

## Geo Elevation10

Technical Product Specification



**ASTRIUM**  
AN EADS COMPANY

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## ABBREVIATIONS

Abbreviations	Description
AOI	Area of interest
CE90	Circular error (90% confidence level)
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
DSM	Digital Surface Model
DTED	Digital Terrain Elevation Data
DTM	Digital Terrain Model
EDM	Editing Mask
EGM96	Earth Gravitational Model 1996
FLM	Filling Mask
GeoTIFF	Tag Image File Format – geocoded
IPM	Interpolation Mask
LE90	Linear Error (90% confidence level)
LSM	Layover – Shadow Mask
ORI	Orthorectified Radar Image
RMSE	Root Mean Square Error
SAR	Synthetic Aperture Radar
SLD	Single line Drain
SM	StripMap (TerraSAR-X acquisition mode)
SOU	Source Mask
VOM	Void Mask
WBM	Waterbody Mask
WGS84	World Geodetic System1984
XML	eXtensible Markup Language

## 1 INTRODUCTION

Astrium GEO-Information Services offers the GEO Elevation portfolio consisting of three core levels of elevation models:

- Elevation30 - off-the-shelf 3D database available for more than 50 Mkm<sup>2</sup> worldwide, derived from both optical (from Reference3D) & radar spaceborne data; 30 m grid spacing.
- **Elevation10** - up-to-date elevation models from specific data acquisition, custom-tailored on AOI surface, derived from spaceborne radar; 10 m grid spacing.
- Elevation+ - airborne based elevation surveys (LiDAR); 1 m grid spacing and better.

This document describes the specification and format of the **Elevation10** products. It provides a brief description of the generation process, the basic characteristics of the Digital Elevation Models and its ancillary data products, and provides an introduction to the validation and verification approach.

In this document the abbreviations for elevation data are used as follows:

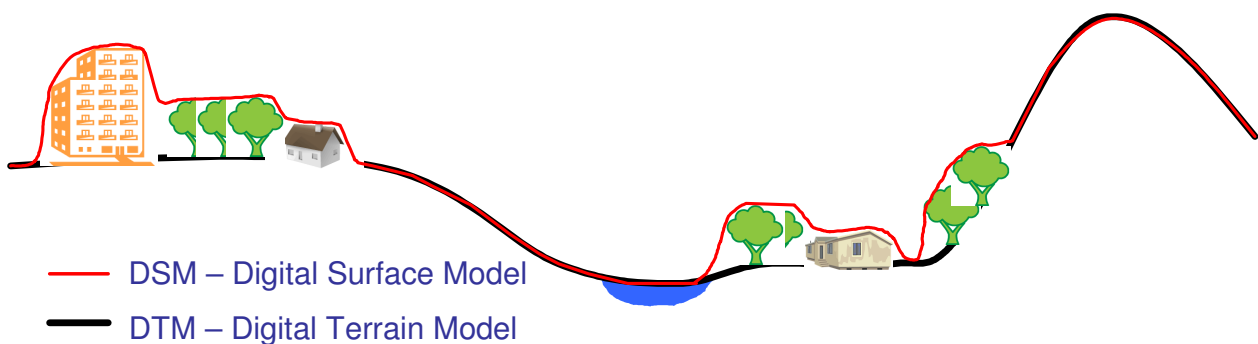
**DEM (Digital Elevation Model):** Generic term for digital elevation models; includes Digital Surface Models (DSM) and Digital Terrain Models (DTM).

**DSM (Digital Surface Model):** Represents the surface as observed by the sensor. All objects (trees, houses etc.) are included in this model.

**DTM (Digital Terrain Model):** Also called "bare earth" representing the ground surface without any objects (trees, houses etc.).

The definitions are visualized in the following figure:

### DEMs – Digital Elevation Models



**Figure 1-1: Characteristics of Digital Surface and Terrain Models**

The following Reference Documents can be provided on request:

RD-01	TerraSAR-X Enhanced Image Product Format Specification, TSXX-ITD-SPE-0012 - available upon request
RD-02	TerraSAR-X Enhanced Image Product Specification, TSXX-ITD-SPE-0009 - available upon request
RD-03	TerraSAR-X Basic Image Product Specification, TX-GS-DD-3302 - <a href="http://infoterra.de/documents">http://infoterra.de/documents</a>

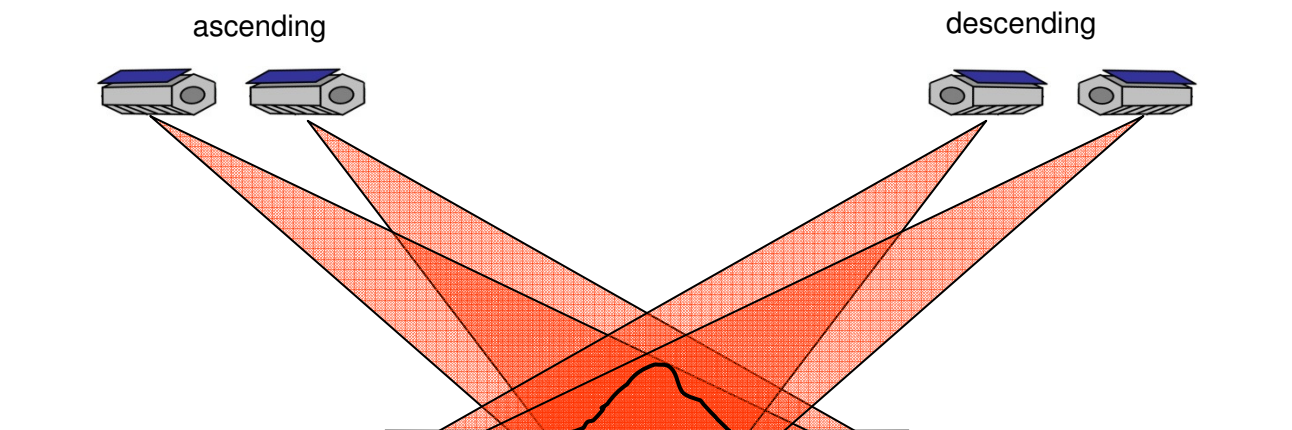
## 2 DATA ACQUISITION

The **Elevation10** products are based on TerraSAR-X radar imagery.

TerraSAR-X is the first commercial German radar satellite with a resolution of up to 1 m. The satellite was launched on June 15th 2007 from the Baikonour Cosmodrome in Kazakhstan and has been in operational service since January 2008. TerraSAR-X can collect data all over the world in different acquisition modes, ranging from 1 m to 18 m resolution at different incidence angles.

The products specified in this document are two kinds of Digital Surface Models (DSM) and the Digital Terrain Model (DTM). These products are generated using TerraSAR-X data stereo pairs and applying radargrammetric techniques.

The products are extracted from TerraSAR-X StripMap Mode stereo pairs (multiple TerraSAR-X basic image products (s. RD-03) acquired at different incidence angles). In order to reduce the influence of SAR-specific effects such as shadow, foreshortening, or layover, DSMs from both orbit directions (ascending and descending) are acquired as displayed in Figure 2-1, processed and merged. The coverage by two orbit directions ensures a complete area-wide survey and guarantees a reliable elevation model extraction.



**Figure 2-1: Elevation10 data acquisition scenario**

### 3 PRODUCT GENERATION

The **Elevation10** portfolio includes three different products, which differ with respect to their level of editing (Table 3-1). The underlying processing steps, the individual editing of the products and the quality assurance are described in detail in the following chapters.

The radargrammetric raw DSM processing and the final quality control are identical for all **Elevation10** product levels.

**Table 3-1: Elevation10 product overview**

Product	Editing Description
<b>Elevation10</b> DSM <sub>basic</sub>	Digital Surface Model <ul style="list-style-type: none"> <li>• Artefact removal</li> </ul>
<b>Elevation10</b> DSM	Digital Surface Model (based on <b>Elevation10</b> DSM <sub>basic</sub> ) <ul style="list-style-type: none"> <li>• Artefact removal</li> <li>• Implementation of specified hydro network - optional</li> </ul>
<b>Elevation10</b> DTM	Digital Terrain Model (based on <b>Elevation10</b> DSM) <ul style="list-style-type: none"> <li>• Processing DSM data to bare earth</li> <li>• Implementation of hydrological consistency - optional</li> </ul>

#### 3.1 DEM PROCESSING

The **Elevation10** products are generated using TerraSAR-X data stereo pairs and applying radar-grammetric techniques. The radargrammetry is based on the matching of homologous points from two images of the same area, which have a different geometry. The process contains of three general processing steps:

- Set up of geometric stereo model
- Raw DSM generation based on stereo matching
- Merging of raw DSM for ascending and descending orbit directions

Output of the radargrammetry process is a raw DSM that still contains void areas and artifacts which are subject to a subsequent DSM editing process.

## 3.2 DEM EDITING

For a continuous and accurate representation of the Earth's surface elevation, the raw DSM needs to be edited. In order to ensure that the **Elevation10** product is consistent, the editing is carried out in two main steps:

The first editing step contains the correction of elevation errors caused by SAR specific characteristics or DSM processing. After that the editing of the water bodies (hydro-enforcement) will be performed if requested.

The DTM editing includes the additional removal of man made features and vegetation which project above bare ground.

DTM editing with additional steps for hydrological applications can also be provided on demand.

### 3.2.1 Elevation10 DSM

The following processing/editing steps and rules are applied to the raw DSM:

- Interpolation of small voids (smaller or equal 8 pixels) and blunders
- Filling of large voids (larger than 8 pixels) and larger artifacts with ancillary DSM data (as available)
- Global or local smoothing, if required
- Additional manual editing, if any artifacts remain present in DSM data

On request, the water bodies and paved runways will be edited, based on the following editing steps and rules:

- Identification and extraction of any water body feature according to Water Body Editing Conventions and feature height measurement. The extent of the water bodies is derived from corresponding TerraSAR-X image data:
  - Permanent water bodies: lakes and reservoirs with an area larger or equal 25,000 m<sup>2</sup> are set to a single elevation
  - Double line drains: rivers and canals with a length of 300 m or larger along medial axis and a width of 90 m or larger perpendicular to the medial axis are flattened with monotonic flow
  - Tidal water bodies: the elevation height is set to 0 m
  - Islands with a minimum area of 12,000 m<sup>2</sup> or a height difference of more or equal to 15 m to the surrounding water surface
  - Coastal infrastructure features are removed, unless they comply with editing rules
- Automatic inclusion of the water body data set into the DSM data set (including correction of shore pixels to ensure a hydrological consistency). The shoreline is always made higher than the water surface elevation.
- Additional manual editing of shorelines according to the morphology of the Earth's surface derived from TerraSAR-X images

- Identification and extraction of paved runways, based on corresponding TerraSAR-X image data. Flattening of extracted runways to a single elevation.

All pixels changed during the editing process are indicated in a dedicated mask, (for details see chapter 5.3) that can optionally be delivered together with the **Elevation10** product.

### 3.2.2 Elevation10 DTM

The aim of the DTM generation is the exclusion of obstruction features above bare ground. The editing approach distinguishes between obstruction features that must be removed from the **Elevation10** DSM data, and hydrological and miscellaneous features that must be implemented or remain in the final product.

The DTM editing includes following steps:

- Removal of obstruction features by smoothing, shifting or interpolation
  - Identification and extraction of obstruction features based on DSM characteristics
  - Removal of obstruction features. Depending on the terrain and surface characteristics within the AOI different methods for the obstruction feature removal are used:
    - Smoothing of smaller single features (e.g. small single buildings, single trees)
    - Interpolation of larger single features (e.g. huge buildings, industrial buildings) and small groups of trees with closed canopy coverage
    - Shifting of obstructed areas (canopy closed areas and densely built up areas). The 3D-measurement of a high number of object feature heights is needed to ensure a plausible representation of the terrain elevation after the shifting.
- A final global smoothing leads to homogeneous DTM representation within the whole AOI
- Hydro enforcement: Insertion of water body features
  - Identification and extraction of any water body feature according to Water Body Editing Conventions (see chapter 3.2.1) and feature height measurement.
  - In addition to the default Water Body Editing Conventions, Single Line Drains (SLD) could be included in the **Elevation10** DTM product on request. A SLD feature is a flowing watercourse that is clearly visible in the TerraSAR-X intensity data but does not reach the default **Elevation10** DSM hydro enforcement editing rules. For hydrological applications a hydrological consistency including SLDs is necessary.
  - Automatic inclusion of water body feature data set (see chapter 3.2.1)
- Implementation of miscellaneous features. Miscellaneous features, such as dams or embankments which affect the hydrological characteristics of the elevation data. These features are edited with regard to the respective extraction rules.
  - Identification and extraction of miscellaneous features (e.g. embankments, dams, open-pit mining)
  - Automatic inclusion of the miscellaneous features into the DTM data set

In theory it is expected that the **Elevation10** DTM elevation is always below the **Elevation10** DSM elevation. In practice, there are some cases where this expectation can not be completely fulfilled. Several reasons lead to **Elevation10** DTM elevation above **Elevation10** DSM elevation:

1. filled-up artificial depressions / sinks
2. elimination of implausible posts based on radar specific effects (layover, shadow, backscatter effects)
3. creation of special features based on 3D measured elevation
4. smoothing affects elevation changes in both directions. Acceptable differences between the **Elevation10 DSM** and **Elevation10 DTM**, based on smoothing applications is  $\leq 5\text{m}$

### 3.3 QUALITY ASSURANCE

The quality assurance concept includes several quality control steps that are performed during the DEM processing and editing, as well as a final quality assurance upon completion of the DEM generation. The quality control steps are:

- Visual assessment of the DEM, supported by shaded relief or difference images calculated on basis of a reference DEM if available, in order to identify any quality deficiencies
- Analytical assessment of the DEM to avoid the appearance of blunders and outliers as well as an incorrect NoData value
- Statistical assessment of the absolute and relative error of the DEM wherever reference data is available.

#### **SAR specific quality impacts**

The **Elevation10** is based on TerraSAR-X SAR imagery. Certain SAR-specific effects may have an influence on the quality of the elevation data.

TerraSAR-X acquires data in a side looking geometry. Due to the acquisition geometry and radar characteristics, relief-dependent effects such as layover, foreshortening or shadow may appear in the data used for generating the raw DSM. Particularly in mountainous areas, such effects can result in invalid information for certain areas in the input data. During DSM processing, this causes void areas in the elevation data.

In the **Elevation10** processing, these void areas are minimized by combining data from the two pass directions (ascending and descending), as these effects differ for the two pass and therefore looking directions of TerraSAR-X (figure 2-1).

Additionally, the following SAR data effects could influence the accuracy of the raw DSM:

- Areas are obscured by other objects
- Mountain tops are included into backscatter values of SAR specific geometric effects such as layover and shadow and can thus not be determined precisely

- Furthermore, the methodology used to produce the DSM (radargrammetry or stereo matching respectively) may have impacts on the quality:
- Homogeneous areas result in homogeneous gray values in the image. A stereo matching for these areas is difficult and may result in uncertainties in height assessments. The same occurs for areas with strong differences in radar backscatter values due to e.g. temporal changes

Generally, the accuracy in flat and gentle terrain is best and decreases with slope.

## 4 VALIDATION CONCEPT

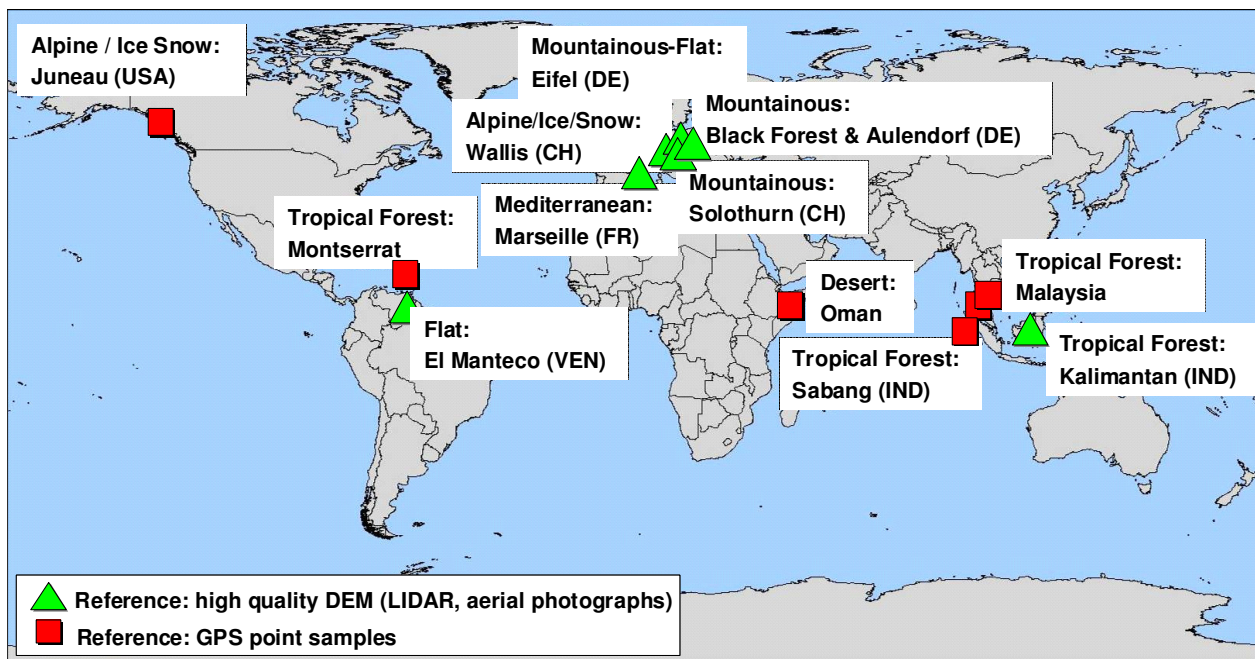
The performance and accuracy values of the **Elevation10** have been proven by an extensive validation and verification campaign, carried out during the product design phase. More than 15 test sites, distributed across the world, have been selected in order to deduce performance and accuracy values, which can be guaranteed for various terrain and land cover types (Figure 4-1).

In order to reliably validate these test sites, a DEM validation workflow was designed. It includes visual and descriptive elements as well as statistical calculations of the absolute vertical error, expressed either in RMSE or in LE90.

The visual and descriptive elements include the visual investigation of the DEM based on a shaded relief and the comparison of profile plots.

The core of DEM validation was the calculation of the absolute vertical error based on reference data. For this purpose, only highly accurate reference data, i.e. either DGPS points or high precision surface models (e.g. from LiDAR sensors), were used.

As the DGPS points provide a particularly high accuracy, (up to a few centimeters) as well as the possibility to collect ground control information all over the world, the accuracy figures in Table 5-1 are based on statistics calculated with reference DGPS measurements only. The validation results based on high precision surface models were primarily used to optimize the DEM-processor during the development phase.



**Figure 4-1: Elevation10 validation areas**

## 5 ELEVATION10 PRODUCT SPECIFICATION

### 5.1 DEM

The specification for the **Elevation10** products DSM<sub>basic</sub>, DSM, and DTM are summarized in Table 5-1. Product samples are depicted in chapter 7.

**Table 5-1: Specification of Elevation10 products**

Method	Radargrammetry based on TerraSAR-X StripMap stereo pairs
Products	DSM <sub>basic</sub> , DSM, DTM
Grid Spacing	10 m
Absolute Vertical Accuracy	5 - 10 m (90% linear error) depending on terrain
Relative Vertical Accuracy	< 5 m (90% linear error)
Horizontal Accuracy	5 - 10 m (90% circular error) depending on terrain
Minimum Order Unit	500 km <sup>2</sup> per order
Data Format	32-bit floating GeoTiff
Vertical Unit	Meter
Projection Information	Universal Transverse Mercator (UTM) projection; units in meters. Horizontal reference datum WGS84, Vertical reference datum EGM96. Other projections on customer's request.
Auxiliary Metadata	Metadata in XML-Format

#### Accuracy level

The accuracy specification of the **Elevation10** is HREGP (HRTI-3) and accordingly between the DTED level 2 and level 3.

#### Grid spacing (posting)

The grid spacing of the **Elevation10** product is sampled to 10 m. The pixel spacing can be changed on customer request, to serve specific applications.

## AOI

The products are delivered in a file containing the complete area of interest (AOI), or in tiled format, depending on the size of the AOI. The DEM tiles cover an area of 100 km x 100 km. There is no overlap between adjacent tiles. The minimum AOI of **Elevation10** products is 500 km<sup>2</sup>, minimum width of an AOI corridor is 20 km.

## Format

All valid values of the DSM are expressed in 32-bit float GeoTIFF format. Data can be delivered in 16-bit signed GeoTIFF format upon request.

NoData values (-32767) are used for areas where the elevation information can not be determined. The vertical unit for measurement of elevation height is meters.

## Projection

The **Elevation10** products are cast in Universal Transverse Mercator (UTM) projection, with units in meters; the horizontal reference datum is the World Geodetic System (WGS84) and the vertical reference datum is the Earth Gravitational Model 1996 (EGM96).

Other projections are available upon request.

## Accuracy (absolute, relative)

*Absolute accuracy* values describe all random or systematic errors of a single point, in horizontal or vertical direction, with respect to the horizontal or vertical datum used. The errors are expressed as a linear or a circular error at a 90 percent probability level. The absolute horizontal accuracy of the **Elevation10** products is derived from the horizontal accuracy of the corresponding Orthorectified Radar Image (ORI<sup>SAR</sup>).

The *relative accuracy* is defined through the consistency of the digital elevation modelling. The relative error is expressed as linear error at a 90 percent probability level based on the difference of processed DEMs of the same area using different acquisitions and overlapping stereo pairs.

## 5.2 METADATA

The metadata information for all delivered product components is included in one metadata xml file. ISO 19115 compliance will be supported with the next product release.

### 5.3 QUALITY LAYERS

The following quality layers are optional, they can be ordered with the product. Samples see chapter 7.

#### **Source Mask (SOU)**

The source mask contains the footprint of all TerraSAR-X StripMap input data sets used for the **Elevation10** generation. The source mask is provided as an ESRI shape file.

#### **Layover and Shadow Mask (LSM)**

The shadow and layover mask provides information on shadow and layover areas in the TerraSAR-X input images, originating from the SAR typical imaging geometry. In layover and shadow areas, no height information can be reconstructed. This leads to void areas in the digital elevation model. The layover and shadow mask is provided as ESRI shape file.

#### **Void Mask (VOM)**

Areas with NoData after radargrammetric processing are flagged in the void mask, according to the coding given in Table 5-2. The void mask is provided as 1-bit GeoTIFF file.

#### **Interpolation Mask (IPM)**

According to the processing rules (see chapter 3.2), this mask represents every interpolated single pixel, as well as voids smaller or equal 8 pixels. The interpolation mask is provided as 1-bit GeoTIFF file.

#### **Filling Mask (FLM)**

The filling mask includes information about the location of voids and artefacts larger than 8 pixels that were filled with available ancillary DEM data. The ancillary DEM sources for these filled areas are annotated in the accompanying text file. The filling mask is provided as 4-bit GeoTIFF file.

#### **Editing Mask (EDM)**

The editing mask represents all pixels which were modified during the DEM editing process. It contains every pixel derived from the interpolation mask, filling mask and water body mask, as well as every pixel modified during automatic or manual editing work (see chapter 3.2.1). The editing mask is provided as 1-bit GeoTIFF file.

#### **Water Body Mask (WBM)**

The water body mask is derived from the corresponding TerraSAR-X basic image product (RD-03) and contains all delineated water body features according to the water body editing conventions (see chapter 3.2.1); i.e. permanent water bodies, double line drains and tidal water bodies. The water body mask is only available if editing of water bodies is performed, and provided as 1-bit GeoTIFF file.

**Table 5-2: Quality layers of Elevation10 products**

Product / Package	DSM <sub>basic</sub>	DSM	DTM	Format	Coding
Source mask (SOU)	X	X	X	ESRI shape	
Layover & Shadow mask (LSM)	X	X	X	ESRI shape	
Void mask (VOM)	X	X	X	1-bit GeoTIFF	0: no void 1: void
Interpolation mask (IPM)	X	X	X	1-bit GeoTIFF	0: no interpolated pixel 1: interpolated pixel
Filling mask (FLM)	X	X	X	4-bit GeoTIFF	0: no filled pixel 1, 2, ... (Coding is described in respective txt-file)
Editing mask (EDM)	X	X		1-bit GeoTIFF	0: no edited pixel 1: edited pixel
Water body mask (WBM)		X	X	1-bit GeoTIFF	0: no water pixel 1: water pixel

## 5.4 ORTHORECTIFIED IMAGE (ORI<sup>SAR</sup>)

The Orthorectified Radar Image (ORI<sup>SAR</sup>) is a product that can be ordered optionally, in addition to any of the two **Elevation10** products.

The ORI<sup>SAR</sup> layers are orthorectified using one image of the TerraSAR-X stereo pair of one orbit direction and the final **Elevation10** DSM. The ORI<sup>SAR</sup> footprints are spatially coincident with the DEM, and so is the projection used. The horizontal spatial resolution of the ORI<sup>SAR</sup> is in accordance to the original TerraSAR-X basic image product. The ORI<sup>SAR</sup> product is delivered in 16-bit integer GeoTIFF format. The pixel spacing of 2.5 m is adjusted to the DEM data. On customer request, pixel spacing can be discussed. For further information on the ORI<sup>SAR</sup> product and details on the delivery format see RD-01 and RD-02.

ORI<sup>SAR</sup> sample data is depicted in chapter 7.

**Table 5-3: Specification of ORI<sup>SAR</sup> product**

<b>Method</b>	Orthorectification based on edited <b>Elevation10</b> DSM
<b>Grid Spacing</b>	2.5 meters
<b>Horizontal Accuracy</b>	5 - 10 m (90% circular error) depending on terrain
<b>Data Format</b>	16-bit GeoTiff
<b>Projection Information</b>	Universal Transverse Mercator (UTM) projection; units in meters. Horizontal reference datum WGS84, Vertical reference datum EGM96
<b>Auxiliary Metadata</b>	Metadata in XML-Format

## 6 PRODUCT DELIVERY FORMAT

### 6.1 NAMING CONVENTION

The file naming convention for the **Elevation10** product is standardized as follows:

TSX1\_DDEM\_AA\_XFFF\_GGYHH\_BB\_CCCCCCCC  
 (example: TSX1\_1DEM\_SM\_E005\_20N53\_46\_20100325)

The black letters are literals and remain unchanged at all times; the red letters have the following meanings (see Table 6-1).

**Table 6-1: Elevation10 product naming convention**

Letter	Meaning	Value / Range
D	DEM product level range	1 - 3
AA	TerraSAR-X Acquisition Mode	SM
X	Describes the location of the centre of the top left pixel. Either “E” for the eastern hemisphere, or “W” for the western hemisphere	E or W
FFF	Longitude in degree	000 - 180
GG	Decimal longitude in degree	00 - 99
Y	Describes the location of the centre of the top left pixel. Either “N” for the northern hemisphere, or “S” for the southern hemisphere	N or S
HH	Latitude in degree	00 - 90
BB	Decimal latitude in degree	00 - 99
CCCCCCCC	Production date of raw DEM	YYYYMMDD

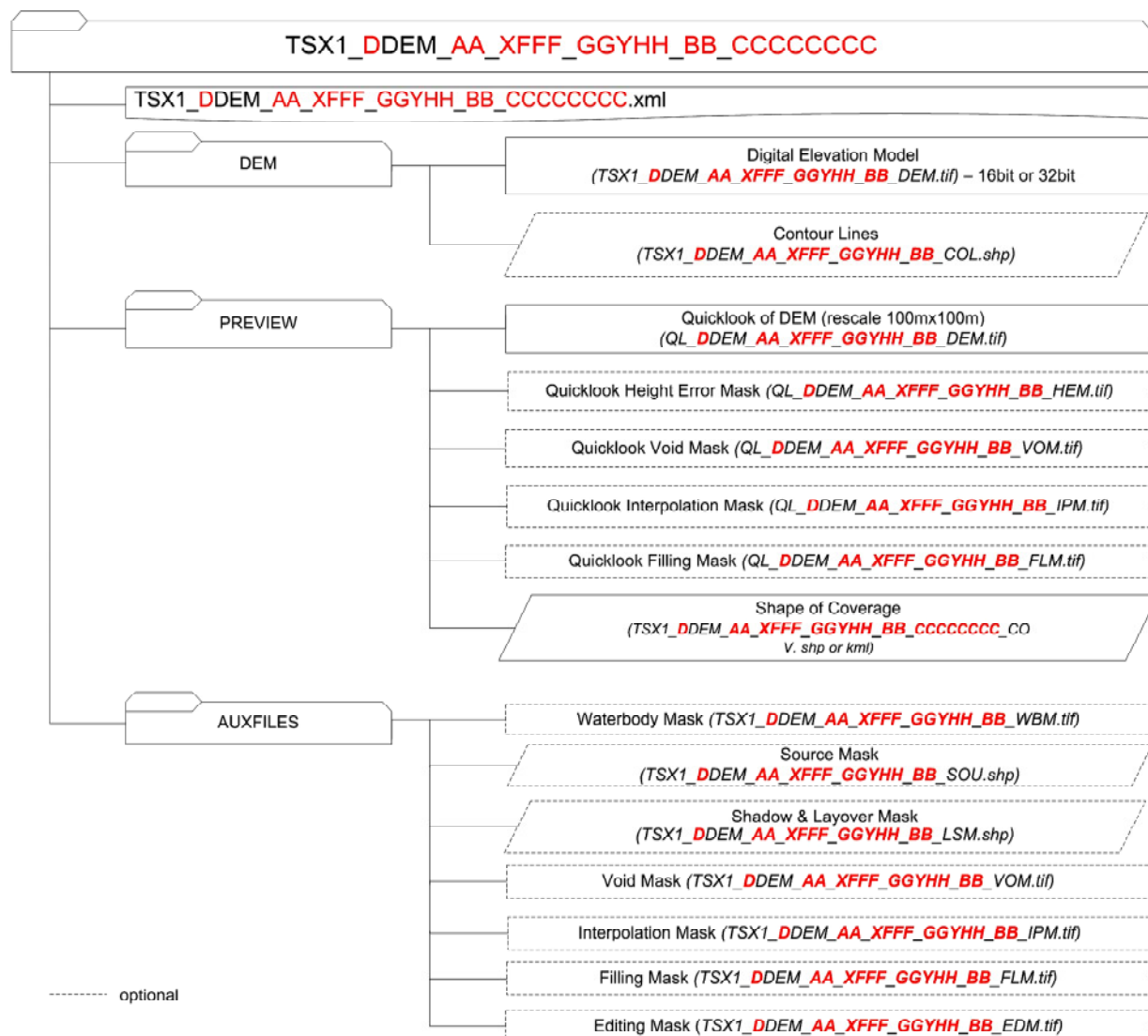
## 6.2 PRODUCT FILE STRUCTURE

The product file format is in accordance to the TerraSAR-X Basic Image Products structure.

All Elevation data are located in the DEM folder. In case of a **Elevation10** DTM, the contour lines will also be placed here, if requested. If an Orthorectified Radar Image (ORI<sup>SAR</sup>) is requested it will be delivered separately.

If auxiliary layers are ordered, they are located in the AUXFILES folder in full resolution. All quicklooks can be found in the PREVIEW folder, which contains a quicklook of the DEM data itself as well as the quicklooks of all auxiliary layers ordered.

Dashed lines indicate optional product components. In case the requested DEM covers an area of interest exceeding 100 km x 100 km, it is delivered in 100 km x 100 km tiles. Each tile is delivered as a separate product.

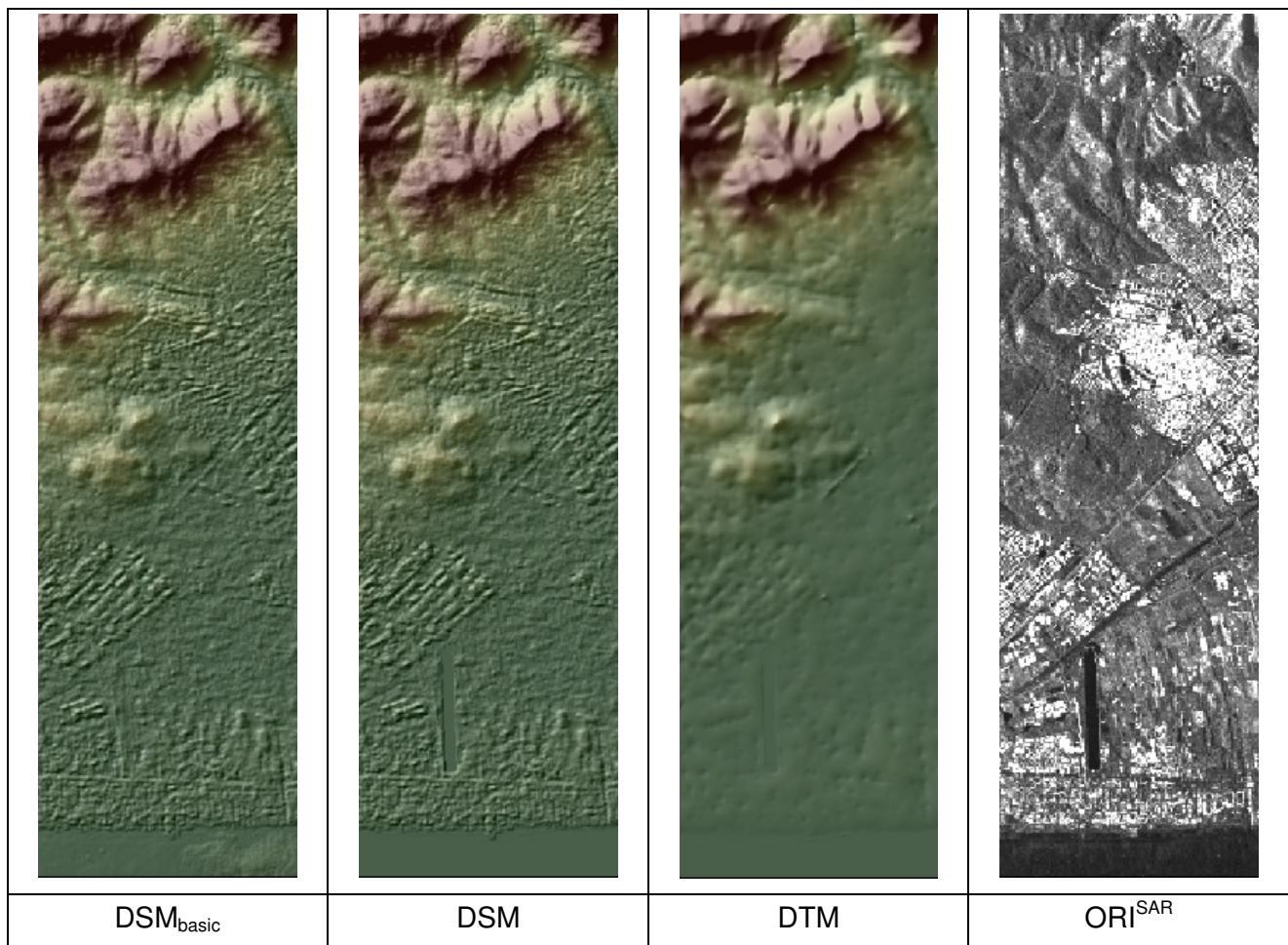


**Figure 6-1: Elevation10 product structure**

## 7 PRODUCT SAMPLE

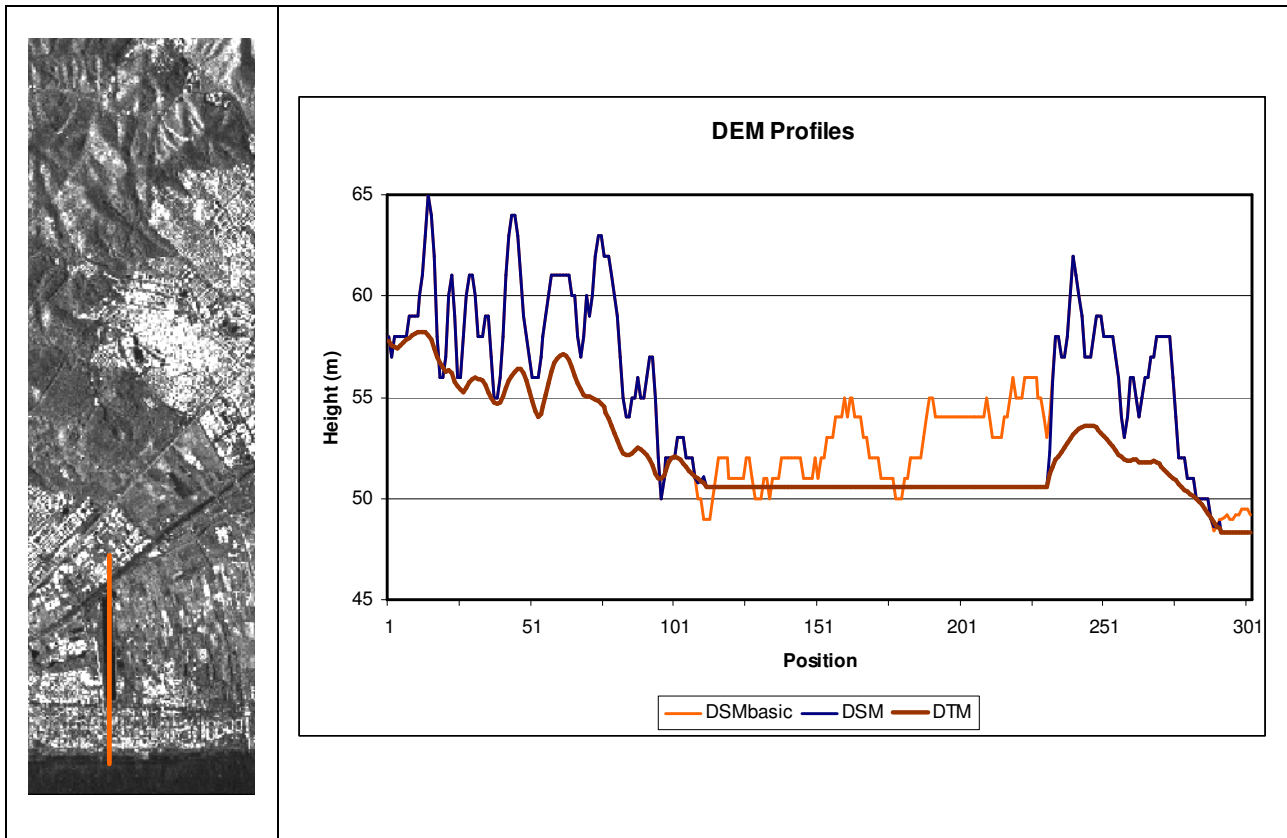
Sample datasets of **Elevation10** products are freely available on the website:  
<http://infoterra.de/free-sample-data>.

In figure 7-1 a close-up view of the test site Barcelona, Spain is shown.



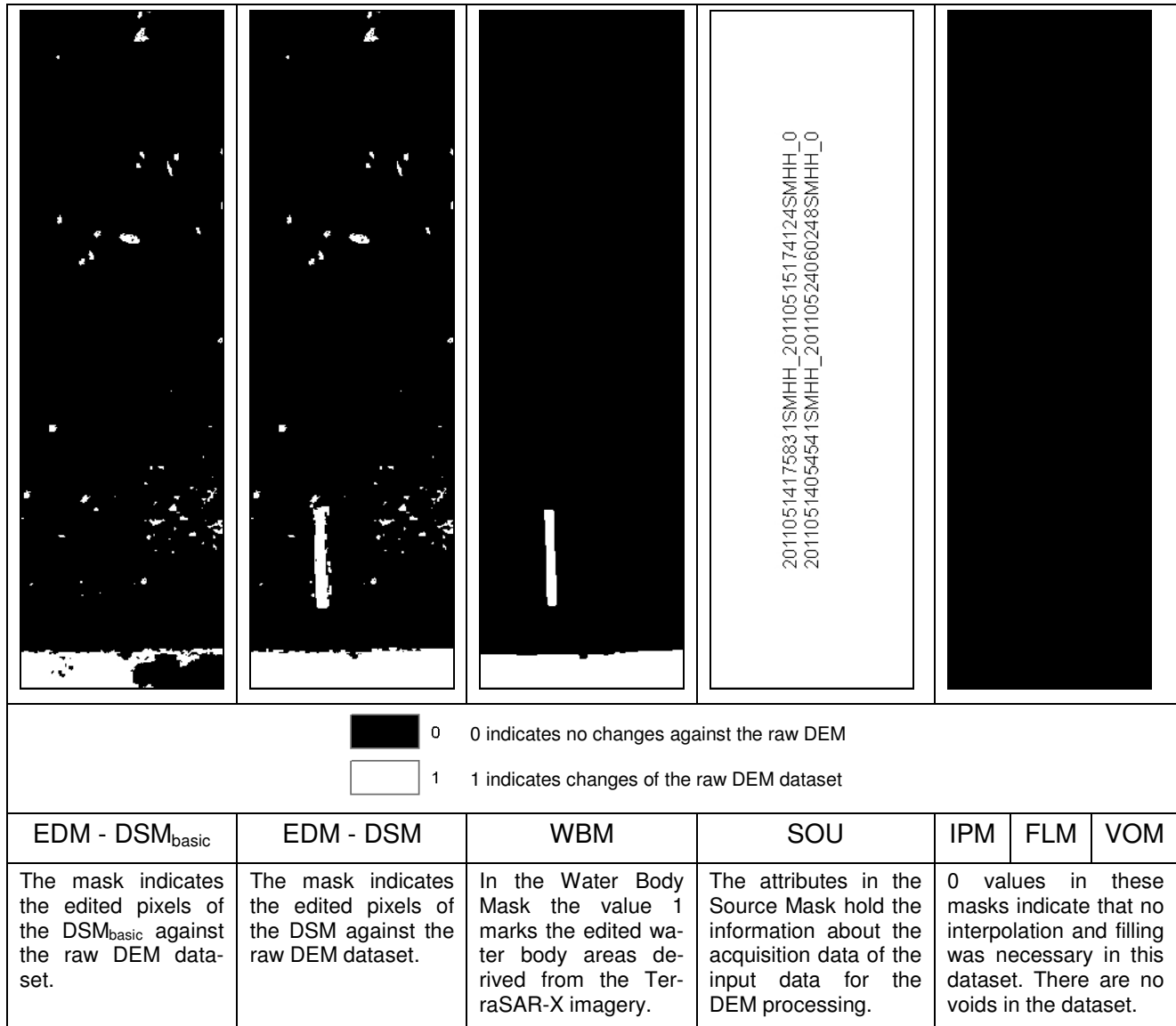
**Figure 7-1: Elevation10 product sample (Barcelona, Spain)**

In figure 7-2 profile plots of the DSM<sub>basic</sub>, DSM and DTM are shown. The profiles clearly show the height difference of the DSM and DTM dataset. Areas with water bodies are visible in the center of the profiles and at the right edge, where DSM and DTM are flattened to one height value. DSM<sub>basic</sub> holds the values from the raw DEM dataset.



**Figure 7-2: Elevation10 profiles (Barcelona, Spain)**

The optional quality layers of the **Elevation10** products are shown in figure 7-3.



**Figure 7-3: Elevation10 quality layers sample (Barcelona, Spain)**