TerraSAR-X and TanDEM-X: Global Mapping in 3D using Radar

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***Abstract*—TanDEM-X (TerraSAR-X Add on for Digital Elevation Measurements) is a national 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.**

The economic revival of the countries around the globe requires appropriate and precise planning documents in all the three dimensions. However, a continuous and up-to-date acquisition by optical sensors is strongly limited by unfavorable weather conditions. Therefore, the easy access to the high-resolution radar missions TerraSAR-X and TanDEM-X gives the global remote sensing community the possibility to participate in one of the most ambitious space programs.

Keywords-X-band; single pass SAR interferometry; digital elevation model; HRTI-3; along track SAR interferometry, Pol-InSAR, digital beamforming, super resolution, bistatic SAR, formation flying

I. INTRODUCTION

Topographic data are building one essential base for information extraction which are of fundamental importance for the environment, economics, human security and to support 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. To fulfil these demands and requirements only a high performance satellite concept will be capable to take the various attributes into account.

At present the global coverage with topographic data at 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 specifications. However, the acquired and processed high resolution DEM's 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, to fulfil the requirements and to provide the vital information for the variety of stakeholders.

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

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

In this paper the results of the scientific and commercial custom requirements endorsed for the TanDEM-X mission proposal are presented. The main focus is given to the evaluation of the questionnaires with regards to the product definition endorsed to the TD-X science members.

II. SCIENCE EXPLORATION

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, represented by Along track interferometry and New SAR techniques, are building the main frame for the grouping of different application areas.

A. Science Applications and Science Team

The demand for exact topographic information is coming from numerous application areas. In the following the application areas have been selected according to the best benefit obtained from TanDEM-X for the three techniques, listed in Fig. 1.

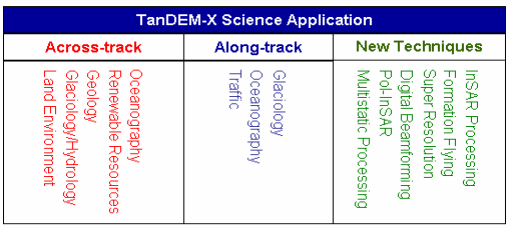

Figure 1. TD-X Science Application Areas

Accurate topographic information provides benefit to the industry, governments, research institutions, citizens and society in a number of ways. The benefit can be either directly obtained from the DEM or by 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 DEM's 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 DEM's for geohazard mapping.
- *Forest*: High spatial resolution DEM's 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 consist of 84 members; each of them being an expert for a particular application or group of applications. From the 84 science members, 68 are interested in Across track InSAR technique, 18 in Along track InSAR technique and 28 in New SAR techniques. Of course, the science team structure is dynamic and the member quantity can change within a scientific area.

B. *Technical Requirements*

In total, three questionnaires have been endorsed to the science team [3,4]. In the first one, a global overview of the application area, 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 TD-X products could be specified. In order to confirm the derived products a third questionnaire has been distributed summarising the main results. Its evaluation will be discussed in the following.

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 third includes the application of the Along track InSAR and the New SAR techniques. Multiple selections were possible. The highest response, with an equal distribution, has been obtained from the first and third defined radar product.

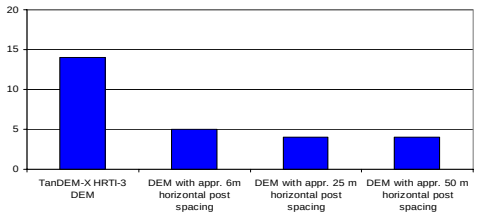

Figure 2. Summary of the required products from the TD-X science team

For the first specified product the majority of the scientist requests a digital elevation model with the specification of HRTI-3 (Fig. 2). Optionally other products could also be delivered having lower post spacing but higher relative vertical resolution. Such products where requested especially for land ice applications. The HRTI-3 DEM product was mainly requested over Asia, Europe and North America, followed by Antarctica and Artica and few requests have been obtained over South America, Africa and Australia.

In addition to the specified TD-X products the reason why the scientists needs a high resolution DEM has also been asked. Fig. 3 points out that the highest need is to map the earth topography with a higher vertical resolution as currently available DEM's offer. Further, the second important issue is the request to have global access to the data set, as seen in Fig. 3. 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.

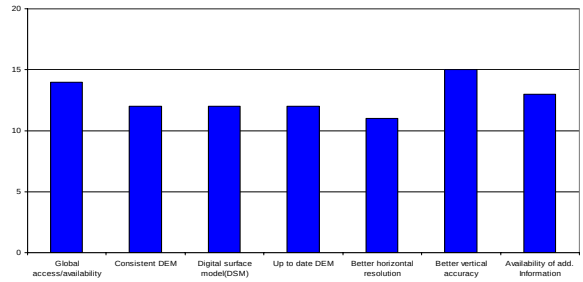

Figure 3. Statistical summary of why the HRTI-3 product is required from the TD-X scientist.

For the new SAR techniques category different operation modes could be chosen by the scientists. 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. These techniques 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.

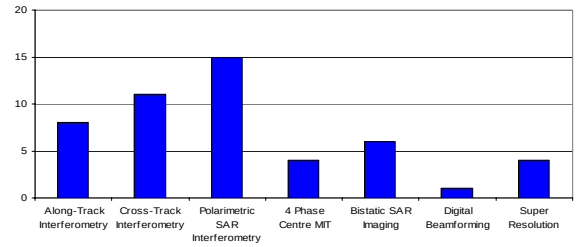

Figure 4 Statistical distribution of the requested modes for the demonstration of the new SAR techniques

C. *National and International Importance*

The scientific community expressed a strong need for a DEM with the HRTI-3 specification for the vertical accuracy evaluation, the development of algorithms and the derivation of geo/bio physical parameters based on DEMs. Further, a strong need for the development of new product parameters derived from New SAR technique modes could be 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 national, European and international programs expressed their strong interest for the TD-X products. The relevance in the programs is tremendous, as not only the pure DEM information about the surface will be of importance but also the derived parameters in different applications will have an enormous increase of information and therefore an influence on the programs.

III. CUSTOM EXPLORATION

A. *Introduction*

Launched in January 2001, Infoterra GmbH is a 100% owned subsidiary of EADS Astrium, Europe's leading space company. Infoterra was founded to prepare and conduct the commercial exploitation of TerraSAR-X and TanDEM-X.

Infoterra was formed by spinning-off the 'Earth Observation Services' division of the former Astrium GmbH, Germany and re-branding of the National Remote Sensing Centre Ltd. (NRSC), UK, and the French ISTAR S.A.. Infoterra has a 200-strong team of highly skilled staff, including experts in cartography, forestry, agriculture, geological exploration, environmental management, and telecommunications planning. In addition, Infoterra's staff is skilled in the development of systems software specific to the management of geographic data. Such a strong market-oriented positioning facilitates a prompt and flexible response to all enquiries within the geo-information community.

Infoterra GmbH is serving and supporting both public and private customers with geo-information on cartography, land use/ land cover, and forestry as well as with a focus on TerraSAR-X, GMES (Global Monitoring for Environment and Security), and thematic mapping services. Infoterra is ISO9001:2000 and ISO 14001 certified and guarantees that all the work is completed according to internationally accepted quality and environmental standards.

B. *Justification*

Commercial exploitation of TanDEM-X will benefit mainly from the global high quality DEM product, the associated update service, and the generation of topographic base data (image and contour line maps). Further applications with commercial potential will be implemented, based on the applications research results (e.g. moving target detection, super resolution, differential InSAR based monitoring).

The DEM quality domain that the TanDEM-X mission can provide is today dominated by offers based on airborne campaigns. 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 of the important defense and security markets 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.

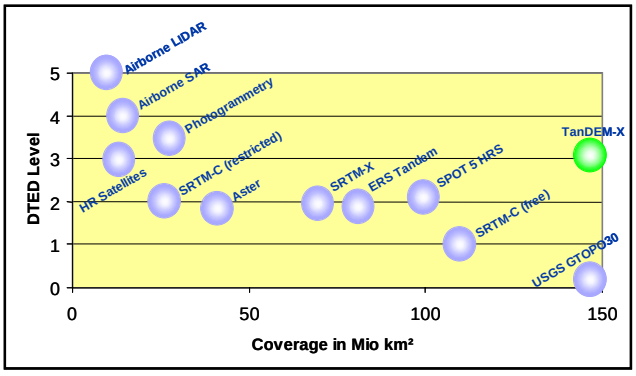

Figure 2. Overview of available sensors and their digital elevation standart.

C. Position of TanDEM-X based Elevation Data

Since high quality DEMs are a prerequisite for the precise image exploitation of highest resolution reconnaissance systems (e.g. orthorectification of high resolution imagery, localization of objects) an essential and standardized basis for global satellite reconnaissance will be established with TanDEM-X.

In addition, a growing demand for high quality DEMs is expected in the public and private markets. While planimetric data are largely available, the third dimension is currently either of insufficient quality or does not exist at all. Examples for programs and project categories under which DEM procurements are expected:

- Structural development (e.g. mapping and irrigation/flood control project)
- Global Monitoring for Environment and Security (GMES) service development and implementation
- National defense mapping and national civil security (e.g. dyke monitoring, flood hazard mapping)
- Commercial projects (e.g. pipeline/powerline planning)

Besides the price benefit, the added values for different commercial products and applications achieved through the TanDEM-X mission are characterized by:

- Homogeneous, consistent and world-wide coverage,
- Standard cross border quality,
- Improvement of the degree of ortho-rectification and data accuracy,
- Development of new products and algorithms.

The added values for commercial products and applications are specified as follows:

- Consistent geodetic reference system (global scale),
- Improved resolution to generate high resolution thematic and topographic maps,
- Change detection due to seasonal and three year operation time,
- Development of a consistent data set,
- Improved infrastructure planning and delineation of land use units,
- Changes in forest cover and state (global),
- Detection of illegal selective logging in forest areas,
- Estimation of 3D canopy descriptor,
- Improved coherence measurements, crop damage assessment and detection of land unit changes,
- Surveillance due to high repetition rate of traffic and ships.

D. Global access to locally limited HRTI-4

Substitution of currently available DTED-2 DEM by the TanDEM-X equivalent DTED-2 products will be attractive due to the higher quality for the same price. Sales to HRTI-4 segment customers who will adopt HRTI-3 as soon as a significantly lower price justifies a somehow lower accuracy. The DEM product will stay valuable in the market for at least another five years after end of mission. However, it is expected that after mission end, DEM sales will enter stagnation, while the demand for update services will grow. Efficient mapping and change detection capabilities of the INSAR concept are attractive in the long term, e.g. in support of GMES services and to satisfy the military needs of having up-to-date data.

TanDEM-X will improve the imaging capacity and response time of the nominal TerraSAR-X. With two spacecrafts in orbit the availability for sustainable services would be considerably saver. Through this an earlier release of the second TerraSAR-X will be achievable. With the German technology based contribution to GMES service infrastructure as well as surveillance and reconnaissance service demands of national and partner defence entities the TerraSAR-X and TanDEM-X line would represent an important asset with a long term perspective.

E. Business Concept

The TanDEM-X implementation will be carried out in a PPP frame (Public Private Partnership) between EADS Astrium GmbH and DLR similar to the TerraSAR-X mission. The observation capacity of TanDEM-X will be 50% for InSAR operations and 50% for compensating the TerraSAR-X capacity contributions to the InSAR mission. Through this capacity swap the nominal TerraSAR-X line can be maintained at committed service capacities. For the purpose of evaluating the viability of a business case based on TanDEM-X the reference product portfolio comprises the HRTI-3 and HRTI-4 quality DEM and an associated long term update service. However, mapping and change detection products and services are considered and will add business opportunities to the case. Infoterra GmbH will exploit the commercial mission part and sell the products and services globally, capitalizing on the customer base and sales network established for the TerraSAR-X based portfolio.

IV. SUMMARY

The result of the endorsed questionnaire to the scientists and commercial customers point out their strong need for a DEM with the HRTI-3 specification. The TanDEM-X mission will be able to fulfil the specification on a global scale in order to guarantee a global access for the users.

TanDEM-X is a unique satellite constellation, which 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.

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