TanDEM-X MISSION STATUS: THE COMPLETE NEW TOPOGRAPHY OF THE EARTH

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ABSTRACT

TanDEM-X (TerraSAR-X add-on for Digital Elevation Measurements) is an Earth observation radar mission that consists of a SAR interferometer built by two almost identical satellites flying in close formation [1]-[4]. With a typical separation between the satellites of 120 to 500 m a global Digital Elevation Model (DEM) with 2 m relative height accuracy at 12 m posting is being generated. While the main mission phase for DEM data acquisition has been finished in 2014, the processing of the global TanDEM-X DEM will be concluded in autumn 2016. Final DEMs are well within specifications and feature a low percentage of void areas. Following the DEM data acquisition the capabilities of this unique mission for new scientific application have been demonstrated. In the meantime the continuation of the joint TerraSAR-X/TanDEM-X mission was approved and will be dedicated to the generation of DEMs with even higher accuracy for selected areas and further scientific experiments.

Index Terms **—** TanDEM-X, bistatic SAR formation, SAR interferometry, global Digital Elevation Model (DEM)

1. MISSION OBJECTIVES

The primary objective of the TanDEM-X mission is the generation of a global Digital Elevation Model (DEM) of the Earth's surface with unprecedented accuracy (see Table 1 below) as the basis for a wide range of commercial applications as well as for scientific research [1].

Parameter	Specification	Requirement
Absolute Height Accuracy	90% linear error (globally)	≤ 10 meters
Relative Height Accuracy	90% linear point-to-point error (in 1° x 1 ° geocell)	≤ 2 meters (slope ≤ 20%)
		≤ 4 meters (slope > 20%)

Table 1. Global DEM Height Accuracy Requirements

It is expected that this data set will become a new reference in geosciences and remote sensing applications since its 3-D information content is ca. 30 times more accurate than the presently available global scale DEM data set (see Fig. 1).

TanDEM-X has reached its main mission goal, the generation of the global DEM. After the commissioning phase, the first four years were dedicated to the data acquisitions for the global DEM. To facilitate dual-baseline phase unwrapping all land masses were covered at least twice in the same looking direction but with different baselines. Difficult mountainous terrain required additional acquisitions viewing from the opposite direction to allow filling gaps due to shadow and layover. The main mission phase dedicated to DEM acquisition has been finished in 2014. By now final DEMs for all land surfaces except Antarctica and small islands have been generated. The quality is well within the expected performance for the global DEM.

The baseline geometry in these first four years of operation was optimized for DEM performance. A limited

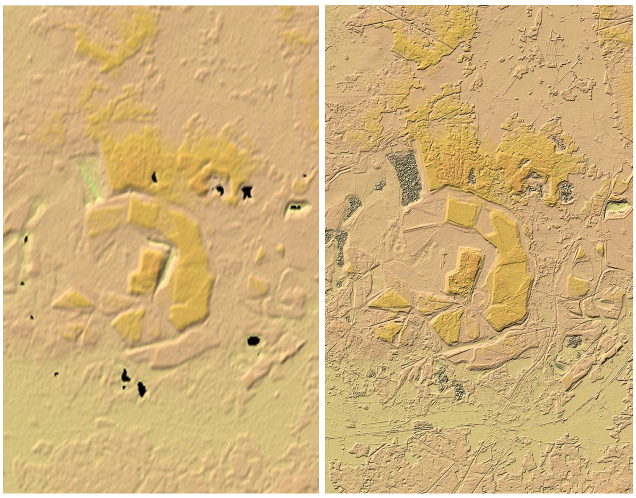

Fig. 1. Comparison between SRTM 1-arcsec DEM (left) and TanDEM-X DEM (right) of an abandoned mining area in Brandenburg, East Germany.

number of scientific acquisitions were included during this mission phase depending on the suitability of the baselines for fulfilling the scientific requirements. In the subsequent dedicated science phase data acquisition the baseline settings were optimized for the secondary objectives of TanDEM-X, like measurements of ocean currents and the demonstration and application of new SAR techniques, with focus on multistatic SAR, polarimetric SAR interferometry, digital beam forming and super resolution.

2. KEY FEATURES OF THE TANDEM-X SYSTEM

The TDX satellite is a rebuild of TSX with only minor modifications. This offers the possibility for a flexible share of operational functions for both the TerraSAR-X and TanDEM-X missions among the two satellites [5]. The TSX and TDX satellites were designed for a nominal lifetime of 5.5 years. Predictions based on the current status of system resources indicate a lifetime for both satellites and a joint operation until at least 2020 and 2018, respectively.

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 a combination of an out-of-plane (horizontal) orbital displacement imposed by different ascending nodes with a radial (vertical) separation imposed by different eccentricities and arguments of perigee. Cross- and along-track baselines ranging from 120 m to 10 km and from 0 to several 100 km, respectively, can be accurately adjusted depending on the measurement requirement [6].

The missions TerraSAR-X and TanDEM-X jointly share the same space segment consisting of the TSX and TDX satellites and are operated using a common ground segment, that was originally developed for TerraSAR-X and that has been extended for the TanDEM-X mission [7, 8, 9, 10].

3. MISSION STATUS

After the launch in June 2010 and the subsequent commissioning phase, global DEM acquisitions started in December 2010. Parallel to the first month of operational data acquisition the team concentrated its efforts on the calibration of the bistatic interferometer. Correction of differential delays between TSX and TDX was necessary to facilitate the utilization of radargrammetry for resolving the 2π-ambiguity band. Phase, delay and baseline calibration have reached such an accuracy level [11], that more than 90% of all so-called Raw DEMs (long data takes are processed to scene based DEMs of 50 by 30 km extension) are within ±10m of DEMs derived from SRTM/ICESat data already before the final calibration step using ICESat data as reference heights. More than 500,000 Raw DEMs have been generated in a fully automated process employing multibaseline interferometric techniques.

The first and second global coverages (except Antarctica) were completed in January 2012 and March

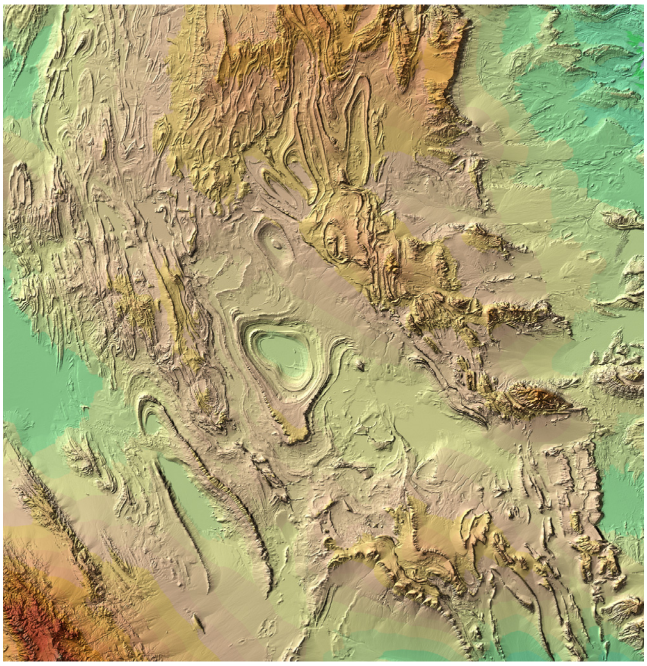

Fig. 2. Shaded relief of the TanDEM-X DEM of a desert area in central Iran showing a nice heart-shaped feature.

2013 respectively. After some gap-filling, Antarctica was mapped for the first time under local winter conditions. In early August 2013 the helix formation was changed to allow imaging of mountainous areas from the opposite viewing geometry [12]. Due to a low SNR, desert areas had to be re-acquired as well, but at steeper incidence angles. Afterwards the satellites were maneuvered back to the original formation and Antarctica was covered again at larger baselines. The primary data acquisition program was concluded mid-2014.

Since the end of 2013 the final calibration and mosaicking chain is fully operational and is about to complete the global DEM consisting of more than 19,000 1 by 1° tiles [13]. A comprehensive system has been established for continuous performance monitoring and verification [14], [15], [16] including feedback to the TanDEM-X acquisition planning for additional acquisitions.

Fig. 3 shows as an example the absolute height accuracy (90% linear error) per tile derived from the comparison of the TanDEM-X heights against ICESat validation points (the majority of ICESat points not being used for DEM calibration). The cumulated absolute height error is with 1.3 m outstanding and one order of magnitude below the 10m requirement. As the system is very well calibrated and tilts and trends are negligible, the relative height accuracy is well described solely by the random errors in the system. It can be calculated from the interferometric coherence and the resulting phase error. It is specified as the point-to-point error within a 1° by 1° tile.

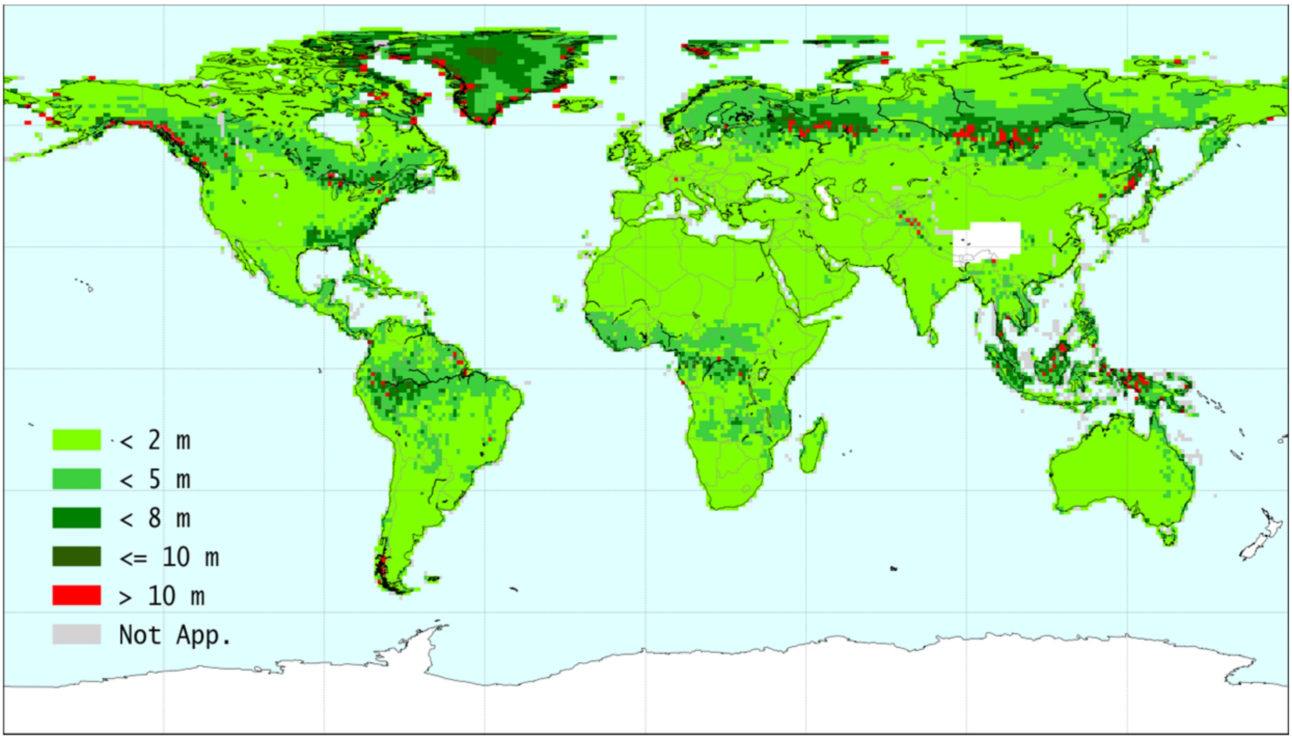

Fig. 3. TanDEM-X DEM absolute height accuracy (90% linear error) per 1° by 1° DEM tile; the cumulated absolute height error is with 1.3 m one order of magnitude below the 10-m requirement.

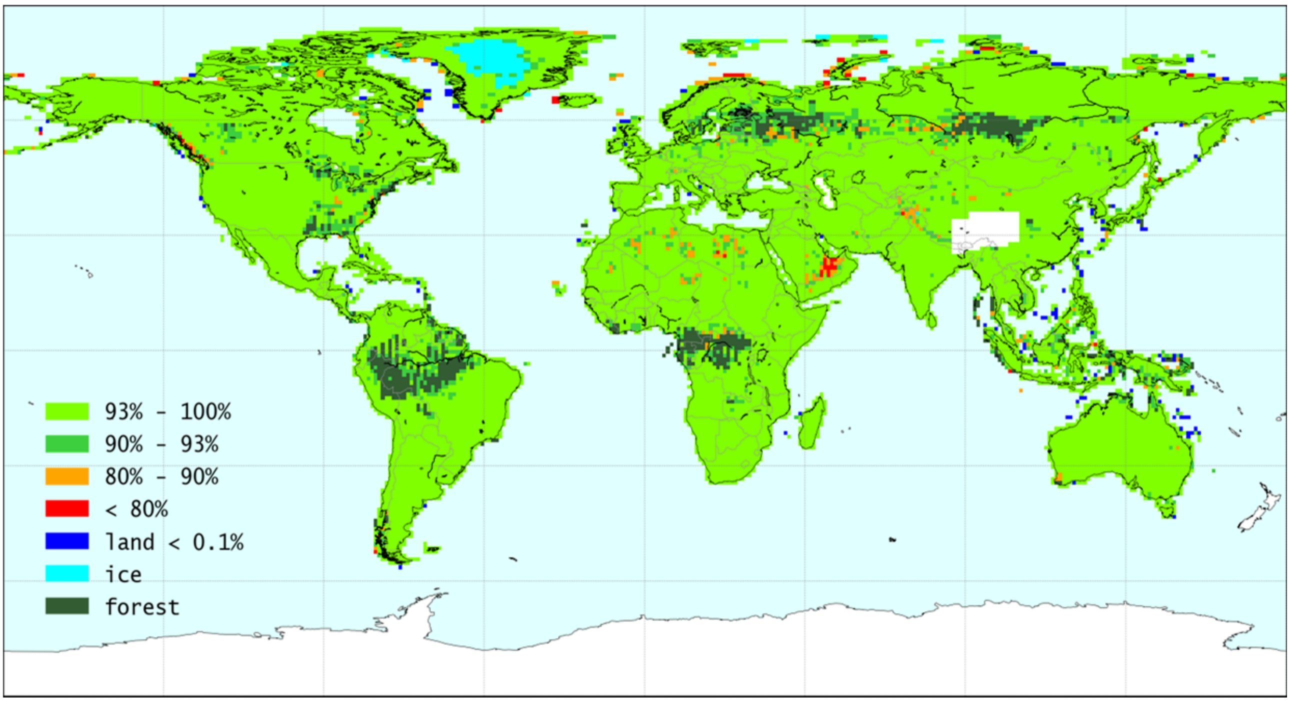

Fig. 4. TanDEM-X DEM relative height accuracy in % confidence level per 1° by 1° DEM tile, considering an accuracy specification of 2 m for flat (slopes up to 20%) and 4 m for steep (slopes higher than 20%) terrain.

As shown in Fig. 4 more than 98.5% of all DEM tiles fulfil the relative height error specification of 2 m (4 m) for flat (steep) terrain. Dense forests and ice covered terrain is excluded from this analysis as volume decorrelation effects deteriorate the coherence estimates.

Finally, compared to SRTM the TanDEM-X DEM features a much lower percentage of void areas, especially in desert areas, a result of the re-acquisition at steeper incidence angles and hence better SNR.

As both satellites are still working very well and have plenty of resources left, an agreement to continue the mission beyond 2015 was concluded between DLR und AIRBUS Defence & Space. Acquisition of interferometric data for and generation of local DEMs of even higher accuracy level (posting of 6 m and relative vertical accuracy below 1m) is the key objective for this new mission phase. If the baseline geometries are suitable further scientific experiments will be included in the timeline as well.

4. CONCLUSION

The TanDEM-X mission opens a new era in spaceborne radar remote sensing. A large single-pass SAR interferometer with adjustable baselines has been formed by adding a second, almost identical radar satellite to TerraSAR-X and flying both satellites in a closely controlled formation.

The generation of the global DEM, the primary mission objective, is nearing completion. Quality and coverage of the data is outstanding. A science phase dedicated to demonstrating applications based on along-track interferometry and new SAR techniques has been finished last year. Continuation of the mission beyond 2015 was approved with the main objective to use bistatic interferometry in close formation flight to generate local DEMs of even higher accuracy level.

TanDEM-X has demonstrated the feasibility of an interferometric radar mission with close formation flight and delivers an important contribution for the conception and design of future SAR missions. One example is Tandem-L, a mission for monitoring dynamic processes on the Earth surface with unprecedented accuracy [17].

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