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A Review on Global and Localised Coverage Elevation Data Sources for Topographic Application

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Abstract. As the need for elevation data grows, it is more vital than ever for users to match the data degree of dependability, precision, and spatial resolution to their specific uses to produce a useful and cost-effective product. This article will describe several sources of elevation data, ranging from space-based to aerial-based techniques, and classify the data according to its respective quality and accuracy. The elevation data sources can be classified into two namely localised or can also be referred to as regional, and global coverage. Among the example of localised sources of elevation data are Light Detection and Ranging (LiDAR) and Interferometry Synthetic Aperture Radar (InSAR). The global sources of elevation data are Shuttle Radar Topography Mission (SRTM), Advanced Spaceborne Thermal Emission and Reflection Radiometer-Global Digital Elevation Model (ASTER), Advanced Land Observing Satellite (ALOSW3D), Global Multi-Resolution Terrain Elevation Data 2010 (GMTED2010), TerraSAR-X add on for daily Digital Elevation Measurement (TanDEM-X), The Ice, Cloud, and land Elevation Satellite-2 (ICESat-2), Radar Satellite (RADARSAT) Constellation Mission (RCM) and Satellite-Derived Bathymetry (SDB). The characteristics of each elevation data source were discussed in terms of its launch date, period of observation, spatial resolution, horizontal and vertical datum, and coverage. Its reliability was described in detail for future topographic applications.

1. Introduction

Elevation data is a computerised depiction of the landscape on Earth. The data can be represented as a set of points (latitude, longitude, orthometric height) or as a grid (raster). The digital elevation models (DEMs) are gridded rasters that have a value for each pixel in the picture, representing the elevation above a model of the Earth with respect to the World Geodetic System 1984 (WGS84) ellipsoid or Geodetic Reference System 1980 (GRS80). The spatial resolution is the size of each rectangular pixel (for example, 2 m x 2 m) [1]. The data may be gathered via a variety of methods, such as airborne laser



sensors, synthetic aperture radar (SAR), photogrammetry using aerial photography or satellite imaging stereo pairs, or surveying. The data is frequently used in engineering works, urban and regional planning, coastal vulnerability and risk assessment as well as environmental development. Plus, with its ongoing development, the elevation data are driving innovation even further by assisting the latest technologies like augmented reality for engineering design and environmental modeling [2].

Currently, the need for elevation data has continued to flourish as the awareness about its reliability and benefits among the users has spread rapidly. However, there are different degrees of elevation data regarding its quality and positioning accuracy, just as there are multiple levels of maps being produced. Every data level serves a purpose, but it is essential to match the data applicable to the level of accuracy, precision, and resolution necessary to produce a suitable and cost-effective output. A better resolution ensures more accurate elevation data in depicting the actual topography of the study area, more expensive the data acquisition and processing [1].

The global coverage elevation data are often described as having low spatial resolution and accuracy. Such information is important for regional environmental modeling, particularly in locations where higher resolution data is lacking. The majority of this information is derived from space-based radar. Although the quality of data and the accuracy of space-based radar cannot be compared to that of aerial LiDAR, space-based radar products have a distinct advantage as they can be generated in any weather, at any time, and in any location throughout the world, from pole to pole [3]. Space-based radar can also monitor relative changes in ground elevation up to mm precision. Such is extremely useful for tracking changes in ground elevation, which is necessary for assessing soil subsidence, polar ice thickness, and other comparable purposes. The great precision of measuring terrain elevation is relative and should not be mistaken with the product's absolute accuracy, since it does not reach that level [1].

Localised coverage elevation data, on the contrary, has better quality and is more accurate than global coverage data. Unfortunately, the data are not free as they are often controlled by commercial or public institutions and are not shared with the public. However, several government agencies may provide this data for free for public use. The data was gathered using two primary methods which are Light Detection and Ranging (LiDAR) and Interferometry Synthetic Aperture Radar (InSAR) [4]. A SAR technique is utilised to obtain elevation data on a restricted scale all over the world. Furthermore, in all weather conditions, InSAR is also successful in mapping topography beneath a thick canopy. However, InSAR data has a lesser resolution and accuracy in comparison to LiDAR data. The global and localised elevation data sources are shown in Table 1 [1].

Table 1. Global and Localised Coverage Elevation Data Sources

Localised Coverage	Global Coverage
<ul style="list-style-type: none"> • Light Detection and Ranging (LiDAR) • Interferometry Synthetic Aperture Radar (InSAR) 	<ul style="list-style-type: none"> • Shuttle Radar Topography Mission (SRTM) • Advanced Spaceborne Thermal Emission and Reflection Radiometer-Global Digital Elevation Model (ASTER) • Advanced Land Observing Satellite (ALOSW3D) • Global Multi-Resolution Terrain Elevation Data 2010 (GMTED2010) • TerraSAR-X add on for daily Digital Elevation Measurement (TanDEM-X) • The Ice, Cloud, and land Elevation Satellite-2 (ICESat-2)

- Radar Satellite (RADARSAT) Constellation Mission (RCM)
- Satellite-Derived Bathymetry (SDB)

2. Localised Coverage Elevation Data Sources

2.1 Light Detection and Ranging (LiDAR)

A LiDAR is an approach to measure the ranges of the survey area using laser technology. The ranges are determined by the time it takes for the reflected light to return to the receiver. By altering the wavelength of light utilised, the observed measurement was then used to create computerised 3D topography of places on the earth's surface, allowing it to produce a map with a very good resolution [5]. It can be classified into two categories which are aerial which consists of topography and bathymetry, and the other category is terrestrial which comprises static and mobile. The data can be utilised in many applications, however, it is frequently utilised in flood modeling, landslide monitoring, forest area mapping, and mining survey [6][7]. The working principles of LiDAR are illustrated in Figure 1.

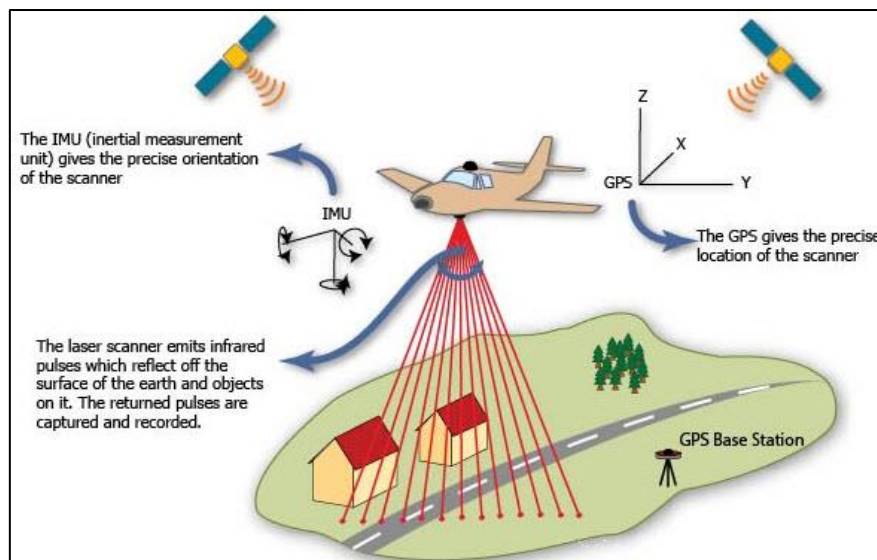


Figure 1. The working principle of LiDAR [2][7]

2.2 Interferometry Synthetic Aperture Radar (InSAR)

InSAR (or IfSAR) stands for interferometric synthetic aperture radar, which is commonly utilised in remote sensing and geodesy. The geodetic-based approach work by employing changes in the phase of the waves returning to the satellite or aircraft, to produce DEMs derived from at least two images from synthetic aperture radar (SAR) [8]. The approach can identify any changes in deformation at mm-scale across a wide range of timescales. Interferometry techniques describe an object on the earth's surface by observing the phase difference of two fluorescent waves coming from one object [8]. InSAR which is one of the methods of SAR currently is widely used for mapping land and ice surface topography, the study of geological structure and classification of rocks, the study of ocean waves and currents, the study of ice characteristics and movement, observation of deformation, and earthquakes. Especially for the field of deformation, InSAR is now a promising technological alternative in deformation research such as land subsidence and earthquake research [4].

In deriving the topography of the survey area, two requirements are compulsory. firstly, the object on the earth's surface must be visible with a high resolution so that an appropriate interpretation and

identification can be performed. Secondly, the image must have a sufficient three-dimensional (3-D) position so that the elevation of the survey area can be determined accurately. Both of these conditions can be achieved by using the InSAR technique. Such achievement is the reason many fields of study are applying InSAR as an approach in deriving the ground elevation. Furthermore, with the launch of the ERS-1 Satellite followed by the ERS-2, this technique is growing, because these two radar satellite systems can produce interferometry data every two days. [8].

The aircraft or satellite vehicles are two approaches that can be utilised to obtain InSAR images. For the aircraft approach, two antennas are utilised simultaneously to perform InSAR imaging with a single pass along the survey area. On the other hand, only one antenna is utilised to obtain InSAR images using a satellite approach by passing the survey area several times (multi-pass) at particular times. Furthermore, the utilisation of a dual antenna can be distinguished by the placement of the antenna, namely the plane position (across-track) and the other is the length of the plane (along-track). [9]. The working principles of InSAR are shown in Figure 2.

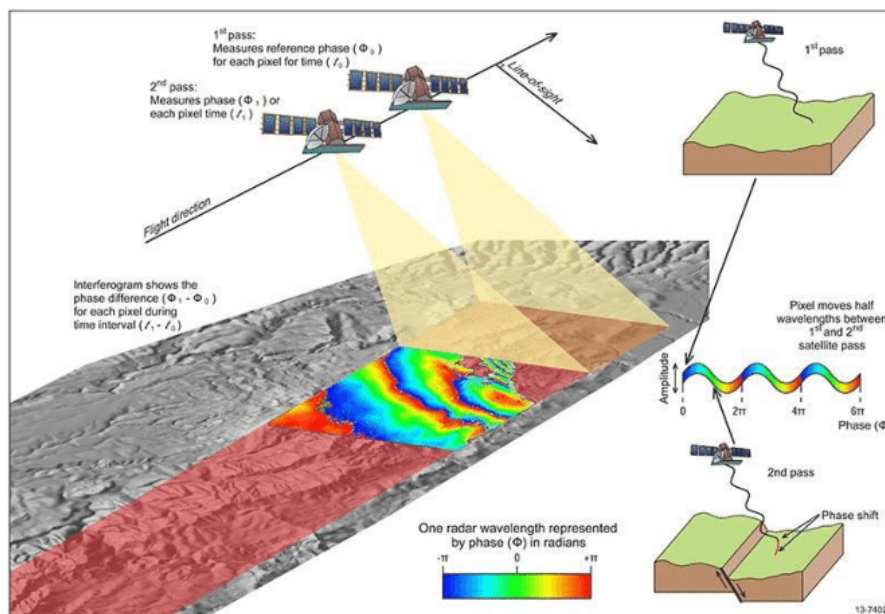


Figure 2. The working principles of InSAR [8]

3. Global Coverage Elevation Data Sources

The global coverage DEMs data are normally utilised to determine the elevation that involves a vast survey area, even though these datasets are slightly lower in terms of resolution and accuracy relatively [10]. Since their information is publicly accessible, a lot of scientists are intrigued to compare its accuracy by utilising various techniques for justification. The general evaluation for the accuracy of DEMs requires measurement by using GNSS that incorporates in-situ measurement with better accuracy as ground-truthing to validate the DEM [11].

3.1 Shuttle Radar Topography Mission (SRTM)

SRTM was developed from the collaboration between the United States of America, Germany, and Italy by deriving the elevation data through radar interferometry. The data acquisition period was conducted for 11 days (11th to 22nd February 2000 [11]). The spatial resolution of the SRTM dataset can be categorised into two namely the 3 arc-seconds (90 m) which is available for public use and 1 arc-second (30 m) which can only be accessed by the United States of America [12]. Its vertical and horizontal accuracy is approximately 16 m and 20 m respectively. SRTM covers land surfaces within 60° N to 56° S and has collected over 80 percent of the Earth's surface. The data refers to the ellipsoid of the WGS84

for horizontal datum and the Earth Gravitational Model 1996 (EGM96) for vertical datum [13]. Figure 3 shows the operating principles of SRTM.

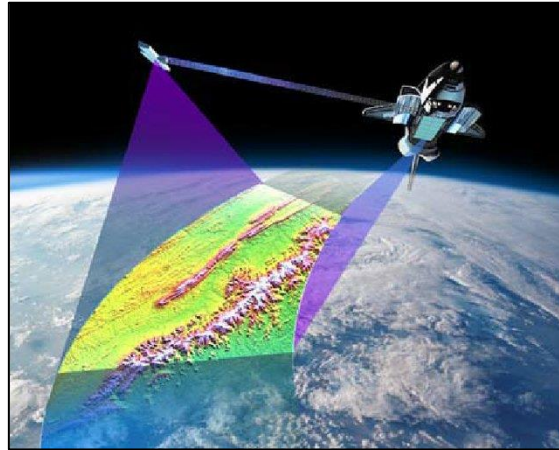


Figure 3. Shuttle Radar Topography Mission (SRTM) [11]

3.2 Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)

In 2009, Japan and the National Aeronautics and Space Administration (NASA) jointly created the ASTER dataset. ASTER is one of the sensors operating on Terra, the satellite launched in December 1999 as part of NASA's Earth Observing System (EOS) mission [14]. ASTER's spatial resolution varies can be divided into three namely 15 m in the visible and near-infrared (VIR), 30 m in the short-wave infrared (SWI), and 90 m in the thermal infrared (TIR). There is an additional channel that is the key to the production of DEM data by ASTER which is called channel 3B with the same nadir as channel 3 (near-infrared) but by using a backward firing angle with an angle of 28° giving a stereo image pair to ASTER [15]. Its data covers 83° North to 83° South. The absolute vertical accuracy of version-1 of ASTER is 20 m. ASTER refers to the horizontal and vertical datum of the WGS84 and EGM96 respectively [11]. Figure 4 shows the operating principles of ASTER.

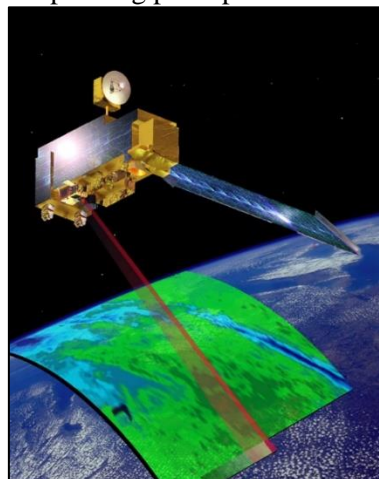


Figure 4. Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) [14]

3.3 Advanced Land Observing Satellite (ALOSW3D)

ALOSW3D was developed by Japan in May 2015 and afterward was made accessible to the public. Before the advancement of the TerraSAR-X add-on daily for Digital Elevation Measurement (TanDEM-X), ALOSW3D is the most accurate DEM data source globally with a resolution of 1 arc-second which is around 30 m mesh version [16]. The AW3D30 is an enhanced version of the 5-m mesh version of the ALOS. Its data covers 60° North to 60° South [16]. It comes in a spatial resolution of 1 arc-second (approximately 30 m). The ALOSW3D information is truly compatible with high-impact research and upcoming studies. Past research has also discovered that the accuracy of ALOSW3D has greater Root Mean Square Error (RMSE) in comparison with other DEM datasets, for example, GDEM derived from the height extraction of GNSS and LiDAR. ALOSW3D uses the WGS84 and EGM96 for horizontal and vertical datum respectively [17]. Figure 5 shows the operating principles of ALOSW3D.

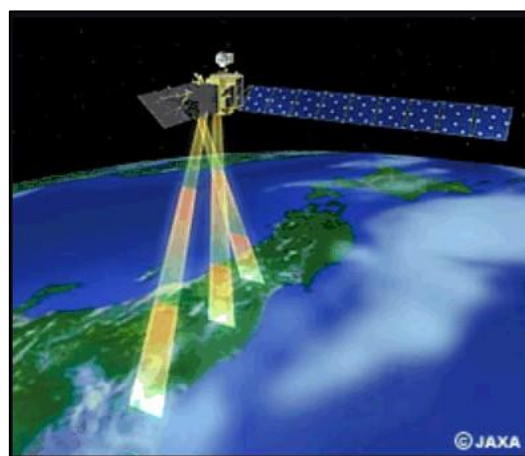


Figure 5. Advanced Land Observing Satellite (ALOSW3D) [16]

3.4 Global Multi-Resolution Terrain Elevation Data 2010 (GMTED2010)

GMTED2010 is an upgraded version of GTOPO3. Its establishment is from a collaboration between the United States Geological Survey (USGS) and the National Geospatial-Intelligence Agency (NGA) in 2010. It has been made public since then. The basis of its elevation data is 11 raster-based elevation sources that use an approach known as DEM fusion, which comprises 3 resolutions on the horizontal spacing of 7.5 arc seconds (approximately 250 m), 15 arc seconds (approximately 500 m), and 30 arc-seconds (approximately 1 km) [18]. A 1 arc-second SRTM Digital Terrain Elevation Data is the GMTED2010 main dataset source. Its data covers 84° North to 90° South [10]. It was developed with respect to a breakline emphasis, systemic subsample, minimum, maximum, and median height, as well as standard elevation deviation. GMTED2010 uses the WGS84 and EGM96 for horizontal and vertical datum respectively [10].

3.5 TerraSAR-X add on for daily Digital Elevation Measurement (TanDEM-X)

A new age in the modeling of a very precise Digital Elevation model with the development of TanDEM-X (TerraSAR-X add on daily for the Digital Elevation Measurement) (DEM). According to [21], its establishment is the world's most comprehensive, consistent, high-precision, and full DEM surface dataset. The mission was generally a common effort by the DLR and AIRBUS Defense and Space [20]. The project was launched in 2010 and based on the aggregation of the interferometrically synthetic aperture radar bistatic X-band data acquisition technique, aimed to create a globally homogenous digital surface model [21]. The mission successfully gathered interferometric data between 90° North and 90° South utilising two satellites TerraSAR-X and TanDEM-X in the X band that operated in near helix formations. TanDEM-X comes which 0.4-arc second for 12 m and 1-arc second for 30 m spatial

resolution respectively. The vertical and horizontal datum of TanDEM-X is the ellipsoidal heights of WGS84 [22]. Figure 6 shows the operating principles of TanDEM-X.



Figure 6. TerraSAR-X add on for daily Digital Elevation Measurement (TanDEM-X) [21]

3.6 The Ice, Cloud, and land Elevation Satellite-2 (ICESat-2)

NASA launched the ICESat-2, on September 15, 2018. ICESat-2 is a satellite mission for measuring the elevation of the ice sheet and the thickness of sea ice, as well as the topography of the earth's surface, characteristics of vegetation, and clouds. It uses the Geoscience Laser Altimeter System (GLAS) which is the world's first laser-ranging (LiDAR) equipment for continuous global earth monitoring. Such achievement was made possible with the installation of the Advanced Topographic Laser Altimeter System (ATLAS) onboard the ICESat-2, primarily designed to assess any variation in polar sea ice and land ice. It gathers elevation data from pole to pole with a spatial resolution of roughly 17 m. Its mapping features have been used in a variety of applications by people all around the world [23]. In an area with a clear coastal ocean, ICESat-2 data can be utilised for bathymetry surveys to a depth up to 25 m. The data covers the whole globe following the orbital passes ground paths. ICESat-2 track data, on the other hand, is provided at 100 m intervals, making it suitable for assessing the terrain elevation in distant places. The latest research has determined that the vertical accuracy of ICESat-2 data is approximately 0.20 m in an open and a gentle slope and 2 m in steep topography [24]. Figure 7 shows the operating principles of ICESat-2.



Figure 7. The Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) [24]

3.7 Radar Satellite (RADARSAT) Constellation Mission

The first commercial Earth observation satellite launched by Canada was RADARSAT-1. RADARSAT-1 was launched from Vandenberg Air Force Base in California on November 4, 1995, into a sun-synchronous orbit (dawn-dusk) above the earth with an altitude of 798 km (496 miles) and an inclination of 98.60°. The RADARSAT Constellation Mission (RCM) consists of three satellites mission managed by the Canadian Space Agency (CSA) for earth observation. In addition to climate research, the RCM also provides data for oil and gas exploration, marine exploration, shipping industry, and other commercial applications. RADARSAT-2 users will be able to access continuous C-band SAR imagery through the RCM, as it will deliver images at a high temporal resolution [25]. Some other uses of data from RADARSAT images are maritime monitoring, disaster management, and ecosystem monitoring. Figure 8 shows the operating principles of RADARSAT.

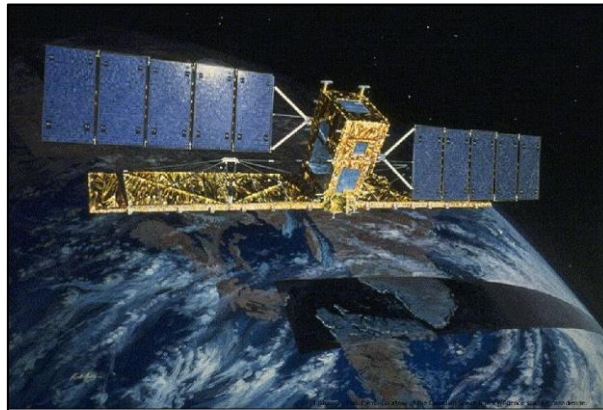


Figure 8. Radar Satellite (RADARSAT) Constellation Mission [25]

3.8 Satellite-Derived Bathymetry (SDB)

Without the need of specialist bathymetric sensors on any vessel or aeroplanes, SDB is one of the most practical breakthroughs in mapping submerged terrain. It is a quick and inexpensive way to get shallow bathymetry data. Although NASA initially introduced it in 1975, to map underwater around the Bahamas and off the coast of Florida, SDB was not widely used until the year 2000 in determining the bathymetry of a coastal region [26]. SDB uses the algorithm that has already been published as well as data from the open-source satellite images such as Landsat 8, SPOT, and WorldView from DigitalGlobe to estimate near-shore bathymetry elevation values. In addition, to estimates, the band or ratio elevation profile, blue, green, and infrared bands are used [27]. Figure 9 shows the working principles of SDB. The sources of global coverage elevation data are shown in Table 2.

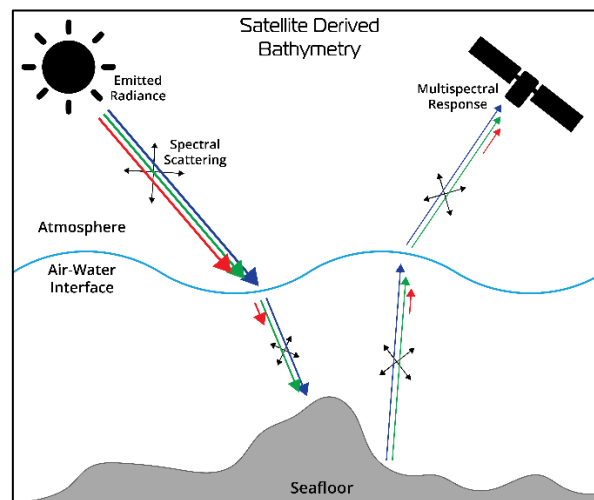


Figure 9. The working principle of Satellite-Derived Bathymetry (SDB) [26]

Table 2. Sources of Coastal DEM data

No	DEM Data Sources	Website
1	SRTM	http://srtm.csi.cgiar.org/
2	ASTER	http://gdex.cr.usgs.gov/gdex/
3	ALOSW3D	http://www.eorc.jaxa.jp/ALOS/en/aw3d30/
4	GMTED2010	http://topotools.cr.usgs.gov/gmted_viewer/viewer.html
5	TanDEM-X	https://download.geoservice.dlr.de/TDM90/
6	ICESat-2	https://nsidc.org/data/icesat-2
7	RADARSAT	https://tpm-ds.eo.esa.int/smcat/Radarsat-2/
8	SDB	https://www.eomap.com/services/multisource-bathymetry-grid/

The limitations of the topics discussed in this article are in the form of a comparison of the global and localised DEM classification were reviewed based on its main data source and provider, release date, data acquisition period, spatial resolution, vertical accuracy, areas covered, and its vertical and horizontal datum. All DEM classifications can be seen in Tables 3 and 4.

Table 3. Comparison between Elevation Data Sources

	ASTER	SRTM30/90	GMTED 2010	ALOSW3D	TanDEM-X
Source of Data	ASTER	Radar	SRTM (main)	PRISM	InSAR
Data Provider	METI /NASA	NASA/ CGIAR-CSI	USGS	JAXA	DLR and AIRBUS
Year of Release	2009	2003	2010	2015	2010
Period of Data Acquisition	2009 - Ongoing	11 Days (during 2000)	-	2015 - Ongoing	2005 – Ongoing
Spatial Resolution	3 VNIR of 15 m 6 SWIR of 30 m 5 TIR of 90 m	1 arc-second for 30 m 3 arc-seconds for 90 m	7.5 arc seconds (approximately 250 m)	1-arc second (30 m)	0.4 arc second (12 m) 1-arc second (30 m)

			15 arc-seconds (approximately 500 m)		
			30 arc-seconds (approximately 1 km)		
DEM Vertical Accuracy	±20 m	±10 to ±16 m	±90 m	±30 m	±10 m
Global Coverage of DEM	83° South to 83° North	60° South to 56° North	84° North to 90° South	60° North to 60° South	90° North to 90° South
Vertical Datum	EGM96	EGM96	EGM96	EGM96	WGS84
Horizontal Datum	WGS84	WGS84	WGS84	WGS84	WGS84

Table 4. Comparison between Elevation Data Sources

	ICESat-2	RADARSAT	SDB	LiDAR	InSAR/IfSAR
Data Source	GLAS	SAR	Landsat 8 SPOT or WorldView	Laser	SAR
Data Provider	NASA	CSA	NASA	-	-
Year of Release	2018	1995	2000	1960	1992
Period of Data Acquisition	2018 – Ongoing	1995 - Ongoing	2000 - Ongoing	Localised	Localised
Spatial Resolution	17 m	3 m	2 m, 10 m, and 15 m – 30 m	10 cm	0.5 m
DEM Vertical Accuracy	0.2 m – 2.0 m	-	Varied	10 cm – 30 cm	< 50 cm
Global Coverage of DEM	88° North and 88°South)	Equatorial latitude every 6 days	Worldwide	Localised	Localised
Vertical Datum	WGS84	WGS84	WGS84	Depend on application	Depend on application
Horizontal Datum	WGS84	WGS84	WGS84		

Conclusion

In a conclusion, for a general topographic application, the LiDAR demonstrates a better DEM vertical accuracy of 10 to 30 cm compared to InSAR with 50 cm for localised elevation data sources. On the other hand, ICESat-2 illustrates the highest DEM vertical accuracy of 0.2 to 2.0 m compared to ASTER, SRTM, GMTED, ALOS3D, TanDEM-X, RADARSAT, and SDB with ±20 m, ±10 to ±16 m, ±90 m, ±30 m and ±10 m respectively for global elevation data sources.

In addition, it can also be concluded that a localised and global elevation data source has its advantages and disadvantages. The localised elevation data promises a better accuracy and resolution

however the price is very expensive, and very limited coverage. On the other hand, even though they are mostly free and easy to access, in addition, coming with a large coverage, the global elevation data sources are less in terms of accuracy and spatial resolution. Therefore, the user himself needs to make a thorough discussion and consideration on the degree of accuracy and resolution required for any topographic application such as mapping, flood modeling, coastal inundation assessment, coastal vulnerability index, road construction, regional planning, survey, and design grape, and many more before deciding for any sources of elevation data.

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