Some Useful Digital Elevation Datasets

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INTRODUCTION

For this special *Cartographic Perspectives* issue on mountain cartography, what better topic to cover than working with digital elevation data? I had originally planned to cover both data sources and provide how-to techniques for working with digital elevation data. I soon realized that even a brief review of data sources ran to many pages and that techniques for working with elevation data will need to wait until a future episode of the *Practical Cartographer's Corner*.

As most practicing cartographers know there is a wealth of digital elevation data available, much of it free (Gamache, 2004, provides a review of datasets and useful evaluations of their quality and usability). The United States government's policy of placing most datasets in the public domain—and distributing them effectively through the Geological Survey, NASA and other agencies—has not only provided terabytes of material but has encouraged the opening of datasets by other national governments. The governments of Canada and Mexico have opened much of their digital geo-data, including elevation data, to public access.

It is beyond the scope of a short summary such as this to enumerate all the elevation datasets available to map makers. I have omitted commercial geographic data and government data not distributed to the public. My summary of selected sources for digital elevation data includes freely available worldwide datasets and publicly released larger scale data from North America.

WORLDWIDE, LOW-RESOLUTION

Several digital elevation datasets provide worldwide coverage. One of the earliest datasets, completed in 1996, came from the U.S Geological Survey and was named GTOPO30. It had a resolution of 30 arc-seconds and was derived from a variety of digital and topographic map sources from U.S. and other national mapping services (USGS, 2011a).

A quick note is helpful here about resolution specifications for digital elevation datasets. The two common units of measure are arc-seconds (or minutes) and meters. Though a single data set is often referred to in both units, they are not strictly convertible. Seconds or minutes of a degree refer to unprojected units of an arc of a sphere and meters refer to measured distance along a line or an arc.

For the GTOPO30 dataset, 30 arc-second data is often referred to as one-kilometer data. One kilometer is only an average cell size. Because lines of longitude converge at the pole, the number of meters in one degree, minute, or second of latitude is lower at the pole and higher at the Equator. Most global elevation datasets are stored in a latitude equals longitude grid (Geographic or Plate Carrée projection) and have a variable resolution in meters per pixel as you move move from low to high latitudes. When examined for a local area or when projected to a UTM grid, these data vary far less and can be referred to in fixed meters per pixel.

GTOPO30 was the primary source for cartographers who needed international elevation data in the 1990s and early 2000s. The USGS created an improved version called SRTM30 that was corrected and updated by use of the SRTM (Shuttle Radar Topography Mission) data described below, but only for the SRTM coverage area of 56° South to 60° North (USGS, 2011b). Figure 1 shows a sample area that highlights the improvement provided by the SRTM data.

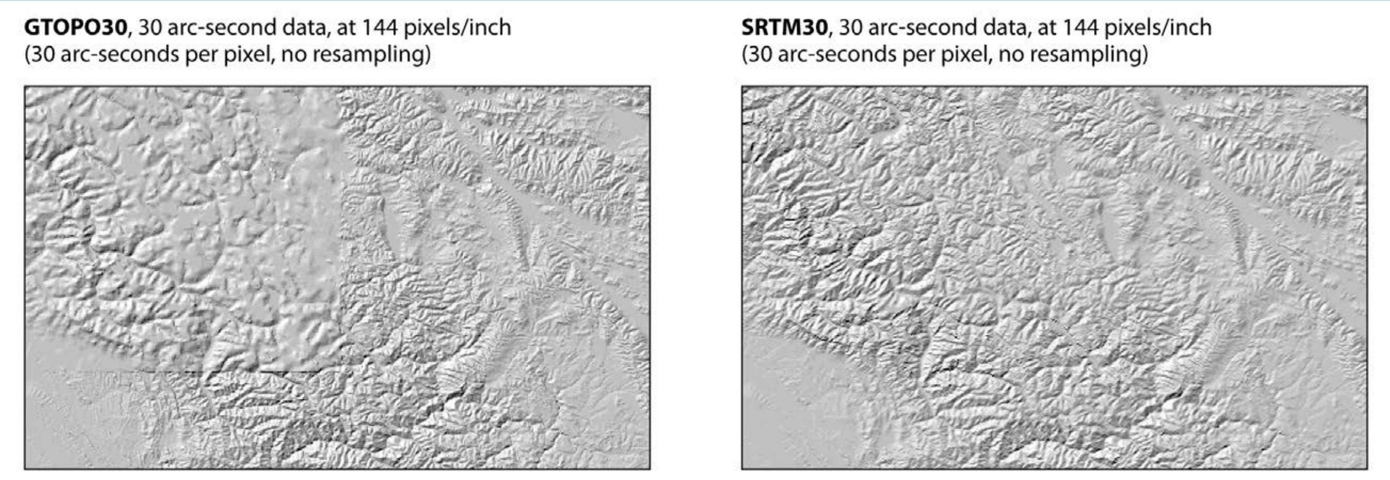

Figure 1. Sample shaded relief images of the western Himalaya along the India/China border, generated from GTOPO30 and SRTM30 data. Note the increased detail of the upper left section of the SRTM image.

Although a little harder to find now that higher resolution data is available, the 30 arc-second data is still a very useful low-resolution world digital elevation dataset. The USGS has direct links to the GTOPO30 (USGS, 2011c) and SRTM30 (USGS, 2011d) data.

WORLDWIDE, HIGH-RESOLUTION

The Shuttle Radar Topography Mission, flown in 2000, resulted in a radical improvement for worldwide digital elevation data. When the data were processed and then released the following couple of years, the best publicly available world elevation data jumped from 30 arc-second resolution to 3 arc-second resolution, a tenfold improvement! For the United States, the U.S. Government also released SRTM 1 arc-second data. See the United States National Aeronautics and Space Administration, Jet Propulsion Laboratory (NASA-JPL) website for detailed information (NASA-JPL, 2011a).

The original SRTM data has been processed and improved by the United States National Geospatial-Intelligence Agency into version 2 and in 2009 a version

2.1. The outline of water bodies has been improved and single pixel errors (spikes and wells) have been eliminated. There are still voids—areas of missing data—due to shadows, phase-unwrapping anomalies, or other radar-specific causes. This is particularly noticeable in high mountain regions, a serious problem for mountain cartographers.

The USGS provides direct access to the SRTM 3 arc-second data for the world (USGS, 2011e) and SRTM 1 arc-second data for the United States (USGS, 2011f). The Global Land Cover Facility at the University of Maryland (2011) also provides access to the same SRTM 3 arc-second data and 1 arc-second data.

Because of the above-mentioned voids in the SRTM data, several groups have worked to improve the 3 arc-second data. They have used a variety of methods to fill the voids and provide a more usable version of the data. One very useful void-filled SRTM dataset was created by Dr. Andy Jarvis and Edward Guevara of the International Center for Tropical Agriculture (CIAT) and Dr. Hannes Isaak Reuter and Dr. Andy Nelson of the Joint Research Centre of the European Commission (2008). Version 4 of this database is available from the Consultative Group on International Agricultural Research, Consortium for Spatial Information (CGIAR-CSI, 2011) and from a mirrored site at King's College London (2011). See Figure 2 for an example of the improved provided by the void-filling process.

A unique source for worldwide digital elevation data is the *Viewfinder Panoramas* site constructed by Jonathan de Ferranti (2011). The site provides custom void-

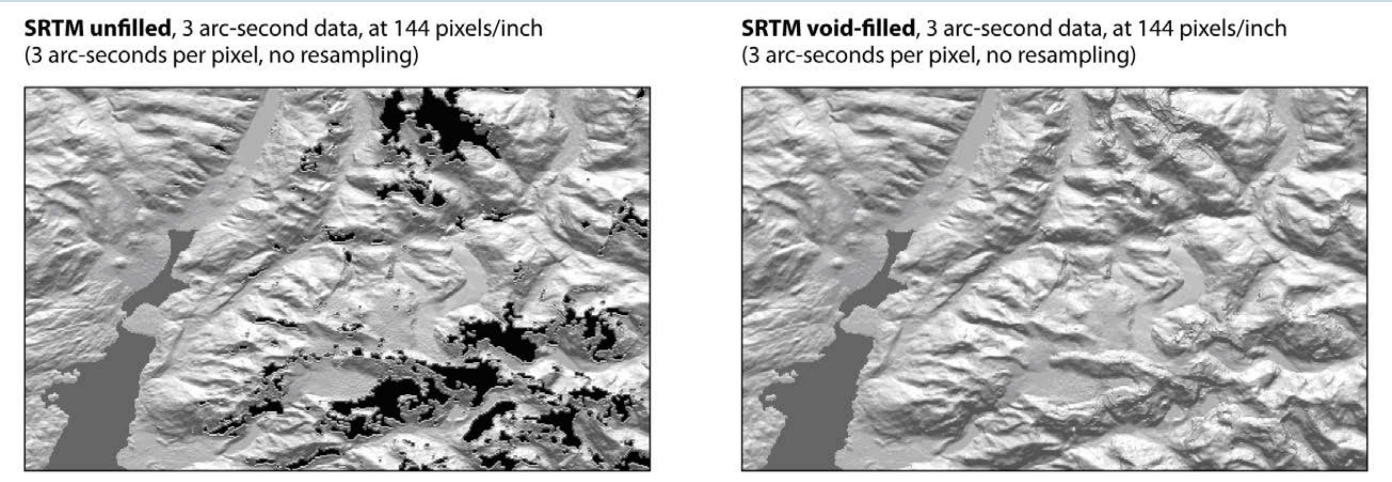

Figure 2. Sample shaded relief images generated from SRTM 3 arc-second data for a section of the Andes Mountains in Chile. The USGS version 2.1 with black areas showing voids is on the left and the CGIAR-CSI void-filled version is on the right.

filled SRTM 3 arc-second data and some higher-resolution data sets for selected mountain regions. It also provides 3 arc-second data (and larger scale) data for areas above 60° North and below 56° South, the poleward limits of the SRTM data. These datasets have been derived from large-scale cartographic contours and other sources and they have been specifically tailored for high-mountain areas.

The site has good coverage for European mountain areas including both 3 arc-second data and 1 arc-second datasets. Figure 3 compares data from the *Viewfinder Panoramas* site to data from the SRTM 3 data showing the higher quality for this area of the Alps.

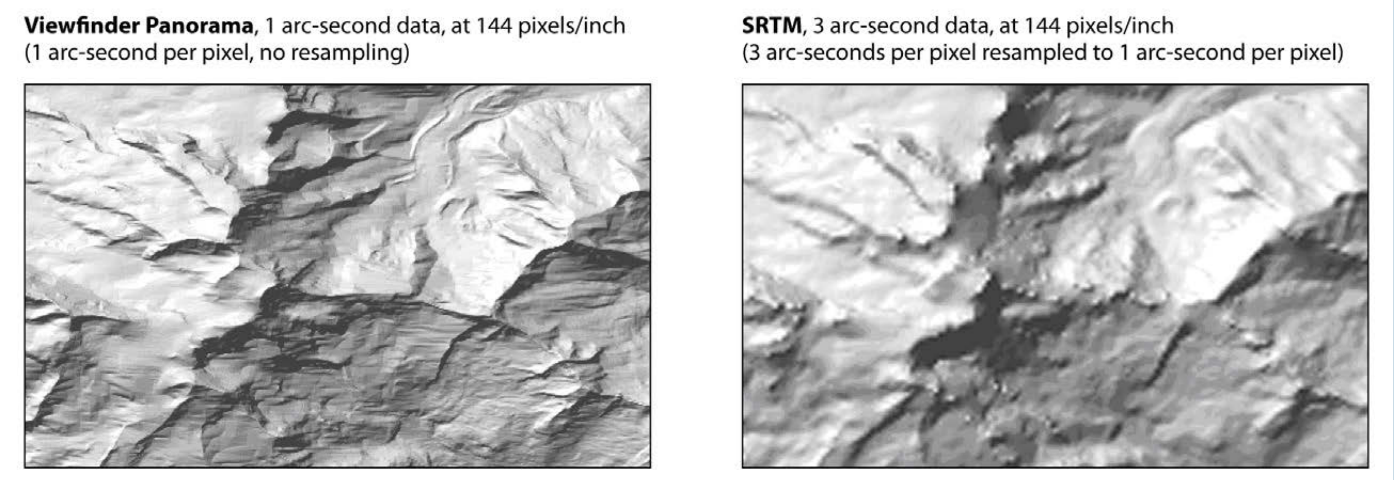

Figure 3. Sample shaded relief image of the Monte Rosa area in the Alps showing the quality of data in the Viewfinder Panoramas *1 arc-second data elevation data set. SRTM 3 arc-second data image is shown for comparison.*

NASA-JPL and Japan's Ministry of Economy, Trade and industry (METI) have recently developed a new global high-resolution digital elevation dataset based on data from the ASTER (advanced spaceborne thermal emission and reflection radiometer) satellite sensor. The ASTER digital elevation data can be downloaded for free, after registration, from both NASA-JPL (2011b) and METI (2011a) websites.

The elevation data are at nominal 1 arc-second (about 30 meters) resolution, even higher than the released SRTM data for non-U.S. areas. But, after testing the quality of three-dimensional terrain views and shaded relief renders from the 30 meter ASTER data, the resulting quality is, at best, equivalent to the 90 meter (3 arc-second) SRTM data, not three times more detailed (see Figure 4, and Gamache, 2004).

UNITED STATES

The primary source for digital elevation data for the United States is the National Elevation Dataset (NED) maintained by the U.S. Geological Survey (USGS). The NED contains the best available raster elevation data for the conterminous United States, Alaska, Hawaii, and territorial islands. It is a seamless nation-wide coverage and has replaced the earlier set of DEM format files produced by USGS on an individual topographic quadrangle basis (USGS, 2011g).

The NED is available in several resolutions. For the United States (other than Alaska), it contains complete 1 arc-second (about 30 meter cells) and 1/3 arc-second (about 10 meter) data and limited 1/9 arc-second (about 3 meter) data. For Alaska, the NED has mostly 2 arc-second data and limited 1 arc-second and 1/3 arc-second data. The USGS has compiled the NED from a variety of sources ranging from cartographic contours to LIDAR data sets and it is continually updating and improving the data. The improvement can be seen in Figure 5, showing a glaciated area on Mount Rainer where the 1/9 arc-second image shows the detail collected using LIDAR technology.

The NED can be downloaded from several sites at USGS. Data access at USGS has recently been consolidated into the viewing and downloading tool at their *National Map* site (USGS, 2011h). There is also a special purpose NED tool for downloading 1 arc-second and 1/3 arc-second data by defining latitude and longitude bounds or by state and county (USGS, 2011i). Using this tool is much quicker than going through the *National Map* viewer.

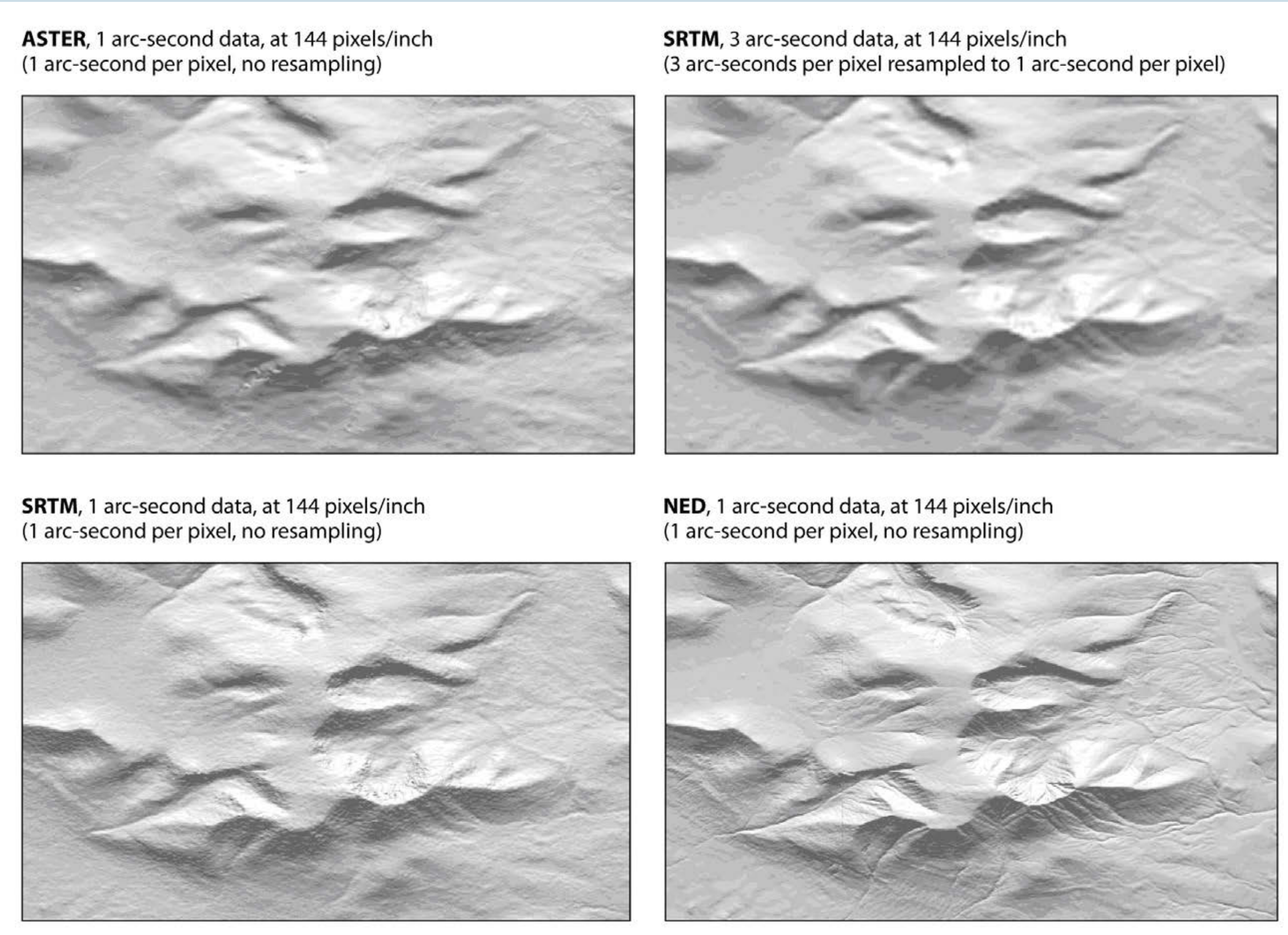

Figure 4. Sample shaded relief images of the Mount Katahdin area in central Maine comparing data sets: ASTER 1 arc-second, SRTM 3 arc-second, SRTM 1 arc-second and NED 1 arc-second. Note the definition of the drainages and the sharpness of the escarpments and cirques in the NED image.

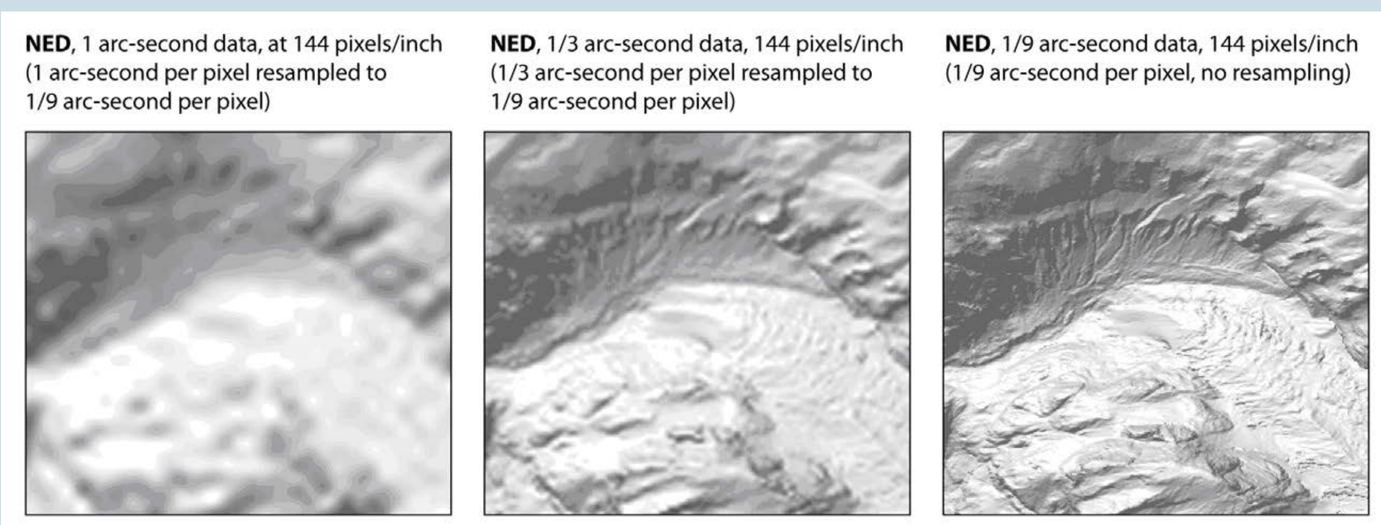

Figure 5. Sample shaded relief images of part of the USGS Mount Rainier West quadrangle generated from NED data at 1, 1/3, and 1/9 arc-second. Note the ability to discern the glacier at 1/3 arc-second image and the glacial crevasses on the 1/9 arc-second image.

CANADA

Digital elevation data collected by the Canadian national government comes from Natural Resources Canada (NRC, 2011) and is available at two resolutions: 3 arc-seconds (about 90 meter) and ¾ arc-second (about 20 meter). These digital elevation datasets are based on the Canadian 1:250,000 and 1:50,000 topographic map series and can be accessed by the quadrangle numbers for those maps.

The data is based on best available sources and some areas have better quality data than others. The provinces contribute data and in Figure 6, you can see that the British Columbia data is superior to that for Alberta and the NRC data in Alberta is similar to the SRTM 3 arc-second data.

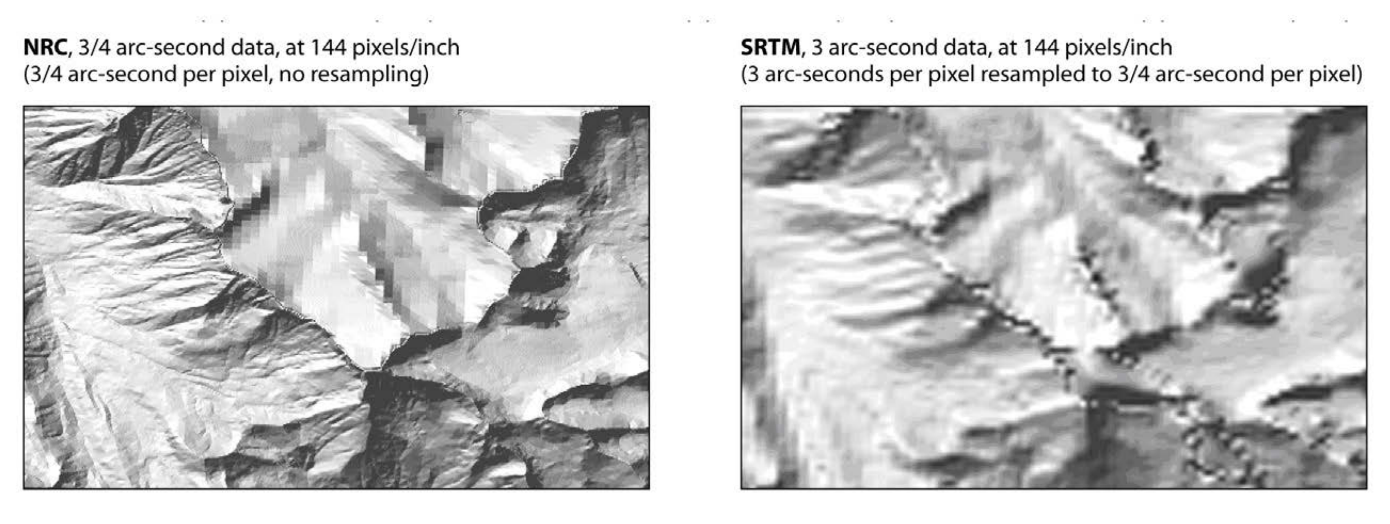

Figure 6. Sample shaded relief image of the Mt. Joffre area on the border of British Columbia and Alberta showing the quality of data in the Natural Resources Canada 1:25000 digital elevation data set. While nominally a ¾ arc-second resolution, the data is uneven and the provincial boundary shows high quality data in British Columbia (to the South) compared to lower quality data in Alberta (to the North). SRTM 3 arc-second data image is shown for comparison.

MEXICO

Digital elevation data for Mexico comes from the Instituto National Estadistíca y Geografía (INEGI, 2011). If your Spanish is good you can complete the registration process and download data based on the Mexican 1:50,000 and 1:25,000 topographic maps. The data is available by quadrangle number or user specified area (up to 2 x 2 minutes). INEGI created the data at 30 meter intervals (about a 1 arc-second resolution) and it provides much greater detail than SRTM 3 arc-second data (Figure 7).

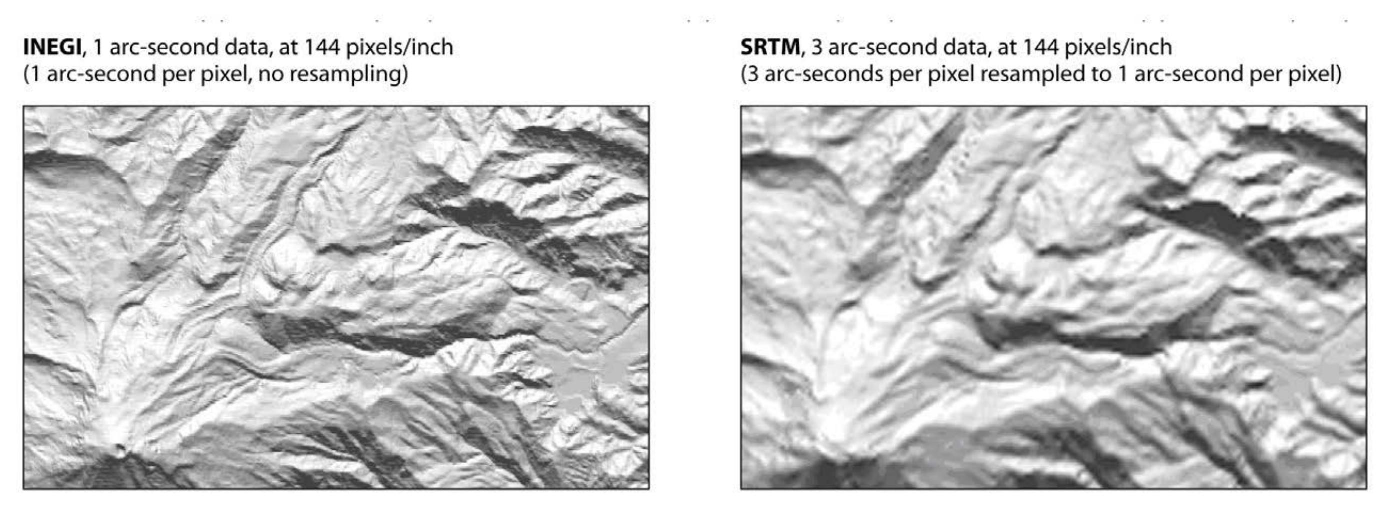

Figure 7. Sample shaded relief image of the Pico de Orizaba area in Mexico showing the quality of data in the INEGI 1 arc-second elevation data set. SRTM 3 arc-second data image is shown for comparison.

BATHYMETRIC DATA

The U.S. National Oceanic and Atmospheric Administration (NOAA) is the best source for free world bathymetry datasets. They released their first world data set in 1988 (with some improvements in 1990). Named ETOPO5 it has bathymetric depths on a 5 minute grid. This was followed by a much higher resolution and higher quality dataset called ETOPO2. The data for ETOPO2 are at 2 minute grid intersections and build primarily on the pioneering work of Walter Smith and David Sandwell (1997). The original ETOPO2, released in 2001, was replaced in 2006 by ETOPO2v2 which incorporated improved data for the Great Lakes, U.S. coastal waters and the Caspian Sea.

In 2008, NOAA released their most detailed worldwide gridded bathymetry, the ETOPO1 dataset, at 1 arc minute resolution (Amante and Eakins, 2009). The ETOPO1 data has superseded the earlier ETOPO5 and ETOPO2 data. It, too, primarily relies on the Sandwell and Smith (2009) bathymetric data derived from sea-surface satellite altimetry measurements and ocean soundings with incorporation of additional detailed datasets.

The datasets are available from NOAA's National Geophysical Data center website: ETOPO5 (NOAA, 1990), ETOPO2 (NOAA, 2006) and ETOPO1 (NOAA, 2008). They include land elevation data in addition to the bathymetry and are very convenient to use when you need both. NOAA also provides Internet tools for accessing its higher-resolution bathymetric data for U.S. coastal and interior lake waters (NOAA, 2011). Figure 8 shows the increasing detail of the ETOPO2, ETOPO1 and Coastal Relief Model data (3 arc-seconds) available from NOAA.

The folks at Scripps Institution of Oceanography at the University of California San Diego have released their own combination land elevation-bathymetry worldwide dataset (SIO-UCSD, 2011). They have merged USGS SRTM30 data and improved 1 arc minute bathymetric data from Smith and Sandwell. This dataset is called SRTM30-Plus and is available at the Scripps website.

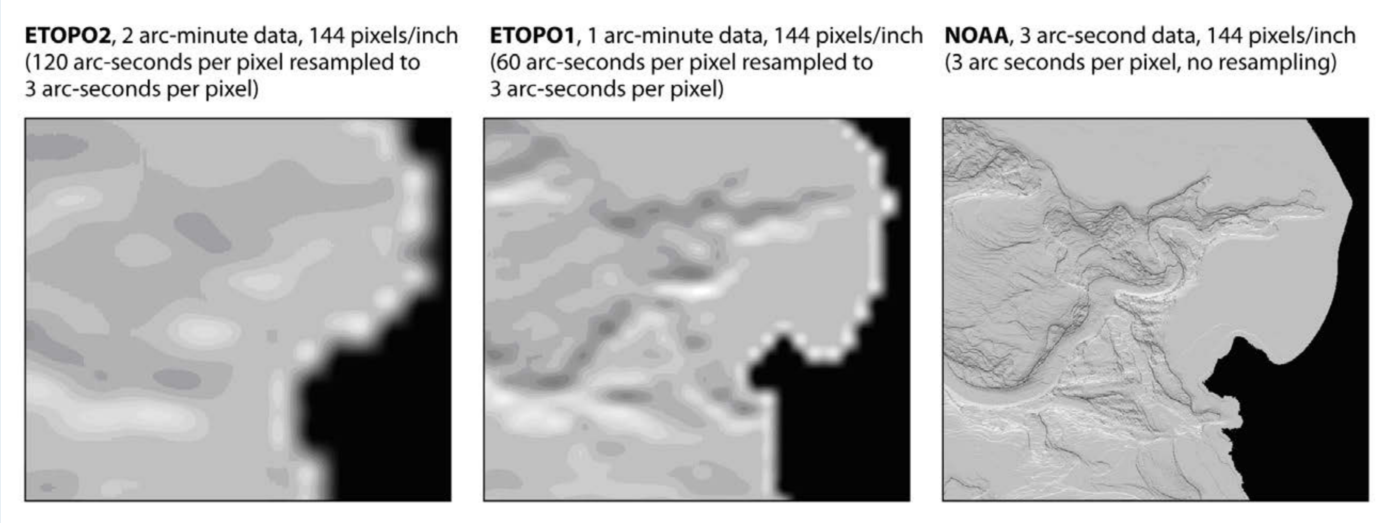

Figure 8. Sample shaded relief image of the Monterey Canyon area off the California coast showing the quality of data in the ETOPO2, ETOPO1 and Coastal Relief Model datasets from NOAA.

Tom Patterson of the U.S. National Park Service has developed a very useful, low-resolution bathymetric dataset called CLEANTOPO2 (Patterson, 2011). It is a version of the SRTM30-Plus dataset from Scripps (at 2 arc minute resolution) that he has improved for small-scale terrain modeling and relief shading. Patterson filled ship paths, voids and other anomalous features of the dataset to improve its usability for geographic visualizations.

CONCLUSIONS AND FUTURE TRENDS

For many practicing cartographers, the two most important freely available digital elevation datasets are the USGS NED (1, 1/3 and 1/9 arc-second) for United States coverage and the SRTM (3 arc-second) data for much of the rest of the world. It is important to note the differences between NED and SRTM data, especially for U.S. areas that are available at 1 arc-second from both. Table 1 summarizes these differences and reflects the different methods of data collection and processing. The bare earth characteristic of the NED is usually more useful for 2-D and 3-D cartographic renderings.

	NED	SRTM
Source Data	Maps/Aerial Photos/LIDAR data	Radar data
Source Resolution	3m, 10m & 30m DEMs	30m
Source Dates	1925–present	February, 2000
Source Type	"Bare-Earth"	"First Return"
Vertical Accuracy	2.44m RMSE measured (root mean square error)	10m RMSE (root mean square error) was the mission specification

Table 1. Table 1. Comparison of NED and SRTM data set characteristics.

Looking to the future, what will be happening with these two important sets of digital elevation data? Additional efforts are underway to better fill voids and otherwise improve the SRTM data, but a big question remains for this dataset. Will the U.S. Government release the SRTM 1 arc-second data for the world beyond the U.S. any time soon? At the USGS, digital elevation data just keeps getting better and better. They update the 1 arc-second and 1/3 arc-second datasets on a scheduled two-month cycle to integrate new and improved elevation source data. For the higher resolution 1/9 arc-second data, the USGS release new datasets on a monthly basis as they are created.

Compared with what was available in the recent past, practical cartographers have access to excellent digital elevation data. It is high resolution and high quality and works well for most small and medium scale uses. For highly detailed large-scale purposes, better public digital elevation data is still needed, especially outside the United States.

Recent developments in the United Kingdom show there is reason for optimism. The Ordnance Survey (2010) has released its *Panorama* product elevation data at 50 meter cell size (approximately 1 arc-second). The elevation data were generated from cartographic contours on the 1:50,000 *Land Ranger* map series. Note that the *Panorama* data were collected between 1970 and 1980 and have not been updated since then. The level of detail is markedly better than the comparable SRTM 3 arc-second data (Figure 9).

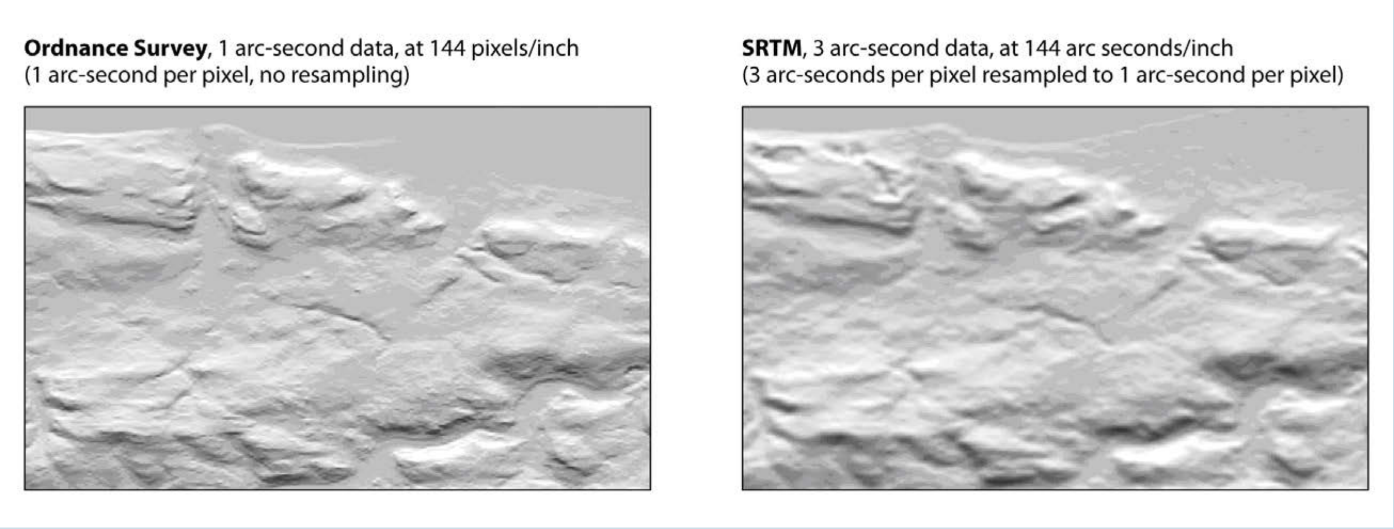

Figure 9. Sample shaded relief image of the North Wales coast showing the quality of data in the Ordnance Survey 50 meter (about 1 arc-second) elevation data set. SRTM 3 arc-second data image is shown for comparison.

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