Introducing the Global Elevation Data Testing Facility

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SUMMARY

One of the major stages in the production of a digital elevation model (DEM) is the development of its accuracy statement. This is typically done by summarising errors contributed at all stages of the DEM production and/or comparison of the assessed DEM with a reference elevation dataset. Obviously, a DEM accuracy statement is less accurate in areas where reference data are not available or are of poor quality, and/or the DEM production technique involves many stages with various types of errors. The Jet Propulsion Laboratory team faced such a situation while working on the production of a near-global DEM from the interferometry data acquired during the shuttle radar topography mission (SRTM) in February 2000. To tackle these obstacles, the task of producing the accuracy statement for the SRTM proved to be extremely time-consuming and very expensive. One of the reasons for this situation was the lack of a test bed for elevation measurements which would be of the highest quality and accuracy and available globally.

In the near future, at least two additional global DEMs—the ASTER DEM and the TanDEM-X—will be available. Some more, perhaps with regional extent, will be produced in the next decade or so. The authors of these DEM will doubtlessly face a similar task to independently verify the accuracy of their products.

In consideration of the difficulties presented above, the global elevation data testing facility (GEDTF) was introduced. The facility will develop and maintain a database of areas of our planet which fulfil certain conditions suitable for the elevation testing purposes. These requirements include: a) flat and homogeneous surface and b) known slope, aspect and elevation of the surface. Among the best candidates fulfilling these requirements are runways of airports, but any other type of natural or man-made areas could also be considered.

In this paper we present a detailed vision, framework, basic requirements and conditions of GEDTF. The paper also details the technological stages in the development of GEDTF that are currently being performed. The first version of the facility should be available online in a few months. The development and maintenance of GEDTF is funded by the government of Brunei Darussalam via its Science and Research programme.

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1. INTRODUCTION

A digital elevation model (DEM) is probably the most common method to represent the topography of the earth's surface (Maune, 2007). DEM, as a final product of work by geometricians, is the subject of rigorous scrutiny for its accuracy and precision and is thus suitable for certain engineering and environmental projects. It is essential to develop a quantitative statement expressing the limitations of the accuracy and applicability of the DEM data product. In essence, two approaches are used:

- Comparing the DEM with some reference data set of higher accuracy; and
- Using the error propagation law to estimate the overall accuracy of technological steps involved in the development of the DEM.

An example of the former strategy is in a paper by Berry, P. A. M. and his team (Berry et al., 2007) while Duren, R., E. and his team demonstrated the latter approach (Duren et al., 1998). There are also known examples of the use of both approaches for the same project (Rodríguez et al., 2005).

The majority of cases use a comparison method. There are, however, serious limitations of this approach, including the usually small spatial extent of the test data set. Also, the accuracy of DEM is dependent upon the properties of the modelled terrain (slope). Despite these limitations, the simplicity of this approach appears to 'soften' any criticism.

There is a current lack of accurate reference elevation data for a regional, continental or global assessment of existing and future DEM data products, as noted by the Degree Confluence Project (Iwaoa, et al., 2008). To address this issue, the Global Elevation Data Testing Facility (GEDTF) was introduced.

The basic premise of the GEDTF is based on a model of the error structure of a DEM, which assumes that the accuracy of a DEM is determined by instrumental errors, object-induced errors (such as slope) and residual errors (Becek, 2008). While the object-induced errors can be calculated (Becek, 2008), the two other types of errors are much more difficult to estimate. Hence, the only reasonable option remains the assessment of their magnitude by field experiments on a test bed.

A suitable test bed would be a relatively large and homogenous flat area to minimize the influence of the object-induced errors (Becek, 2008). It was noted from earlier tests that runways fulfil these requirements. Some natural features such as the *Salar de Uyuni* in Bolivia, are also found to be suitable.

The proposed GEDTF is a database of the anthropogenic and natural features that are suitable for testing elevation data and can be freely accessed through an Internet portal. It is hoped that the database can be enhanced by contributions and suggestions from individuals and organizations.

2. DEM ERROR MODEL

A model of a DEM is outlined here, based on a paper by K. Becek (2008). The variance of the DEM can be expressed using Equation (1):

$$\sigma^2 = \sigma_I^2 + \sigma_T^2 + \sigma_E^2 \tag{1}$$

where the subscripts ***I***, ***T***, and ***E***, refers to instrumental, object-induced, and residual errors.

The variance of the object induced error can be analytically calculated from Equation (2):

$$\sigma_T^2 = \frac{1}{12} d^2 \tan^2(s) \tag{2}$$

where d is the pixel size, and
s is the slope within the pixel.

Obviously, for the flat terrain ($s = 0$). the DEM variance is zero. Therefore, the DEM error consists of instrumental and residual errors only. This fact allows for comprehensive investigations of specific characteristics of these types of errors, which may lead to the development of error mitigation strategies or improvements in instruments. Now, the task is to identify suitable (i.e. flat and homogeneous) surfaces, which are evenly distributed across the project area. Depending on the spatial extent of the project, this task might be very difficult and costly (JPL, 2005). However, as Becek (2008) recently demonstrated, the surface of runways may be used as a cheaper and more robust site for testing elevation data sets.

The data collected in the GEDTF may be used in many different ways. For instance, for the elevation data testing, a profile of the runway from the tested data set is compared with the GEDTF runway elevation data. This approach has been used to test the Shuttle Radar Topography Mission (SRTM) data (Becek, 2008).

3. THE ELEVATION DATA TEST SITE

3.1 Runways

Runways are specific man-made constructions that essentially fulfil all the requirements of an "ideal" test site of the elevation data sets, according to the model of DEM error presented above. Runways are useful for this indicated purpose due to their following characteristics:

- Flat surface (slope is usually less than 1°);
- Homogeneous surface (asphalt, concrete);

- Significant length (1 – 4km);
- Width (15 – 60m);
- Free from obstructions;
- Technical parameters are in the public domain;
- Homogenous and highly technical conditions; and
- Distributed across the world.

A centreline or longitudinal profile of a runway is not usually perfectly horizontal. This detailed knowledge of the longitudinal profile of the runway would be very useful for GEDTF purposes. Without this piece of data on runways, an approximation of the profile has to be performed (Becek, 2008).

3.2 Other man-made structures

It may be envisioned that there are other man-made structures that possess qualities required for a test site, such as stretches of highways, large sport fields and open spaces. The main problem with these features is that they are rather unique and, unlike runways, are not found around the world, except for perhaps football or cricket fields. Also, these objects are much smaller than a runway (~100m by ~100m). Nevertheless, it would be very beneficial for the GEDTF project to include them in the database.

3.3 Natural features

A famous and well-documented natural object that is suitable as a test site for elevation data sets is the *Salar de Uyuni* in Bolivia (Lamparelli, 2003). This site has already been used to calibrate some space-based instruments including ICESat (Fricker et al., 2005). Similar objects do exist in the world, such as flat areas in deserts or dry lakes. Records of these objects, once documented, will be included gradually into the GEDTF database.

4. THE GLOBAL ELEVATION DATA TESTING FACILITY

The Global Elevation Data Testing Facility is a database of objects that fulfil the above-mentioned requirements of a test site. Most of these objects are runways. Figure 1 shows the distribution of the majority of the runways on the globe. The record structure includes the following fields:

- Runway number (an approximate magnetic bearing of the runway);
- Coordinates of the ends of the runway;
- Elevation of the ends of the runway;
- Length;
- Width; and
- Surface material.

The major source of the GEDTF data was a web-based aeronautical database available at http://worldaerodata.com/. Meanwhile, the Air Nav portal http://www.airnav.com/ provided most of the data for US airports. Selected statistics are shown in Table 1.

Table 1: Basics statistics on records in the GEDTF as of 1st March 2010.

Records	Mean Length	Mean Width	Most frequent Surface	Highest/Lowest Runway
8235	1838 m	36 m	Asphalt-75%	4176m/-380m

The continental spread of the test sites include the following approximate number of airports: Africa: ~800; Australia: ~650; Eurasia: ~3400; Islands: ~20; North America: ~2000; South America: ~1350; and Others: ~160. It is expected that the number of test sites, especially in North America, will grow to approximately 3000 by the end of March 2010.

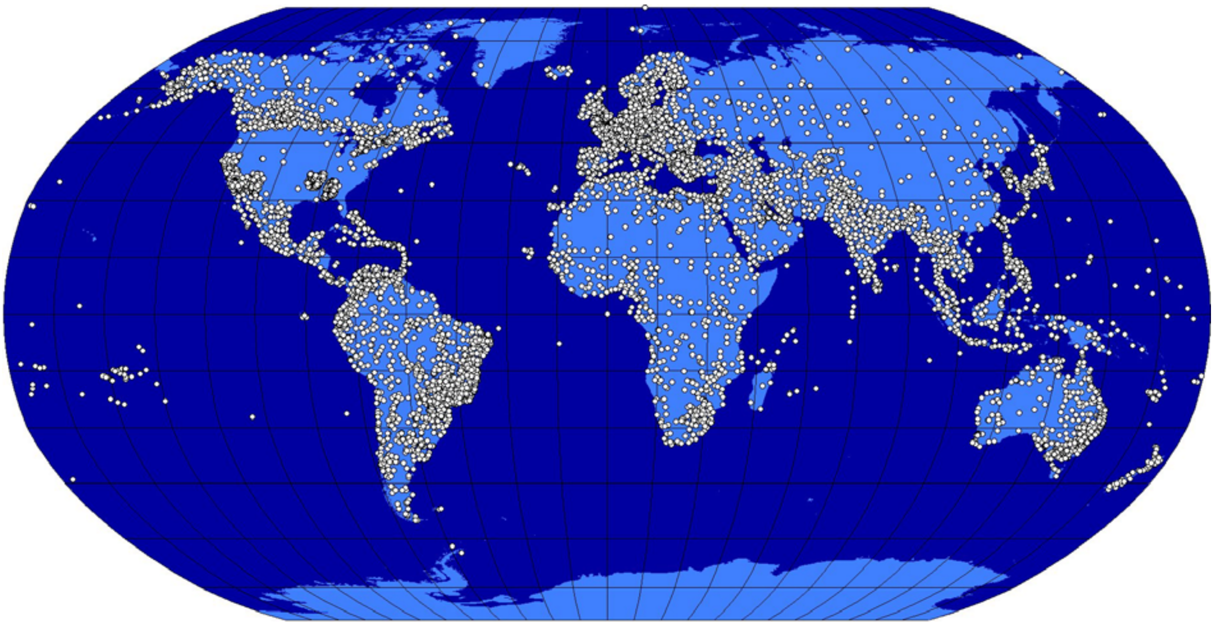

Figure 1. A map showing about 8,235 runways around the world. Many sites in the Unites States are still not shown.

It is desired that the GEDTF be enriched not only by including more records, but also by adding more attributes and accurate data to the database. An extremely useful attribute of a runway for the GEDTF would be its detailed centreline and cross-centreline profiles. For example, the Terminal Aeronautical Global Navigation Satellite System (GNSS) Geodetic Survey Program may provide these new attributes (NGA, 2005).

This program is designed to provide a highly-accurate, ground truth surveyed coordinates of the runways. The required accuracy of the coordinates will be better than 0.25 meters and both the ellipsoidal and orthometric heights will be provided. The program will cover most countries in the world, and most importantly, the database will be unclassified and is accessible at www.gedtf.org. The proponents of the GEDTF also hope to be able to collaborate with individuals and organizations to improve the quality and universality of the facility.

5. CONCLUSION

The dynamic progress in the development of interferometric synthetic aperture radar (InSAR) technology, marked by an extraordinary achievement of the Shuttle Radar Topography Mission in 2000 in the form of a global digital elevation data product, clearly indicates that many similar missions will follow in the future. One such program, known as TanDEM – X, is already underway. In addition, optical sensors are being used to produce the digital elevation data products, such as ASTER DEM or SPOT DEM Precision. All of these and future products will need to be assessed in terms of accuracy. The proposed accuracy model of a DEM is straightforward and easy to implement. The Global Elevation Data Testing Facility was introduced as a free service designed to provide all relevant data on available test sites in the area of interest. It is hoped that the GEDTF will be maintained and further developed by individuals and organizations through all forms of support.

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BIOGRAPHICAL NOTES

Dr Kazimiers Becek obtained his PhD from the Technical University Dresden, Germany, in 1987. He worked at the School of Surveying, UNSW, Sydney, Australia, from 1989 to 1994 before joining the Phone Directories Company, Gold Coast in 1995 as head of the company's cartography and data acquisition department. He also worked for the Queensland State government and the Gold Coast City local government from 1998. In 2003 he began working at the Geography Department, University of Brunei Darussalam, teaching Surveying, Photogrammetry, Remote Sensing, Cartography and GIS. His research interests include modeling or environmental systems and applications of active remote sensing methods for environmental studies. He has published papers in numerous conference proceedings and in the Geophysical Research Letters.

Khairunnisa Ibrahim received her MSc in Environmental Informatics from University of Leicester, UK in January 2010. She is currently working as a lecturer in environmental studies at Universiti Brunei Darussalam, where she graduated with a BA degree (major in geography) in 2006. Between 2006 and 2008 she worked as a journalist at one of the English newspapers in Brunei, *The Brunei Times,* reporting on local news and issues, particularly those with regards to the environment and the Heart of Borneo conservation project between Brunei, Malaysia and Indonesia. Her research interests include applications of GIS and remote sensing for environmental and development studies, conservation and sustainable development.

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