VALIDATING GLOBAL DIGITAL ELEVATION MODELS WITH DEGREE CONFLUENCE PROJECT INFORMATION AND ASTER-DEM ON GEO GRID

K. Iwao[a,*], N. Yamamoto [a], D. Patton[b], S. Kodama[a],R.Nakamura[a], M.Matsuoka[a], Tsuchida[a], S. Sekiguchi[a], E. Tsukuda[a]

[a]National Institute of Advanced Industrial Science and Technology, Tsukuba Central 2, Umezono 1-1-1, Tsukuba, Ibaraki 305-8568 Japan – (iwao.koki, yamamoto.naotaka, s.kodama, r.nakamura, m.matsuoka, s.tsuchida, s.sekiguchi, e-tsukuda)@aist.go.jp

[b] Canadian Information Systems; Bowker Avenue, Victoria, BC, Canada - davep@confluence.org

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ABSTRACT:

There are two major freely available global digital elevation datasets, known as GTOPO30 and SRTM. To know the accuracies of those data in global scale, relative evaluation of these data and validation with global scale are performed. We compared elevation values of GTOPO30 and SRTM 30 arc second datasets globally and found there are places in the world with more than kilometres differences in elevation especially in mountainous areas. Not only in mountainous areas, in planes also differed much. The values of SRTM are not always higher than that of GTOPO30. These differs exist randomly in global scale. Not only elevation, but also slope inclination and aspect of those data also very differ. To evaluate these differs, we develop a system, namely "Science DCP", which enables to validate these global DEMs at degree confluences, latitude and longitude integer degree intersections, in the world. ASTER DEM elevation data, field visit GPS elevation information from Degree Confluence Project, where in DCP were used as validation data. By using this system, we found that there exist distortions in the two datasets especially near 60-70 west longitudes. So we focused on 13°S 73°W where the values of these two datasets elevation differs about 600 m and where the values of these datasets much well. By using this system, user can easily validate global DEMs and the accuracy of global DEM will be improved.

1. BACKGOUND

1.1 Importance of global DEMs

GTOPO30 (Gesch et al., 1996) and SRTM (Farr et al., 2000), which are known as Global Digital Elevation Model data, are used in various applications such as visualization of geology, hydrologic modelling, remote sensing data processing. For example, HYDRO1k (USGS, 2000) is a geographic database developed to provide comprehensive and consistent global coverage of topographically derived data sets, including streams, drainage basins and ancillary layers derived from the GTOPO30. Whereas, HydroSHEDS (Lehner et al., 2006), Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales, is a mapping product that provides hydrographical information for regional and global-scale applications in a consistent format. It offers a suite of geo-referenced data sets (vector and raster) at various scales, including river networks, watershed boundaries, drainage directions, and flow accumulations based on SRTM. Those data are widely used for global earth simulation such as global water cycle modelling (Alcamo, et al., 2000).

1.2 Validation of global DEMs

GTOPO30, completed in late 1996, was developed over a three year period through a collaborative effort led by staff at the U.S. Geological Survey's EROS Data Center (EDC), is a global digital elevation model (DEM) with a horizontal grid spacing of 30-arc seconds (approximately 1 kilometer) and was derived from several raster and vector sources of topographic information.

The Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth. SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000. SRTM data was used to update the older USGS GTOPO30 global DEM, by averaging to 30-arc second resolution and replacing GTOPO30 between the latitudes of 60° north and 56° south. As for these data, verification is performed, respectively. For example, to validate GTOPO30, SLA: Shuttle Laser Altimeter data was used (Harding et al., 1999). Sun et al also used SLA for validation of SRTM (Sun et al., 2003).ERS-1 and ENVISAT satellite altimeter data also used for near-global validation of the SRTM DEM (Berry et al., 2007). Also two datasets are compared each other at volcano (Gerstenecker, et al., 2005). According to those reports, accuracies of GTOPO30 and SRTM30 are less than several hundred meters generally. However there is very limited to compare these DEMs globally. GTOPO30 has a horizontal grid spacing of 30 arc seconds which corresponds to 21,600 rows by 43,200 columns in Geographic projection. Usually, elevation data are provided as 16-bit data, total amount of the size run into about 1.74 gigabytes, which might be one of the reasons why global scale comparison were not well performed till now.

1.3 Proposed methods for global DEMs validation

The validation methods proposed in the past focused on statistical evaluation using a small amount of validation information in global scale. Some researcher used satellite altimetry data for global validation of DEMs. Those are not a "ground" based actual information.

* Corresponding author. Koki Iwao iwao.koki@aist.go.jp

Gorokhovich and Voustianiouk used field data for assessment of SRTM (Gorokhovich and Voustianiouk, 2006). However, the field data were taken in USA and Thailand. Properly speaking, numerous, spatially balanced field surveys over the entire earth are preferable, but it was very difficult for any one researcher or a small group of researchers to conduct a thorough field survey over the entire earth. We develop a system, namely "Science DCP for DEM", which enables to validate these global DEMs at degree confluences in the world.

We propose to use the Degree Confluence Project (the ''DCP'') derived information (DCPwebsite, 1996 http://www.confluence.org/). The objective of the DCP is for participants to visit the latitude and longitude integer degree intersections (the ''confluences'') and document the state of the surroundings. In this study, we propose a method to develop validation information for DEMs based on the information collected by the DCP, and demonstrate the usefulness of the ''DCP-derived information''. We use elevation information obtained from DCP GPS readings. While this GPS reading value is just a point elevation value, spatial distortions in 30-arc second square should be considered. ASTER-DEM elevation information for a 30-arc second square covering the DCP confluence is used to derive an elevation deviation. The ASTER Digital Elevation Model (DEM) product is generated using bands 3N (nadir-viewing) and 3B (backward-viewing) of an ASTER Level-1A image acquired by the Visible Near Infrared (VNIR) sensor. We use this ASTER-DEM elevation information.

1.4 Science DCP on GEO Grid

ASTER-DEM data is not freely accessible, so we plan to provide the deviation information through our system named GEO Grid. The GEO (Global Earth Observation) Grid is an E-Infrastructure to accelerate GEO sciences, based on the concept of using a set of Grid and Web service technologies to virtually integrate whole datasets, via a common and easy to use access management system (Sekiguchi et al., in press). GEO Grid uses OGC (Open Geospatial Consortium) standards such as WCS (Web-Coverage Service), and manages security issues so that it can handle commercial data such as ASTER. Approximately 140TB of the ASTER data (1,400,000 scenes) stored in the hard disk based on GEO Grid and can easily produce DEM on-demand bases in near real time, and those data are still updated daily bases on GEO Grid with huge computing resources. Under the GEO Grid, we started up a so-called "Science DCP" web site which federates GTOPO30, SRTM, DCP and ASTER-DEM with our system to easily validate existing global DEMs under the above secured environments.

1.5 Objectives of this study

The objectives of this study is to compare GTOPO30 and SRTM 30-arc second data globally, develop a system to validate these datasets by using ground based and satellite based validation information. Based on the result of the comparison, we evaluate the reason of differences /agreements in two datasets by using this system.

2. DATASETS

2.1 GTOPO30

GTOPO30 is a global DEM based on data derived from eight sources of elevation information, including raster and vector datasets (U.S. Geological Survey., GTOPO30 website:
http://edc.usgs.gov/products/elevation/gtopo30/gtopo30/html).
The list of the eight data sources are as follows:

- Digital Terrain Elevation Data
- Digital Chart of the World
- USGS Digital Elevation Models
- Army Map Service Maps
- International Map of the World
- Peru Map
- New Zealand DEM
- Antarctic Digital Database

About half of the part was originally comes from Digital Terrain Elevation Data, DTED. DTED was used as the source for most of Eurasia and large parts of Africa, South America, Mexico, Canada, and Central America. Data processing are reported by Verdin and Greenlee (1996), Bliss and Olsen (1996), and Gesch and Larson (1996).

2.2 SRTM

The SRTM data sets result from a collaborative effort by the National Aeronautics and Space Administration (NASA), the National Geospatial-Intelligence Agency (NGA), German and Italian space agencies to generate a near-global digital elevation model (DEM) of the Earth using radar interferometry. The SRTM radar contained two types of antenna panels, C-band and X-band. The near-global Digital Elevation Models (DEMs) used in this study is made from the C-band radar. The Land Processes Distributed Active Archive Center (LPDAAC), and the Seamless Data Distribution System (SDDS), EROS Data Center (EDC) distribute those products. There is a difference between the data distributed via these organizations in 30-arc second data in producing the data from original 1-arc second data. SDDS provide sub-sampled data whereas LPDAAC provide averaged data (NASA, available online). by the same method the NGA uses to generate DTED level 1 data, namely by "subsampling". Also there are several versions in the project. In this project, we use version two of 30" world – averaged data provided by LPDAAC.

2.3 Degree Confluence Project

The DCP was initiated by Alex Jarrett in February 1996. Since then, volunteers have conducted visits at confluences around the world. Visitors to any of the confluences may use the DCP website to register photographs taken at the confluence together with text about their visit, which collectively can form the basis for a ''Current Site Description (CSD)'' of the confluence. Any number of CSDs may be registered for a single confluence by anyone who has visited the site. This provides information regarding that confluence over varying periods. The WGS84 system is used for locating the confluence. For all of the 64,442 possible confluences, 16,180 meet the goals of the project confluence. Near the poles and oceans are discounted from having a CSD. Positional errors of the visits must be within 100 m. As of Oct 2007, a total of 5,205 confluences have been visited at least once, which covers about 20% of all possible confluences (24,482) on or close to land. In this study, we propose a method for developing validation information for

DEMs based on the information collected by the DCP, and demonstrate the usefulness of the ‘‘DCP-derived information’’. We use altitude information obtained from DCP GPS readings.

2.4 ASTER DEM

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is a research facility instrument provided by the Ministry of Economy, Trade and Industry (METI, former MITI), Tokyo, Japan to be launched on NASA's Earth Observing System morning (EOS-TERRA) platform in 1998. ASTER has three spectral hands in the visible near-infrared (VNIR), six bands in the shortwave infrared (SWIR), and five bands in the thermal infrared (TIR) regions, with 15, 30, and 90 m ground resolution, respectively (Yamaguchi et al., 1998). The VNIR subsystem has one backward-viewing band for stereoscopic observation in the along-track direction, with a base-to-height ratio of 0.6. The vertical accuracy of the DEM data generated from the Level-1A data is 20 m with 95% confidence without ground control point (GCP) correction for individual scenes. Geolocation accuracy that is important for the DEM datasets is better than 50 m. (Fujisada et al., 2005).

Approximately 140TB of the ASTER data (1,400,000 scenes) are observed and archived on GEO Grid. In this research, elevation value of each DCP, maximum and minimum elevation values in 30-arc second square are queried, and average and variance are calculated for the latest acquired ASTER data covering DCPs.

3. RESULTS

3.1 Comparison of GTOPO30 and SRTM30 in global scale

To compare two datasets, we downloaded GTOPO30 and SRTM30 respectively.
GTOPO30 (USGS):
http://edc.usgs.gov/products/elevation/gtopo30/gtopo30.html
SRTM30 (LPDAAC/NASA averaged):
ftp://e0srp01u.ecs.nasa.gov/srtm/version2/

GRASS GIS version 6.2 is used to process these data (Neteler and Mitasova, 2007). The DEMs are downloaded as tiles and imported into GRASS GIS using r.in.gdal command, then creates a composite raster map layer for each DEM using r.patch command. Then difference in these two elevation map was calculated using r.mapcalc command. Figure 1 shows the difference as global map. Figure 2 focused on mountainous area around Venezuela where elevation of GTOPO30 is higher than that of SRTM30. This area covers Guiana Highlands.

Figure 1. GTOPO30 - SRTM30

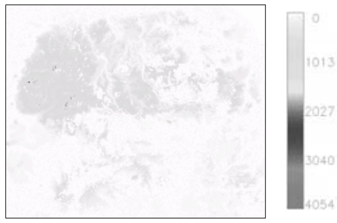

Figure 2. GTOPO30 - SRTM30 (Plus area only)

This result shows that there are places where the elevation of GTOPO30 is about 4,000 m higher than that of SRTM30. Not only in mountainous area, had we focused on low elevation area. Figure 3 shows around Tokyo. Both data are masked to focus 0-10 m only then compared. The range of the outcome is ±19 m.

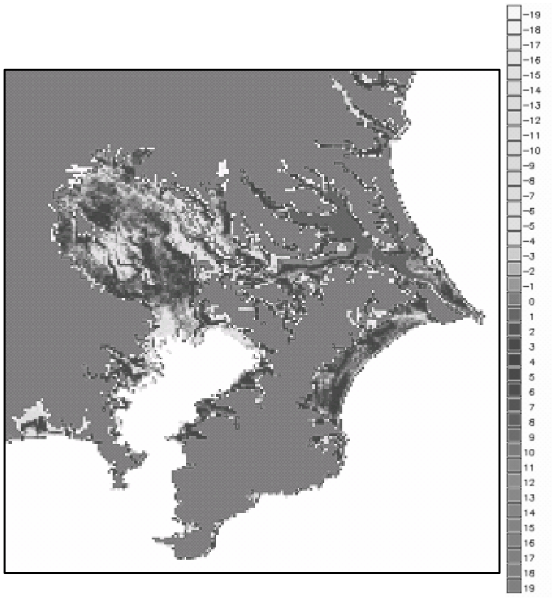

Figure 3. GTOPO30 – SRTM30 (Around Tokyo)

Not only mountainous area, but also low elevation area also differs. Next, slope inclination and aspect also evaluated. The maximum slope inclination of GTOPO30 was 65 degree, whereas that of SRTM30 was 74 degree. Figure 4 shows differences in aspect.

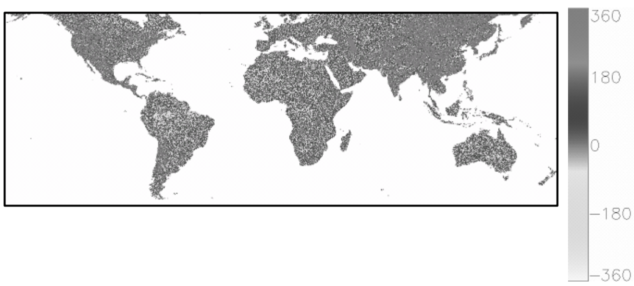

Figure 4. Aspect GTOPO30 - SRTM30

The difference in aspect means that if we develop hydrological map directly from these DEMs, the outcome completely differs.

3.2 Implementation of Science DCP

To evaluate these errors, we develop a system, namely "Science DCP", which enables to validate these global DEMs at degree confluences, latitude and longitude integer degree intersections, in the world. Figure 5 shows login page of Science DCP.

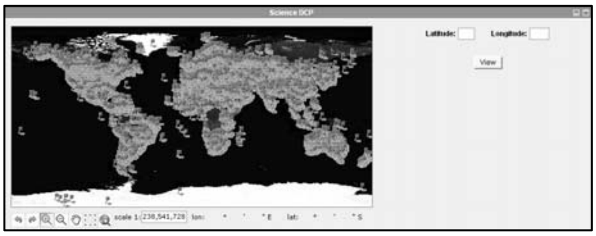

Figure 5. Science DCP login page

For each point, three kind of information are given. First, Field visit photos are provided by DCP. With these photos, user can easily imagine the land cover and/or landscape of each DCP point. If the point not visited, blank space with a message "This confluence has not been visited or indexed" is given in this space. Second, elevation information from multiple data is shown. Sample list of the data is shown in Figure 6.

SRTM30:	144 m
GTOPO30:	160 m
DCP #1:	166 m
ASTL1A_0603131035510612149011.dat:	
ASTER Height #1:	179 m
ASTER30 Height #1:	180.5 m
ASTER30 Height Max #1:	203 m
ASTER30 Height Min #1:	154 m
ASTER30 Height Variance #1:	8.3

Figure 6. Sample list of elevation information at 60°N 11°E

Here, SRTM30 and GTOPO30 values are extracted in advance. DCP #1 value comes from GPS reading from DCP. If GPS readings are given by multiple visits, list of DCP increase. Last five lines are given from ASTER DEM. The latest ASTER with is selected and elevation of the point is extracted. Also average, maximum, minimum, and variance in 30-arc second covering DCP are given.

The distribution of differences between GTOPO30 and SRTM30 at DCPs are shown in Figure 7.

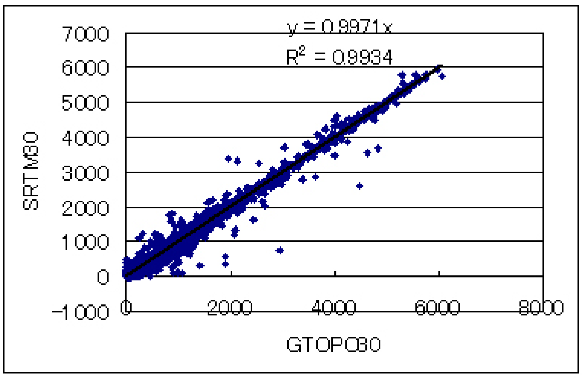

Figure 7. SRTM30 vs. GTOPO30 at DCPs

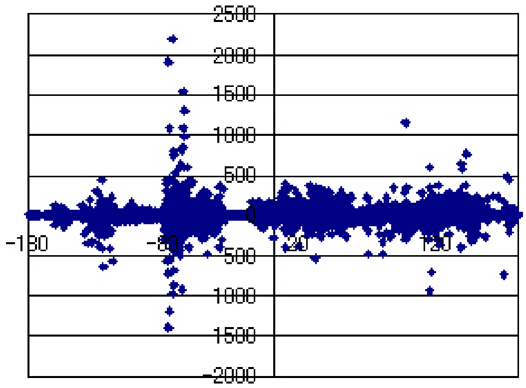

Figure 8. Distortions in the two datasets at DCPs (GTOPO30 – SRTM30 x: longitude in degree , y: differences in meter)

Both two data correlate each other at DCPs, however about one kilometre differs exists. This graph means that there exist distortions in the two datasets especially near 60-70 west longitudes.

4. DISCUSSION

By using Science DCP, elevation values of GTOPO30 and SRTM30 at confluences are evaluated. Two confluences at 13°S 73°W, 7.4 km (4.6 miles) N of Rayancalla, Cusco, Peru and 46°N 109°W, 10.2 miles (16.4 km) NNW of Molt, Stillwater, MT, USA.

13°S 73°W:
SRTM30: 3699 m
GTOPO30: 3022 m
ASTL1A_0406171516110705079000.dat:
ASTER Height #1: 3855 m
ASTER30 Height #1: 3811.3 m
ASTER30 Height Max #1: 4006 m
ASTER30 Height Min #1: 3633 m
ASTER30 Height Variance #1: 88.1

ASTER image covering this point as centre is shown in Figure 9.

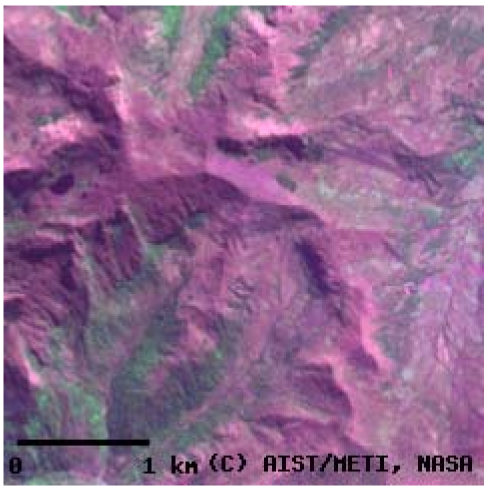

Figure 9. ASTER image around 13°S 73°W

This confluence is already visited once in May 2004. Though elevation value was not given from GPS readings, we can easily imagine that here is a steep mountainous area from photo and text information. It will be a possible reason why these two elevation value differs.

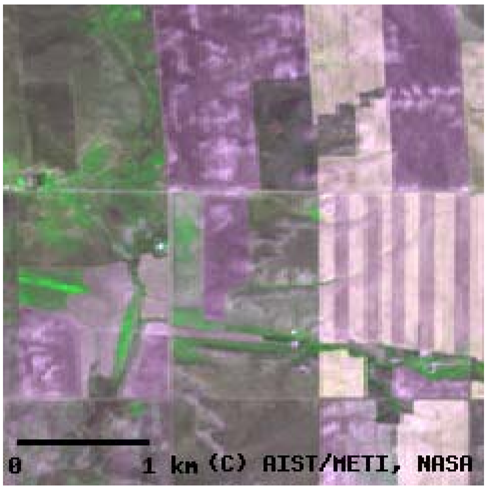

Figure 10. ASTER image around 46°N 109°W

46°N 109°W:
SRTM30: 1273 m
GTOPO30: 1278 m
DCP #1: 1275.9 m
ASTL1A_0509081816580703049027.dat:
ASTER Height #1: 1250 m
ASTER30 Height #1: 1248.8 m
ASTER30 Height Max #1: 1269 m
ASTER30 Height Min #1: 1225 m
ASTER30 Height Variance #1: 9.3

Texture of farmland can be seen from ASTER image in figure 10. As shown above, all the value looks similar even though relatively highland. According to the DCP, this is high plains ranch land and farmland. ASTER variance also shows that this area is planes.

5. CONCLUSION

We developed new method/system for validating global digital elevation models (DEMs) such as GTOPO30 and SRTM30. Ground based GPS reading value and relatively high resolution satellite derived DEM are used in the system. We demonstrated the usefulness of this system and found that there exist distortions in the two datasets especially near 60-70 west longitudes. Points where the differences exist and not exist are evaluated using this proposed system. We demonstrated the usefulness of this system for global DEMs validation. This system will be useful for global DEM inter comparison and leads to improve the accuracy of global DEM.

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