TANDEM-X MISSION STATUS

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ABSTRACT

TanDEM-X (TerraSAR-X add-on for Digital Elevation Measurement) opens a new era in spaceborne radar remote sensing [1]. A single-pass SAR interferometer with adjustable baselines in across- and in along-track directions is formed by adding a second (TDX), almost identical spacecraft to TerraSAR-X (TSX) and flying the two satellites in a closely controlled formation. With typical across-track baselines of 200-400 m a global Digital Elevation Model (DEM) with 2 m relative height accuracy at a 12 m posting will be generated. Beyond that, TanDEM-X provides a highly reconfigurable platform for the demonstration of new SAR techniques and applications. The TDX satellite was launched on June 21st , 2010 from Baikonur. After finishing the Commissioning Phase early December 2010 data acquisition for the global DEM commenced.

Index Terms - TanDEM-X, bistatic SAR formation, single-pass interferometry, new SAR techniques

1. MISSION OBJECTIVES

Beyond the generation of a global TanDEM-X DEM as the primary mission goal, local DEMs of even higher accuracy level (posting of 6 m and relative vertical accuracy of 0.8 m) and applications based on Along-Track Interferometry (ATI) like measurements of ocean currents are important secondary mission objectives. Along-track interferometry will also allow for innovative applications to be explored and can be performed by the so-called dual-receive antenna mode on each of the two satellites and/or by adjusting the along-track distance between TSX and TDX to the desired value. Combining both modes will provide a highly capable along-track interferometer with four phase centers. The different ATI modes will e.g. be used for improved detection, localization and ambiguity resolution in ground moving target indication and traffic monitoring applications. Furthermore TanDEM-X supports the demonstration and application of new SAR techniques, with focus on multistatic SAR, polarimetric SAR interferometry, digital beam forming and super resolution.

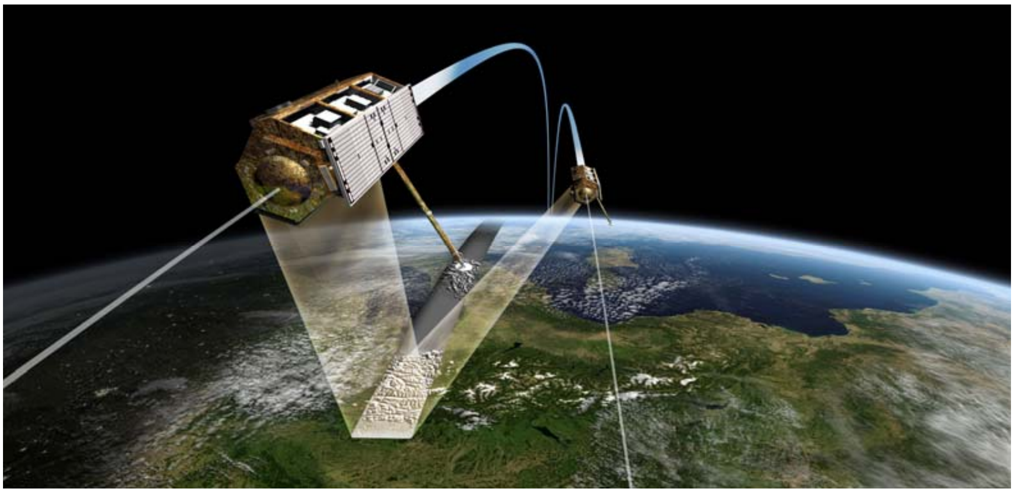
Fig. 1 TerraSAR-X and TanDEM-X flying in close formation

TanDEM-X has an ambitious time schedule to reach the main mission goal. After the commissioning phase, the first two years are dedicated to the global DEM acquisitions, followed by six months of additional acquisitions to cover difficult terrain. The baseline geometry in these first years is optimized for DEM performance. If the baselines are suitable, a limited number of scientific acquisitions can be included already during this phase. After the DEM acquisitions even larger baselines can be adjusted for higher accuracy DEMs on local scales and for the exploration and demonstration of scientific experiments.

2. THE TANDEM-X SPACECRAFT

The TDX satellite is a rebuild of TSX with only minor modifications [2]. This offers the possibility for a flexible share of operational functions for both the TerraSAR-X and TanDEM-X missions among the two satellites.

During the last phase of the TSX spacecraft development, the SAR instrument design was extended to allow exchange of synchronization pulses to support coherent operation of both SAR instruments during bistatic operation. Six sync horns on each satellite provide a quasi-omnidirectional coverage. An additional propulsion system based on high-pressure nitrogen gas is accommodated on TDX. This cold gas system provides smaller impulses than the hydrazine system on both satellites (which is used for orbit maintenance) and supports formation flying by fine orbit control of the TDX satellite. The TDX solid state mass memory capacity is 768 Gbit which is doubled compared with TSX to support the collection of the enormous amount of DEM data.

Fig. 2 Fully integrated TanDEM-X satellite

The TDX satellite is designed for a nominal lifetime of 5 years. Predictions for TSX based the current status of system resources indicate at least one extra year (until the end of 2013) of lifetime, providing the required 3 years of joint operation.

3. THE GROUND SEGMENT

The missions TerraSAR-X and TanDEM-X jointly share the same space segment consisting of the TSX and TDX satellites orbiting in close formation and are operated using a common ground segment [3], that was originally developed for TerraSAR-X and that has been extended for the TanDEM-X mission. Specific new developments are described in the following.
The spatial baseline between the TSX and TDX is derived at mm accuracies from on-board GPS measurements taken by the two-frequency IGOR GPS receivers.

A key issue in operating both missions jointly is the different acquisition scenarios: whereas TerraSAR-X requests are typically single scenes for individual scientific and commercial customers, the global DEM requires a global mapping strategy. This strategy has also to account for the current formation flying geometry which, in turn, depends on the orbit parameters selected and for any given orbit configuration permits generating a digital elevation model only within a certain latitude range.

The two satellites will downlink their data to a global network of ground stations: Kiruna in Sweden, Inuvik in Canada, O'Higgins in the Antarctic, and Chetumal in Mexico. The global acquisitions for digital elevation model alone will absorb a data volume of more than 350 terabytes. After a brief quality check, the data will be recorded on tape and shipped to DLR in Oberpfaffenhofen for processing and archiving.

The entire processing chain is a new TanDEM-X specific development [4]. However, it consists of individual modules which strongly benefit from the TerraSAR-X and the Shuttle Radar Topography Mission (SRTM) heritage. Major design drivers result from the acquisition strategy which requires the combination of several (global) coverages and application of multi-baseline processing techniques based on supporting intermediate products. Absolute height calibration will rely on globally distributed reference elevation data provided by the laser altimeter from the NASA ICESat mission.

4. CLOSE FORMATION FLIGHT

An orbit configuration based on a helix geometry has been selected for safe formation flying. The helix like relative movement of the satellites along the orbit is achieved by combination of an out-of-plane (horizontal) orbital displacement imposed by different ascending nodes with a radial (vertical) separation imposed by the combination of different eccentricities and arguments of perigee. Since the satellite orbits never cross, the satellites can be arbitrarily shifted along their orbits. This enables a safe spacecraft operation without the necessity for autonomous control. Cross- and along-track baselines ranging from 200 m to 10 km and from 0 to several 100 km, respectively, can be accurately adjusted depending on the measurement requirement.

Although the passive stability of the Helix orbit prevents collisions in principle, a number of mechanisms have been introduced in the satellite design to safeguard against collision and mutual illumination risks:

- In addition a safe mode based on the magnet torquers for attitude control was introduced on both satellites. Unlike the hydrazine propulsion system, employing the magnet torquers for attitude control will not lead to any orbit deviation. To complement this additional safety feature, the ground operating concept has been modified to ensure that the ground segment can respond swiftly enough to any problems on the space segment.

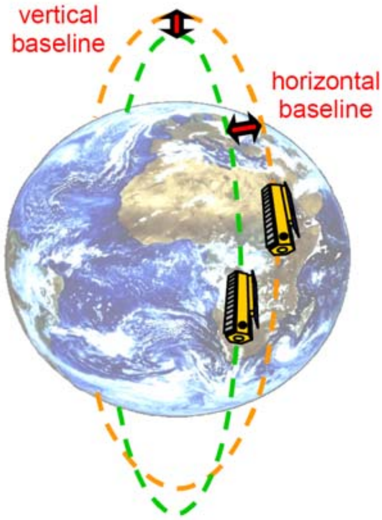

Fig. 3 The HELIX orbit concept

- To avoid mutual illumination, exclusion zones have been defined, orbit segments in which one of the two satellites is not allowed to transmit radar pulses. Moreover, the synchronization link between the two satellites can be used to check each other's operating status. If the sync signals received do not exceed pre-defined thresholds it is assumed the partner satellite has problems and the radar transmission will be immediately suppressed. Lastly TDX is equipped to receive telemetry data from TSX and to react on any non-nominal operating status.

5. MISSION STATUS

In the first few weeks after launch the along-track distance was reduced from 16000 to 20 km and TDX was already maneuvered into a Helix orbit with 1.3 km horizontal separation. Thereby the movement due to the Earth's rotation during 3 seconds (corresponding to 20 km distance) was compensated and the same ground tracks as TSX were achieved to facilitate cross-calibration between the two SAR systems.

The subsequent monostatic commissioning phase [5] was dedicated to calibration and performance verification [6] and revealed calibration accuracies [7] and overall performance of the TDX SAR system and its products as good as for TSX. Comprehensive testing of the various safety measures has been performed in parallel to check-out activities on the new ground segment elements. In a Formation Flight Review early October "green light" was given for entering the close formation, which was achieved on October 14th.

Bistatic DEMs are being acquired since then. With TDX delivering identical single SAR product quality as TSX, the TerraSAR-X Mission is running operationally on both satellites since October 25th. That means that user orders for high resolution SAR data will be acquired by either TSX or TDX whereby the selection is performed by the mission planning depending on the available resources and by considering criteria like the exclusion zones.

The bistatic commissioning phase of the TanDEM-X mission concentrated on checking out the complete bistatic chains from acquisition planning to bistatic and interferometric processing and generation of so-called raw DEMs. Key features of the mission like the synchronization system and the determination and calibration of the baselines [8] had to verified for operational bistatic imaging and fully automated elevation model generation. Global DEM acquisitions have started after successful completion of an extensive test and verification program in December 2010.

Interferometric Performance

The fundamental quantity in analysing the interferometric performance is the coherence between the monostatic and the bistatic SAR image. It includes error contributions due to volume, temporal and baseline decorrelation or limited signal-to-noise ratio. The bistatic image coherence is directly correlated with the height accuracy of the corresponding DEM, where high coherence values translate into a low height error and vice versa. DEM quality statistics over the datataken areas indicate that the achieved accuracy is very promising: the absolute height accuracy in average is less than 10 meters at 12 meters posting. Fig. 4 presents a global map of the coherence for all the operational data takes acquired up to August 2011. The coherence values (from red to green) indicate that a good data quality is achieved. The acquired landmass (coloured plus grey areas) up to August 2011 amounts to over 75% for the first of the two global acquisitions. The DEM-acquisition plan strategy therefore performs as expected.

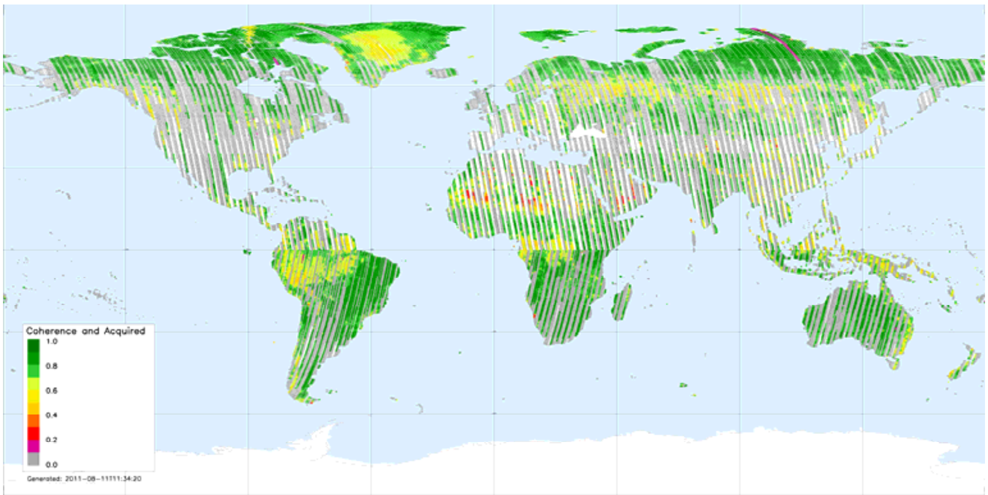

Fig. 4 Global coherence map generated in August 2011.

Relative Height Error Results

The requirement on the relative vertical accuracy of the global DEM depends on the terrain relief: 2 m for low and medium relief terrain (predominant slope between 0% and 20%) and 4 m for high relief terrain (predominant slope greater than 20%), whereby the accuracy is expressed as linear errors in a 90% confidence interval within a 1° x 1° lat/lon cell.

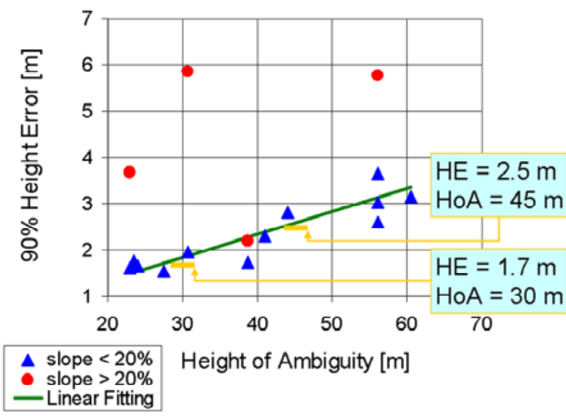

Fig. 5 Summary of the relative height error performance. In green is linear fitting through the measured values, yellow bars indicate the predicted performance.

Fig. 5 presents the results obtained from the analysis of several test sites, acquired with different geometries and classified as soil and rock terrain. Even if the final DEM will be obtained by the combination of at least two global acquisitions, for some test sites one acquisition is already sufficient to meet the required specification. A linear fit through the height error estimates shows a good agreement with DEM performance simulations [9]: a height error of 1.7 m and 2.5 m is predicted for height of ambiguity (HoA) of 30 m and 45 m, respectively (yellow bars in Fig. 5).

Calibration Of The Bistatic Interferometer

Interferometric calibration of the bi-static system is an essential task for TanDEM-X. The processing relies on radargrammetry to resolve the correct height of ambiguity band in order to correctly tie down the interferogram and DEM. Although the design of both instruments is nearly identical, the components show slightly different characteristics. Deviations are only visible in the bi-static case comparing both instruments directly and incorporating highly accurate baselines.

The final interferograms and also the DEMs itself are derived from the interferometric phase. The first results of DEMs acquired repeatedly over the same test site show stable phase behaviour of the instrument. Slight residual trends correlated to the orbital position (argument of latitude) are still under investigation but appear to be removable during processing.

In Fig. 6 a comparison between an extract from the SRTM DEM (left) and one from the TanDEM-X DEM (right) reveals the high accuracy and the high level of detail, like highway crossings, offered by that TanDEM-X.

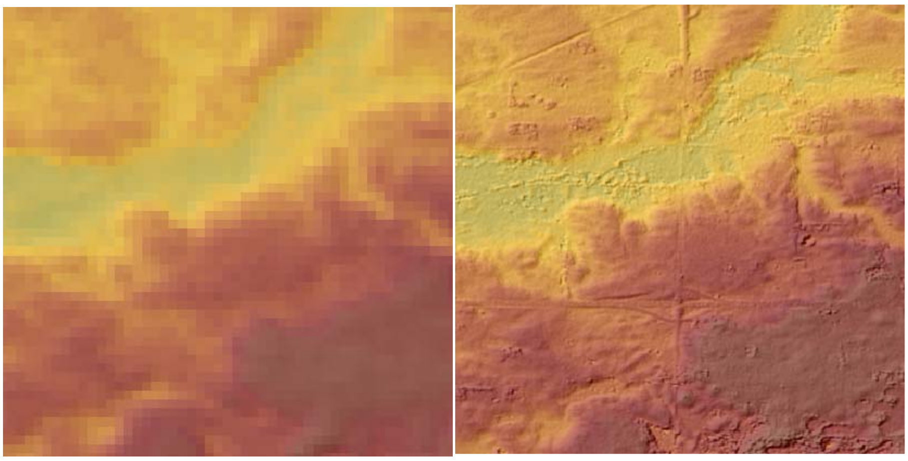

Fig. 6 Comparison of SRTM DEM (left) and TanDEM-X DEM (right) generated in July 2011.

6. REFERENCES

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