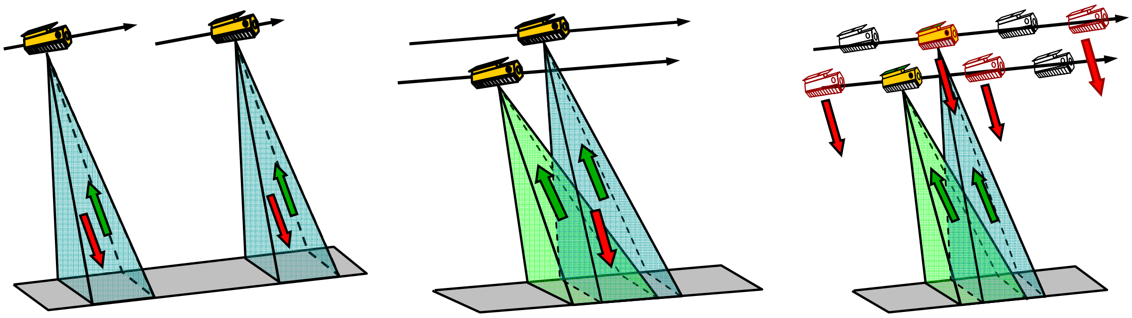

Figure 0-2: Data acquisition modes for TanDEM-X: Pursuit monostatic mode (left), bistatic mode (middle), and alternating bistatic mode (right).

The three interferometric configurations may further be combined with different TSX and TDX SAR imaging modes like Stripmap, ScanSAR, Spotlight, and Sliding Spotlight.

Operational DEM generation is planned to be performed using the bistatic InSAR Stripmap mode shown in Figure 2 in the middle. This mode uses either TSX or TDX as a transmitter to illuminate a common radar footprint on the Earth’s surface. The scattered signal is then recorded by both satellites simultaneously. This simultaneous data acquisition makes dual use of the available transmit power and is mandatory to avoid possible errors from temporal decorrelation and atmospheric disturbances.

2.3 Acquisition Concept

As the TanDEM-X mission is based on the TerraSAR-X mission, it must be ensured that both missions will achieve their mission goals simultaneously. To assure this, all TerraSAR-X data takes will be distributed almost homogenously onto the two satellites. This will leave enough satellite resources free to fulfill the TanDEM-X mission goals. For data acquisition a Joint TerraSAR-X & TanDEM-X Acquisition Concept has been developed (Fiedler et al, 2008) which is capable of handling acquisition requests of both missions based on the simple priority concept already established for the TerraSAR-X mission. According to this concept, the TanDEM-X data takes for global DEM generation are planned well in advance for a long time span (e.g. one year) and are set to high priority. These data takes are summarized in the so-called DEM acquisition timeline.

To achieve the goal of deriving a consistent HRTI-3 quality DEM, the height of ambiguity for all data takes should be homogeneous. The HELICES are optimized accordingly for this time span with respect to each region that has to be mapped. The optimization is done in such a way that the height of ambiguity is changing slowly for a given beam and latitude. The advantage of considering slow satellite formation drifts besides reducing fuel consumption is that acquisitions might be repeated in subsequent repeat cycles, e.g. in case of data loss. Due to the fact of slowly changing HELICES, the height of ambiguity will be almost equal and due to the increasing baseline no quality loss would occur but processing and especially phase unwrapping might become increasingly difficult and erroneous.

Note that after adjustment of a certain realization of HELIX parameters the desired height of ambiguity is only available in a certain latitude zone. Therefore the DEM acquisition plan shows a clear pattern of latitude zones which are subsequently mapped. Southern and northern latitudes can be mapped with the same formation setting by using ascending orbits for one and descending orbits for the other hemisphere. It is obvious that due to meridian convergence near the poles the distance between two adjacent ground projected tracks of TSX/TDX is decreasing with increasing latitude and hence a smaller number of swaths must be recorded with increasing latitude.

With a complete timeline, the whole Earth can be recorded within somewhat less than one year. Because the complete mission time is three years, it is possible to map the Earth twice with two different heights of ambiguity. Mapping the Earth twice will facilitate phase unwrapping and will lead to the derivation of a global DEM according to the HRTI-3 quality standard. Of course, there are some regions which lie in the radar shadow within the first two years, or even have foreshortening. These regions will be identified during the first two years. During these 2 years a map of difficult terrain like e.g. shadow and foreshortening will be generated. This will serve for the next mission phase as input, where mountainous regions, shadowed areas will be mapped again. Also recording of the so-called crossing orbits (see section 3.2), which are extra long data takes at an almost fixed equator spacing to allow for additional calibration of the final DEM, shall be done in this mission phase. At the end of this mission phase, the satellites will be separated in along track, e.g. such that their respective ground tracks on the Earth's surface will be separated by one day. Then, repeat pass interferometry with one day time interval will be possible. During the along track separation, bi-static experiments with large bistatic angles might be performed.

The acquisition concept has to address a large number of constraints of which only a few shall briefly be mentioned here:

- **Masking of water areas:** A "landmask" provides information of regions that have to be mapped.
- **Instrument On-Time:** To cover all data a mean orbit usage in the order of ~180 s is planned. The imaging time within an orbit is limited by power as well as instrument maximum-transmit-time constraints, but also by satellite mass memory capacity, data downlink scenario and of course by other data take requests, e.g. for the TerraSAR-X mission. In general, long data takes are favored for the global DEM to facilitate mosaicking and calibration.
- **Blocking of positions:** It is essential for the TerraSARX mission that TanDEM-X is not blocking the same geographical position for many adjacent repeat cycles.
- **Exclusion Zones:** Mutual RF interference between the two satellites is an aspect that requires special consideration due to the close formation flying. Illuminating one satellite by the other with the radar antenna shall not be possible at all during the TanDEM-X mission. The approach is to define angular exclusion zones around each satellite for SAR operation, not only on-ground in the mission planning environment, but also onboard in terms of Failure Detection, Isolation and Recovery (FDIR) mechanisms.

Another subject besides deriving the DEM are the so-called scientific data takes or science products, with which new techniques shall be demonstrated. During timeline optimization, it is important to allocate enough time to derive these products. As it is expected, that not all scientific acquisition requests are compatible with the HELIX settings prescribed by DEM generation, there are at least three month freely available at the end of the mission where, as an example, very large baselines could be realized for superresolution. Very large baselines will also allow for acquiring special data to perform digital beam forming, local HRTI-4 DEM generation, bi-static experiments and other radar data products.

2.4 Synchronization

The bistatic data acquisitions are based on the use of two independent oscillators for modulation and demodulation of the radar pulses. The impact of oscillator phase noise in bistatic SAR has been analyzed in (Krieger et al, 2006) where it is shown that oscillator noise may cause significant errors in both the interferometric phase and SAR focusing. The stringent requirements for interferometric phase stability in the bistatic mode will hence require an appropriate relative phase referencing between the two SAR instruments or an operation in the alternating bistatic mode. For TanDEM-X, a dedicated inter-satellite X-band synchronization link will be established by a mutual exchange of radar pulses between the two satellites. For this, the nominal bistatic SAR data acquisition is shortly interrupted, and a radar pulse is redirected from the main SAR antenna to one of six dedicated synchronization horn antennas mounted on each spacecraft. The pulse is then recorded by the other satellite which in turn transmits a short synchronization pulse. By this, a bidirectional link between the two radar instruments will be established which allows for mutual phase referencing without exact knowledge of the actual distance between the satellites. On ground, a correction signal can then be derived from the recorded synchronization pulses which compensates the oscillator induced phase errors in the bistatic SAR signal.

In addition, synchronization is also required for data take commanding. TSX and TDX trigger the start of a data take via GPS, but the PRF timing is then derived internally from the Ultra Stable Oscillators (USO). A deviation of the two USO frequencies will hence lead to a drift of the receiving window of one satellite with respect to the transmit event of the other satellite and may by this prevent a proper recording of the echo signal. TanDEM-X accounts for this by introducing leap pulse repetition intervals (PRIs) which readjust the position of the receiving window.

3. PREDICTED DEM GENERATION PERFORMANCE

3.1 Error Sources

A detailed height performance model has been developed for the Bistatic Mode, the main mode for DEM generation (Krieger et al, 2007). The performance prediction for the height error is based on the following error contributions, of which noise-like, randomly distributed errors already exhaust most of the 2 m relative error margin allowed for an area of 100 km × 100 km:

– Inaccuracies in the baseline determination (between the SAR antenna phase centers) with contributions e.g. from the GPS differential carrier phase measurements.
– Phase errors in the radar instruments
– Performance degradation due to both noise equivalent σ_0 (NESZ) and signal to noise ratio (SNR) during SAR data acquisition and interferogram generation, quantization errors from block adaptive quantization,
– Limited co-registration accuracy and processing errors, residual errors in the DEM mosaicking process and quality of the reference height information
– Distributed range and azimuth ambiguities

To achieve the required accuracy, "low frequency" parts of the errors which appear as biases or drifts in terms of the length of one data take have to be minimized. Examples of systematic slow changing errors for baseline determination are inaccuracies in the relative orbit and attitude determination of the TanDEM-X helix formation and variations in the SAR antenna phase centre. On instrument side, slow errors occur due to remaining interpolation errors after internal calibration and phase drifts during synchronization pulse sequences in the amplifiers not compensated by the internal calibration. When a data take is acquired, these phase errors lead to a height error in the resulting raw DEM.

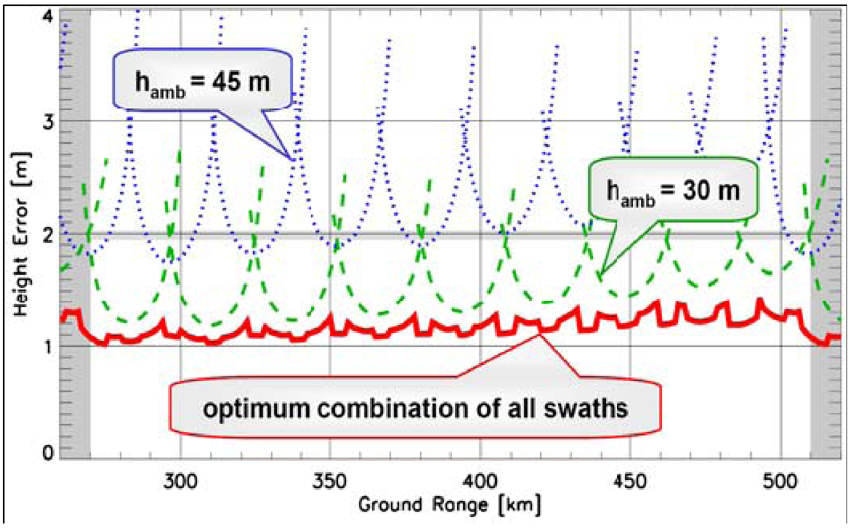

Figure 0-3: Height accuracy for a height of ambiguity of 45 m and 30 m. The solid curve shows the error resulting from the combination of multiple swaths. All errors are point-to-point height errors for a 90% confidence interval**.**

Figure 3 shows the predicted point-to-point height errors for the 90% confidence interval assuming two sets of DEM data acquisitions with two fixed heights of ambiguity of 30 m and 45 m. Note that the two acquisition sets use mutually displaced beams to further improve the performance. The height error from the combination of all acquisitions is shown in solid style yielding an almost constant performance with an accuracy which is well below the 2 m requirement for HRTI-3.

3.2 Calibration Approach

Several data take adjustments and calibration strategies were considered and resulted in a calibration and adjustment procedure that is performed during mosaicking of the multitude of raw DEMs into a single, global product. It includes a fusion of two global coverages (in different HELIX formations) with displaced swathes (clapboard pattern) as shown in Figure 3 using at least two baselines as large BLs are sensitive to phase unwrapping (PU) errors.

Relative corrections can be derived by exploiting concurring swath overlaps (Figure 3) and crossing orbits (Figure 4) in the data take scenario. Crossing orbits require a reconfiguration of satellite formation but allow mapping of regions at the northern hemisphere in descending orbits, at the southern hemisphere in ascending orbits with the same geometry as in previous mission phases. Specially chosen bundle block adjustment techniques are applied in different ways depending on the scenario configuration to balance the height error realisations.

Absolute height calibration requires accurate height references. The references have to be adequately distributed depending on the data take adjustment scenario. Coverage on all significant isolated land masses and a known accuracy which fulfils the requirements are pursued, with the aim of guaranteeing the correct adjustment of the elevation models by the TanDEM-X Mosaicing and Calibration Processor (MCP).

This can be achieved by using global data sets (e.g. ICESat radar altimeter data), which provide very useful information even in regions of the planet where the access to height data is limited or unreliable. However, local height calibration targets are still necessary, due to their high accuracy, particularly in regions where global data may have blind spots and for validation purposes. Here GPS tracks, corner reflectors, transponders or local highly accurate DEMs from airborne LIDAR, photogrammetry and SAR could be used.

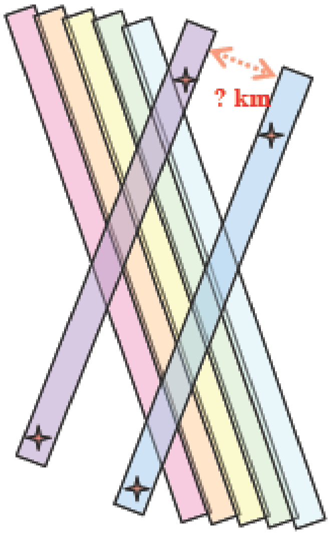

Figure 0-4: Ascending orbits scene with reference points and two crossing orbits

4. DEM PRODUCT FORMAT

Primary objective of the TanDEM-X mission is the generation of a consistent high-resolution global Digital Elevation Model (DEM) which shall be the basis for scientific research as well as for commercial DEM production for applications which require topographical data. It is expected to be completed about 4 years after the launch for 90% of the Earth’s land surface. Nonetheless an intermediate version is available as soon as the first global coverage is completed.

The specification for standard DEMs is aligned with the emerging HRTI-3 standard, where the acronym HRTI stands for High-Resolution Terrain Information, but some modifications have been made to take into account the different user requirements. The major modification concerns the availability of different trade-offs between horizontal and vertical resolution. Other modifications concern e.g. the vertical datum where it was decided to use the WGS 84 ellipsoid instead of the Mean Sea Level. Table xx compares the different DEM standards.. The relative vertical accuracy given in the table is defined as 90% linear point-to-point error over a 1° x 1° ce.

Specification	Spatial Resolution	Vertical Accuracy (90%, linear error)		Absolute Horizontal Accuracy (90%, circular error)
		Absolute	Relative	
DTED-1	90 m x 90 m	< 30 m	≤ 20 m	≤ 60 m
DTED-2	30 m x 30 m (1 arc sec @ equator)	< 18 m	≤ 12 m ≤ 15 m)*	≤ 20 m
HRTI-3	12 m x 12 m (0.4 arc sec @ equator)	≤ 10 m	≤ 2 m ≤ 4 m)*	≤ 10 m
HRTI-4	6 m x 6 m (0.2 arc sec @ equator)	< 5 m	≤ 0.8 m ≤ 1 m)*	≤ 10 m

Table 0-2: NGA (NIMA) Standards for Digital Elevation Models
)* for terrain with predominant slope >20%

To represent the elevation data on a global scale, the TanDEM-X DEM products will be provided on a fixed latitude and variable longitude grid as shown in the table below.

Zone	Latitude (North/South)	Latitude pixel spacing	Longitude pixel spacing
I	0° – 50°	0.4’’	0.4’’
II	50° – 60°	0.4’’	0.6’’
III	60° – 70°	0.4’’	0.8’’
IV	70° – 80°	0.4’’	1.2’’
V	80° – 85°	0.4’’	2.0’’
VI	85° – 90°	0.4’’	4.0’’

Table 0-3: **Latitude-dependent pixel spacing**

The definition of pixel spacing for the final storage of the DEM product has to be clearly distinguished from the independent post spacing which represents the spatial distance between mutually independent elevation data. No explicit definition of the independent post spacing is provided by the emerging HRTI-3 standard. To avoid different independent post spacings in latitude and longitude as well as inhomogeneties in the DEM performance, a fixed distance will be used for the independent post spacing at all latitudes.

The DEM product is stored and delivered in tiles:

Zone	Latitude (North/South)	Tile Size (Latitude x Longitude)	Latitude pixel spacing	Longitude pixel spacing	Size (MB)
I	0° – 50°	1° x 1°	0.4’’	0.4’’	891
II	50° – 60°	1° x 1°	0.4’’	0.6’’	595
III	60° – 70°	1° x 2°	0.4’’	0.8’’	890
IV	70° – 80°	1° x 2°	0.4’’	1.2’’	596
V	80° – 85°	1° x 4°	0.4’’	2.0’’	712
VI	85° – 90°	1° x 4°	0.4’’	4.0’’	356

Table 0-4: DEM storage in tiles

ACKNOWLEDGEMENT

The TanDEM-X project is partly funded by the German Federal Ministry for Economics and Technology (Förderkennzeichen 50 EE 0601).

REFERENCES

Ulaby F. T., Dobson C.: Handbook of Radar Scattering Statistics for Terrain. Norwood, MA, Artech House, 1989

National Imagery and Mapping Agency (NIMA): High Resolution Terrain Information (HRTI): Performance Specification, MIL-PRF-89048, 2000

Stangl M., Werninghaus R., Schweizer B., Fischer C., Brandfass M., Mittermayer J., Breit H.: TerraSAR-X technologies and first results, IEE Proc. - Radar, Sonar and Navigation, vol. 153, pp. 86-95., 2006

Fiedler H., Krieger G., Zink M., Geyer M., Jäger J.: The TanDEM-X Acquisition Timeline and Mission Plan, submitted for EUSAR 2008

Krieger G., Younis M.: Impact of Oscillator Noise in Bistatic and Multistatic SAR, IEEE Geoscience and Remote Sensing Letters, vol. 3, pp. 424- 428, 2006

Krieger G., Moreira A., Fiedler H., Hajnsek I., Werner M., Younis M., Zink M.: TanDEM-X: A Satellite Formation for High Resolution SAR Interferometry, IEEE Transactions on Geoscience and Remote Sensing, vol. 45, no. 11, Nov. 2007

BIOGRAPHICAL NOTES

Johannes Boeer, born in 1977, received the Diploma degree in electrical engineering from the University of Karlsruhe (TH) in 2004. Since 2004, he has been with the Microwaves and Radar Institute of the German Aerospace Center, Oberpfaffenhofen, working in the Instrument Operations and Calibrations Segment of TerraSAR-X and TanDEM-X.

Hauke Fiedler

Hauke Fiedler received the Diploma degree in physics and the Dr. degree in astronomy from the Ludwigs-Maximilians-Universität of Munich, Munich, Germany, in 1994 and 2000, respectively. From 1994, he was working in the Cataclysmic Binary Group, Institute of Astronomy and Astrophysics with his work focused on hard and soft X-ray interacting binaries, echo tomography, accretion disks, and related subjects. Since 2001, he has been with the Microwaves and Radar Institute, Germany Aerospace Center, Oberpfaffenhofen, Germany. He is working on future satellite missions for remote sensing with synthetic aperture radar, particularly on formation and configuration concepts including astrodynamics, bi- and multistatic SAR performance analyses, mission planning, and satellite mechanics..

Gerhard Krieger

Gerhard Krieger (M'03) received the Dipl.-Ing. (M.S.) and the Dr.-Ing. (Ph.D.) degrees (honors) in electrical and communication engineering from the Technical University of Munich, Munich, Germany, in 1992 and 1999, respectively. From 1992 to 1999, he was with the Ludwig-Maximilians-University, Munich, where he was an interdisciplinary research scientist on the modeling of biological and technical vision systems. Since 1999, he has been with the Microwaves and Radar Institute (HR), German Aerospace Center (DLR), Oberpfaffenhofen, Germany. Since 2001, he has been the Head of the New SAR Mission Group at DLR (HR), and since 2008 he is heading the Radar Concept Department. Currently he is also appointed as the Systems Engineer of the TanDEM-X mission. His research interests include the development of innovative remote sensing system concepts based on radar interferometry, tomography, bi- and multi-static satellite formations, digital beamforming, as well as advanced signal and image processing techniques.

Manfred Zink

Manfred Zink received the Dipl.-Ing. degree in physics from the Technical University of Graz, Graz, Austria, in 1987, and the Dr.-Ing. degree from the University of Stuttgart, Stuttgart, Germany, in 1993. In 1988, he joined the Microwave and Radar Institute, German Aerospace Center (DLR). He has pioneered the calibration techniques for both air- and space borne SAR sensors and was responsible for building up the Oberpfaffenhofen calibration site. He was the Lead X-SAR Calibration Engineer for both SIR-C/X-SAR missions in 1994 and for the SRTM mission in 2000. In August 2000, he was with the European Space Agency (ESA) and took over the responsibility for the calibration/validation of the ASAR onboard the ENVISAT satellite. After successful in-orbit commissioning of the ASAR, he was appointed as the Principal System Engineer for Phase B of ESA's TerraSAR-L Program. In May 2005, he returned to the Microwaves and Radar Institute, DLR, Oberpfaffenhofen, Germany, where he is currently heading the Satellite SAR Systems Department. He is also managing the TanDEM-X Ground Segment development, which is a joint project performed by DLR's Center of Excellence for Advanced High-Resolution and 3-D SAR Technologies and Applications.

Markus Bachmann

Markus Bachmann received the Dipl.-Ing. degree in electrical engineering from the University of Karlsruhe, Germany, in 2005. He joined the Microwaves and Radar Institute of the German Aerospace Centre (DLR) in the same year, where he works in the HR calibration group. He was involved in the successful calibration of the TerraSAR-X satellite in 2007, responsible for calibrating the TerraSAR-X radar antenna. In the TanDEM-X project, he is work package manager of the calibration system and involved in the design of the acquisition planning system.

Jaime Hueso Gonzalez

Jaime Hueso González was born in Castellón (Spain) in 1979. He studied Telecommunication Engineering at the Polytechnic University of Valencia (Spain), obtaining his Master Degree in 2003, with the specialization on microwaves and communications. He worked for two years (2004-2005) as Microwave Engineer in the European Space Agency (ESA-ESTEC, The

Netherlands), researching on microwave filter design, high power testing and the multipactor effect on spaceborne microwave waveguides. Since 2006 he has been working with the German Aerospace Center (DLR) in Oberpfaffenhofen (Germany), as Calibration Engineer for the TerraSAR-X and TanDEM-X projects, specializing on satellite SAR technology.

CONTACTS

Johannes Boeer
Microwaves and Radar Institute
German Aerospace Center (DLR)
Muenchner Str. 20
82234 Wessling
GERMANY
Tel. + 49 8153 28 3508
Fax + 49 8153 28 1449
Email: johannes.boeer@dlr.de
Web site: http://www.dlr.de/hr/en/

Dr. Hauke Fiedler
Microwaves and Radar Institute
German Aerospace Center (DLR)
Muenchner Str. 20
82234 Wessling
GERMANY
Tel. + 49 8153 28 2385
Fax + 49 8153 28 1449
Email: hauke.fiedler@dlr.de
Web site: http://www.dlr.de/hr/en/

Dr. Gerhard Krieger
Microwaves and Radar Institute
German Aerospace Center (DLR)
Muenchner Str. 20
82234 Wessling
GERMANY
Tel. + 49 8153 28 3054
Fax + 49 8153 28 1449
Email: gerhard.krieger@dlr.de
Web site: http://www.dlr.de/hr/en/

Dr. Manfred Zink
Microwaves and Radar Institute
German Aerospace Center (DLR)
Muenchner Str. 20
82234 Wessling
GERMANY
Tel. + 49 8153 28 2356
Fax + 49 8153 28 1449
Email: manfred.zink@dlr.de
Web site: http://www.dlr.de/hr/en/

Markus Bachmann
Microwaves and Radar Institute
German Aerospace Center (DLR)
Muenchner Str. 20
82234 Wessling
GERMANY
Tel. + 49 8153 28 2395
Fax + 49 8153 28 1449
Email: markus.bachmann@dlr.de
Web site: http://www.dlr.de/hr/en/

Jaime Hueso Gonzalez
Microwaves and Radar Institute
German Aerospace Center (DLR)
Muenchner Str. 20
82234 Wessling
GERMANY
Tel. + 49 8153 28 3112
Fax + 49 8153 28 1449
Email: jaime.hueso@dlr.de
Web site: http://www.dlr.de/hr/en/