TanDEM-X: Mission Status and Science Activities

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Abstract

The paper provides an up-to-date overview of the German TanDEM-X satellite mission status and its ongoing science activities. The global digital elevation model (DEM) of TanDEM-X became available in 2016 and surpassed all expectations: It has 99.9% coverage, 12-m posting, absolute height accuracy of approximately 1 m and a relative height error (standard deviation) of 0.8 m. This unique data set has been available since then for commercial and scientific applications. In addition, a low-resolution version of the global digital elevation model with 90-m posting has been released for free download for scientific applications. Since 2017 new interferometric acquisitions have been started with the goal to generate a global change layer which will register all the changes of the Earth topography occurred since the first acquisitions of TanDEM-X. The acquisition for the global change layer was completed by mid-2020. Since then a new science phase of TanDEM-X with a focus on interferometric acquisitions over forest, ice sheets and permafrost regions are ongoing.

1 TANDEM-X MISSION

TanDEM-X (TerraSAR-X add-on for Digital Elevation Measurement) is successfully operating now already since 2010 and has celebrated his 10 years of operation in 2020 (**Figure 1**). Not only the mission performance, but also the data acquired opened a new era in spaceborne radar remote sensing and scientific insight.

A single-pass SAR-interferometer with adjustable baselines in across- and in a long-track direction was formed by adding a second (TDX), almost identical spacecraft to TerraSAR-X (TSX) and flying the two satellites in a closely controlled formation.

TDX has SAR system parameters which are fully compatible with TSX, allowing not only independent operation from TSX in a mono-static mode, but also synchronized operation (e.g. in a bi-static mode). With typical across-track baselines of 200-600 m DEMs with a spatial resolution of 12 m and relative vertical accuracy of 2 m has been generated.

The Helix concept provides a save solution for the close formation flight by combining a vertical separation of the two satellites over the poles with adjustable horizontal baselines at the ascending/descending node crossings.

Beyond the generation of a global TanDEM-X DEM as the primary mission goal, applications based on cross-track as well as along-track interferometry (ATI) are important secondary mission objectives.

Furthermore, TanDEM-X supports the demonstration and application of new SAR techniques, with focus on multi-static SAR, polarimetric SAR interferometry, digital beamforming and super resolution.

The data performance is regularly assessed over stable calibrators and shows very little deviation over the whole mission life time. Securing a stable data performance.

Figure 1. *The mission is being carried out in the scope of a Private-Public-Partnership between DLR and Airbus Defense and Space.*

1. DATA REQUESTS AND ACQUISITION

The CoSSC (Coregistered Single look Slant range Complex) science proposal submission for data requests is still available through the TanDEM-X Science Service System (https://tandemx-science.dlr.de). Some additional features were implemented to alleviate the handling and the use of the web-based interface.

The main difference to the TerraSAR-X mission is the procedure for data ordering. TanDEM-X is following a systematic data acquisition. The main reason for this was its high requirement on the DEM performance and this provides minor flexibility to other mission configurations for science proposals during a specific time. As the main data acquisition for the TanDEM-X DEM was completed, the mission started to acquire still systematically DEM data over all land surfaces for a global change layer (2017-2020).

In addition, science data takes are regularly acquired upon request and are still placed in the gaps left by the systematic DEM acquisitions for the change layer. For a controlled handling the scientists cannot order the data takes autonomously for a specific date as in the case of TerraSAR-X, but the science coordination is trying to place the science requests on best effort basis according to the best possible acquisition timeline and satellite resources.

Data takes over individual test sites can be requested via science proposal in bistatic as well as in alternating bistatic configuration.

The supported imaging modes are Stripmap and all Spotlight modes (except Staring Spotlight) in Single and Dual pol configurations. The alternating bistatic mode is available in single pol configuration only.

The ScanSAR imaging mode is not supported in this case. The ATI as well as the Quadpol mode is currently not available, because the Dual Receive Antenna (DRA) mode has been disabled for both satellites. The Helix configuration has been changed by a swap of the two satellites in September 2017.

DEM acquisition activities are in the Northern hemisphere performed in descending orbits, and for the Southern hemisphere in ascending orbits.

The available cross-track baselines are in the range of the first two mission years (roughly between 150 and 300m). Interferometric applications, where a cross track baseline is needed (e.g., for local DEMs or forest height estimation) should follow this strategy as well, especially if the test site is located in higher latitudes (north of +30°, or south of -30°).

Since June 2020 during the second science phase over focused regions regular and consistently data are acquired. The focused areas are forest, permafrost and cities (**Figure 2**). The acquisition will be completed in June 2021 and will then be repeated until 2022.

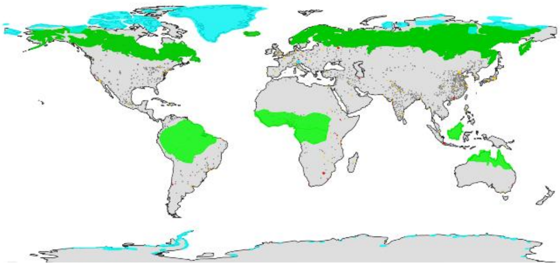

Figure 2. *Data coverage of regions of interest for the science phase forest (green), permafrost (blue) and cites (grey, yellow and red points).*

2. DIGITAL ELEVATION MODEL PRODUCTS

The standard TanDEM-X DEM with 0.4 arcseconds (~12m) pixel spacing is a product derived from multiple TanDEM-X acquisitions (minimum two and for difficult terrain up to 8 additional acquisitions also from different viewing angles) and is available since September 2016 via a science proposal for the global land masses, including Antarctica and the land masses north of 60°.

The specification of the DEM products is given in Table 1. The global TanDEM-X DEM is displayed in **Figure 3**.

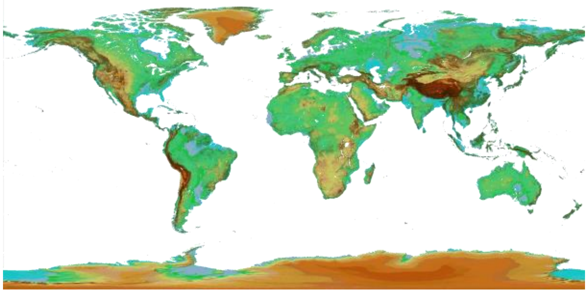

Figure 3. *Global Digital Elevation Model produced by TanDEM-X).*

Additionally, standard TanDEM-X DEM product variants are available with a pixel spacing of 1 arcseconds (30 m), and 3 arcseconds (90 m) respectively. The 12 m and 30 m TanDEM-X DEM products are still available for scientific purposes and can be requested via science proposal on a regional scale at the Science Service System (https://tandemx-science.dlr.de).

Since 2017 and lasting until end of 2020 the so called TanDEM-X 2020 DEM has been acquired. This product substitutes the High Resolution DEMs (HDEMs). The 2020 DEM is an entirely new acquisition of the global land masses. Hence, the product will provide the changes in the Earth topography between the time frame from 2010-2014 and 2017-2020.

The data collection has been completed in June 2020 (**Figure 4**). Around 19780 data takes have been successfully acquired and are currently processed to Raw DEMs and coregistered SLC data. In the second step they will be mosaiced and opened to the science community in two years.

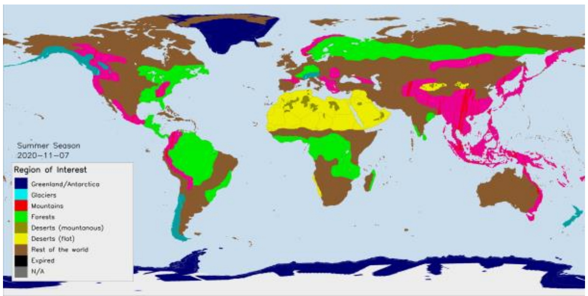

***Figure 4**. Data coverage of regions of interest for the TanDEM-X 2020 DEM.*

In October 2018 the distribution of the global 90-m TanDEM-X DEM has been launched and is freely available for scientific applications.

The data can be downloaded by a simple FTP, similar to SRTM DEM download, without any quota restrictions or science proposal submission.

In the last months around 5 million 90-m TanDEM-X DEM products have been downloaded (https://geoservice.dlr.de/web/dataguide/tdm90/).

DEM Product	Spatial Resolution Absolute	Horizontal Accuracy CE90	Absolute Vertical Accuracy LE90	Relative Vertic Accuracy
TanDEM-X DEM (standard product 0.4 arcsec)	~12 m (0.4 arcsec @ equator)	<10 m	<10 m	< 2 m (slope @ 2 < 4 m (slope > 2 90% linear point point error withi area of 1°x1°
TanDEM-X DEM (1 arcsec)	~30 m (1 arcsec @ equator)	<10 m	<10 m	Not specified
TanDEM-X DEM (3 arcsec)	~90 m (3 arcsec @ equator)	<10 m	<10 m	Not specified

***Table 1**. TanDEM-X DEM specification table. In October 2018 a low-resolution version of the global digital elevation model (DEM) with 90-m posting has been released for free download for scientific applications.*

3. Coordinated Data Acquisition with the Spanish PAZ Mission

The German satellites of the TerraSAR-X/TanDEM-X (TSX/TDX) mission and the Spanish PAZ satellite have launched a coordinated data acquisition announcement of opportunity. Beforehand experiments have been launched to assess the interferometric performance of the combined use of TSX/TDX and PAZ repeat pass data. It could be demonstrated that there is a good quality obtained by the TanDEM-X and PAZ pairs. On the one hand, the geolocation accuracy is very similar for both missions which makes possible the combination of both missions for increased revisit time. On the other hand, the interferograms obtained between both sensors present good coherences and no degradation is observed in comparison with interferometric pairs between acquisitions of the same sensor. Moreover, the possibility to obtain interferograms with a temporal difference of just 4 and 7 days instead of 11 days reduces the temporal decorrelation improving the coherence. In this regard, it has been shown that temporal decorrelation over the dense forest near Neustrelitz, a test site in Germany, is the main limitation at X-band, and even four days may be enough to completely decorrelate the signal. However, over the not so dense forest near Madrid, the test site in Spain, the decorrelation is not so strong. Over agricultural areas the coherence obtained by these pairs is generally higher. However, a dual behavior has been observed. The fields that do not present a change appear with high coherence while those that change between the acquisitions exhibit a significant drop in the coherence. It is worth noticing that the number of changing fields increases with the temporal distance between pairs, reducing the overall coherence on the scene. Here it is worth mentioning that the analysis was performed in winter, and a different agricultural field dynamic may be observed in summer, for instance. Finally, over urban areas some pixels may preserve high coherence over time, corresponding to stable man-made structures. To illustrate the quality of the obtained interferometric TanDEM-X and PAZ four days interferometric pairs, some DEMs have been generated over Madrid and Albacete test sites. The quality obtained is generally good and has been compared with single-pass bistatic acquisitions. The effect of temporal decorrelation and residual phase due to repeat-pass acquisitions over the obtained DEMs has been briefly analyzed. While temporal decorrelation may lead to phase unwrapping errors resulting into errors at small scales, residual phase components like atmospheric phase may lead to large scale variations. These variations, however, are inherent to any repeat-pass acquisition and are not related to the interoperability between sensors.

The good data performance makes it possible to open selected test sites for the science community. The TSX/TDX -PAZ constellation with an optimized revisit time and increased acquisition capacity is available to the science community in the frame of joint announcement of opportunity call. The call includs the definition of specific reference super test sites, specifically selected to cover a wide range of application areas, such as agriculture, forestry, volcanology, sea ice, glaciers and others. Interested users will be kindly asked to submit their proposals to DLR [22] and INTA [23] for the independent revision and approval of each institution with the request to have joint data acquisitions. Different acquisition scenarios can be considered by the users as follows. 1) Acquisition of pursuit monostatic datasets (combination of PAZ and one out of TerraSAR-X or TanDEM-X), which can be utilized for, e.g., repeat pass interferometry; (repeat pass of 4–7 days). 2) Combination of all three satellites will allow the derivation of two pursuit monostatic pairs (PAZ-TerraSAR-X, PAZTanDEM-X) 3) One bistatic image pair (TerraSAR-X-TanDEM-X) for advanced studies. The latter will e.g., allow interferometry studies of temporal decorrelation for natural targets, or allow the derivation of change detection products, or pseudoquad-pol datasets. This article could prove that the performance of the joint experiments is of high quality when combining TSX/TDX with PAZ to retrieve coregistered SLC data with a higher repeat time than acquiring them independently. The datasets acquired over the selected sites are unique and will open up new opportunities for the development of a wide range of applications.

4. SUMMARY

An update of the TanDEM-X mission status and the planed science activities will be presented at IGARSS 2022. TanDEM-X has successfully achieved its primary mission objective, the generation of a global digital elevation model (DEM) with unprecedented accuracy.

Despite being well beyond their design lifetime, both satellites are still fully functional and have enough consumables for operation into the 2020s.

Besides the data collection of a global TanDEM-X 2020 DEM, the bistatic operation of TanDEM-X offers unique opportunities for highly innovative scientific applications as well as for the demonstration of new imaging techniques that is currently continuing.

Further on the coordinated data acquisition between TSX/TXD and PAZ provides new opportunity to study highly dynamic changes with acquisition times of 4 and 7 and 11 days in repeat.

5. REFERENCES

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