

MAPPING TERRESTRIAL IMPACT CRATERS WITH THE TANDEM-X DIGITAL ELEVATION MODEL

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ABSTRACT

We use the global digital elevation model (DEM) generated in the TanDEM-X mission for mapping the confirmed terrestrial impact structures in the Earth Impact Database of the Planetary and Space Science Center (PASSC) at the University of New Brunswick, Canada. The TanDEM-X mission generates a global DEM with unprecedented properties. The achieved global coverage together with the improved accuracy (in the sub-10 m range) and spatial resolution (12 m at the equator) opens new opportunities in impact crater research based on terrestrial space-borne remote sensing data. It permits both for simple and complex craters investigations of the morphology of the particular structure (rim height, central uplift, ring-like patterns, elevation profiles) and of the surrounding terrain (local deformation, drainage patterns) of outstanding quality.

1 Terrestrial Impact Craters

1.1 Impact Crater Record

Terrestrial impact craters are the relics of collisions of the Earth with Solar System objects of different sizes. Such collisions were frequent in the distant past when the Solar System was young but even today solid bodies from interplanetary space occasionally hit the terrestrial surface. With the discovery that a large impact occurred at the boundary of the Cretaceous and Tertiary periods causing, or at least contributing to, a major extinction 65 million years ago it became apparent that impacts have considerable consequences for the evolution and the development of life on our home planet. Investigating impacts has thus turned into an exciting research field combining Solar System astronomy, astrobiology, geophysics, geology, mineralogy and even paleontology.

The record of impact craters engraved in the terrestrial crust has accumulated over time. On all planets with solid surfaces, moons and asteroids, impact craters are normally the dominant surface characteristic. On the Moon, Mercury and Mars the heavily cratered highlands display impacts dating back to the time of the *Late Heavy Bombardment* about 3.8-4.1 billion years ago. The lack of global tectonic activity and erosion over the lunar or planet's lifetime led to the preservation of most of these features until the present day. On

Earth, in contrast, the crust underwent continuous modification due to various processes such as plate tectonics, erosion, sedimentation and glaciation. This prevented the development of an unbiased impact record. Only the ancient continental shields provide opportunities for detecting very old impact structures. In other areas, craters of a certain size have remained sufficiently intact only if they were formed rather recently or if their large size has prevented them from being eroded beyond recognition. Currently about 180 terrestrial features are considered to be of impact origin.

Since the end of the *Late Heavy Bombardment*, the impact rate is considered to be constant [1], although episodes with a higher or lower collision rate cannot be ruled out. More complete counts of terrestrial impacts over a broad size range are needed for more accurate estimates of their frequency, a parameter required even to make base decisions regarding impact hazard mitigation measures (e.g. see [2]).

1.2 Impact Crater Morphology

The structure formed by an impact depends on various parameters such as the impactor's size, its hypervelocity, its incidence angle and its composition [1]. Also the properties of the target rock play a role. Small impactors produce structures which are best described as 'simple', i.e. a bowl-shaped depression

with an uplifted rim and a diameter in the order of less than a few kilometres. Larger impactors cause larger craters with central uplifts or, in the extreme cases, even concentric rings. Once formed, an impact crater is modified over time by the Earth's geological processes. As a result, craters might no longer exhibit their unique simple or complex shape. Also the target site can change, e.g. the filling of depressions with water, abrasion of rock. Finally a distinct geological feature can be left which is not easily recognized as having been formed by an impact. Therefore impact crater detection cannot rely on finding circular structures. An unambiguous confirmation of the impact nature of such a feature can only be accomplished by on-site studies aiming at providing evidence for shock-metamorphic effects.

1.3 Impact Crater Catalogue

There are numerous compilations of terrestrial impact structures. However only a few follow the strict approach of listing only features verified by on-site measurements. A commonly accepted catalogue is the *Earth Impact Database* of the Planetary and Space Science Center (PASSC) at the University of New Brunswick, Canada [3]. It contains 184 confirmed entries with about 125 being listed as 'exposed'. A significant number of craters are not visible but are fully submerged or buried under ground where they can only be studied by drilling and/or geophysical investigations.

2 Impact Craters and the TanDEM-X DEM

2.1 Space-borne Remote Sensing of Impact Craters

With the advent of space-borne remote sensing, large portions of the Earth's surface, including remote areas, can be imaged and analysed in detail. Such data represent a valuable resource for finding impact crater candidates where on-site follow-on studies then have to find the 'smoking gun' of shock effects. Most space-borne images are captured in the visible or infrared wavelength range. In all those cases, solar illumination or environmental conditions, e.g. clouds, are crucial factors in identifying topographic features. At low solar incidence angles, crater rims can cast distinct shadows making detection an easy task, while at small solar zenith angles the same structure could almost be hidden in the local topography. In the past two decades, space-borne SAR sensors have provided another opportunity. In particular, when Digital Elevation Models (DEM) can be derived from the acquired radar data, they provide 3D information, unaffected by image feature contrast or local weather conditions (see **Figure 1**).

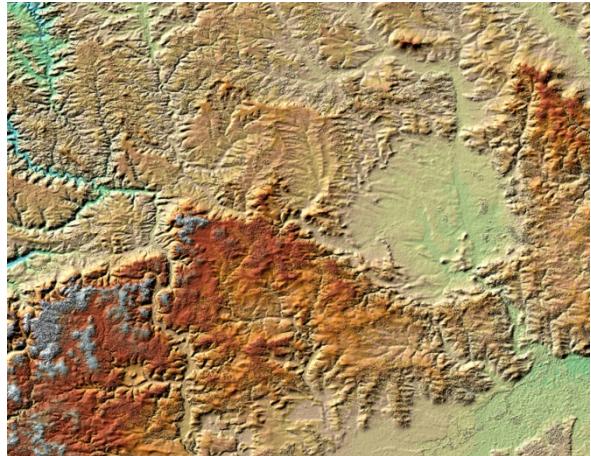


Figure 1 The Ries (\varnothing 24 km) and Steinheim (\varnothing 3.8 km) impact craters in a DEM derived from ERS-1/ERS-2 SAR data acquired 1995 [4].

An impact crater survey based on radar images acquired with ERS-1 and ERS-2 exists, but is limited to a small sample ($N = 20$) without exploiting digital elevation capabilities [5]. The general aspect of how to identify crater-like features in remote sensing data, optical or microwave, has meanwhile obtained wider attention, e.g. [6]-[9]. The main targets of such studies are, however, solar system bodies with abundant cratering such as Mars, the Moon or Mercury where the crater record allows drawing conclusions about the past evolution of the corresponding body.

The most precise space-borne DEM so far has been generated from SRTM X-band data. It complied to the DTED-2 standard, i.e. relative and absolute accuracies in the order of 15 m and a spatial resolution of 30 m at the equator, but only covered about 40% of the Earth's surface between 56°S and 60°N. The DEM from the C-band instrument on-board SRTM provided continuous coverage in that latitude range, but was generally reduced in spatial resolution. Currently existing DEM data from space-borne radar missions have been used for studying individual impact structures, e.g. [10].

2.2 Early Assessment of the TanDEM-X DEM

The TanDEM-X mission generates a global DEM with unprecedented properties [11]. The achieved global coverage together with the improved accuracy (in the sub-10 m range) and spatial resolution (12 m at the equator) opens new opportunities in impact crater research based on terrestrial space-borne remote sensing data. It permits both for simple and complex craters detailed investigations of the morphology of the particular structure (rim height, central uplift, ring-like patterns, elevation profiles) and of the surrounding terrain (local deformation, drainage patterns) of outstanding quality.

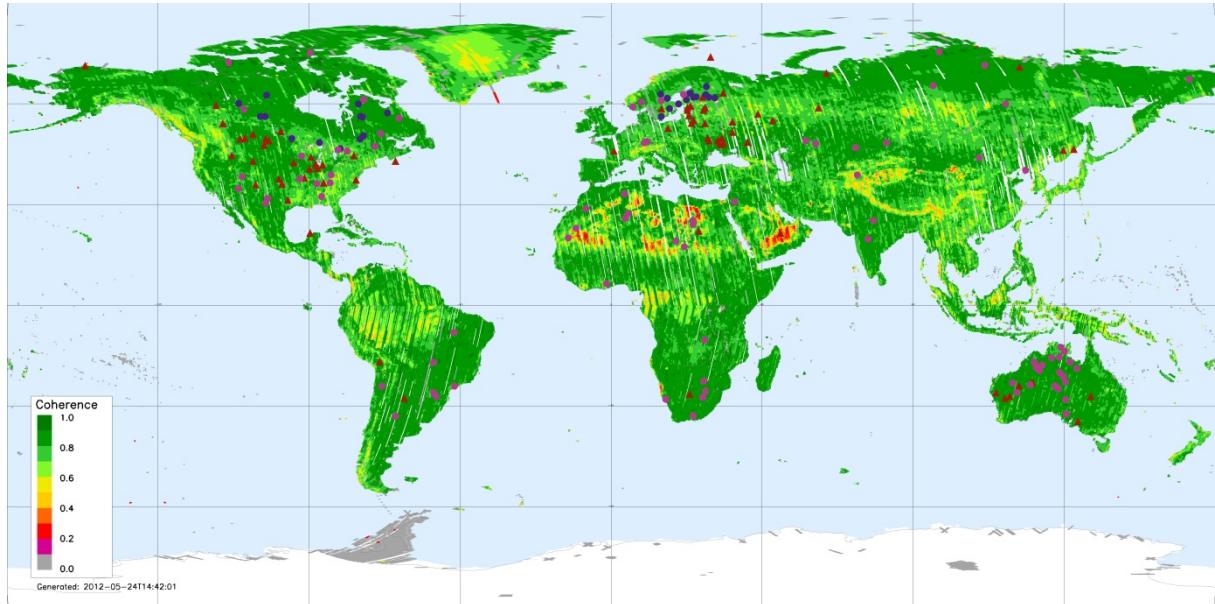


Figure 2 Coverage of the TanDEM-X DEM after the first year acquisitions with ‘coherence’ used as a quality indicator together with the locations of the impact craters in the *Earth Impact Database*. Purple (simple and complex structures) and blue (submerged structures) dots indicate detection in the TanDEM-X DEM. Triangles illustrate non-detections.

We have already analysed the database of quality monitoring (QM) products generated in the DEM processing environment when the individual X-band acquisitions are processed to yield the interim raw DEM data, including high resolution DEM images (2D and 3D). This preliminary approach yielded about 100 sites from the *Earth Impact Database* where either a simple, complex (mostly eroded) or partially submerged structure could be identified (see **Figure 2**). First quantitative conclusions such as relations between detectability and crater properties were also drawn (see **Figure 3**).

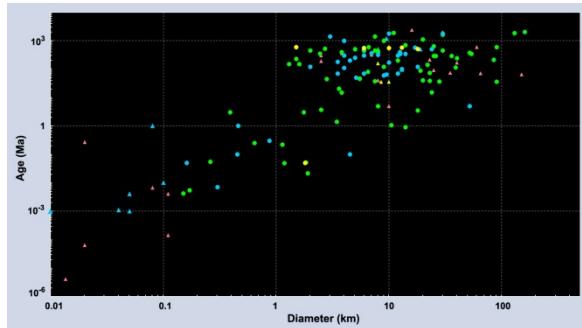


Figure 3 Detections of impacts from the Earth Impact Database in TanDEM-X QM products. Filled circles indicate detections, triangles non-detections with blue and yellow denoting structures with upper and lower age limits.

Exemplary cases of several impact structures as seen in TanDEM-X QM maps are given in **Figures 4–6**. These graphs provide an impression of what level of detail can be achieved once the final TanDEM-X DEM with maximum accuracy will be available.

2.3 Outlook

Our initial purpose is to generate a TanDEM-X impact crater reference catalogue. The catalogue can be used for further detailed studies of specific impact structures or the development of search algorithms in selected areas.

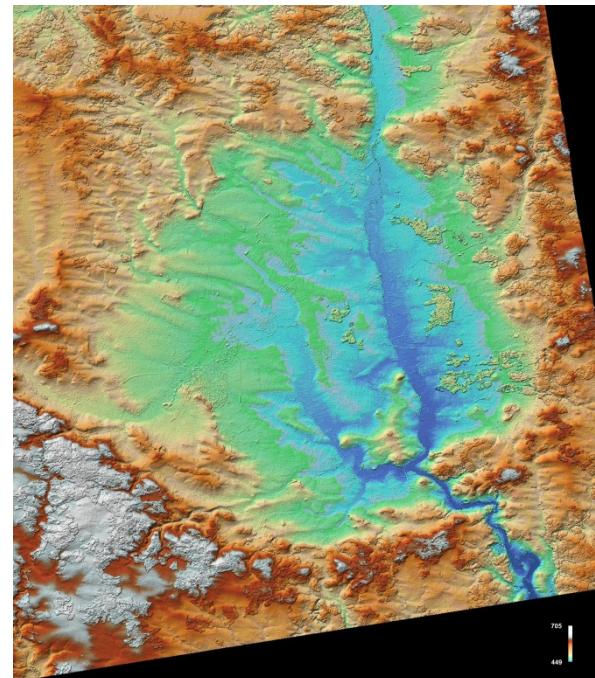


Figure 4 The Ries impact crater (\varnothing 24 km). Colour coding is such that blue indicates minimum and white maximum elevation values.

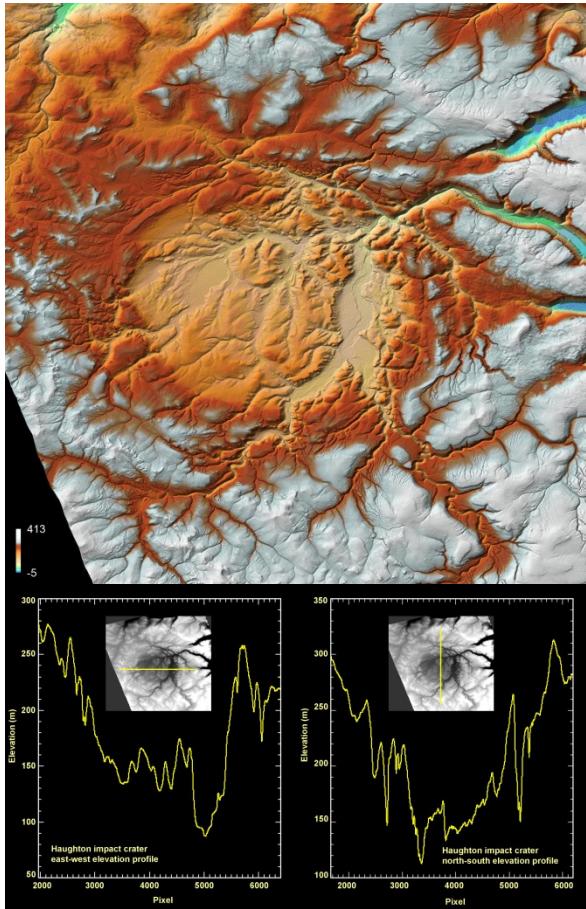


Figure 5 The Haughton impact crater (\varnothing 23 km) on Devon Island, Canada (top) together with east-west and north-south elevation profiles derived from TanDEM-X DEM data (bottom).

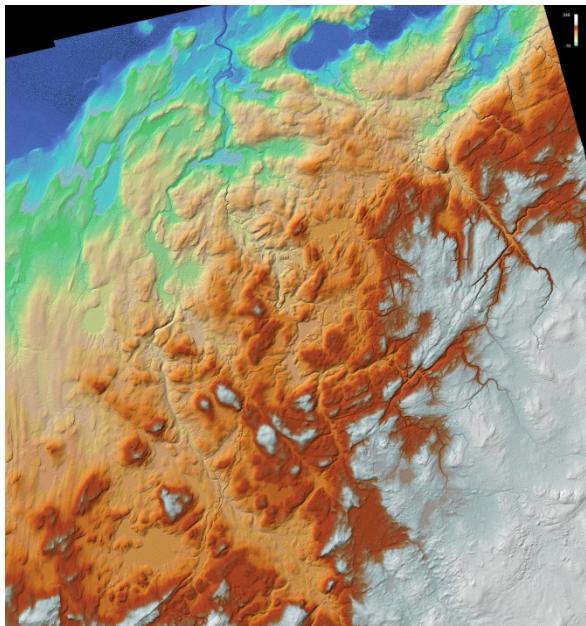


Figure 6 The recently confirmed Tunnunik impact crater (\varnothing ~25 km) on Victoria Island, Canada.

References

- [1] French, B.M.: *Traces of Catastrophe. A Handbook of Shock-Metamorphic Effects in Terrestrial Meteorite Impact Structures*. LPI Contribution 954, Lunar and Planetary Institute, Houston, 1998
- [2] Harris, A.W., et al.: *A Global Approach to Near-Earth Object Threat Mitigation*. IAA Planetary Defense Conference, International Academy of Astronautics, Bucharest, 2011
- [3] *Earth Impact Database*. Planetary and Space Science Center (PASSC), University of New Brunswick, Canada
(<http://www.passc.net/EarthImpactDatabase>)
- [4] Gottwald, M.: *Radarbilder zeigen Einschlagskrater auf der Erde*. SuW, 10, 2000, pp. 832-833
- [5] Chicarro, A., et al.: *ERS synthetic aperture radar imaging of impact craters*. ed. R.A. Harris, ESA SP-1275, Noordwijk, Netherlands: ESA Publications Division, ISBN 92-9092-985-5, 2003
- [6] Marchuk, A.G., Simonov, K.V.: *Detecting possible impact craters on the Earth's surface using the DEM data processing*. Bull. Nov. Comp. Center, Math. Model in Geoph., 10, 2005, pp. 59-66
- [7] Bue, B.D., Stepinski, T.F.: *Machine Detection of Martian Impact Craters From Digital Topography Data*. Geoscience and Remote Sensing, IEEE Transactions on, 45(1), 2007, pp.265-274
- [8] Krøgli, S.O.: *Automatic extraction of potential impact structures from geospatial data – examples from Finnmark, Northern Norway*. Ph.D. Dissertation, Department of Geosciences, Faculty of Mathematics and Natural Sciences, University of Oslo, 2010
- [9] Salamunićcar, G., Lončari, S.: *Method for Crater Detection From Martian Digital Topography Data Using Gradient Value/Orientation, Morphometry, Vote Analysis, Slip Tuning, and Calibration*. Geoscience and Remote Sensing, IEEE Transactions on, 48(5), 2010, pp. 2317-2329
- [10] Reimold, W.U., et al.: *Investigation of Shuttle Radar Topography Mission data of the possible impact structure at Serra da Cangalha, Brazil*. Meteoritics & Planetary Science, 41, 2006, pp. 237-246
- [11] Krieger, G., Moreira, A., Fiedler, H., Hajnsek, I., Werner, M., Younis, M., Zink, M.: *TanDEM-X: A Satellite Formation for High-Resolution SAR Interferometry*. IEEE Trans. Geosci. Remote Sens., 45, 11, 2007, pp. 3317-3341