Identifying Global Elevation Data for Research

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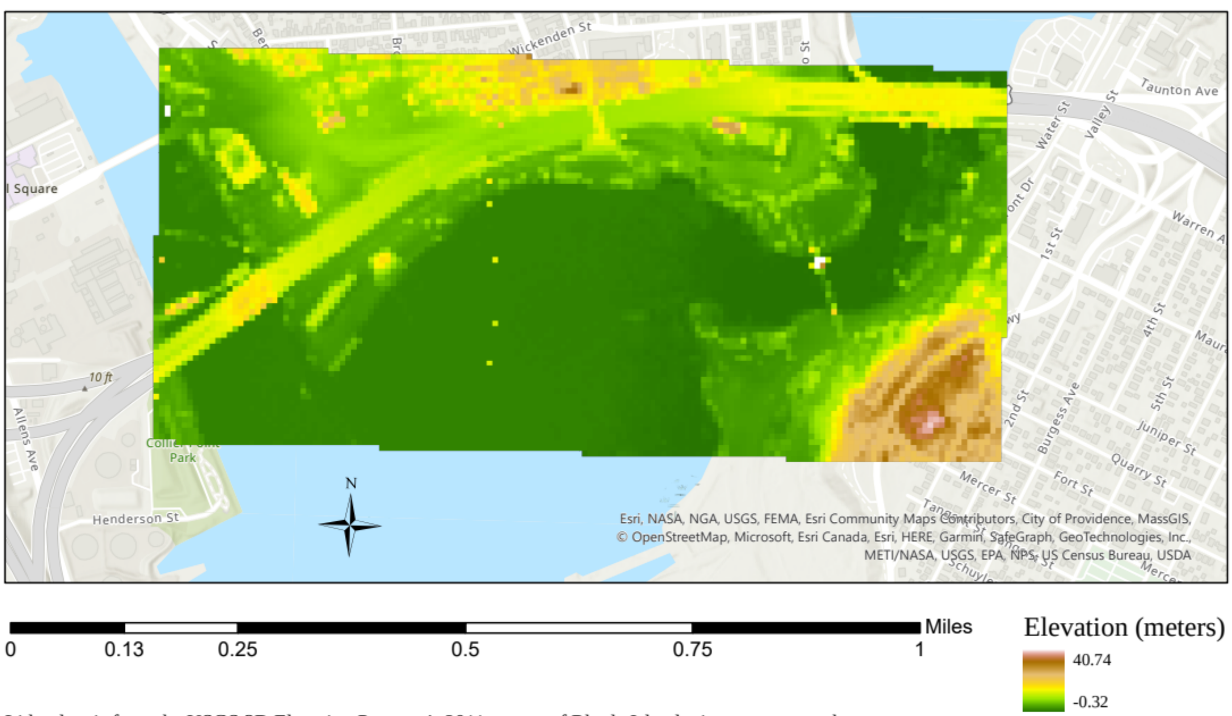
Introduction

This tutorial introduces and compares several digital sources of global elevation data. First, I identify important attributes to look for when choosing a Digital Elevation Model (DEM) data source. Then, I present a table which lists some commonly used global-coverage DEM data products and compares their key attributes. Finally, I describe some of the key differences between major DEM data collection technologies, and explain how these differences result in different DEM products having different kinds of uncertainty associated with them.

The image below shows what a DEM looks like when a range in elevation values for a given geographic area is represented in GIS software using a range of colors:

Digital Elevation Model for India Point Park, Providence, RI



Lidar data is from the USGS 3D Elevation Program's 2011 survey of Rhode Island, via opentopography.org.

This DEM (cell size: 10 meters) was derived after classifying overlap and reclassifying ground points using ESRI's aggressive classification algorithm.

Color scheme: ESRI Elevation #10, stretched from minimum to maximum

Processing and cartography: Ethan McIntosh, for ANTH 2202 at Brown University

Background and Terminology

Digital Elevation Models (DEMs) are georeferenced raster images whose pixel values represent land elevation. They are used across a wide variety of disciplines in both the social and natural sciences. Within GIS software, DEMs can form the basis for terrain maps, hydrological models, viewshed analyses, and more.

The term DEM is somewhat slippery. In many contexts, it is used to refer specifically to representations of bare-earth elevation that exclude trees, buildings, or other surface objects, which are also known as Digital Terrain Models (DTMs). However, in other contexts, including this guide, DEM is a more general term meant to encompass both DTMs and Digital Surface Models (DSMs), which represent the elevation of all objects on the surface, including the tops of trees and buildings. Most DEM data products are meant to be DTMs, but some are actually DSMs, so it's important to be aware of which type of DEM you need and choose a data product appropriately.

Attributes to look for when choosing a DEM

When searching for DEM data, the first important consideration for choosing a product is knowing whether that product includes data for your particular study area. Many of the DEM data products listed as having global coverage only cover certain latitudes, for example, with limited or no coverage near the poles.

Besides spatial coverage, it's also important to know whether a given DEM has voids (a.k.a. missing values/pixels with null or NoData values). For some applications, it may be important to have a void-free product, while for others, it may be okay to have some missing values.

It's also important to consider a DEM product's spatial resolution. Many global-coverage products report their horizontal resolution in arc-seconds. These units are not fixed-distance – rather, one arc-second is a fraction of a degree of latitude or longitude, and a single arc-second thus represents a larger east-west distance at the equator than it would at other latitudes.

To convert a DEM whose cell size is in arc-seconds into a DEM with a cell size measured in fixed surface distances, one would use GIS software to project that raster into a projected coordinate system. In this guide, I list the arc-second spatial resolutions of various DEM products as well as their approximate corresponding resolutions in meters.

Another consideration for the use of DEMs in some applications is the vertical accuracy of the elevation values. In this guide, I report vertical root mean square error (RMSE) values for various DEM products, but it's important to note that for a product to have a certain RMSE does not mean it will be that accurate in all terrain types and places. RMSE should instead be thought of as more of an "average" accuracy across large areas.

To get a better estimate of how a given DEM product might perform for a specific application, one would want to consult studies that evaluate the absolute error of that DEM product's elevation values compared to GPS or LiDAR-based ground-truth elevation values for a particular terrain type or geography.

Global-coverage DEM product comparison

In the table below, I compare five publicly available global-coverage DEM datasets, taking information about each of their attributes from their respective product websites. Each product's name has a link to its respective website. I also consulted a study which assessed the vertical accuracy of several of these DEM products in multiple terrain types and geographies.

Technology	Name	Coverage	Finest Resolution	Vertical RMSE	Void-Free?
InSAR	GMTED2010	90°S to 84°N	7.5 arc-seconds (230m)	30m	Yes
InSAR	SRTM	56°S to 60°N	1 arc-second (30m)	9m	Sometimes
InSAR	TDM90	Full globe	3 arc-seconds (90m)	10m	No
SSI	ASTER	83°S to 83°N	1 arc-second (30m)	17m	Yes
SSI	AW3D30	60°S to 90°N	1 arc-second (30m)	5m	Yes

Differences in the capabilities, limitations, and uncertainties associated with different DEM data sources stem largely from differences in the technologies used to collect the data. The following section identifies some key differences between the major technologies used to generate DEMs, including stereoscopic satellite imagery (SSI), interferometric synthetic aperture radar (InSAR), and light detection and ranging (LiDAR), and what those differences mean for the quality and extent of the corresponding elevation data.

DEM data collection technologies

Most modern DEMs are produced using remotely sensed data of some kind. Differences in coverage, resolution, and accuracy between DEM products are often driven by the basic features and limitations of the underlying remote sensing technologies.

Broadly speaking, the data that is used to generate DEMs can either be collected by satellites or by lower-flying aircraft. Satellites orbit hundreds or thousands of kilometers above the earth's surface and can cover the whole globe relatively quickly, whereas aircraft fly at much lower altitudes (roughly 2km or lower), and typically generate higher-accuracy elevation data but for smaller areas.

Light Detection and Ranging (LiDAR)

Perhaps the most widely used technology for generating DEMs from aircraft-based missions is Light Detection and Ranging (LiDAR). Nanosecond-long laser pulses are fired toward targets on the surface, and the timing and intensity of the pulses that return to the sensor are used to determine the elevation of the targets. On LiDAR missions over vegetated or urbanized areas, multiple returns are detected from each laser pulse, which are used to statistically classify and separate ground elevations from vegetation or building elevations, thereby enabling the production of either DTMs (bare-earth elevations) or DSMs (surface object elevations).

DEMs based on LiDAR missions are only publicly available for a handful of countries. In the United States, for example, the USGS's 3D Elevation Program flew a series of LiDAR missions to produce DEMs with resolutions down to 1/3 arc-seconds (roughly 10 meters per pixel) and 1/9 arc-seconds (roughly 3 meters per pixel), and even 1-meter DEMs for some regions. The 3DEP's 1/3 arc-second seamless (void-filled) DEM product claims a vertical RMSE of 0.82 meters, which is excellent for most applications. These products are all downloadable from The National Map.

There is no freely available full-coverage global LiDAR dataset. Some commercial vendors claim to offer global LiDAR data, but further inspection of a leading contender reveals that their dataset only includes 56 countries, and I could not determine whether their coverage in these countries is void-free. Studies that use elevation data in parts of the world where LiDAR data is not publicly available therefore either commission their own site-specific LiDAR surveys or use data from global-coverage DEMs based on satellite data.

Satellite-based technologies

In general, DEMs derived from satellite data have lower spatial resolution and lower vertical accuracy than DEMs using aircraft-based LiDAR, but satellite-based DEM products have more global coverage, and their resolutions and accuracies are good enough for many applications.

One satellite-based technology for measuring elevation is stereoscopic satellite imagery (SSI), in which a satellite takes an image of the same target location from different angles along its orbit, taking advantage of the differences in viewing geometry in each image to calculate the elevation of the target. Over heavily vegetated or built-up areas, much of what the satellite detects is not the ground itself, but surface objects. This introduces error in applications where these data are used as bare-earth elevation values.

Another widely used satellite-based technology for generating DEMs is interferometric synthetic aperture radar (InSAR), or radar interferometry. Similar to stereoscopic satellite imagery, InSAR involves comparing data from different angles to calculate target elevation. However, with InSAR, the satellite actively generates pulses of electromagnetic radiation at radio-wave frequencies (i.e., each wave is several centimeters long) and then collects the returning pulse, rather than passively collecting an image of the visible light or near-infrared radiation (i.e., a micron or less in wavelength) that reflects off the surface due to the Sun's illumination, as is done in stereoscopic satellite imagery.

The longer wavelengths involved in radar mostly penetrate through vegetation and other surface objects, meaning that the return pulses come from the bare earth more than they do the elevation of surface objects. This gives InSAR technology some advantage in producing accurate models of bare-earth elevation in vegetated or built-up areas compared to stereoscopic satellite imagery.

A downside of InSAR-derived DEM data is that they tend to have more areas of missing values due to uncertainties and errors in data collection compared to stereoscopic satellite imagery, especially over highly mountainous areas. However, missing values affect all satellite data to some degree, and most DEM products therefore include some fraction of data that is either taken from other sources or interpolated in order to fill voids. More information about the specific void-filling procedures and data sources for individual DEM products can be found on their respective product websites.

For more information on elevation data, a good starting place is the USGS FAQ page on DEMs.