A TanDEM-X: Mission and Science Exploration during the Phase A Study

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Abstract

TanDEM-X (TerraSAR-X Add on for Digital Elevation Measurements) is a national mission proposal for a new generation SAR satellite operating at X-band in single pass SAR interferometry. The single pass SAR interferometric constellation is realised by two independent X-band satellites flying in formation and has the goal to deliver a global digital elevation model in a HRTI-3 specification. In this paper the scientific exploration will be presented. TanDEM-X has been accepted for realisation in March 2006 following a successful demonstration.

1 Introduction

Topographic data form one essential base for information extraction of fundamental importance for environment, economics, human security and decision makers. In order to provide reliable information of the Earth's surface the Digital Elevation Model (DEM) needs to be up to date, consistent, accurate, high resolution and unrestricted available. Only a high performance satellite concept is capable to fulfil the demands and meet the high requirements.

At present the global coverage with topographic data with sufficiently high spatial resolution is inadequate or simply not available for scientific and governmental use. SRTM was a first step to meet the requirements of the scientific community for a homogenous, highly reliable DEM with DTED-2 specification.

Requirement	Specification	DTED-2	HRTI-3
Relative Vertical Accuracy	90% linear Point to point Error over 1° x1°	< 12 m (slope < 20%) <15 m (slope >20%)	< 2 m (slope <20%) < 4 m (slope >20%)
Absolute Vertical Accuracy	90% linear error	< 18 m	< 10 m
Relative Horizontal Accuracy	90% circular error	<15 m	< 3 m
Absolute Horizontal Accuracy	90% circular error	< 23 m	< 10 m
Spatial Resolution	Independent pixels	30 m (1 arc sec)	12 m (1 arc sec)

Table 1. Comparison of DTED-2 and HRTI-3

However, the acquired and processed high resolution DEM are not globally available (SRTM has mapped the earth between 60 N and 56 S) and have in X-band wide gaps at lower latitudes. The concept of TanDEM-X (**T**erraSAR-X **a**dd-o**n** for **D**igital **E**levation **M**easurement) has the potential to close the gaps, fulfil the scientific requirements and provide the vital information for the variety of applications.

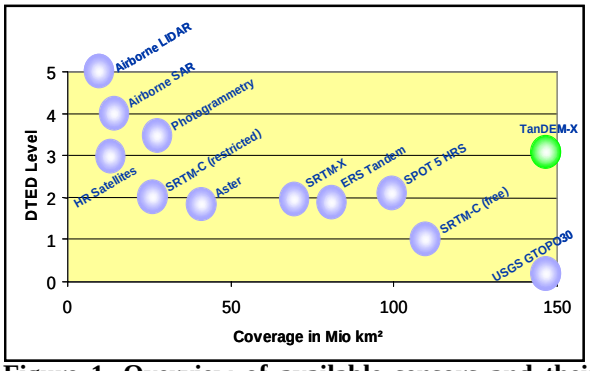

Figure 1. Overview of available sensors and their digital elevation standart [4].

The goal of TanDEM-X is the generation of a global DEM with an unprecedented accuracy corresponding to HRTI-3 specifications (Tab. 1). This goal will be achieved by means of a second SAR satellite (TDX) flying in a close formation configuration with TerraSAR-X (TSX). In [1],[2] a more detailed description concerning the satellite system and expected performance of TanDEM-X is presented.

The DEM quality level that the TanDEM-X mission can provide is today dominated by airborne sensors (see Fig. 1). There is currently no system or process available to provide a global service for HRTI-3 and in specific cases HRTI-4 DEMs with short response time. This requirement can only be fulfilled by

a space-borne SAR system. Optical systems require cloud free weather conditions and therefore often fail to fulfil the global response time demand. Airborne systems lack in global mapping capability.

In this paper the results of the scientific requirements endorsed by the TanDEM-X science team are presented. The main focus is given to the evaluation of the questionnaires with regards to the product definition endorsed to the TDX science members. TanDEM-X is a flexible and multimode satellite which delivers - due to its manifold system configuration - a wide variety of application possibilities. Beside the Across Track Interferometry technique two other main techniques, namely Along Track Interferometry and New SAR Techniques, are building the main frame for the different application areas.

2 Science Applications and Science Team

The demand for exact topographic information is coming from numerous application areas. The following application areas have been selected according to the best benefit obtained from TanDEM-X and classified into the three techniques, as listed in Fig. 2.

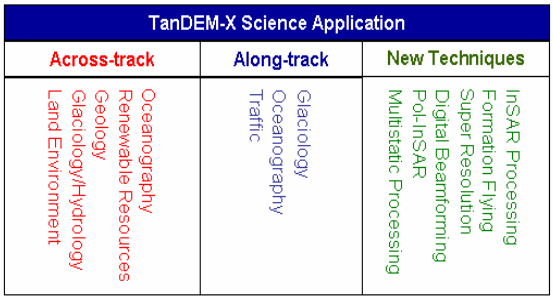

Figure 2. TDX Science application areas.

Accurate topographic information provides benefit to the industry, governments, research institutions, citizens and society in numerous ways. The benefit can be either directly obtained from the DEM or derived information. In the following, for each scientific technique of TanDEM-X the demands are highlighted.

Across-track SAR interferometry technique:

- *Topography*: High resolution DEM with global access for topographic mapping.
- *Navigation*: Strong need of a world wide precise and reliable terrain data base.
- *Glaciology*: Accurate maps of surface topography are a key pre-condition for monitoring and modelling glacier mass balance, glacier climate interactions and run-off from glacier basins.
- *Hydrology*: High spatial resolution DEMs for regional flood plain mapping.
- *Oceanography*: High spatial resolution for the estimation of two-dimensional ocean wave spectra and the determination of wind fields.
- *Geology*: High spatial resolution DEMs for geohazard mapping.
- *Forest*: High spatial resolution DEMs for horizontal tree structure estimation.

Along track SAR interferometry technique:

- *Oceanography*: High spatial resolution ocean current fields and river current estimation.
- *Traffic*: High spatial resolution for traffic flow estimation.
- *Glaciology*: High spatial resolution for ice mass flow estimation.

New SAR Techniques:

- *Multistatic SAR / Super Resolution / Digital Beamforming*: Demonstration of new SAR techniques.
- *Polarimetric SAR interferometry*: Demonstration of the vegetation structure estimation and improvement of conventional DEM's.

The science team consists of approx. 100 scientists; each of them being an expert in a particular application or group of applications. From the 100 science members, 66 % are interested in Across Track InSAR technique, 13 % in Along Track InSAR technique and 21 % in New SAR Techniques.

3 Technical Requirements

In total, three questionnaires have been distributed to the science team [3,5]. In the first one, a global overview of the application areas, the scientific relevance and the operation status have been evaluated. In the second, specific performance, operational and product requirements related to the application areas have been endorsed. From the first two questionnaires a first evaluation of the justification and the technical requirements for the three TanDEM-X techniques has been made and TDX products have been specified accordingly. In order to confirm the defined products a third questionnaire has been distributed summarising the main results. Its evaluation will be discussed in the following.

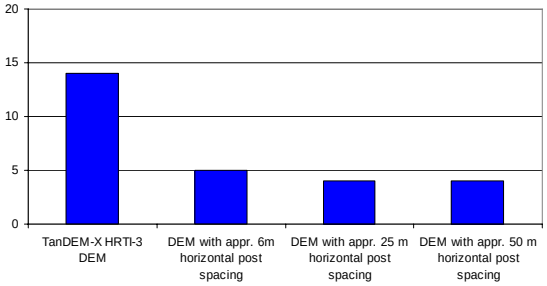

Figure 3. Summary of the required products from the TDX science team.

In the third questionnaire three main products have been specified, one related to the HRTI-3 DEM specification, the second to customized DEM and the third to radar data products. The last product includes the application of the Along Track InSAR and the New SAR Techniques. Multiple selections were possible.

The highest interest has been noted for the first and third products.

For the DEM product the majority of the scientist requested a DEM with HRTI-3 specification (Fig. 3). Optionally other products could also be acceptable with lower post spacing but higher relative vertical resolution. Such products were requested especially for land ice applications. The HRTI-3 DEM product was requested mainly over Asia, Europe and North America, followed by Antarctica and Artica and few requests have been obtained over South America, Africa and Australia.

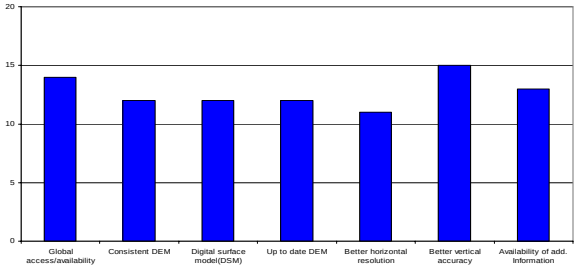

Figure 4. Statistical summary of the reasoning for the HRTI-3 product is required from the TDX scientist.

In addition to the specified TDX products the reason why the scientists need a high resolution DEM has been asked. Fig. 4 points out that the highest need is a higher vertical resolution as currently available DEMs offer. Further, the second important issue is the request to have global access of DEM data sets. Nevertheless, the scientists requesting the HRTI-3 DEM product also like to have the geocoded SAR image, a coherence map and a height error map of the desired scene available.

For the new SAR techniques category different operation modes could be chosen by the scientists (Fig 5). The most preferable one was the demonstration of the polarimetric SAR interferometry application, followed by the specific Across Track InSAR and Along Track InSAR techniques, as well as supper resolution technique. Some of these have been already demonstrated in space, but will be firstly operated in single pass InSAR mode with an X-band high resolution satellite configuration, whereas the multistatic SAR and the digital beamforming modes are real demonstration modes, which will be firstly operated in space.

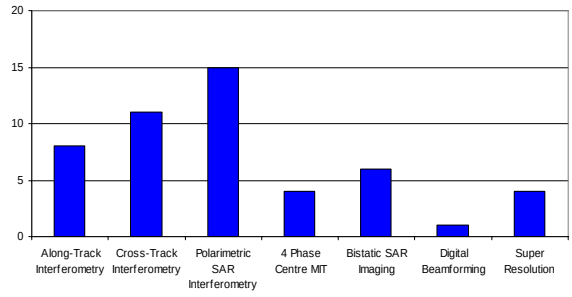

Figure 5 Statistical distributions of desired modes for the demonstration of new SAR techniques.

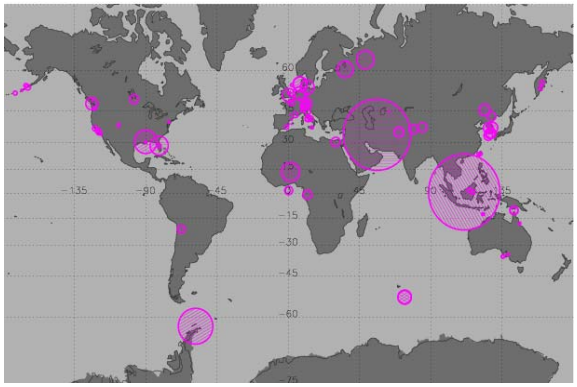

Figure 6 Geographical location of the desired test sites for the new SAR techniques. Different sizes of the circles corresponding to the size of the desired areas of interest.

The geographical interest for experimental demonstrations is highest in Europe (as seen in Figure 6), followed by the other continents and countries. In comparison to the standard DEM products, where the average area per request is about 880320 km², in the new techniques the requests where for much smaller areas of about 3382 km² in average.

For all three techniques the importance of TanDEM-X for the different applications has been requested to be rated. In Fig. 7 (top) the results for the HRTI-3 product from the scientific community has been rated to be important, very important or even unique. The uniqueness of the along track InSAR and the new SAR technique products has been highly rated by the science team Fig.6 (bottom).

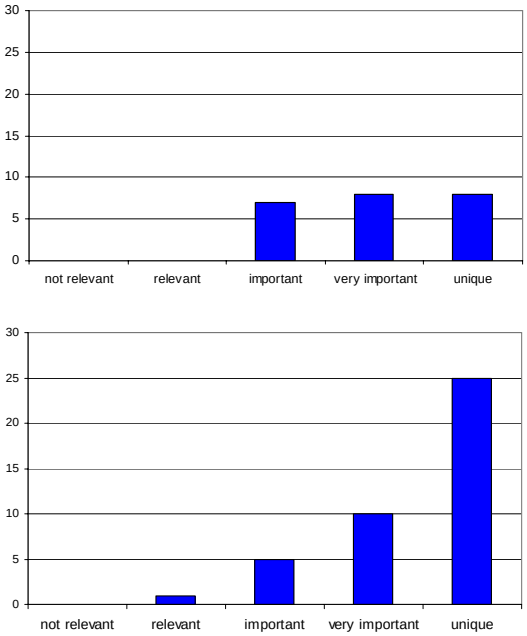

Figure 7 Summary of the rated importance for the HRTI-3 (above) and the along-track as well as the new SAR techniques (lower) from the endorsed questionnaire.

4 National and International Relevance

The scientific community expressed a strong request for a DEM with HRTI-3 specification for the vertical accuracy evaluation, the development of algorithms and the derivation of geo/bio-physical parameters. Furthermore, a strong need for the development of new product parameters derived from New SAR Technique modes has been expressed. National and International experts are equally strong represented in the science team. This enforces the scientific needs on national as well as international basis. Beside the nationality of the team member's also representatives from national, European and international programs expressed their strong interest for the TDX products.

5 Compliance Matrix

After the definition of the TanDEM-X data products and the demonstration of their acceptance, the remaining task was to demonstrate the compliance of the TanDEM-X data products with the TanDEM-X preliminary mission design. For this, a reference mission scenario has been developed. The main focus in developing this mission scenario was to keep it as simple as possible, while taking into account as many user requirements as possible. The mission scenario can be further optimized in later mission phases, enabling an appropriate consideration of more, changing, or new user requirements. The main criteria used for compliance evaluation was the expressed scientific requests for the different data products, the preliminary system performance prediction and the preliminary mission design. The evaluation has been made separately for the two TanDEM-X data products, first for the DEM data products and then for the radar data products. The main difference is that for the DEM only few variations of the image parameters (namely the DEM specifications) are available, whereas for the radar data products the variability is manifold.

Three classes of compliance have been defined according to the following schema:

The scientific requirements

I. are compliant with the present preliminary mission design and the performance predictions;

II. can partially be fulfilled with the preliminary mission scenario or require slight modification

III. require major modifications of the preliminary mission scenario or are not feasible.

Overall, the statistical evaluation shows that 77 % of the scientific requests are fully compliant with he preliminary mission concept of TanDEM-X, 18 % can be still considered to be integrated in the mission concept in consultation with the scientists, and 5 % of the requests cannot or only with major modifications be integrated into the suggested mission scenario (see Figure 8).

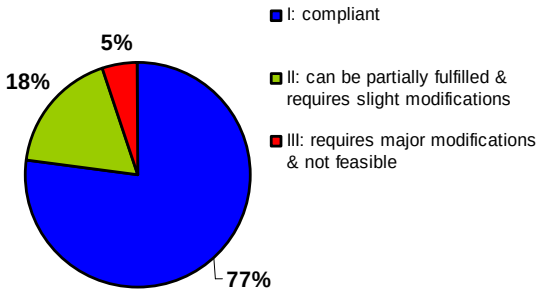

Figure 8 Compliance with the preliminary mission design for both TanDEM-X data products.

6 Summary

The result of the questionnaire endorsed to the scientists point out the strong scientific need for a DEM with HRTI-3 specification [5]. The TanDEM-X mission will be able to fulfil the specifications on a global scale and guarantee a global data access for the users.

TanDEM-X is a unique satellite constellation that enables to provide an operational product and allows at the same time to demonstrate the acquisition of new SAR data products. Triggered from the TD-X operation mode an important step in a new information dimension will be made.

Acknowledgment

We like to thank the TanDEM-X science team members for their invaluable scientific contributions.

References

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