The Shuttle Radar Topography Mission (SRTM) Collection

1.0 Introduction

The Shuttle Radar Topography Mission (SRTM) data sets result from a collaborative effort by the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA - previously known as the National Imagery and Mapping Agency, or NIMA), as well as the participation of the German and Italian space agencies, to generate a near-global digital elevation model (DEM) of Earth using radar interferometry. The SRTM instrument consisted of the Spaceborne Imaging Radar-C (SIR-C) hardware set modified with a Space Station-derived mast and additional antennae to form an interferometer with a 60-meter long baseline (Kobrick, 2006). A description of the SRTM mission can be found in Farr and Kobrick (2000) and Farr et al. (2007), and radar interferometry is explained in Rosen et al. (2000).

Synthetic aperture radars are side-looking instruments that acquire data along continuous swaths. The SRTM swaths extend from about 30degrees off-nadir to about 58degrees off-nadir from an altitude of 233 kilometers (km), and thus are about 225 km wide. During the data flight, the instrument operated at all times the orbiter was over land and about 1,000 individual swaths were acquired over the ten days of mapping operations. The length of the acquired swaths ranges from a few hundred to several thousand km. Each individual data acquisition is referred to as a "data take."

SRTM was the primary (and virtually only) payload on the STS-99 mission of the Space Shuttle Endeavour, which launched February 11, 2000 and flew for 11 days. Following several hours for instrument deployment, activation and checkout, systematic interferometric data were collected within a 222.4-hour period. The instrument operated almost flawlessly and imaged 99.96% of the targeted landmass at least one time, 94.59% at least twice, and about 50% at least three or more times. The goal was to image each terrain segment at least twice from different angles (on ascending, or north-going, and descending, or south-going, orbit passes) to fill areas shadowed from the radar beam by terrain.

This 'targeted landmass' consisted of all land between 56- degrees south and 60- degrees north latitude, which comprises almost exactly 80% of Earth's total landmass. The coverage reaches somewhat further north than south because the side-looking radar looked toward the north side of the Shuttle.

NASA Version 3.0 SRTM (SRTM Plus) data includes topographic data from non-SRTM sources to fill the gaps ("voids") in earlier versions of SRTM data. The primary fill data are from the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) sensor on NASA's Terra satellite, which has imaged Earth stereoscopically in near-infrared wavelengths since 1999 (Yamaguchi et al., 1998; Fujisada et al., 2011). The secondary fill is mostly USGS GMTED2010 elevation data (Global Multi-resolution Terrain Elevation Data), which are lower resolution derived from many sources (Danielson and Gesch, 2011). The USGS National Elevation Dataset (NED) (Gesch et al., 2002) was used instead of GMTED2010 for the United

States (except Alaska) and northern Mexico.

2.0 Data Set Characteristics

All SRTM data are divided into tiles extending over 1-degree x 1-degree of latitude and longitude, in “geographic” projection.

Table 1: Data Set Characteristics for each product of the SRTM Collection

Short Name	Collection	Data Product	Extent	Rows / Columns	Spatial Resolution
SRTMGL3	SRTM	Global 3 arc-second	Global	1201 / 1201	3 arc-second
SRTMGL30	SRTM	Global 30 arc-second	Global	**See ** in section 2.1.4**	30 arc-second
SRTMGL3N	SRTM	Global 3 arc-second number	Global	1201 / 1201	3 arc-second
SRTMGL3S	SRTM	Global 3 arc-second sub-sampled	Global	1201 / 1201	3 arc-second
SRTMSWBD	SRTM	Water Body Data Shapefiles & Raster Files	Global	3601 / 3601	1 arc-second
SRTMUS1	SRTM	US 1 arc-second	United States	3601 / 3601	1 arc-second
SRTMUS1N	SRTM	US 1 arc-second number	United States	3601 / 3601	1 arc-second
SRTMIMGR	SRTM	Global SRTM Swath Image Data	Global	3601 / 3601	1 arc-second
SRTMIMGM	SRTM	Global SRTM Combined Image Data	Global	3601 / 3601	1 arc-second

2.1 SRTM Topography

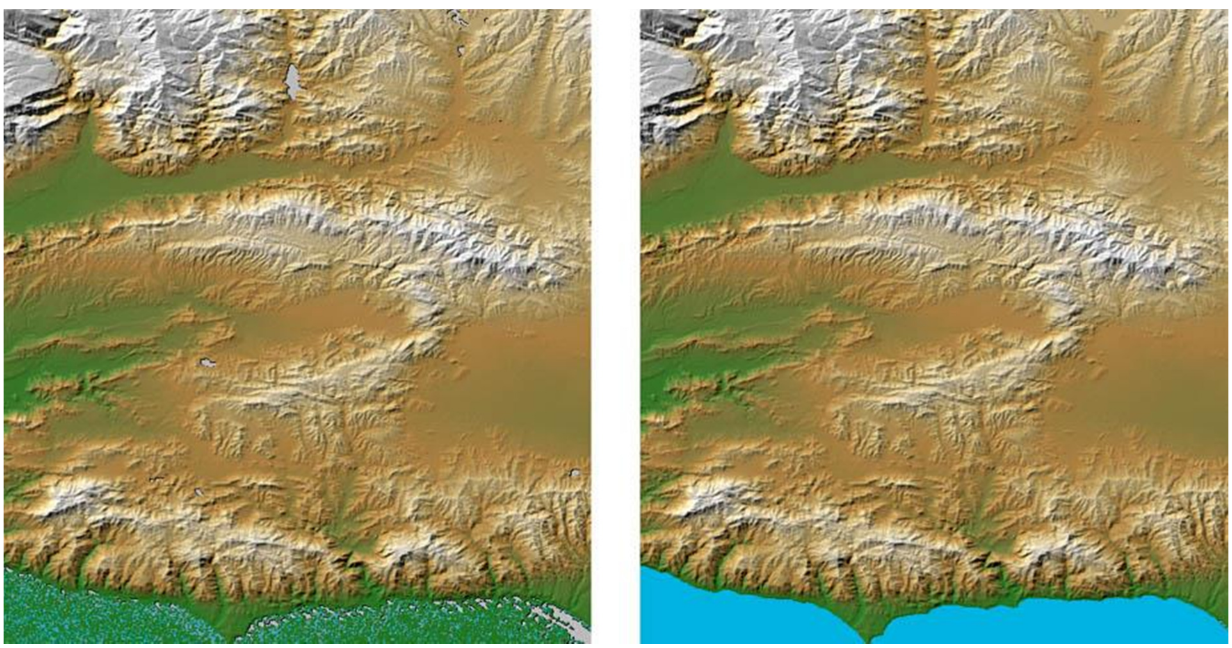
2.1.1 Versioning

SRTM data have undergone a sequence of processing steps resulting in data versions that have different characteristics. All processing has occurred at 1arc-second (about 30 meters) postings. Three (3) arc-second (about 90 meters) data are freely available for worldwide coverage. One (1) arc-second data coverage is freely available for non-restricted areas.

Version 1.0: SRTM radar echo data were processed in a systematic fashion using the SRTM Ground Data Processing System (GDPS) supercomputer system at the NASA Jet Propulsion Laboratory. This processor transformed the radar echoes into strips of digital elevation data - one strip for each of the 1,000 or so data swaths. These strips were eventually mosaicked into 14,549 one-degree by one-degree tiles. The data were processed on a continent-by-continent basis beginning with North America and proceeding through South America, Eurasia, Africa, Australia and Islands, with data from each continent undergoing a “block adjustment” to reduce residual errors. The data were arranged in SRTM format, detailed in Section 3 below, and made available online from the U.S. Geological Survey (USGS) as Version 1.0.

Each SRTM data tile contains a mosaic and blending of elevations generated by averaging all data takes that fall within that tile. Since the primary error source in synthetic aperture radar data is speckle, which has the characteristics of random noise, combining data through averaging reduced the error by the square root of the number of data takes used. SRTM data takes ranged from a minimum of one (about 5% of the coverage) up to as many as 24 (very little of the coverage). Typical coverage was 2-3 data takes.

Version 2.1: Next, NGA applied several post-processing procedures to the SRTM data including editing, spike and pit removal, water body leveling and coastline definition. Following these "finishing" steps, data were returned to NASA for distribution to the scientific and civil user communities as well as the public. These data are referred to as Version 2.0. Version 2.1 corrects some minor errors found in the original Version 2.0 three arc-second product. B e l o w , Figure 1 shows a portion of tile N34W119.hgt, demonstrating the difference between the edited (Version 1.0) and unedited (Version 2.0) data.



Version 1.0 – Unedited   Version 2.1 – Edited

Figure 1: N34W119 – Malibu Coast and Simi Valley, California
Ocean (bottom) and small lakes (e.g., center top) are flattened with shoreline elevations.

Version 3.0: Elimination of the gaps, or voids, in the SRTM DEM was the primary goal of a project under the NASA MEaSUREs (Making Earth System Data Records for Use in Research Environments) Program. Ultimately, this was achieved by filling the voids with elevation data primarily from the ASTER GDEM2 (Global Digital Elevation Model Version 2) and secondarily from the USGS GMTED2010 elevation model or the USGS National Elevation Dataset (NED). Below, Figure 2 shows the SRTM Genealogy, demonstrating the different agencies and processing techniques applied to the original SRTM V1.0 data.

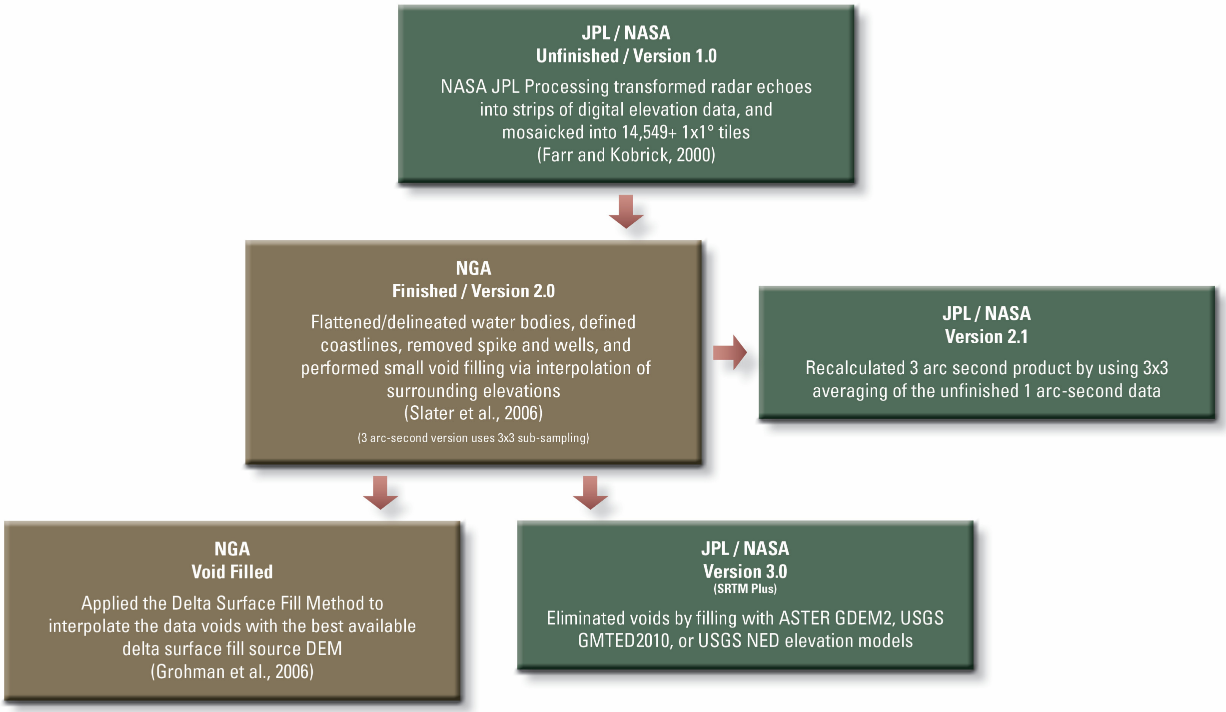


Figure 2: SRTM Genealogy

The Sensor Information Laboratory Corporation of Japan used more than one million ASTER scenes to produce GDEM2 (Fujisada et al., 2012). (ASTER is a joint project of NASA and Japan's Ministry of Economy, Trade and Industry, and now, Japan Space Systems.) At its best, GDEM2 is comparable to full resolution SRTM elevation data, but it is much less consistent in quality. This is primarily due to ASTER being an optical system. Clouds can obscure its views. (SRTM, a radar system, looked through clouds.) Both ASTER and SRTM can have difficulty in very steep and rugged terrain, but ASTER has some advantage there due to its more nadir view (the stereo pair includes a nadir view). Thus, ASTER DEMs generally can fill SRTM voids in rugged terrain that are not often obscured by clouds. Elsewhere, both sensors have difficulty in smooth, flat terrain such as desert sand sheets, where little of the SRTM radar signal was reflected back to the Shuttle, and where ASTER stereoscopy is hindered by the lack of Earth surface patterns to correlate between the two views.

GDEM2 is void-free, but it does not consist entirely of ASTER elevation measurements. Some areas in GDEM2 consist of American or Canadian national elevation data sets, or SRTM 3arc-second data, or NGA elevation data from undisclosed sources. Meanwhile, some GDEM2 ASTER elevations (where the alternative sources were not available) are cloud tops that are hundreds (or even thousands) of meters above the ground surface. Fortunately, most GDEM2 coverage does not have these problems in the extreme (but some does).
GDEM2 was merged with SRTM by retaining all of the SRTM Version 2.1 data and using a modified Delta Surface Fill algorithm (Grohman et al., 2006) to fill just the voids. This is

essentially a “rubber sheet” methodology in which GDEM is matched to SRTM vertically and gently warped to meet seamlessly the SRTM void edges. Another technique was developed to detect significant errors in GDEM2, based upon its inconsistency with SRTM, and to reintroduce voids at those locations. These new voids were then filled with GMTED2010 or NED data.

GMTED2010 was used at its finest level of spatial detail, 7.5 arc-seconds, but was interpolated to 1arc-second postings to blend with the SRTM DEM that was partially filled with GDEM2. Again, a modified Delta Surface Fill algorithm was used to fill the remaining voids with GMTED2010, but NED was used instead of GMTED2010 for the United States (except Alaska) plus northern Mexico (north of 25- degrees north latitude).

Ancillary 1-byte (0 to 255) “NUM” (number) files were produced for SRTM NASA Version 3.0. These files have names corresponding to the elevation files, except with the extension “.NUM” (such as N37W105.NUM). The elevation files use the extension “.HGT”, meaning height (such as N37W105.HGT). The separate NUM file indicates the source of each DEM pixel, and the number of ASTER scenes used (up to 100), if ASTER, and the number of SRTM data takes (up to 24), if SRTM. The NUM file for both 3arc-second products (whether sampled or averaged) references the 3x3 center pixel. Note that NUMs less than 6 are water and those greater than 10 are land.

1 = Water-masked SRTM void *
2 = Water-masked SRTM non-void *
5 = GDEM elevation = 0 in SRTM void (helped correct ocean masking)
11 = NGA-interpolated SRTM (were very small voids in SRTMv1)
21 = GMTED2010 oversampled from 7.5 arc-second postings
25 = SRTM within GDEM **
31 = NGA fill of SRTM via GDEM***
51 = USGS NED (National Elevation Dataset)
52 = USGS NED via GDEM
53 = Alaska USGS NED via GDEM
72 = Canada CDED via GDEM (Canadian Digital Elevation Data)
101-200 = ASTER scene count (count limited to 100)
201-224 = SRTM swath count (non-voided swaths) Actual maximum = 24

* Water-masked in SRTMv2 by NGA using its SRTM Water Body Database (SWBD). (NGA: National Geospatial-Intelligence Agency).
** GDEM used SRTM 3arc-second data, oversampled to 1arc-second postings, as fill at some locations. Rarely some of these interpolations are at locations of void within the original 1arc-second SRTM.
*** GDEM used a version of SRTM supplied by NGA that included elevation measurements from undisclosed sources.

2.1.2 Processing Steps

All Version 3.0 processing occurred at the original 1arc-second postings. Products released at 3 arc-seconds were derived from the final 1arc-second DEM. Version 3.0 processing steps are as follows:

1-2: Prepare GMTED2010

(1) GMTED2010 was found to have geo-location errors in much of Africa (and vicinity) and parts of South America. It was determined that these errors correspond to the SPOT DEM inputs to GMTED2010, and they consist of one full GMTED2010 pixel (7.5 arc-seconds) shift to the southwest (for Africa) or east (for South America) for some 1x1-degree latitude-longitude quads. The correction consisted of shifting those quads into proper position and interpolating the consequent pixel-wide gaps at the trailing edge.

(2) GMTED2010 was then resampled to 1arc-second postings by bi-cubic interpolation to match the full-resolution SRTMv2 and GDEM2. Bi-cubic interpolation can introduce artifacts in some topographic features such as sea cliffs and mesas, including the introduction of some elevation values outside the range of the input pixel values (e.g., extrapolation). But in general, bi-cubic interpolation was found to produce far fewer artifacts than bi-linear interpolation.

3: Use GDEM2 to edit the SRTM water mask

(3) SRTM voids were filled with an elevation of 0 if the pixel has an elevation of 0 in GDEM2. This was found to improve greatly the topographic representation of shorelines, especially near sea cliffs by avoiding interpolations across voids that overlap steep coastal mountains (or high terraces) and flat offshore water, where there should be a topographic inflection at the shoreline.

4-6: Apply a modified Delta Surface Fill method to fill SRTM voids with GDEM2

(4) Subtract SRTM elevations from GDEM2 elevations, but retain the SRTM voids (that remain after Step 3). This is the GDEM2-SRTM delta surface.

(5) Fill the GDEM2-SRTM delta surface voids mostly via iterative edge-growing interpolation: In each iteration, each void pixel that borders any non-void pixel is interpolated from the nearest non-void pixels in each of 16 directions (north, south, east, west, northwest, southwest, northeast, southeast, and the eight directions intermediate to those eight: NNE, ENE, ESE, SSE, SSW, WSW, WNW, NNW). Each of the 16 reference pixels is weighted by the inverse square root of its distance. The effect of the inverse square root is to weight most heavily the closest pixels but to minimize the influence of distance variations for the more distant reference pixels. In other words, close pixels are most important in the interpolation and their relative closeness matters, while far pixels are less important in the interpolation and their relative distance does not matter (much). This edge-growing interpolation is applied in 50 iterations. The iterations greatly help to smooth the interpolation because the reference pixels in each successive step were themselves interpolated in the previous step. Note that delta surfaces of DEMs are entirely noise (e.g., , errors of some sort) in either SRTM or GDEM or both. The goal here is to characterize the broader systematic differences between the DEMs without being too subject to the higher spatial frequency random errors. Thus, smoothing is important for the interpolation. After 50 iterations, the smaller voids already are filled. Meanwhile, for the larger voids, the high spatial frequency random errors along the void edges largely are suppressed, such that any remaining void pixels can be filled in one last step (no edge growing) via a final interpolation applied to all remaining void pixels. The delta surface is now complete (void free).

(6) Subtract the delta surface from GDEM2. The result is the original SRTM DEM, where it already existed, with its voids filled by GDEM2, which has been adjusted in height and by gentle warping to merge seamlessly with SRTM.

SRTM Non-Void Areas	= GDEM2 – GDEM2 – SRTM)
	= SRTM
SRTM Void Areas	= GDEM2 – [filled (GDEM2 – SRTM)]
	= GDEM2 with adjustments to fit SRT

<u>7: Use the Delta Surface itself as an error check for GDEM2 quality</u>

(7) The DEM now is spatially complete, but is it accurate? If we assume that the original SRTM DEM is accurate, then the delta surface measures probable errors in the void fills. If GDEM2 exactly matched SRTM, then the delta surface would be all zeroes, and the interpolated voids would also (of course) be all zeroes. Any differences from zero indicate an error that is assumed to be in GDEM2 (although that is not always true). These do not affect the final DEM where SRTM is not void since SRTM is used (unchanged) in the final DEM. However, large values in the delta surface (+/- differing from zero) indicate a significant inconsistency between SRTM and GDEM2, such as a cloud elevation in GDEM2. Much experimentation was used to determine an optimum threshold to reject some void fills as errors. A threshold of 80 meters was found to catch most obvious errors while minimizing the rejection of apparently good elevation values. Using this threshold, voids were reintroduced to the GDEM2-filled SRTM DEM where the delta surface was equal to or outside +/-80 meters. Note again that this is only in original SRTM voids and is often only part(s), if any, of each void.

<u>8: Fill- remaining voids with GMTED2010 or NED</u>

(8) Repeat Steps 4-6 (above) using GMTED2010 instead of GDEM2, and use the DEM from Step 7 (above) instead of SRTM. This is a (modified) Delta Surface Fill of the rejected parts of the GDEM fill of SRTM.

NED, instead of GMTED2010, was used in the 48 conterminous United States and northern Mexico (N25-29W65-125) plus Hawaii (N19-23W154-161).

The final DEM now is complete: SRTM is filled with GDEM2, except where discordant. GMTED2010 or NED is used to fill those areas.

2.1.3 One arc-second (“30 meter”) and 3arc-second (“90 meter”) postings

SRTM data are organized into individual rasterized tiles each covering 1 - degree of latitude by 1 -degree of longitude. Sample spacing for individual data points is either 1 arc-second (United States and territories) or 3 arc-seconds (worldwide), referred to as SRTM1 and SRTM3, respectively. Since 1 arc-second at the equator corresponds to roughly 30 meters in horizontal extent, the SRTM1 and SRTM3 are sometimes referred to as "30 meter" or "90 meter" data. (Note: a void-free 30arc-second (about one kilometer) Version 1.0 product, referred to as SRTM*30 was also produced, with voids filled with the GTOPO30 elevation model.) With postings of 1, 3, and 30 arc-seconds, corresponding to nominal postings at 30, 90, and 1,000 meters, and with versions numbering 1, 2, and 3, users should take care to reference these data specifically by “arc-seconds” or “meters” as well as by “version.”

For Version 2.1, there is a difference between the data distributed via download from the Land Processes Distributed Active Archive Center (LPDAAC), and those available from the Earth Resources Observations and Science (EROS) Center through the Long Term Archive (LTA). Three arc-second sampled data from the LTA have been generated from the 1 arc-second data by “sampling.” In this method, each 3arc-second data point is generated by selecting the center sample of the 3x3 array of 1arc-second points that surround the post location. For the LPDAAC 3arc-second data each point is the average of the nine (3x3) 1arc-second samples surrounding the post, as illustrated in Figure 3.

Many analysts feel that the averaging method produces a superior product by decreasing the high frequency ”noise” that is characteristic of radar-derived elevation data. This is similar to the conventional technique of “taking looks,” or averaging pixels in radar images to decrease the effects of speckle and increase radiometric accuracy, although at some cost of horizontal resolution. The true spatial resolution of SRTM 1arc-second data generally is estimated to be in the range of 50-80 meters. Thus, the 1arc-second postings (beneficially) oversample the data. Three arc-second postings derived by sampling exclude some detail. Three arc-second postings derived by averaging use all the original postings but, in effect, blur them. The result is that the sampled 3arc-second data has a slightly finer spatial resolution (about 100 meters), but with more noise, in comparison to the averaged 3arc-second data, which has a slightly courser spatial resolution (about 112 meters), but with less noise.

For Version 3.0, 3arc-second data were derived using the sampling method and also the averaging method, and each is available for download.

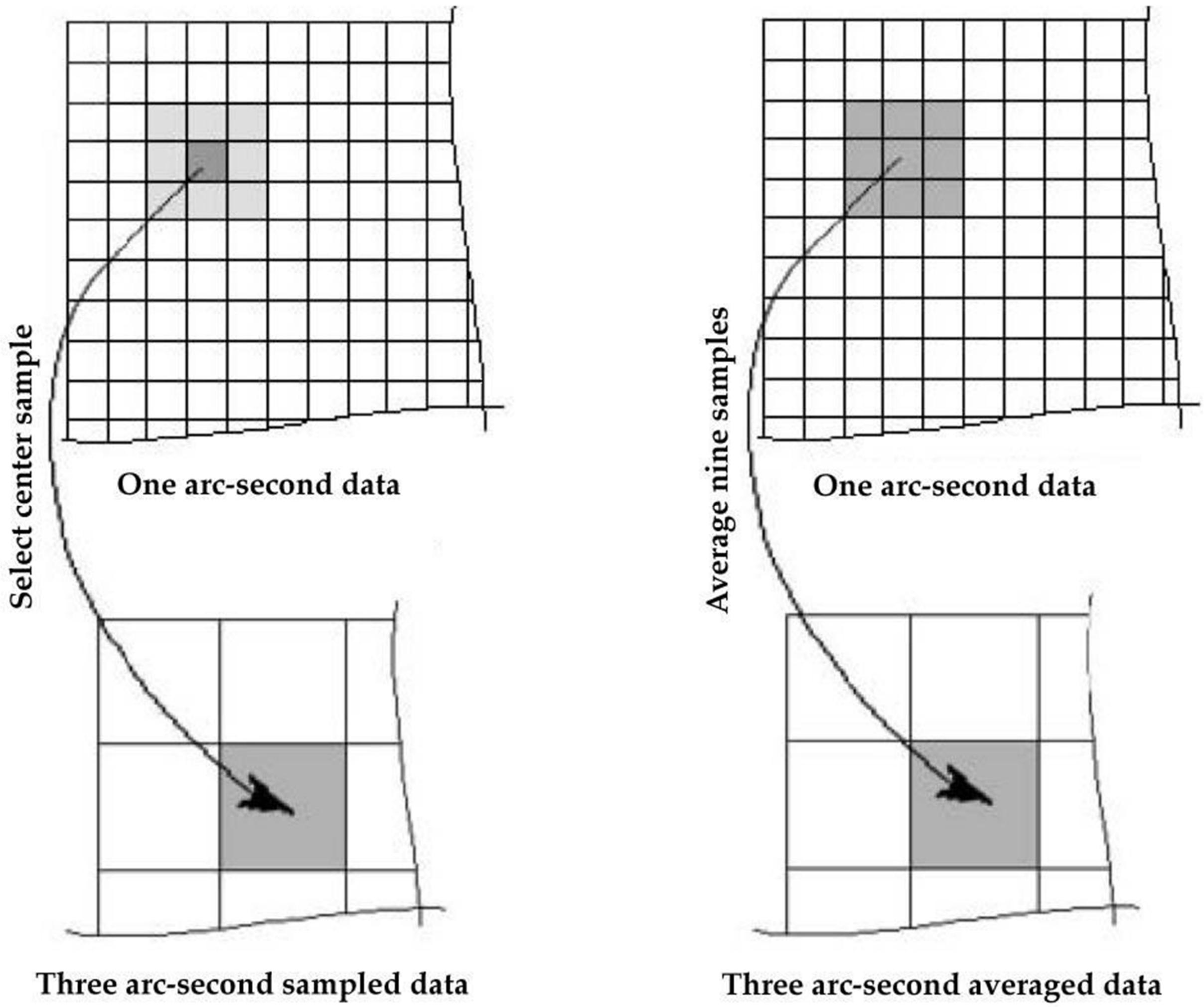


Figure 3: Deriving 3 arc-second data from 1 arc-second data: Sampling Method versus Averaging Method. (I would change One arc-second to 1 arc-second in the above diagrams. I would also change Three arc-second to 3 arc-second in the lower two captions to be consistent with your Figure 3 caption.

2.1.4 SRTM Topography Data Format

The names of individual data tiles refer to the latitude and longitude of the southwest (lower left) corner of the tile. For example, N37W105 has its lower left corner at 37 degrees north latitude and 105 degrees west longitude and covers (slightly more than) the area 37-38 degrees N and 104-105 degrees. To be more exact, the file name coordinates refer to the geometric center of the lower-left pixel, and all edge pixels of the tile are centered on full-degree lines of latitude and/or longitude.

SRTM*1 data are sampled at 1arc-second of latitude and longitude and each file contains 3,601 lines and 3,601 samples. The rows at the north and south edges as well as the columns at the east and west edges of each tile overlap (and are identical to) the edge rows and columns in the adjacent tile. SRTM*3 data are sampled at 3 arc-seconds and contain 1,201 lines and 1,201 samples with similar overlapping rows and columns.

** The SRTMGL30 data set are sampled at 30 arc-seconds and cover the full extent of latitude from 90 degrees south to 90 degrees north, and the full extent of longitude from 180 degrees west to 180 degrees east. The SRTMGL30 data set is made up of 33 tiles. The area from 60 degrees south latitude to 90 degrees north latitude and from 180 degrees west longitude to 180 degrees east longitude is covered by 27 tiles, with each tile covering 50 degrees of latitude and 40 degrees of longitude. Antarctica (90 degrees south latitude to 60 degrees south latitude and 180 degrees west longitude to 180 degrees east longitude) is covered by 6 tiles, with each tile covering 30 degrees of latitude and 60 degrees of longitude. The 27 tiles that individually cover 50 degrees of latitude and 40 degrees of longitude each have 6,000 rows and 4,800 columns. The 6 Antarctica tiles that individually cover 30 degrees of latitude and 60 degrees of longitude each have 3,600 rows and 7,200 columns. There is no overlap among the tiles so the global data set may be assembled by simply abutting the adjacent tiles.

The data are in "geographic" projection (also known as equirectangular or plate carrée), which is to say a raster presentation with respectively equal intervals of latitude and longitude in the vertical and horizontal dimensions. More technically, the projection maps meridians to vertical straight lines of constant spacing, and circles of latitude (“parallels”) to horizontal straight lines of constant spacing. This might be thought of as no projection at all, but simply a latitude-longitude data array.

Height files have the extension .HGT, and the DEM is provided as two-byte (16-bit) binary signed integer raster data. Two-byte signed integers can range from -32,767 to 32,767 meters and thus can encompass the range of elevations found on Earth. There are no header or trailer bytes embedded in the file. The data are stored in row major order, meaning all the data for the northernmost row (row 1) are followed by all the data for row 2, etc.

All elevations are in meters referenced to the WGS84/EGM96 geoid (NGA, 1997; Lemoine, 1998).

The two-byte data are in Motorola "big-endian" order with the most significant byte first. Most personal computers, and Macintosh computers built after 2006 use Intel ("little-endian") order so byte swapping may be necessary. Some software programs perform the swapping during ingest.

Voids in Versions 1.0 and 2.1 are flagged with the value -32,768. There are no voids in Version 3.0.

2.2 SRTM DEM IMAGES

For the DEMs, data from every acquisition that crossed a tile were mosaicked and combined, so there is only one data file for each 1 degree tile. However, for the image data, 2 types of data sets are available:

1.) Swath Image Data – For this data set, every data take that crossed a tile was saved as a separate file (no mosaicking or combining) so that some files may contain only partial data. In addition, because of the SCANSAR technique involved, each SRTM swath was comprised of four overlapping sub-swaths. Data from each sub-swath is also included as a separate file, so every image pixel acquired by SRTM is included in this data set.
2.) Combined Image Data – This data set was produced by averaging all image data in a 1 degree x 1 degree tile, similar to the DEM. This produced a single smoother, by uncalibrated image for each tile.

Both types of SRTM image data are sampled at 1 arc-second of latitude and longitude and each file contains 3,601 lines and 3,601 samples. The rows at the north and south edges as well as the columns at the east and west edges of each tile overlap and are identical to the edge rows and columns in the adjacent tile.

This sampling scheme is sometimes called a "geographic projection," but of course it is not actually a projection in the mapping sense. It does not possess any of the characteristics usually present in true map projections. For example, it is not conformal, so that if it is displayed as an image geographic features will be distorted. However, it is quite easy to handle mathematically, can be easily imported into most image processing and GIS software packages, and multiple tiles can be assembled easily into a larger mosaic (unlike the troublesome UTM projection, for example.)

2.2.1 SRTM Swath Image Data

There are two files for each sub-swath that passes through a tile:

*.mag – radar sub-swath image data
*.inc – local incidence angle for each sample in the corresponding *.mag file

The SRTM swath-image product provides the mean surface backscatter coefficients of the mapped areas. This required the image processor to be radiometrically calibrated. For SRTM, the goals for absolute and relative radiometric calibration respectively were 3 dB and 1 dB. The SRTM main antenna was the major source of calibration error as it was a large active array antenna. In the spaceborne environment, both zero-gravity unloading and the large variation in temperature caused distortions in the phased array. Hundreds of phase shifters and transmit / receive modules populated the C-band antenna panels. Monitoring the performance of each module was very difficult, causing inaccuracies in the antenna pattern predictions, in particular in elevation, as the beams were spoiled to obtain a wide swath. Therefore, antenna elevation pattern correction coefficients were derived with empirical methods using data takes over the Amazon rain forest. As the Amazon rainforest is a homogeneous and isotropic area, the backscatter coefficient is almost independent of the look angle. Without compensation, a scalloping effect would have been visible in the sub-swath and full-swath images.

Speckle noise is present in the swath image data. This is a characteristic of coherent imaging systems and appears as a random, high-frequency, salt-and-pepper effect. Most imaging radar systems average many ”looks” to reduce speckle, however SRTM was optimized for a wide swath and thus acquired only 1-2 looks per sub-swath causing a relatively high-speckle noise level. This is one reason why the combined image data set, described later, was produced.

Because local incidence angle is so important for interpretation of radar images, a file containing that information is provided for each of the sub-swath image files. The values are calculated from the position of the Shuttle and the DEM. They represent the angle between the radar beam and the local normal to the surface at each pixel. Because this information could be used to “back-calculate” a full resolution DEM, the incidence-angle pixels were averaged 3x3 and sampled back to 1 arc-second to remain registered with the corresponding image file.

Figure 4, below, shows a portion of tile N34W119, demonstrating the characteristic of the swath image and incidence angle data sets and the difference with the topographic data.

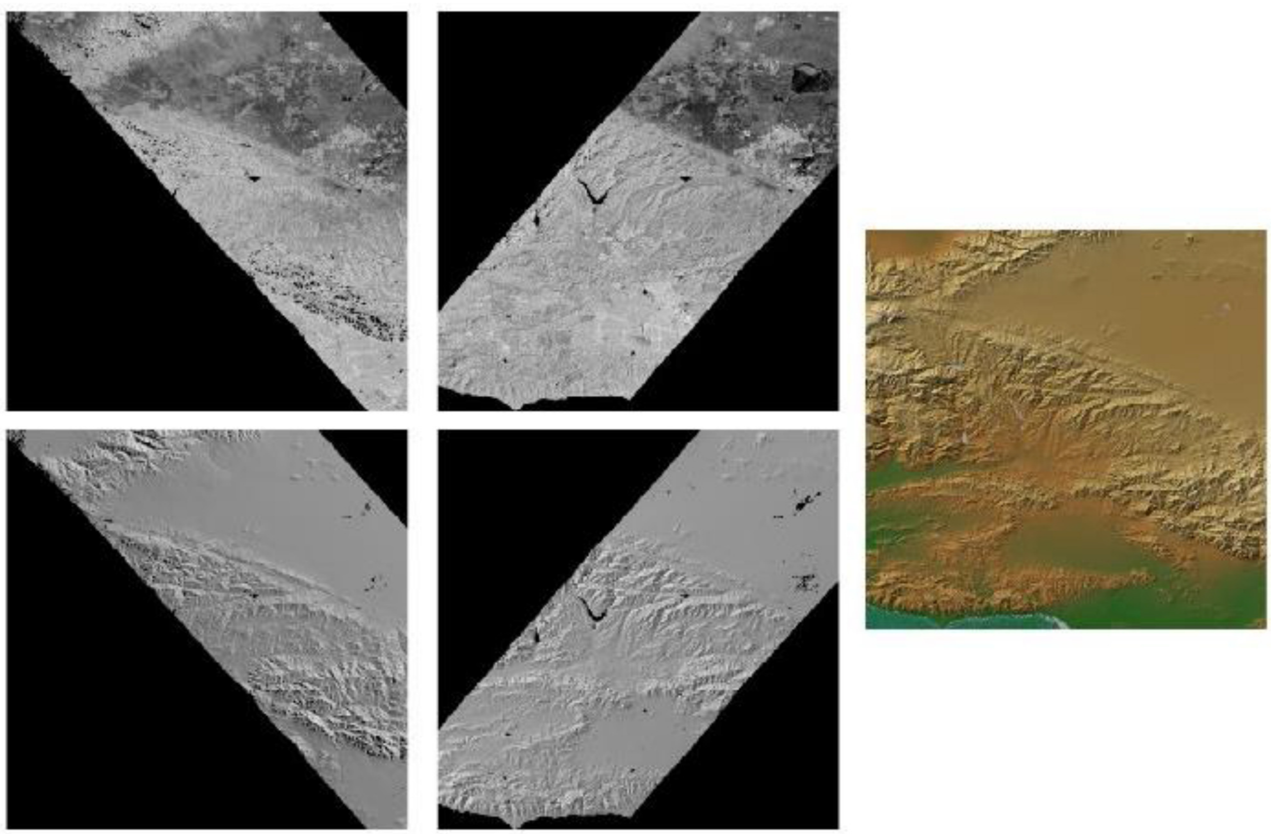


Figure 4: Comparison of SRTM swath image data and SRTM DEM for tile N34W119 (Los Angeles, CA). Left: Descending sub-swath N34W119_072_100_SS2_1_01. Upper left: Image file, Lower left: Incidence angle file. Center: Ascending sub-swath N34W119_114_030_SS4_1_01. Upper center: Image file, Lower center: Incidence angle file. Right: SRTM DEM for the same tile, shaded-relief and elevation color-coded.
Note that the voids in the DEM (shown in grey) correspond to black areas in the image and incidence angle file. The incidence angle files look like shaded-relief topography because

they're calculated in a similar way. Note that the rough, vegetated, mountains are bright in the images, while the smoother Mojave Desert tends to be dark.

As with the DEM files, the first 6 characters of each file name indicate the geographic coordinates of the center of the lower left (southwest) sample of each file. For swath image files, this is followed by 6 numbers that indicate the data take number, consisting of the orbit number followed by a serial number for that orbit. This is followed by a sub-swath number, which increases outward from the spacecraft nadir point, and also is the key to the polarization for that sub-swath. The remaining numbers were not used and are always the same.

- SS1 = sub-swath 1 HH polarization approx. 30 degrees - 40 degrees look angle
- SS1 = sub-swath 2 VV polarization approx. 41degrees - 48 degrees look angle
- SS1 = sub-swath 3 VV polarization approx. 47 degrees - 53 degrees look angle
- SS1 = sub-swath 4 HH polarization approx. 52 degrees - 59 degrees look angle

Example: File N34W119_072_100_SS2_1_01.mag has its lower left sample centered on 34 degrees N latitude, 119 degrees W longitude, was the 100th data take on orbit 72, and includes data from sub-swath 2 indicating VV polarization.

Image brightness, or magnitude, in the swath image data is given as 8 bits/sample, with the values indicating radar cross section, scaled linearly between -50 dB and +40 dB. Data numbers (DN) can be converted to backscatter cross section in dB using the expression dB = 0.3529*DN - 50. There are no header or trailer bytes embedded in the file. The data are stored in row major order (all the data for row 1, followed by all the data for row 2, etc.)

Local incidence angle is provided as 16-bit integer data in a simple binary raster. There are no header or trailer bytes embedded in the file. The data are stored in row major order (all the data for row 1, followed by all the data for row 2, etc.). The pixel values represent hundredths of a degree (e.g., . 4,321 = 43.21 degrees).

Because the incidence angle data are stored in a 2-byte binary format, users must be aware of how the bytes are addressed on their computers. The incidence angle data are provided in Motorola or IEEE byte order, which stores the most significant byte first ("big endian"). Systems such as Sun SPARC and Silicon Graphics workstations and older Macintosh computers use the Motorola byte order. The Intel byte order, which stores the least significant byte first ("little endian"), is used on DEC Alpha systems and most personal computers. Users with systems that address bytes in the Intel byte order may have to "swap bytes" of the incidence angle data unless their application software performs the conversion during ingest.

2.2.2 SRTM Combined Image Data Set

The objective of the SRTM combined image data set was to produce the smoothest mosaicked image data possible. Specifically, every pixel in the mosaic output is an average of all the image pixels in that location. Pixels with a value of 0 (voids) were not counted. Because SRTM imaged a given location with two polarizations (VV and HH) and at a variety of look and azimuth angles, this means that quantitative scattering information has been lost as technicians sought to produce a smoother image product. Quantitative scattering information is preserved in the SRTM swath image product, described earlier.

There are two combined image files for each tile:

*.img is the SRTM image mosaic
*.num gives the number of pixels averaged for each output pixel

As with the DEM files, the file name indicates the geographic coordinates of the center of the lower left (southwest) sample of each file. The combined image files are 8 bits/samples, with the values indicating uncalibrated radar brightness. The *.num file is also given as 8 bit/sample, with the value being the number of pixels averaged to create the output pixel. This value is typically 0 (for a void pixel) to 10 or more.

3.0 References

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4.0 Web sites of interest

NASA/JPL SRTM:
http://www2.jpl.nasa.gov/srtm/

U.S. Geological Survey:
http://srtm.usgs.gov/

ASTER Project:
http://asterweb.jpl.nasa.gov/

GMTED2010:
https://lta.cr.usgs.gov/GMTED2010

National Elevation Dataset (NED):
http://ned.usgs.gov/