

Automatic Editing of the TanDEM-X Global DEM

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Abstract

The spaceborne TanDEM-X mission successfully acquired and processed a global Digital Elevation Model (DEM) from interferometric bistatic SAR data at X-band. The product has been delivered in 2016 and is characterized by an unprecedented vertical accuracy. It can now be freely accessed by the scientific community in its 12 m (prior the submission of a scientific proposal) and 90 m (global) versions. Such a DEM is unedited, which means that it is the pure result of the interferometric SAR processing and subsequent mosaicking. Residual gaps, resulting from unprocessable data, are still present and water bodies are not flattened to the corresponding shore altitude. This paper reports on the developed algorithms at DLR for a fully automatic editing of the global TanDEM-X DEM, which comprise gaps filling and water editing. The result is a new global gap-free DEM product at 30 m resolution, which can now be used for processing the upcoming TanDEM-X ChangeDEM layer, as well as for a large variety of scientific applications.

1 Introduction

The global TanDEM-X DEM has been derived from bistatic X-band radar data, acquired between 2010 and 2015 by the two German twin SAR satellites TerraSAR-X and TanDEM-X. It shows an unprecedented quality for a global product, with an overall absolute height accuracy at 90% confidence level well below the 10 m mission specification [1]. Such a product is the result of the interferometric processing and subsequent mosaicking of overlapping acquisitions only. No further editing process has been applied, which means that water bodies appear noisy and residual gaps, due, e.g., to missing data or geometric distortions, have not been filled. An example is presented in figure 1.

From the original unedited 12 m resolution global DEM product, delivered by the German Aerospace Center (DLR), a 90 m unedited version has been recently made available free of charge for scientific purposes [2]. A global edited version at 12 m resolution can be purchased from Airbus Defence & Space [3], while edited 30 m and 90 m posting versions are available for free through the EU Copernicus DEM [4].

Digital Elevation Models (DEM) are nowadays of fundamental importance for a large variety of scientific and commercial applications. Precise and up-to-date information about the Earth's topography is required in many geoscience areas, such as geology, forestry, glaciology, oceanography, and hydrology. As an example, for the assessment of hydrogeological risk or the estimation of damages in case of natural hazards, the availability of a reliable DEM, which is gap-free and shows no discontinuities in presence of water bodies, represents a very valuable reference.

The urgent need for an easily accessible edited version of the TanDEM-X global DEM for both, scientific and data processing tasks has boosted the development of a fast and

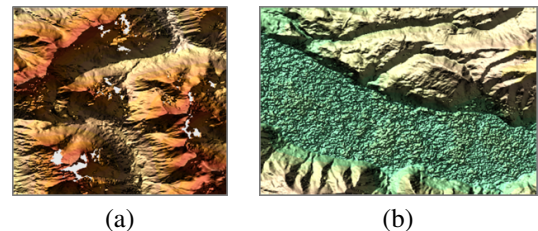


Figure 1 (a) Example of gaps still present in the global TanDEM-X DEM over high-relief terrain (white) due to geometric distortions in the original data (shadow and layover), (b) example of an unedited noisy water body.

completely automatized editing procedure for filling gaps and flattening water bodies.

2 Editing Framework

The high-level flow chart of the entire editing procedure is depicted in figure 2. First, overlapping pixels among neighbouring geocells have to be properly homogenized in order to avoid discontinuities and inconsistencies. Then the water body layer (WBL) derived from the individual TanDEM-X acquisitions [5] is considered. For each input DEM geocell, typically extending by $1^\circ \times 1^\circ$ in latitude and longitude [8], void pixels and WBL are properly segmented and classified into the following classes:

- *Solid Big*: extended gap area caused by missing acquisitions,
- *Water*: water identified through the reference WBL and small gaps with high probability of being part of the detected adjacent water body,
- *Water side*: gap neighboring a water body,

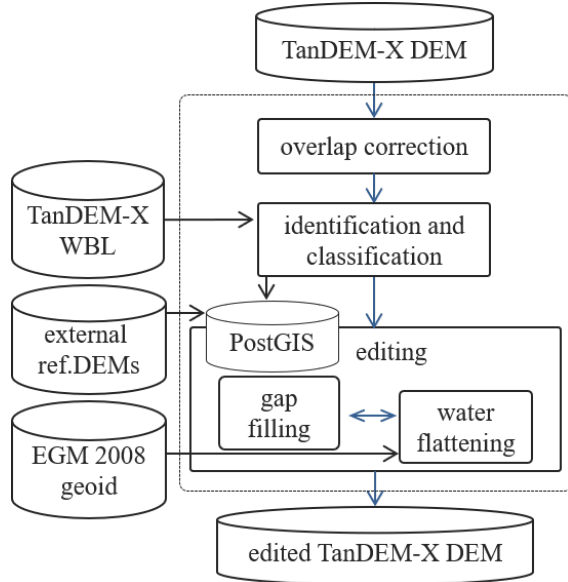


Figure 2 High-level flow chart of the developed automatic framework for DEM editing.

- *Disperse*: small gap located in the vicinity of other gaps of the same kind,
- *Small*: small isolated gaps,

An example is presented in figure 3.

Moreover, the gaps that are on the vicinity of the border are considered to be merged to the neighbour geocell, which is then considered as an individual geocell.

The resulting water is segmented into bodies and classified into ocean, lake and river depending on their characteristics. Ocean are considered water bodies that cover at least of one rim of a geocell and have a missing corner adjacent geocell. As the WBLs resolution of 50m some rivers are fragmented, which can result in a difficulty to make a correct classification of rivers and lakes. Specific rules such as ratio aspects are introduced to distinguish between both of them.

Finally, either voids or water editing is performed on each isolated and classified segment. Geocells are edited in parallel and the gaps or water bodies inside them are edited sequentially. Specific details on the editing procedures are presented in sections 3 and 4. Furthermore, details on the applied method to edit the pixels is saved into a 16 bit mask.

3 Gaps Filling

Different editing approaches are used depending first on the availability of a reference DEM and second on the type of the considered gap. The principle of the different interpolation approaches is shown in figure 4.

The most reliable available external reference is selected based on an a priori prioritization depending first on the height accuracy and second on the acquisition sensor similarity (e.g. first LiDAR, then SRTM, and so on). In case a reference DEM is available (figure 4 (a)), an approach

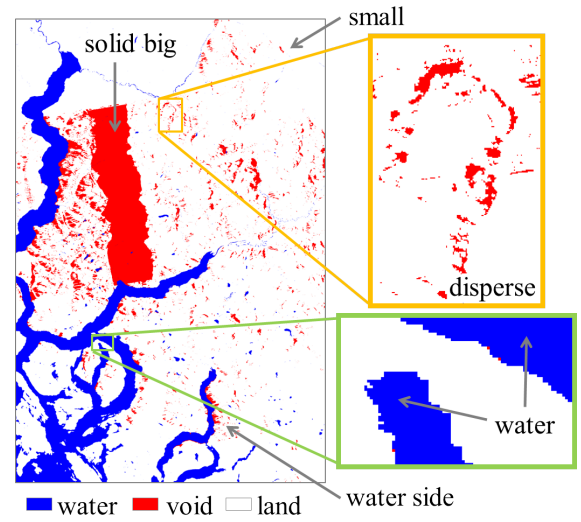


Figure 3 Segmented DEM image and associated classification tags as detailed in section 2.

called *stable delta surface fill*, which has been derived from the *delta surface fill* interpolation [6] is applied. The approach considers tie-points, used for anchoring the reference DEM to the TanDEM-X one. These are selected after computing a so-called *unreliable height mask*. The latter avoids fixing the external reference to unreliable pixels within the TanDEM-X DEM. In particular, *small* and *disperse* with very small or no *unreliable height mask* may present residual non-rigid shifts with respect to the external reference, requiring a fine co-registration between the two data sets, prior to the interpolation process. Subsequently, the delta DEM is calculated and the gap is interpolated. Additionally, a low pass filter is introduced here in the filled delta space. Finally, the filled gap is the result of combining the co-registered reference and the low-pass interpolated delta gap.

In the particular case, when no reference is found, a linear interpolation is performed for *small* isolated pixels 4 (b), while a inverse distance weighted interpolation is applied in other cases 4 (c).

Moreover, the resulting height is compared to the reference and histograms as well as the RMSE value of the height differences are saved in order to have a performance overview of the edition.

4 Water Flattening

The water bodies are flattened for each available TanDEM-X DEM geocell, after all geocells are processed a harmonization is performed. For oceans, height information based on the Earth Gravitational Model 2008 (EGM08) [7] is applied to smooth the water surface. This ensures a consistent and correct adaptation of the water height along the long shorelines and even geocell borders. For lakes, the height of the DEM pixels surrounding the lake is extracted. An histogram of the shoreline heights is calculated. From the peak to the left we choose the height that

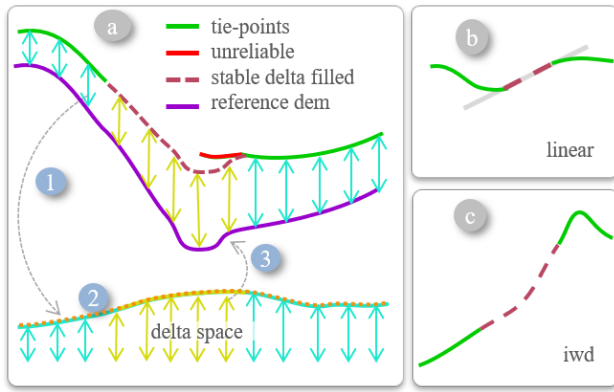


Figure 4 Gap filling approaches: (a) interpolation where external reference DEM is available using a co-registered external reference DEM (purple) through the following steps: (1) valid delta map (turquoise), (2) gap interpolation on the delta space (yellow), and its low-pass (orange) (3) is finally added to the reference to get the filled value (bordeaux). DEM reliable pixels are depicted in green. (b) and (c) are interpolation without an external reference. (b) Small isolated gaps: linear, (c) others: inverse distance weighted interpolation.

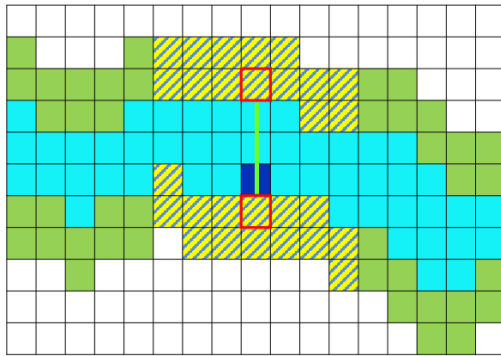
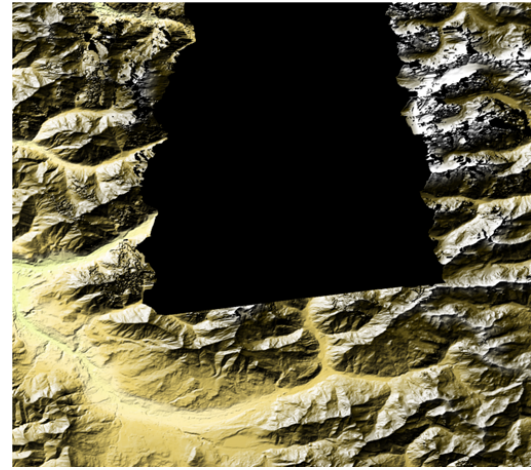
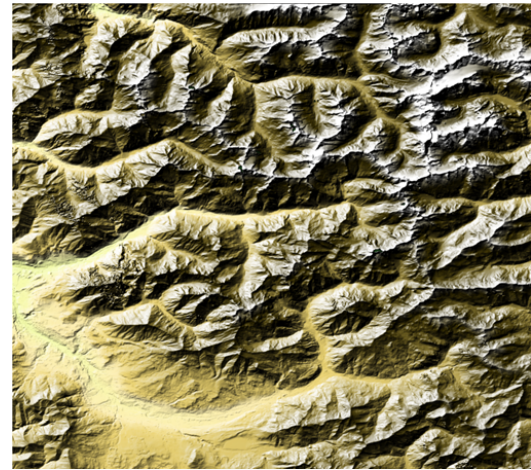


Figure 5 River editing approach considers 2 pixel shoreline of a river.

equals the drop to one fourth of the maximum of the histogram. This is considered to be the mean height of the undulated (EGM08) height of the lake. The river editing approach is the most complex and time-consuming one. Figure 5 shows a model of the used approach. In the case of rivers, water height is determined pixel-wise. First the two row pixel river shoreline are inspected (green) to increase the robustness of the estimation. Let us now consider the blue pixel. First, the two nearest shorelines pixels on each side of the river are identified (red frame). Several neighbouring pixels around these two initial ones contouring the river bed (dashed yellow/green) are taken into account. The 30th percentile is then calculated and interpreted as predominant shoreline for this blue pixel. Afterwards, the river height value is chosen to be one and half meter below its shoreline height. Finally, each water body touching the border of a geocell is considered to be harmonized with the neighboring geocell. Moreover, a quality



(a)



(b)

Figure 6 Example of gaps filling over high-relief terrain: (a) unedited global TanDEM-X DEM, (b) edited version.

check threshold is performed to flag possible wrong estimations.

5 Results

The editing of the global TanDEM-X DEM, besides the already edited Antarctica and Greenland [10], has started. Up to date over 3500 geocells have been processed. The complete zones of New Zealand, Australia, Europe, and South America have been already edited. The quality is very promising and the RMSE is mostly under 15 meters. An example of gaps filling over an extended mountainous area is presented in figure 6. Here, the extended gap in sub-figure (a) has been filled using a high-resolution LiDAR reference (b). An exemplary result of the water editing approach is shown in figure 7.

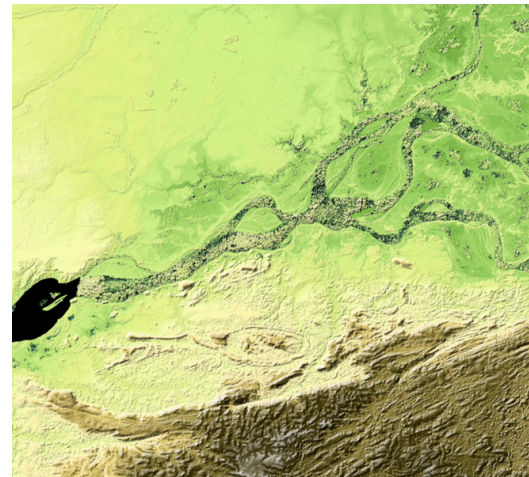
6 Conclusions

This paper presents an overview of the automatic editing of the global TanDEM-X DEM, developed at the German

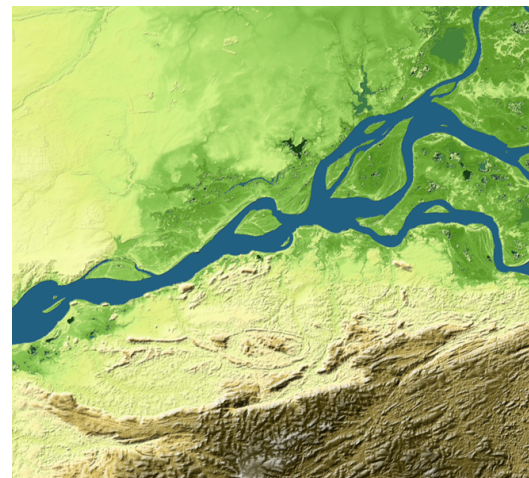
Aerospace Center (DLR) Microwaves and Radar Institute. The algorithm is designed to be fast and fully automatic at global scale. It comprises two main components: gap filling and water flattening. It processes on a geocell basis, considering the fusion of the gaps/water bodies at the border of the geocells for consistency. First, gaps and water bodies are properly classified. Individual techniques are then developed for the different type of gaps in presence/absence of an external reference DEM. When one is available, the stable delta interpolation method is applied. Otherwise an interpolation is considered depending on the type of gap, i.e. linear or inverse distance weighted interpolation. For water flattening, three different procedures have been developed. The Earth Gravitational Model 2008 is considered for oceans and its undulation is used for lakes flattening after finding the representative value of the shoreline. For rivers, a complex estimation of the shoreline is derived. Finally, the main editing information is saved into the editing mask, which is associated to the output product. The overall edition process is managed by a high-level framework and runs automatized without any need of a manual operator. The performance analysis and quality checks have shown promising results. The editing of the product has already started to be used as reference DEM for the processing of the upcoming TanDEM-X Change DEM layer [9, 11].

7 Literature

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(a)



(b)

Figure 7 Example of water editing: (a) unedited global TanDEM-X DEM, (b) edited version.