WorldDEM™ - A New Era of Global Elevation Information

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Abstract.
The WorldDEM is a game changing disruptive technology providing a seamless world height model. The two radar sensors TerraSAR-X and TanDEM-X acquire data from space absolutely reliably, as they operate independent of cloud coverage and lighting conditions. The worldwide homogeneous acquisition guarantees a global DEM with no break lines at regional or national borders and no heterogeneities caused by differing measurement procedures or data collection campaigns staggered in time.

With the successful launch of the German radar satellite TanDEM-X on June 21st, 2010, a new era of global digital elevation information provision has commenced. Together with TerraSAR-X, TanDEM-X forms a high-precision radar interferometer acquiring the data basis for a global homogeneous digital elevation model called WorldDEM. The dataset is available in different product types: unedited and edited elevation models. The edited product contains the flattening of water bodies and the correction of artifacts introduced by the SAR effects like layover and shadow.

For applications like defence and security, aviation and hydrological modelling standardization of the specification is important in order to get reliable and comparable information on global scale. The validation approach for WorldDEM is a strict workflow which results in reliable figures for the absolute accuracies.

This paper will introduce the different WorldDEM products and details about the validation of the accuracies are given. Additionally some examples for WorldDEM applications are discussed.

Keywords: WorldDEM, TanDEM-X Mission, high quality global Digital Elevation Model

1. Introduction

Digital elevation models (DEM) are key for many commercial and scientific activities, e.g. for analyzing and predicting environmental and geophysical processes or events for crisis intervention planning, like flood and risk mapping, for applications in hydrology, forestry, ortho-rectification of multi-source geo-data and mapping, infrastructure planning and navigation. In the oil and gas business, for example, elevation information is essential for performing feasibility studies, exploration, development and management of oil and gas fields. The requirements are increasing with respect to availability, coverage, accuracy and homogeneity of elevation information. The quality and reliability of elevation models is of fundamental importance. Today, many DEM products derived from various airborne and spaceborne systems are offered to the market. Large area height information, especially global DEMs, are quite often mosaics of data from various sources with many differing data of different accuracies, resolutions, time differences, formats and projections. The results are hardly uniform and of same quality at each point on Earth (Gantert et al. 2011).

The WorldDEM derived from the TanDEM-X DEM acquired during the TanDEM-X mission, is the first worldwide, pol-to-pole digital elevation model out of one source. The TanDEM-X mission (TerraSAR-X add-on for Digital Elevation Measurements) was realized in the of a public–private partnership (PPP) between the German Aerospace Center (DLR) and Airbus Defence and Space. Airbus DS holds the exclusive commercial marketing rights for the data and is responsible for the adaptation and refinement of the elevation model to the needs of commercial users worldwide (Riegler 2013).

In this article the TanDEM-X mission concept, the data acquisition and the production of the data to the unique, standardized WorldDEM products is described as well as the validation of the products. Some examples for applications are given.

2. The TanDEM-X Mission

The primary goal of the mission is the generation of a world-wide, consistent, homogenous, and high precision digital surface model (DSM).

The concept of the mission is to complete the global homogeneous DEM in the shortest possible time frame. To achieve this ambitious goal the acquisition plan is optimized for time-efficient coverage of the Earth's entire landmass. As a result the acquisitions are not recorded region by region but rather in the style of a jigsaw. Seemingly random acquisitions are made in different locations across the globe and piece by piece the jigsaw is completed with the overall picture becoming visible once all pieces are assembled.

For data collection the two satellites operate in the bi-static interferometric StripMap mode. In this mode one satellite transmits the radar signal to illuminate the Earth's surface, while both satellites record the signal's backscattering. This simultaneous data collection avoids possible interferometric data errors due to temporal decorrelation and atmospheric disturbances.

Within four years data over each spot on Earth was collected at least twice. To ensure a reliable homogeneous quality of the global coverage areas with steep terrain and complex land cover like tropical rainforest were covered even three or four times. Latter areas are identified from the previously collected data. For the third and fourth coverage an even more complex satellite operation adjustment was performed. At the start of the TanDEM-X mission the TanDEM-X satellite circled around the TerraSAR-X satellite anti-clockwise. After the satellite swap the direction is now clockwise. This change effects that mountainous terrain is viewed from a different viewing angle to eliminate missing information due to radar effects (Krieger et al. 2007).

The ground segment processing at the DLR is adapted to the phases of the data acquisition schedule. In a systematic data driven processing step all SAR raw data are processed to so-called raw DEMs performed by one single processing system, the Integrated TanDEM Processor. Key elements of the interferometric processing chain are the timing and phase synchronization as well as instrument corrections, approximation of the bi-static acquisition geometry, high resolution image co-registration, spectral matching of time variant azimuth spectra, unwrapping of steep phase gradients on small scales, and finally consistent geocoding of all product layers. These raw DEMs are input for the Mosaicking and Calibration Processor, which produces the DEM (Kosmann et al. 2010, Wessel et al. 2008).

Output is the so-called TanDEM-X DEM, a global elevation dataset. No additional post-processing is applied. SAR specific artefacts due to the terrain or processing artefacts stay untouched.

3. WorldDEM Products

WorldDEM is the commercial product line product produced by Airbus DS. Based on the TanDEM-X DEM different standardized elevation products are developed and launched to the market. The WorldDEM product line consists of two DSMs, representing the Earth's surface including heights of buildings and other man-made objects, trees, forests and other vegetation: an unedited and an edited DSM to cope up to various requirements and applications (s. Figure 1).

The unedited DSM product is called WorldDEMcore. In a first step the TanDEM-X DEM is transformed from the ellipsoidal heights (WGS84-G1150 datum) into geoid heights (EGM2008) which is the established reference for most applications. Additionally, the metadata are converted in a format compliant to ISO 19115.

No editing or smoothing is applied to this product. That means all SAR specific artefacts in the terrain, e.g. foreshortening, layover or shadowing, or over water, such as voids or spikes and wells, remain in the WorldDEMcore data. All processing artefacts, e.g. not identical pixels in the overlap area of two geocell borders, are not removed. WorldDEMcore is a product of interest for users with individual specification for certain applications as well as for users who want to do value-adding in-house.

The edited product is the WorldDEM which is produced based on the WorldDEMcore product. The editing of WorldDEMcore is necessary to reduce impacts of SAR-specific data features and artefacts in the elevation model. The WorldDEM editing process can be described in two major steps. The terrain editing step comprises the correction of terrain artefacts caused by SAR specific characteristics (e.g. layover and shadow) or the DSM processing. Since water areas are not representing plausible elevations editing of water bodies is required to produce a high quality elevation model. This second processing step comprises the extraction and editing of water body features according to the WorldDEM editing specifications. For this “hydro editing” of the WorldDEM data, three different types of water body features are defined: ocean, lake, river.

Finally the extracted and classified water features are edited. According to its feature type, a water body feature is “flattened” to a single elevation (ocean, lakes) or to monotonic flowing elevations (rivers). The water flattening process includes ensuring that the shoreline elevations of a water body are never below the elevation of the water surface.

The terrain and hydro editing process is followed by a Quality Control (QC). This QC check consists of a combination of automatic tools and visual inspection of the data by an independent operator. This check is a thematic validation and is performed according to ISO 2859.

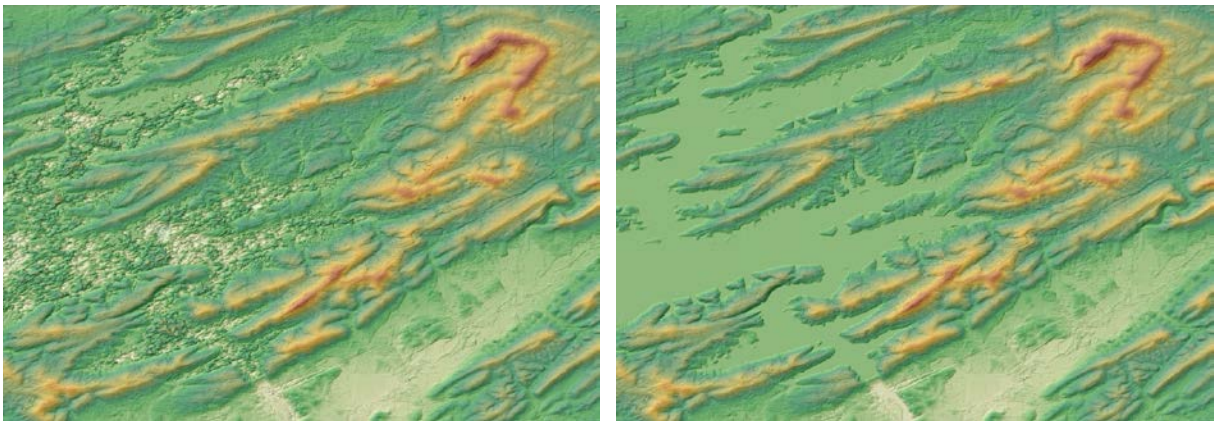

Figure 1. Left: WorldDEMcore (unedited); Right: WorldDEM (edited) – Site: Lake Ouachita, Hot Springs, Arkansas, USA)

4. WorldDEM Quality and Accuracy

Within the generation of the TanDEM-X DEM and further processing to the WorldDEM the accuracy and quality of the DEM will be checked in several steps. In the processing of the single raw DEMs a first plausibility check is performed. During the further mosaicking and calibration step reference data are used to assess the quality of the generated DEM product.

As reference data in the processing steps SRTM (Shuttle Radar Topography Mission) DEM data and height measurements from the ICESat (Ice, Cloud, and land Elevation Satellite) mission are used (Gruber et al. 2009, Wessel et al. 2009).

A further check of the accuracy is carried out during the production of the WorldDEMcore product. The quality parameters of the TanDEM-X DEM and additional analysis of the delivered quality masks are taken as input for the accuracy assessment.

As during editing to the WorldDEM product artifacts are removed, void areas are filled and water bodies are flattened a final quality assessment and accuracy measurement is carried out after editing and finalization of the product generation.

Due to the cutting edge technologies used for producing the WorldDEM, starting with the data acquisition and data processing performed by DLR and post-processing by Airbus DS including strict quality assurance processes, the high quality of WorldDEM products in terms of homogeneity and accuracy is ensured. The accuracy and level of detail exceed by far the expectations of a 12m-raster DEM.

The validation results show that the accuracy of the WorldDEM products is even better than determined in DLR’s TanDEM-X mission goals. The absolute vertical accuracy is better than 4 m (linear error 90%). The specification for WorldDEM is summarized together with the accuracy of the product in Table 1.

Table 1. WorldDEM Specification and Accuracy

Specification Parameter		Value
Data type		32 Bit, floating
Projection		Geographic coordinates
Coordinate Reference System	Horizontal	WGS84-G1150
	Vertical	EGM2008
Pixel spacing		0.4 arcsec (approx.12 m)
Vertical Unit		Meter
Absolute Vertical Accuracy		< 4 m (90% linear error based on global product)*
Relative Vertical Accuracy		< 2 m (slope ≤20%) < 4 m (slope > 20%) (90% linear point-to-point error within an area of 1°x1°)
Absolute Horizontal Accuracy		< 6 m (90% circular error)*

* based on ongoing validation results (TanDEM-X Mission Goal: < 10 m)

5. Validation

Validation of DEM products is an important topic for the generation of a reliable product specification. Quality assurance of the WorldDEM product is an important factor with a strong focus from Airbus DS side. In order to provide reliable figures an intensive validation campaign is carried out within the product development phase.

A similar campaign has already been performed for the Elevation10 product, a TerraSAR-X data based elevation model product generated on the basis of radargrammetry (Hennig et al. 2010).

5.1 Validation Approach

An increasing number of elevation data providers and new elevation data generation technologies with varying system designs have led to a wide range of accuracies of the data. The lack of a commonly adopted and established validation approach and guidelines, especially for high-resolution and high-accurately DEMs, results in an incomparableness of elevation data from different providers and sources. For elevation data a demanding knowledge of the quality is of required as elevation model are the base layer for further geospatial applications such as ortho-rectification, topographic mapping or surface analysis.

The validation approach of the WorldDEM contains three main steps: (1) visual inspection, (2) profile plot analysis with reference data and (3) a detailed statistical analysis of the absolute vertical accuracy. For the statistical analysis a variety of available reference datasets is used, like SRTM DEM, Lidar DEM and DGPS measurements, depending on availability. Additionally a slope and land cover based analysis is performed (Figure 2).

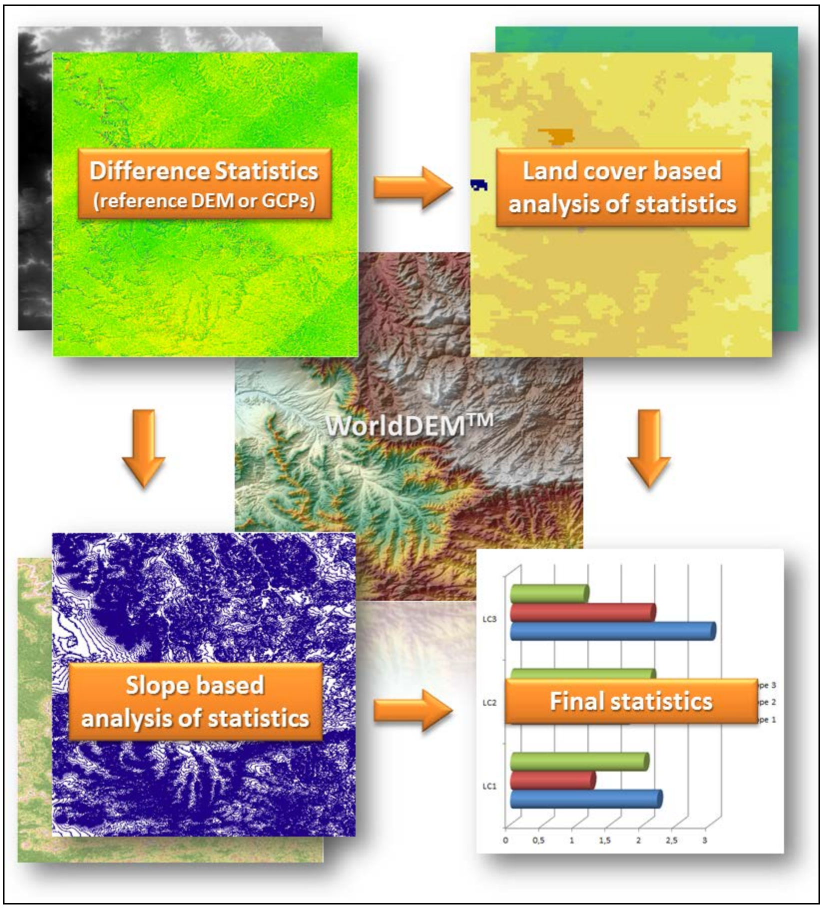

Figure 2. WorldDEM validation approach

5.2 Validation Results

For a test site in southern Australia a validation has been performed. The AOI contains four geocells in a corridor of almost 400 km length between 131° and 135° eastern latitude and 31° southern longitude. The area is mainly covered by desert with small bushes and trees and some built-up areas in an overall flat terrain (Figure 3). As reference data the globally available ICESat data have been used. A filtering of the data has been applied in order to remove points over water bodies and with a bad quality flag in the ICESat attributes. The statistical calculations are based on 4516 ICESat points (Table 2).

Table 2. ICESat based statistics for the test site in Australia

	[m]
Mean	-1.3
RMSE	1.4
LE90	**2.3**

With an overall accuracy of 2.3 m Linear Error 90 % (LE90) the absolute calculated accuracy shows much higher accuracy than specified. The result shows, that the specification is based on very conservative values in order to fulfill the accuracy even in areas which are more difficult.

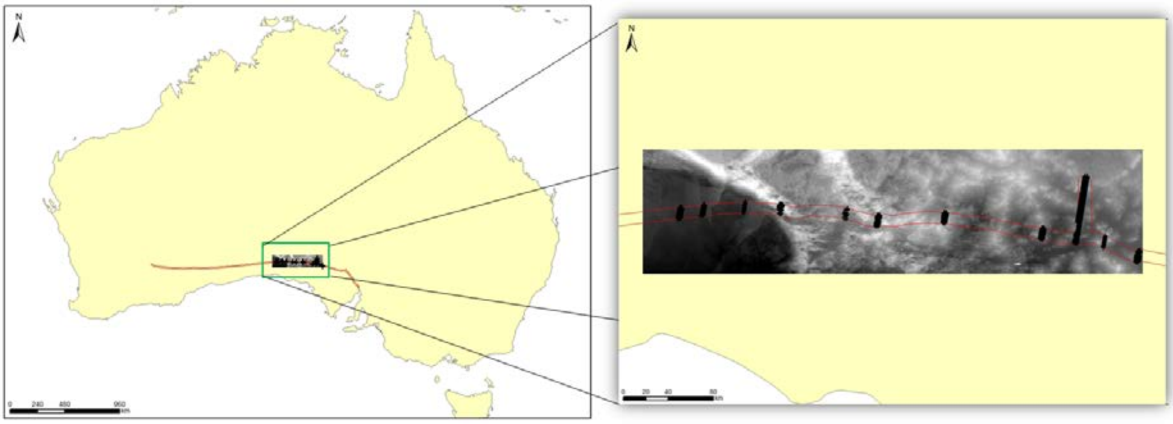

Figure 3. WorldDEM validation testsite: "Indian Pacific Railway, Australia"; ICESat data distribution

6. Applications

Elevation models are used in a wide range of applications, from image ortho-rectification and base topographic mapping to the more specialized geospatial needs of defense, homeland security, intelligence and military engineering interests. As WorldDEM is globally available as a homogeneous, seamless and high accurate dataset, it provides a new dimension for applications on a global scale (Riegler 2013).

For a variety of topics a globally standardized, homogeneous cross-border dataset is required. Some key application areas are: defence and security, aviation, hydrological modeling oil, gas and mineral industry and ortho-rectification services.

6.1 Defence, Security and Aviation

In the field of military actions, rescuing in case of natural hazards and aviation missions are spread around the globe, independend from administrative areas. The availability of geodata for mission planning and in-situ application is typically heterogenious and not standardised depending on governmental actions. For these purposes WorldDEM provides a specified reliable dataset which could be applied around the globe, independend from local data availability.

The example in Figure 4 shows the analysis of WorldDEM data and a land cover layer for potential helicopter landing zones in an area in southern germany, applicable e.g. for mountain rescuing.

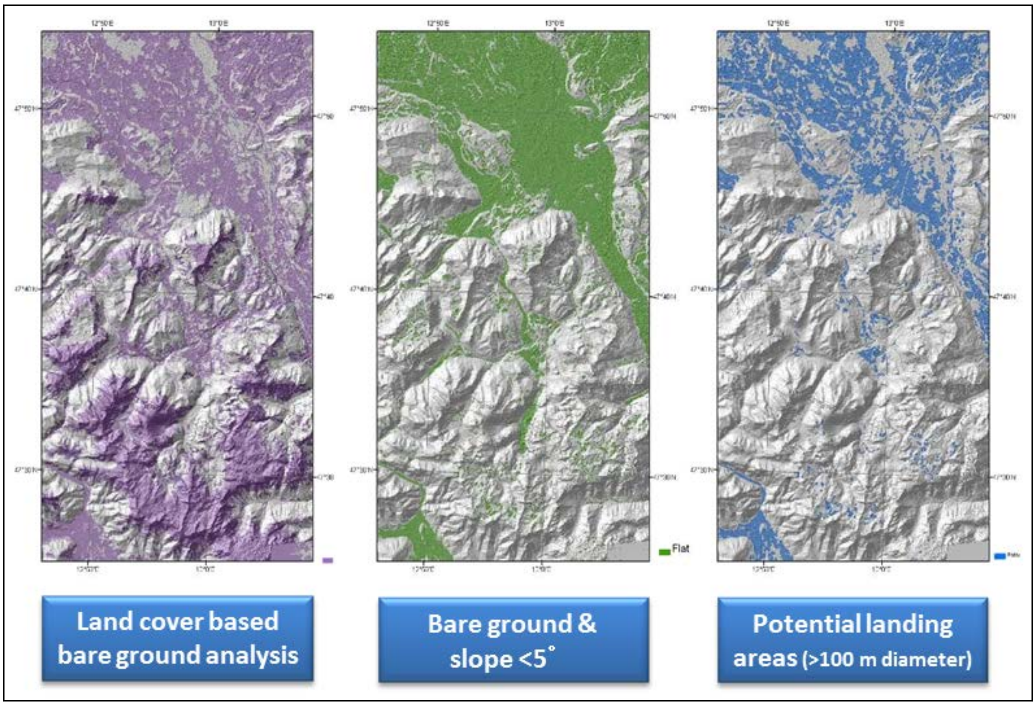

Figure 4. WorldDEM based analysis of potential helicopter landing zones - Area of Berchtesgarden, Germany)

6.2 Hydrological Modeling

Flooding of rivers and sea level rise-up is a topic on all continents. Every year thousands of people die because of flooding. In order to protect humanity the identification of potential flooding areas is important. A high accurate and reliable elevation dataset would support the analysis of these areas and will save thousands of lives.

The usage of different elevation datasets for a shoreline analysis is shown in Figure 5. Globally available datasets have been used for the study: (a) WorldDEM, (b) ASTER GDEM (30m) and (c) SRTM (90m). WorldDEM shows the highest accuracy compared to reference data like optical data.

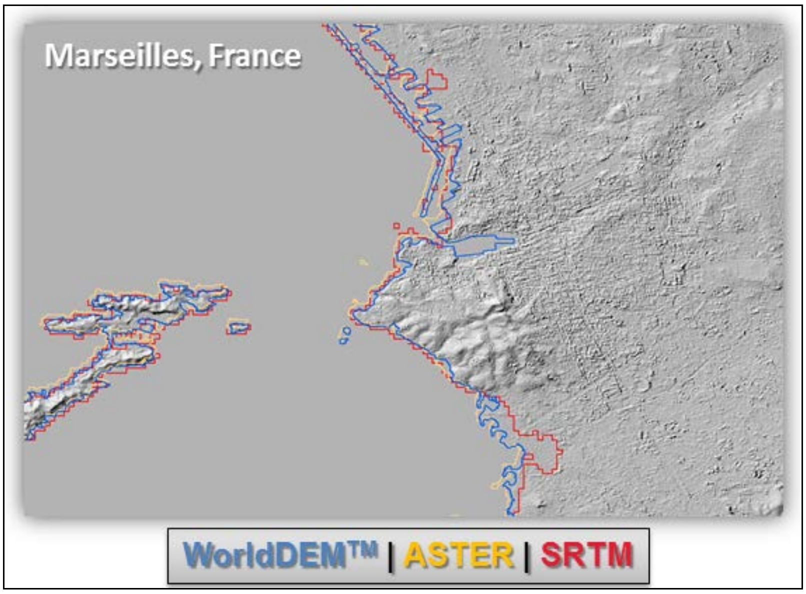

Figure 5. Analysis of shoreline in Marseilles, France based on different DEM datasets

7. Conclusion and Outlook

WorldDEM is globally available as a homogeneous, seamless and high accurate dataset, it provides a new dimension for applications on a global scale (Riegler 2013).

The global availability, high accuracy and level of detail of the WorldDEM products provide a new dimension for applications on global scale with high quality requirements. The homogeneity of the WorldDEM products guarantees elevation information without any seamlines or heterogeneities e.g. along administrative borders, supports standardized processes and yields to comparable results.

The WorldDEM product line will be extended by a Digital Terrain Model (DTM) product soon. WorldDEM DTM will represent the elevation of bare earth, vegetation and man-made objects will be removed. Additionally, Airbus DS plans to provide an expanded portfolio of global geo-information layers, including Global Ocean Shoreline, Waterbody Map, and Global Airport / Harbour Map based on the WorldDEM data.

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