TERRESTRIAL IMPACT CRATERS – THE TANDEM-X VIEW

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ABSTRACT

In the past years we have exploited the TanDEM-X elevation model for impact crater research. This is the first high-resolution global DEM which permits accessing all confirmed impact structures. The high horizontal and vertical accuracies, coupled with the dense pixel grid, ensure that the DEM is well suited to study the morphologies of simple and complex craters over a wide diameter range.

Index Terms — Impact craters, TanDEM-X, DEM

1. INTRODUCTION

Impact cratering is a fundamental process on the surfaces of large and small bodies in the Solar System. In the early history of Earth, when zillions of small objects populated interplanetary space, this process occurred at rates much higher than today. However even today the number of small bodies orbiting the Sun between the large planets counts in millions. About 18,000, the Near Earth Asteroids - NEAs, are known to approach Earth closer than 1.3 AU and ~1,800 of them, the Potentially Hazardous Asteroids – PHAs, have a minimum intersection distance with Earth of $< 7.5 \times 10^6$ km. Ongoing all-sky surveys increase these numbers continuously. When such an object collides with Earth, it occurs with hypervelocities of more than 11.2 km s^{-1}. Hypervelocity impacts are unique because of their (1) enormous energy release, i.e. energy is defined by impactor's kinetic energy), (2) instantaneous effects, i.e. crater of 1 km forms in few seconds, (3) energy release is almost point-like, (4) extreme pressures and temperatures, i.e. several hundred GPa and several thousand °C, (5) unique shock-metamorphic effects, i.e. mineral deformation, melting, etc. and (6) rarity of events. The extreme conditions at impact cannot be produced by other geological phenomena. Therefore the shock-metamorphic modifications in the target rocks are an unambiguous tracer of a hypervelocity impact. Detecting those provides the only confirmation for a suspected impact structure.

2. THE TERRESTRIAL IMPACT CRATER RECORD

Earth is the planet with the most active surface. Plate tectonics, erosion, sedimentation change its face over geological periods and epochs. Other tectonic activities such as volcanism or earthquakes modify the terrestrial topography on shorter time scales. 70% of our home planet's surface is, in addition, covered by water. Since the ocean floors attain a maximum age of about 200×10^6 years, a large part of the terrestrial surface cannot provide an archive for Earth's geological past. While on other Solar System bodies without an atmosphere and open water the impact structures accumulated with time provides insights into their early history, on Earth the geological processes changing its surface erased most of the scars of previous impacts.

Currently approx. 190 impact structures have been found on Earth based on the strict criteria of shock-metamorphism (Fig. 1). They are listed in the Earth Impact Database (EID) at the Planetary and Space Science Center of the University of New Brunswick [1]. The EID entries are of different preservation status. Young, simple craters still display the bowl-shaped depression with an elevated rim. Larger structures can display fragments of their eroded morphology. Sometimes even those have been erased and the impact exposure is limited to outcrops without having left a trace in the topography. A considerable fraction of the EID is hidden from direct view buried underground. They can only be studied by drilling or geophysical methods.

The number of confirmed structures grows at a rate of about 1-2 new listings per year. How many impact structures can be expected on Earth at all? Estimates of the number of terrestrial impact structures still undiscovered suggest that the terrestrial crater record mainly lacks structures with diameters <6 km [2]. About 340 impact discoveries can be expected with approx. 250 of them falling in the range 0.25-1 km. Their ages will be short on geological time scales because craters of that size usually erode quickly beyond recognition.

3. TANDEM-X AND THE TERRESTRIAL IMPACT CRATER RECORD

The TanDEM-X DEM is the first space-borne elevation data set with global coverage permitting mapping with high vertical resolution in the order of meters and an independent pixel spacing of only slightly more than 10 m for all known confirmed impact structures. This is a considerable improvement as compared to the previous DEM from SAR

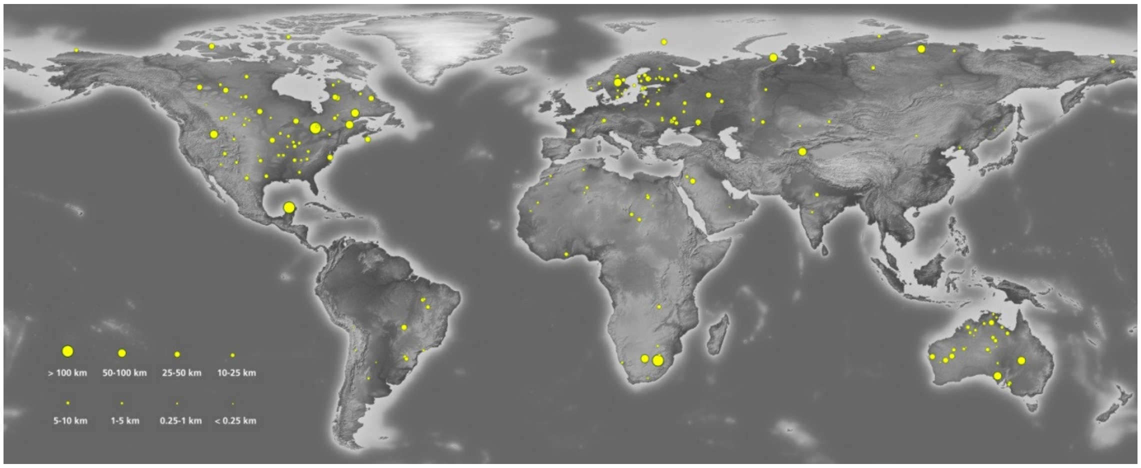

Fig. 1: The terrestrial impact structures as listed in the Earth Impact Database. The symbol size is a measure for the crater diameter (made with Natural Earth).

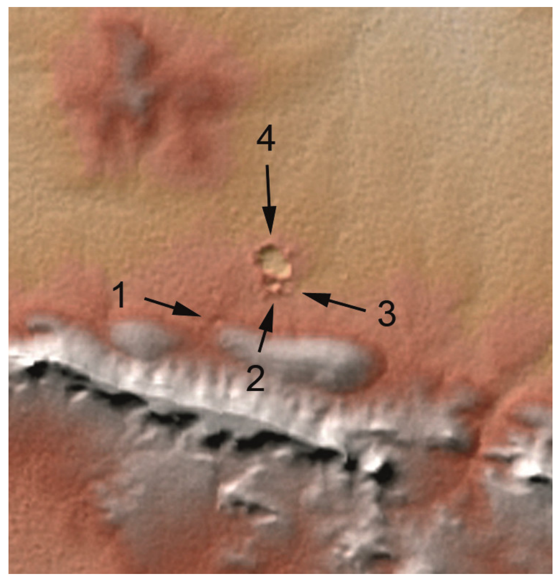

Fig. 2: The Henbury crater field in Australia's Northern Territory in a 2.7 × 2.7 km^2 scene. It comprises about 13-14 craters ranging in size between 6-180 m. In the TanDEM-X DEM structures as small as no. 1 with a diameter of 60 m can be discerned. No. 4 is the largest with 180 m, no. 2 and 3 measure 85 and 70 m.

interferometry, the SRTM 1" DEM, since not only does the pixel spacing increase by a factor of 2.5 but now also the sample of craters with latitudes above 60°N are within reach. Impact structures range in diameter from 14 m (Carancas/Peru) to 160 km (Vredefort/South Africa). With a pixel spacing of approx. 12 m all craters smaller than about 50-100 m are difficult to detect in the TanDEM-X DEM (Fig. 2). The exact limit also depends on the texture of the scene. Dry, arid ground allows recognizing smaller features while in vegetated areas a 100 m wide crater can still be masked out by the tree canopy. The smallest crater which can be recognized in a topographic map produced with TanDEM-X DEM data is Kamil/Egypt with a diameter of 45 m while Ilumetsä/Estonia, measuring 80 m, is hard to detect since it is located in an area with forest patches. Craters with diameters <1 km are particularly interesting because this is the diameter range where the terrestrial crater record is deficient. Our analysis of the small crater subsample from the EID demonstrates that TanDEM-X can be regarded as a source for reliably extract morphometric parameters or even identifying candidates in this size range. Meanwhile we have achieved a complete mapping of all entries of the EID [3].

4. VARIOUS DEM IN COMPARISON

Of particular interest was how the TanDEM-X DEM compares with other global elevation models. We tested the TanDEM-X DEM for several craters against the SRTM 1" DEM, the ASTER GDEM version 2 and the ALOS DEM. In addition, regional models based on LiDAR data had been included when available. Two examples are shown below: Ries in Germany, a mid-sized crater with a diameter of 24 km and Kara in Siberia, a 65 km wide structure without a prominent morphology.

Ries Crater (lat = 48°53'N, long = 10°37'E) with a diameter of 24 km is located in Bavaria/Germany in a well-developed, vegetated area. For reference, we used the "bare Earth" elevation model DGM10 derived from laser scanning with a resolution of 10 m. Fig. 3 illustrates the hillshaded TanDEM-X DEM and the LiDAR DEM. Comparison with other space-borne DEMs included SRTM, ASTER and ALOS. For another test we choose a 16 × 9 km^2 large area in the eastern Ries. It includes the Wennenberg as a mark of the inner ring, various forest patches, and is cut through by the small Wörnitz River. Fig. 4 displays this region for all 4 space-borne DEMs. On large scales TanDEM-X and SRTM agree well. The denser pixel grid and the higher vertical resolution, however, permits to even identify roads, smaller

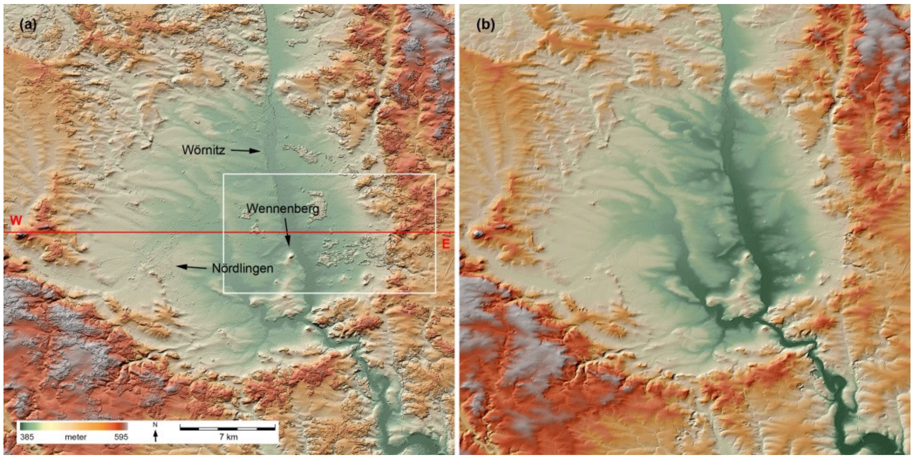

Fig. 3: The Ries crater in a hillshaded digital elevation map generated from TanDEM-X data (a) and from a LiDAR DEM (b). The horizontal line in (a) marks the W-E transect (Fig. 5) and the box the scene for the comparison between the various space-borne DEMs (Fig. 4). The crater structure is clearly outlined in both. TanDEM-X DEM, however, shows the local forests which form the "first return" of the X-band sensor where the LiDAR DEM is flat.

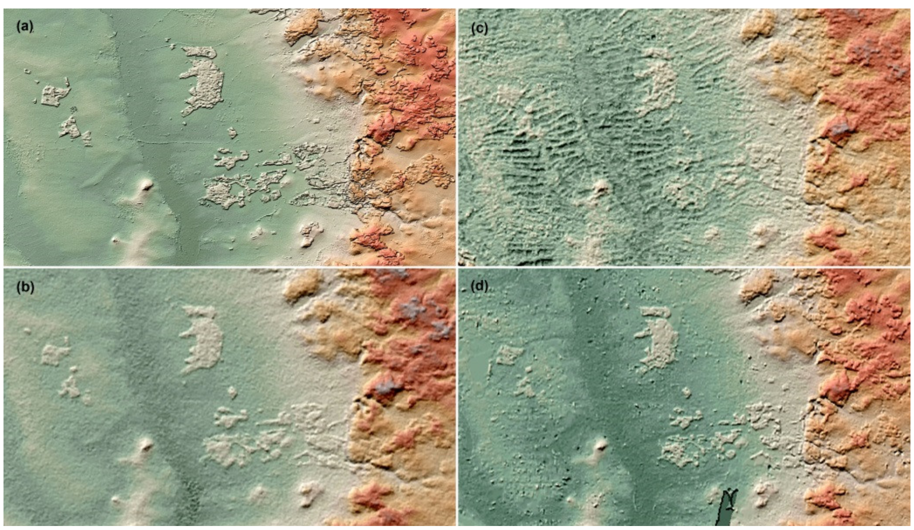

Fig. 4: Part of the Ries crater in a hillshaded map derived from TanDEM-X (a), SRTM (b), ASTER (c) and ALOS (d) illustrating the spatial resolution and accuracy of the four DEMs.

patches of vegetation and individual farmland. The two elevation models derived from stereo image pairs, ASTER and ALOS, exhibit artefacts at various levels. The corresponding W-E profile is shown in Fig. 5. On the selected vertical scale the LiDAR DEM, TanDEM-X, SRTM and ALOS are almost indistinguishable in the flat parts whereas woodland introduces obvious spikes in the space-borne data sets. The ASTER profile displays the largest scatter.

The Kara structure (lat = 69°05'N, long = 64°20'E) is a large impact in Siberia with an estimated diameter of 65 km. In topography it is only recognizable as a flat depression with a depth of about 150 m. Being located beyond the Arctic Circle, Kara could not be studied with SRTM data and the TanDEM-X DEM provides the first high-resolution data set for detailed morphological studies. Comparison was therefore made with the ASTER and the ALOS DEMs only (Fig. 6). ASTER displays a small amount of data voids but is characterized by a high noise level and several artefacts. Noise levels are reduced in the ALOS data. However, more than 10% of the area in Fig. 6 is lacking elevation data. In addition, large scale artefacts are present. TanDEM-X maps Kara and environs in full detail. This is also obvious in the NW-SE profile cut through the center of Kara's depression (Fig. 7).

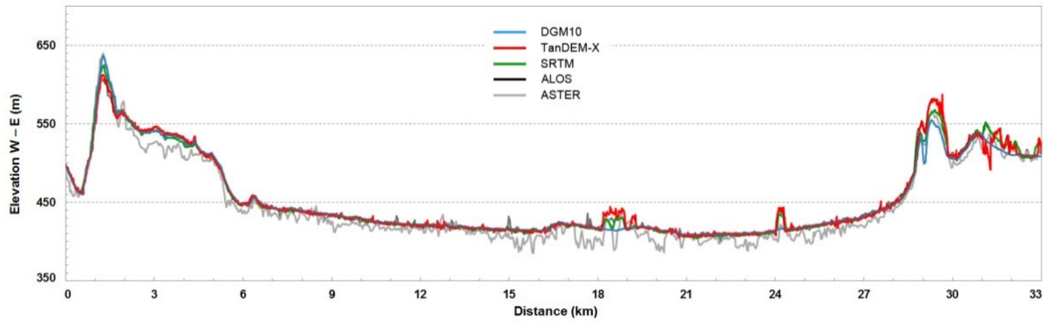

Fig. 5: W-E elevation profile through the Ries crater along the transect shown in Fig. 3a using the 5 studied DEMs.

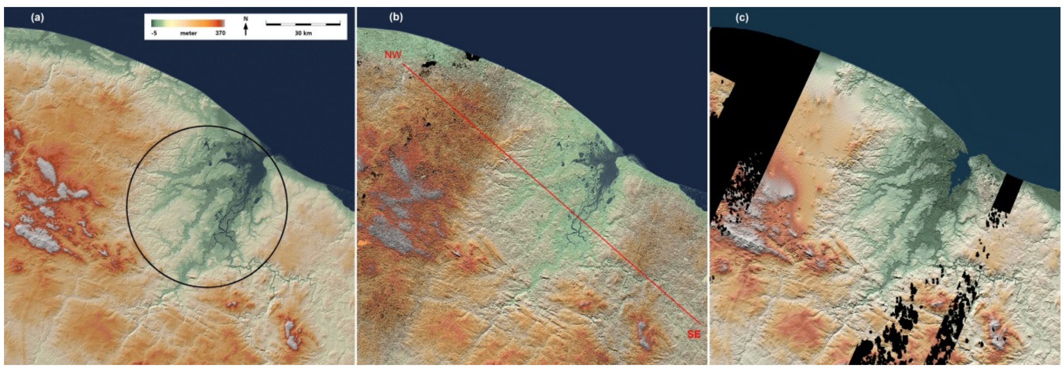

Fig. 6: The Kara impact structure. In the TanDEM-X map (a) the Kara location and diameter is indicated by the black circle. The ASTER scene (b) shows the location of the NW-SE transect of Fig. 7. ALOS (c) has considerable data voids, marked in black.

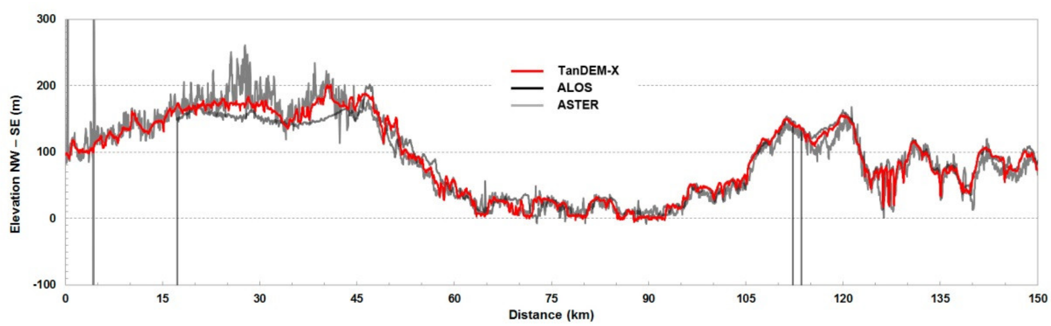

Fig. 7: NW-SE elevation profile through the Kara structure along the transect shown in Fig. 6b using the 3 available DEMs.

6. CONCLUSION

The TanDEM-X DEM is the first global high-resolution data set permitting morphological studies of all terrestrial impact craters. Our analyses presented here illustrate the improvements achieved in comparison with other existing space-borne DEMs: SRTM 1”, ASTER V2 and ALOS. It also sets a lower limit of 50-100 m for detecting small impacts. For craters with a diameter larger than 100 m the TanDEM-X DEM provides reliable morphometric properties.

7. REFERENCES

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