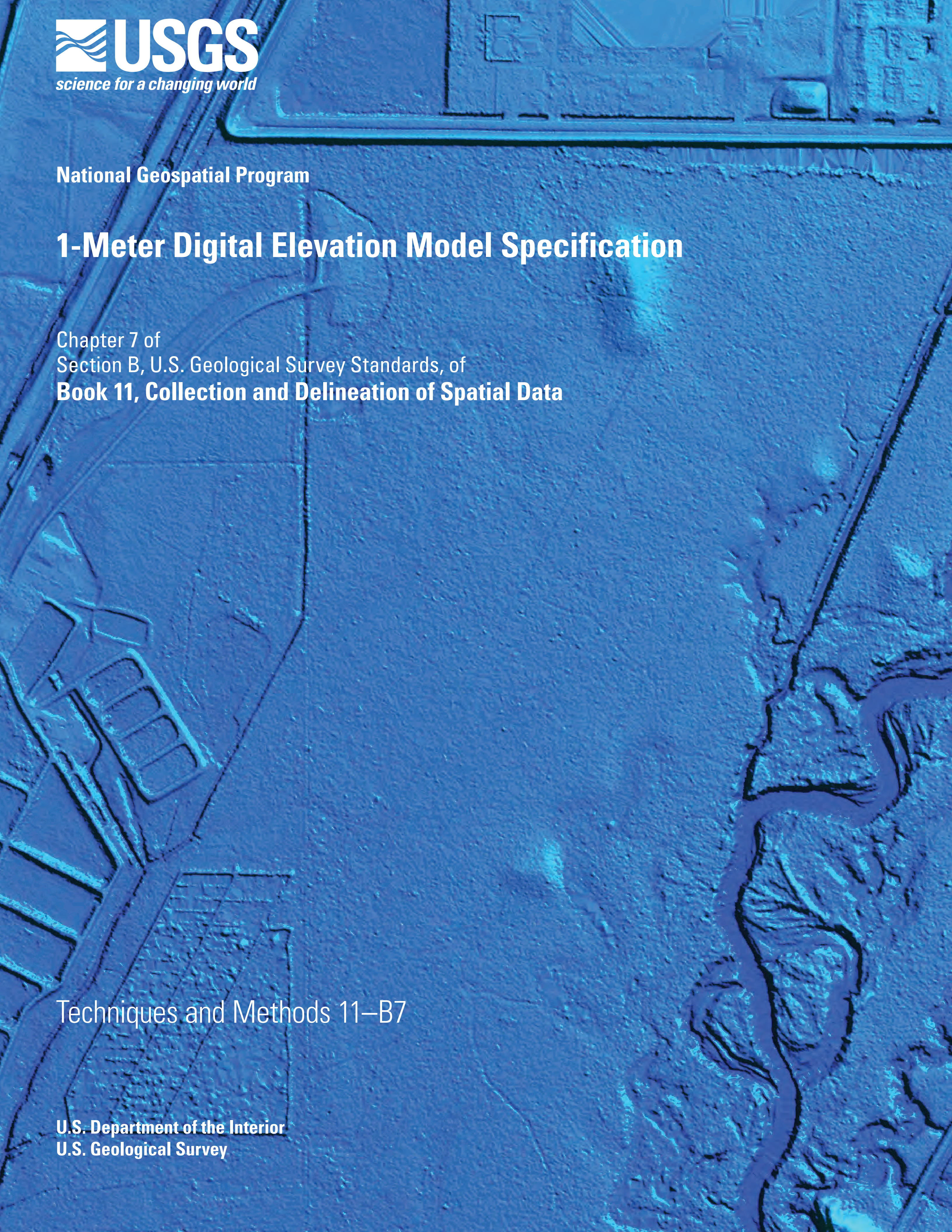

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National Geospatial Program

1-Meter Digital Elevation Model Specification

Chapter 7 of
Section B, U.S. Geological Survey Standards, of
Book 11, Collection and Delineation of Spatial Data

Techniques and Methods 11–B7

U.S. Department of the Interior
U.S. Geological Survey

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By Samantha T. Arundel, Christy-Ann M. Archuleta, Lori A. Phillips,
Brittany L. Roche, and Eric W. Constance

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2015

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International System of Units to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	39.37/12	U.S. Survey foot (ft)
meter (m)	1/0.3048	International foot (ft)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	0.0002471	acre
square kilometer (km^2)	247.1	acre
square meter (m^2)	10.76	square foot (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this specification, refers to the distance above the geoid, unless specifically referenced to the ellipsoid.

Abbreviations

3D	3-dimensional
3DEP	3D Elevation Program
DEM	digital elevation model
FGDC	Federal Geographic Data Committee
GPS	Global Positioning System
ifsar	interferometric synthetic aperture radar
IMU	Inertial Measurement Unit
lidar	light detection and ranging
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NEEA	National Enhanced Elevation Assessment
NPD	nominal pulse density
NPS	nominal pulse spacing
NVA	nonvegetated vertical accuracy
QA	quality assurance
QC	quality control
RMSE	root mean square error
$RMSE_z$	RMSE in the *z* (elevation) dimension
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
VVA	vegetated vertical accuracy

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1-Meter Digital Elevation Model Specification

By Samantha T. Arundel, Christy-Ann M. Archuleta, Lori A. Phillips, Brittany L. Roche, and Eric W. Constance

Abstract

In January 2015, the U.S. Geological Survey National Geospatial Technical Operations Center began producing the 1-Meter Digital Elevation Model data product. This new product was developed to provide high resolution bare-earth digital elevation models from light detection and ranging (lidar) elevation data and other elevation data collected over the conterminous United States (lower 48 States), Hawaii, and potentially Alaska and the U.S. territories. The 1-Meter Digital Elevation Model consists of hydroflattened, topographic bare-earth raster digital elevation models, with a 1-meter x 1-meter cell size, and is available in 10,000-meter x 10,000-meter square blocks with a 6-meter overlap. This report details the specifications required for the production of the 1-Meter Digital Elevation Model.

Introduction

The Office of Management and Budget designates the U.S. Geological Survey (USGS) as the lead agency for the collection and distribution of topographic elevation data (White House Office of Management and Budget, 2002). The specifications in this report pertain to the processing and quality control of the 1-meter digital elevation model (DEM) dataset produced for The National Map.

Purpose and Scope

The purpose of this report is to provide detailed specifications for the 1-meter DEM product distributed through The National Map. This report does not define procurement requirements for the initial light detection and ranging (lidar) or other elevation datasets used to create the final 1-meter DEM dataset. For more information on lidar procurement specifications, refer to Heidemann (2014).

Applicability

The specifications in this report are applicable to the 1-meter DEM dataset produced by the USGS for the conterminous United States (lower 48 States), Hawaii, and potentially Alaska and the U.S. territories.

Requirement Terminology

Individual requirements that are defined in the "specifications" section of this report use "shall" or "will" statements, which have a specific meaning in the context of a specification requirement:

- A "shall" statement means that the requirement must be met in all cases.
- A "will" statement indicates that the requirement is expected to be met wherever possible, but exceptions to implementation may exist.

Background for the 1-Meter Digital Elevation Model

The USGS began production of a standard 1-meter DEM in January 2015 (Arundel and others, 2015). The 1-meter DEM is produced primarily from high-resolution lidar data obtained through the 3-Dimensional Elevation Program (3DEP), but is also augmented with contributed data that meet source requirements defined in this report. Before the inception of the 1-meter DEM, the highest-resolution standard DEM available for the Nation was 1/9 arc-seconds (about 3 meters). The National Enhanced Elevation Assessment (Dewberry, 2012), which led to the establishment of the 3DEP, revealed a wide range of applications that demanded nationwide elevation data at spatial resolutions of 1 meter or finer (table 1). To help meet the needs of the broad elevation data user community, the USGS enhanced its elevation product suite in 2015 with several new product offerings, including a standard 1-meter DEM.

Table 1. Top ten ranked National Enhanced Elevation Assessment critical applications.

[Modified from Snyder, 2012]

Rank	National Enhanced Elevation Assessment critical applications
1	Flood risk management
2	Infrastructure management
3	Natural resources conservation
4	Agriculture and precision farming
5	Stream resource management
6	Water supply
7	Wildfire management
8	Aviation safety
9	Geologic resource assessment
10	Forest resources management

The 1-meter DEM is a bare-earth DEM representing the topographic surface of the Earth and consists of a collection of DEM data from numerous acquisition projects transformed to a common spatial reference system and delivered in a standard format. The 1-meter DEM is seamless within the geographic extent of each acquisition project, but blending, edge matching, and mosaicking are not done between projects. Data are not retired or replaced in the 1-meter dataset unless unacceptable quality issues are revealed after incorporation. New project data may partially or completely overlap the spatial extent of previously incorporated projects. Geographic coverage of the 1-meter DEM increases as new high-resolution lidar, and potentially data collected with other technologies that meet source requirements, become available to the USGS. The 1-meter DEM will eventually replace the 1/9 arc-second DEM as the highest-resolution standard USGS DEM.

Product Overview

The 1-meter DEM product is a hydroflattened, topographic bare-earth raster DEM, with a 1-meter x 1-meter cell size. Organized by data collection project, it is suitable for general mapping purposes and contour generation. This elevation layer is created from high-resolution elevation data that are inspected for adherence to USGS quality control standards (U.S. Geological Survey, 2015a). The 1-meter DEM consists of 1-kilometer x 1-kilometer data tiles that are stored and delivered with an additional 6-cell overlap; therefore, tile dimensions are 10,012-meter cells on both the *x* and *y* axes. Rasters contain elevation values in meters derived through bilinear interpolation, stored as floating point doubles, and delivered as ERDAS Imagine files (.img) (Library of Congress, 2015). Metadata are provided in a separate file.

Specifications

Source Data Requirements

Collection technology.—The 1-meter DEM is expected to be produced almost entirely from lidar. Other source data (for example, photogrammetry) may be used, provided these data meet or exceed the spatial resolution and accuracies specified in this report. Lidar sources shall meet the requirements that are current with the date of lidar production, which may be draft version 13 or a later version of “USGS Lidar Base Specification” (Heidemann, 2014).

Horizontal resolution.—The nominal pulse spacing of lidar source data shall be less than or equal to 1 meter. Horizontal resolution of source data from technologies other than lidar shall be proven suitable for producing a DEM product at 1-meter or finer resolution.

Vertical accuracy.—Source data for the 1-meter DEM shall meet the 3DEP Quality Level 2 10.0-centimeter (cm) root mean square error (RMSE) threshold for vertical accuracy.

Spatial Reference System

The horizontal coordinate reference system shall be Universal Transverse Mercator (UTM), North American Datum of 1983 (NAD 83) (fig. 1). The horizontal units shall be meters. Elevation values shall be orthometric heights, North American Vertical Datum of 1988 (NAVD 88). The vertical units shall be decimal meters. As realizations of datums and geoid models are updated and improved, these references will differ across component collections within the overall 1-meter DEM product. In addition to the information listed above, the metadata shall identify the datum realization and specific geoid model for each tile.

Distribution Tiling

Distribution tiles shall be provided in their respective UTM zone. Distribution tiles that straddle a UTM zone boundary shall be made available in each UTM zone. The tiling scheme shall be nominally 10,000 meters x 10,000 meters. Each distribution tile shall contain a 6-pixel overlap; therefore, the spatial extent of each tile shall be 10,012 meters x 10,012 meters (fig. 1).

Horizontal Resolution

The 1-meter DEM shall have a horizontal ground resolution of 1 meter in both the *x* and *y* dimensions.

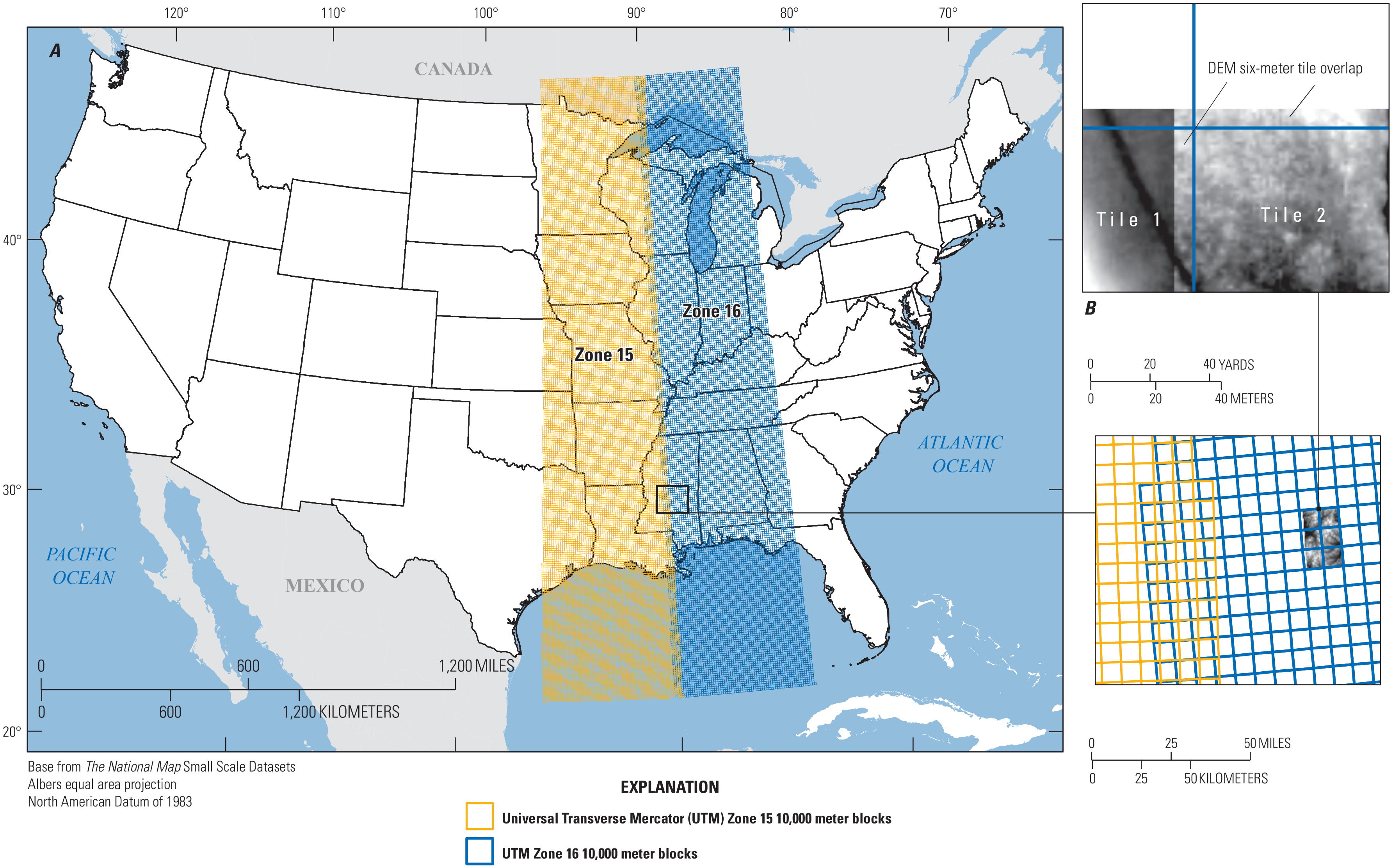

Figure 1. 1-Meter DEMs shall be produced in 10,000-meter x 10,000-meter blocks with a 6-meter tile overlap, and duplicate tiles being produced where Universal Transverse Mercator (UTM) zones overlap. *A*, Example of 10,000-meter x 10,000-meter blocks cast on two UTM zones. Inset shows closeup of area where duplicate tiles will be provided for each bordering zone. *B*, Close up showing 6-meter tile overlap.

Horizontal Accuracy

It is difficult to quantitatively test the horizontal accuracy of the lidar source data from which most of the 1-meter DEM is produced. Factors such as Global Positioning System (GPS) accuracy, Inertial Measurement Unit (IMU) precision, flying height, and calibration control all affect positional accuracy (American Society for Photogrammetry and Remote Sensing, 2015). Because these factors differ across collections, the horizontal accuracy of the overall 1-meter DEM is variable. In most cases, the horizontal accuracy is expected to be within 1 meter.

Vertical Accuracy

The target non-vegetated vertical accuracy of the 1-meter DEM shall be 19.6 cm accuracy at the 95-percent confidence level. This accuracy is equivalent to the 10-cm root mean square error in the *z* dimension ($RMSE_z$) Vertical Accuracy Class within the American Society for Photogrammetry and Remote Sensing (2015), and meets the 3DEP Quality Level 2 vertical accuracy threshold of plus or minus (±) 10 cm $RMSE_z$. The $RMSE_z$ in vegetated areas may be greater than the $RMSE_z$ in nonvegetated areas. Related error and accuracy values are shown in table 2. Although a slight dilution of vertical accuracy may be introduced through reprojection of source data into the UTM coordinate system, the 1-meter DEM product is expected to retain this level of accuracy.

Table 2. Relationship of vertical accuracy class to nonvegetated root mean square error in the elevation dimension, nonvegetated accuracy at the 95-percent confidence level, and vegetated accuracy at the 95th percentile.

[Modified from table B.7 in American Society for Photogrammetry and Remote Sensing (2015). $RMSE_z$, root mean square error in the *z* (vertical) dimension; cm, centimeter; NVA, nonvegetated vertical accuracy; VVA, vegetated vertical accuracy]

Vertical accuracy class	Absolute accuracy		
	$RMSE_z$ nonvegetated (cm)	NVA at 95-percent confidence level (cm)	VVA at 95th percentile (cm)
10 cm	10.0	19.6	30

Digital Elevation Model Surface Treatment

The 1-meter DEM product shall be a hydroflattened topographic DEM that is suitable for general mapping purposes and contour generation. Water surface elevations are established to support improved cartographic appearance only.

Georeferencing Information

Georeferencing information shall be identified in the appropriate location within the raster file header (.img), external support files (for example, .aux), and metadata.

Data Source and Tile Dates

The source-data date for the 1-meter DEM shall be the earliest month and year of the project data acquisition. The tile date shall be the month and year the project or tile was incorporated into the 1-meter DEM dataset.

Distribution and Supporting File Formats

The 1-meter DEM shall be delivered in 32-bit floating-point raster, ERDAS .img format (Library of Congress, 2015). The USGS may offer additional or alternative file formats for distribution in the future.

Void Areas

Void areas in tiles (that is, areas within the rectangular distribution tile extent but outside the acquisition project boundary) shall be coded using a unique “NODATA” value, and this value will be the same for all component projects. This value shall be recorded in the appropriate location within the raster file header (.img), external support files (for example, .aux), and metadata.

Metadata

Metadata for the 1-meter DEM data shall be provided in Extensible Markup Language (XML) (Bray, Paoli, and others, 2008) formatted files compliant with the Federal Geographic Data Committee (FGDC) Content Standard for Digital Geospatial Metadata. The USGS may offer additional or alternative metadata formats in the future. See appendix 1 for an example of metadata provided with a 1-meter DEM.

Spatial Metadata

Spatial metadata in the form of an Esri® shapefile (Esri, 1998) shall be supplied for the 1-meter DEM and may be accessed at the following The National Map metadata download page: http://nationalmap.gov/3DEP/3dep_prodmetadata.html. Polygonal footprints of the contributing area of each source dataset provide spatial context, with attached attributes describing the characteristics of the source data, such as its original resolution and production method (fig. 2). A user might, for example, use this metadata to identify parts of a study area during a particular timeframe. A list and description of these attributes are shown in appendix 2.

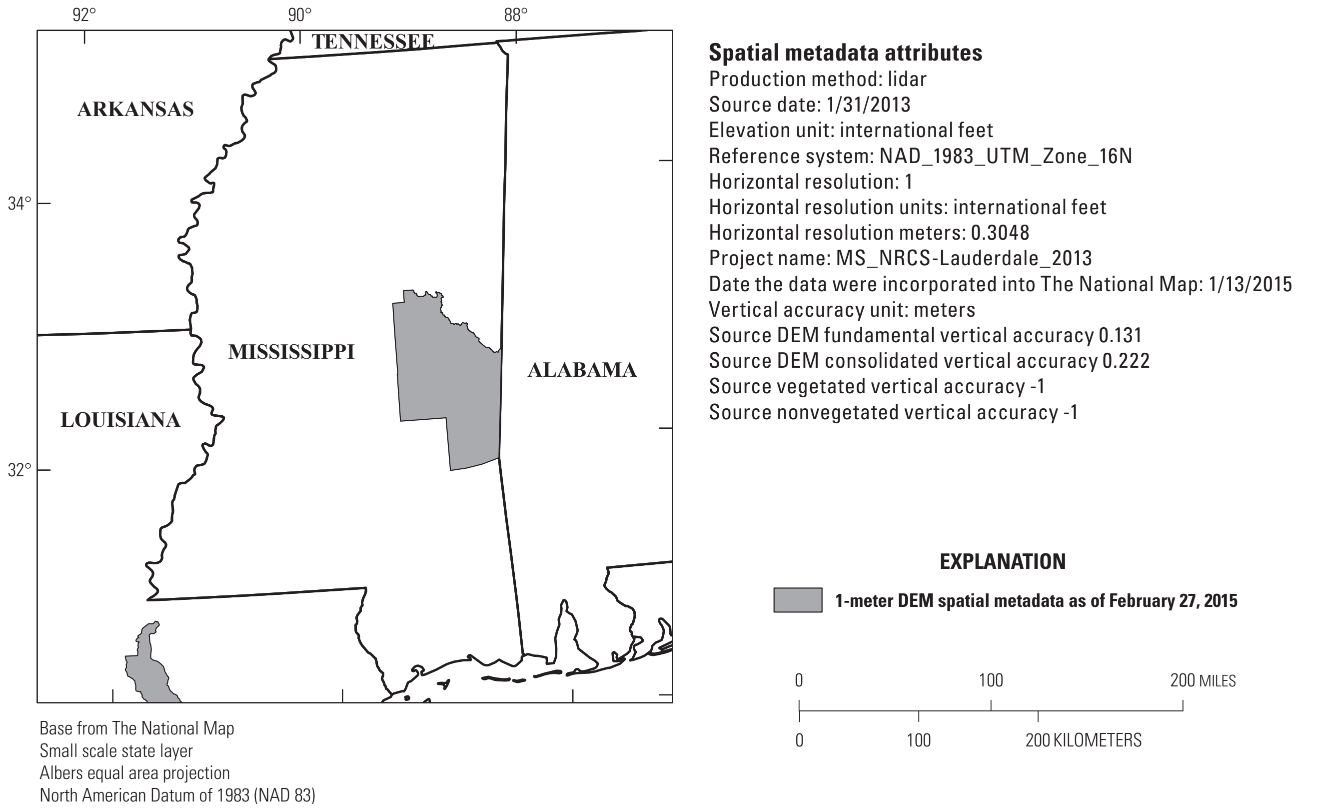

Figure 2. Example of spatial metadata for available 1-meter digital elevation models (DEMs) by light detection and ranging (lidar) project area as of February 27, 2015, for the Lauderdale, Mississippi, project area.

Quality Assurance and Control

All incoming source data shall be examined and tested to ensure suitability for inclusion in the 1-meter dataset. Production of the 1-meter DEM shall be automated to minimize opportunities for introducing errors and to enforce quality assurance (QA) checks throughout the process. System processes and software shall be rigorously tested to ensure consistent product quality and minimal dilution of accuracy from the source data. Following production processing, a final QA inspection shall be done of the new DEM product using the same checks as applied to incoming project DEM data.

Maintenance

The 1-meter DEM is updated continually as additional datasets meeting the requirements described in the “Source Data Requirements” section are obtained by the USGS. Updates will typically include the entire spatial coverage of an acquisition project or delivery lot; therefore, updates may overlap, partially or entirely, the spatial extent of other projects in the 1-meter DEM.

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Glossary

[Glossary modified from Heidemann (2014)]

A

accuracy The closeness of an estimated value (for example, measured or computed) to a standard or accepted (true) value of a particular quantity. *See* precision.

- **absolute accuracy** A measure that accounts for all systematic and random errors in a dataset. Absolute accuracy is stated with respect to a defined datum or reference system.
- **accuracy$_r$ (ACC$_r$)** The National Standards for Spatial Data Accuracy (NSSDA) (Federal Geographic Data Committee, 1998) reporting standard in the horizontal component that equals the radius of a circle of uncertainty, such that the true or theoretical horizontal location of the point falls within that circle 95 percent of the time. $ACC_r=1.7308*RMSE_r$.
- **accuracy$_z$ (ACC$_z$)** The NSSDA reporting standard in the vertical component that equals the linear uncertainty value, such that the true or theoretical vertical location of the point falls within that linear uncertainty value 95 percent of the time. $ACC_z=1.9600*RMSE_z$.
- **horizontal accuracy** The horizontal (radial) component of the positional accuracy of a dataset with respect to a horizontal datum, at a specified confidence level. *See* accuracy$_r$.
- **positional accuracy** The accuracy of the position of features, including horizontal and vertical positions, with respect to horizontal and vertical datums.
- **vertical accuracy** The measure of the positional accuracy of a dataset with respect to a specified vertical datum, at a specified confidence level or percentile. *See* accuracy$_z$.

arc-second (arcsecond, arcsec) An angular unit of measurement. A second of arc (arcsecond, arcsec) is 1⁄60 of an arc minute; 1⁄3,600 of a degree; and 1⁄1,296,000 of a circle.

B

bare earth (bare-earth) Digital elevation data of the terrain, free from vegetation, buildings, and other manmade structures. Elevations of the ground.

C

calibration (light detection and ranging [lidar] systems) The process of identifying and correcting for systematic errors in hardware, software, or data. Determining the systematic errors in a measuring device by comparing its measurements with the markings or measurements of a device that is considered correct. **Lidar system calibration** falls into two main categories:

- **instrument calibration** Factory calibration includes radiometric and geometric calibration unique to each manufacturer's hardware, and tuning the hardware to meet the performance specifications for the model being calibrated. Instrument calibration can only be assessed and corrected by the instrument manufacturer.
- **data calibration** The lever arm calibration determines the sensor-to-Global Positioning System (GPS)-antenna offset vector (the lever arm) components relative to the antenna phase center. The offset vector components are redetermined each time the sensor or aircraft GPS antenna is moved or repositioned. Because normal aircraft operations can induce slight variations in component mounting, the components are normally field

calibrated for each project, or even daily, to determine corrections to the roll, pitch, yaw, and scale calibration parameters.

cell (pixel) A single element of a raster dataset. Each cell contains a single numeric value of information representative of the area covered by the cell. Although the terms "cell" and "pixel" are synonymous, in this specification "cell" is used in reference to nonimage rasters such as digital elevation models (DEMs), whereas "pixel" is used in reference to image rasters such as lidar intensity images.

checkpoint (check point) A surveyed point used to estimate the positional accuracy of a geospatial dataset against an independent source of greater accuracy. Checkpoints are independent from, and may never be used as, control points on the same project.

classification (of lidar) The classification of lidar point cloud returns in accordance with a classification scheme to identify the type of target from which each lidar return is reflected. The process allows future differentiation between bare-earth terrain points, water, noise, vegetation, buildings, other manmade features and objects of interest.

confidence level The percentage of points within a dataset that are estimated to meet the stated accuracy; for example, accuracy reported at the 95-percent confidence level means that 95 percent of the positions in the dataset will have an error with respect to true ground position that are equal to or smaller than the reported accuracy value.

consolidated vertical accuracy (CVA) Obsolete; replaced by the term vegetated vertical accuracy (VVA). *See* percentile, vegetated vertical accuracy.

control point (calibration point) A surveyed point used to geometrically adjust a lidar dataset to establish its positional accuracy relative to the real world. Control points are independent from, and may never be used as, checkpoints on the same project.

D

datum A set of reference points on the Earth's surface from which position measurements are made and (usually) an associated model of the shape of the Earth (reference ellipsoid) to define a geographic coordinate system. Horizontal datums (for example, the North American Datum of 1983 [NAD 83]) are used for describing a point on the Earth's surface, in latitude and longitude or another coordinate system. Vertical datums (for example, the North American Vertical Datum of 1988 [NAVD 88]) are used to measure elevations or depths. In engineering and drafting, a datum is a reference point, surface, or axis on an object against which measurements are made.

digital elevation model (DEM) resolution The linear size of each cell of a raster DEM. Features smaller than the cell size cannot be explicitly represented in a raster model. DEM resolution may also be referred to as cell size, grid spacing, or ground sample distance.

digital elevation model (DEM) *See* four different definitions below:

- A popular acronym used as a generic term for digital topographic and bathymetric data in all its forms. Unless specifically referenced as a digital surface model (DSM), the generic DEM normally implies *x*, *y* coordinates and *z* values of the bare-earth terrain, void of vegetation and manmade features.

- As used by the U.S. Geological Survey (USGS), a DEM is the digital cartographic representation of the elevation of the land at regularly spaced intervals in *x* and *y* directions, using *z* values referenced to a common vertical datum.

- As typically used in the United States and elsewhere, a DEM has bare-earth *z* values at regularly spaced intervals in *x* and *y* directions; however, grid spacing, datum, coordinate systems, data formats, and other characteristics may differ widely.

- A "D-E-M" is a specific raster data format once widely used by the USGS. These DEMs are a sampled array of elevations for ground positions at regularly spaced intervals.

E

elevation The distance measured upward along a plumb line between a point and the geoid. The elevation of a point is normally the same as its orthometric height, defined as *H* in the equation:

$$H=h-N,$$

where

h is equal to the ellipsoid height and
N is equal to the geoid height.

F

fundamental vertical accuracy (FVA) Obsolete, replaced by the term nonvegetated vertical accuracy (NVA). *See* nonvegetated vertical accuracy, accuracy, confidence level.

G

geographic information system (GIS) A system of spatially referenced information, including computer programs that acquire, store, manipulate, analyze, and display spatial data.

geospatial data Information that identifies the geographic location and characteristics of natural or constructed features and boundaries of earth. This information may be derived from—among other things—remote sensing, mapping, and surveying technologies. Geospatial data generally are considered to be synonymous with spatial data; however, geospatial data always are associated with geographic or Cartesian coordinates linked to a horizontal or vertical datum, whereas spatial data (for example, generic architectural house plans) may include dimensions and other spatial data not linked to any physical location.

H

horizontal accuracy Positional accuracy of a dataset with respect to a horizontal datum. According to the NSSDA, horizontal (radial) accuracy at the 95-percent confidence level is defined as ACC_r.

hydrologically flattened (hydroflattened) Processing of a lidar-derived surface (DEM or triangulated irregular network [TIN]) so that mapped water bodies, streams, rivers, reservoirs, and other cartographically polygonal water surfaces are flat and, where appropriate, level from bank to bank. Additionally, surfaces of streams, rivers, and long reservoirs demonstrate a gradient change in elevation along their length, consistent with their natural behavior and the surrounding topography. In traditional maps that are compiled photogrammetrically, this process is accomplished automatically through the inclusion of measured breaklines in the digital terrain model however, because lidar does not inherently include breaklines, a DEM or TIN derived solely from lidar points will depict water surfaces with unsightly and unnatural artifacts of triangulation. The process of hydroflattening typically involves the addition of breaklines along the banks of specified water bodies, streams, rivers, and ponds. These breaklines establish elevations for the water surfaces that are consistent with the surrounding topography, and produce aesthetically acceptable water surfaces in the final DEM or TIN. Unlike hydroconditioning and hydroenforcement, hydroflattening is not driven by any hydrologic or hydraulic modeling requirements but solely by cartographic mapping needs.

I

intensity (lidar) For discrete-return lidar instruments, intensity is the recorded amplitude of the reflected lidar pulse at the moment the reflection is captured as a return by the lidar instrument. Lidar intensity values can be affected by many factors such as the instantaneous setting of the instrument's Automatic Gain Control and angle of incidence and cannot be equated to a true measure of energy. In full-waveform systems, the entire reflection is sampled and recorded, and true energy measurements can be made for each return or overall reflection. Intensity values for discrete returns derived from a full-waveform system may or may not be calibrated to represent true energy.

Lidar intensity data make it possible to map variable textures in the form of a gray-scale image. Intensity return data enable automatic identification and extraction of objects such as buildings and impervious surfaces and can aid in lidar point classification. In spite of their similar appearance, lidar intensity images differ from traditional panchromatic images in several important ways:

- Lidar intensity is a measure of the reflection of an active laser energy source, not natural solar energy.
- Lidar intensity images are aggregations of values at point samples. The value of a pixel does not represent the composite value for the area of that pixel.
- Lidar intensity images depict the surface reflectivity within an extremely narrow band of the infrared spectrum, not the entire visible spectrum as in panchromatic images.
- Lidar intensity images are strongly affected by the angle of incidence of the laser to the target and are subject to unnatural shadowing artifacts.
- The values on which lidar intensity images are based may or may not be calibrated to any standard reference. Intensity images usually contain wide variation of values within swaths, between swaths, and between lifts.

For these reasons, lidar intensity images must be interpreted and analyzed with unusually high care and skill.

L

LAS A public file format for the interchange of 3-dimensional (3D) point cloud data between data users. The file extension is .las.

light detection and ranging (lidar) An instrument that measures distance to a reflecting object by emitting timed pulses of light and measuring the time difference between the emission of a laser pulse and the reception of the pulse's reflection(s). The measured time interval for each reflection is converted to distance. This distance conversion, combined with position and attitude information from GPS, Inertial Measurement Unit (IMU), and the instrument itself, allows the derivation of the 3D point location of the reflecting target's location.

M

metadata Any information that is descriptive or supportive of a geospatial dataset, including formally structured and formatted metadata files (for example, eXtensible Markup Language [XML]-formatted Federal Geographic Data Committee [FGDC] metadata), reports (collection, processing, Quality Assurance/Quality Control [QA/QC]), and other supporting data (for example, survey points, shapefiles).

N

nominal pulse spacing (NPS) As a common measure of the density of a lidar dataset, NPS is the typical or average lateral distance between pulses in a lidar dataset, typically expressed in meters and most simply calculated as the square root of the average area per first return point. This value is predicted in mission planning and empirically calculated from the collected data, using only the first (or last) return points as surrogates for pulses. As used in this specification, NPS refers to single swath, single instrument data, whereas aggregate NPS describes the overall pulse spacing resulting from multiple passes of the lidar instrument, or a single pass of a platform with multiple lidar instruments, over the same target area. The term NPS is more commonly used in low-density collections (greater than or equal to 1 meter NPS) with its inverse, nominal pulse density (NPD), being used in high-density collections (less than 1 meter NPS). Assuming meters are being used in both expressions, NPS can be calculated from NPD using the formula $NPS=1/\sqrt{NPD}$.

nonvegetated vertical accuracy (NVA) Replaces fundamental vertical accuracy (FVA). The vertical accuracy at the 95-percent confidence level in nonvegetated open terrain, where errors should approximate a normal distribution. *See* fundamental vertical accuracy.

O

overage Those parts of a swath that are not necessary to form a complete single, nonoverlapped, gap-free coverage with respect to the adjacent swaths. In collections designed using multiple coverage, overage are the parts of the swath that are not necessary to form a complete nonoverlapped coverage at the planned depth of coverage. In the LAS Specification version 1.4 (American Society for Photogrammetry and Remote Sensing, 2011), these points are identified by using the incorrectly named "overlap" bit flag. *See* overlap.

overlap Any part of a swath that also is covered by any part of any other swath. *See* overage.

P

percentile A measure used in statistics indicating the value below which a given percentage of observations (absolute values of errors) in a group of observations fall. For example, the 95th percentile is the value (or score) below which 95 percent of the observations may be found.

There are different approaches to determining percentile ranks and associated values. This specification recommends the use of the following equations for computing percentile rank and percentile as the most appropriate for estimating the VVA. Note that percentile calculations are based on the absolute values of the errors because it is the magnitude of the errors, not the sign, that is of concern.

The percentile rank (n) is first calculated for the desired percentile using the following equation:

$$n = (((P100)^* (N\text{-}1))+1) \tag{1}$$

where

- n is the rank of the observation that contains the *Pth* percentile,
- P is the proportion (of 100) at which the percentile is desired (for example, 95 for 95th percentile), and
- N is the number of observations in the sample dataset.

Once the rank of the observation is determined, the percentile (Q_p) can then be interpolated from the upper and lower observations using the following equation:

$$Q_p = (A[n_w]+(n_d{}^*(A[n_w+1]\text{-}A[n_w]))) \tag{2}$$

where

- Q_p is the *Pth* percentile, the value at rank n;
- A is an array of the absolute values of the samples, indexed in ascending order from *1* to N;
- $A[i]$ is the sample value of array A at index i (for example, n_w or n_d), in which i must be an integer between *1* and N;
- n is the rank of the observation that contains the *Pth* percentile;
- n_w is the whole number component of n (for example, 3 of 3.14); and
- n_d is the decimal component of n (for example, 0.14 of 3.14).

pixel *See* cell.

point classification The assignment of a target identity classification to a particular lidar point or group of points.

point cloud One of the fundamental types of geospatial data (others being vector and raster), a point cloud is a large set of three dimensional points. As a basic geographic information system (GIS) data type, a point cloud is differentiated from a typical point dataset in several key ways:

- point clouds are almost always 3D,
- point clouds have an order of magnitude more features than point datasets, and
- individual point features in point clouds do not typically possess individually meaningful attributes; the informational value in a point cloud is derived from the relations among large numbers of features

See raster, vector.

precision (repeatability) The closeness with which measurements agree with each other, even though they may all contain a systematic bias. *See* accuracy.

R

raster One of the fundamental types of geospatial data (others being vector and point cloud), a raster is an array of cells (or pixels) that each contain a single piece of numeric information representative of the area covered by the cell. Raster datasets are spatially continuous; with respect to DEMs, this quality creates a surface from which information can be extracted from any location. As spatial arrays, rasters are always rectangular; cells are most commonly square. Co-located rasters can be stored in a single file as layers, as with color digital images. *See* raster, vector.

resolution The smallest unit a sensor can detect or the smallest unit a raster DEM depicts. The degree of fineness to which a measurement can be made. “Resolution” is also used to describe the linear size of an image pixel or raster cell.

root mean square error (RMSE) The square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points. The RMSE is used to estimate the absolute accuracy of both horizontal and vertical coordinates where standard or accepted values are known, as with GPS-surveyed checkpoints of higher accuracy than the data being tested. In the United States, the independent source of higher accuracy is expected to be at least three times more accurate than the dataset being tested. The standard equations for calculating horizontal and vertical RMSE are provided below:

- **RMSE**$_r$ The horizontal root mean square error in the radial direction that includes both x and y coordinate errors.

$$(RMSE_x2+ RMSE_y2) \tag{3}$$

where

$RMSE_x$ is the RMSE in the x direction, and
$RMSE_y$ is the RMSE in the x direction.

- **RMSE**$_x$ The horizontal root mean square error in the x direction (easting).

$$(x_n\text{-}x'_n)2N \tag{4}$$

where

x_n is the set of N x coordinates being evaluated,
x'_n is the corresponding set of checkpoint x coordinates for the points being evaluated,
N is the number of x coordinate checkpoints, and
n is the identification number of each checkpoint from 1 through N.

- **RMSE**$_y$ The horizontal root mean square error in the y direction (northing).

$$(y_n\text{-}y'_n)2N \tag{5}$$

where

y_n is the set of N y coordinates being evaluated,

y'_n is the corresponding set of checkpoint y coordinates for the points being evaluated,

N is the number of y coordinate checkpoints, and

n is the identification number of each checkpoint from 1 through N.

- **$\mathbf{RMSE}_z$** The vertical root mean square error in the z direction (elevation).

$$(z_n\text{-}z'_n)2N \tag{6}$$

where

z_n is the set of N z values (elevations) being evaluated,

z'_n is the corresponding set of checkpoint elevations for the points being evaluated,

N is the number of z checkpoints, and

n is the identification number of each checkpoint from 1 through N.

S

supplemental vertical accuracy (SVA) Obsolete; Merged into the VVA. *See* percentile, vegetated vertical accuracy.

swath The data resulting from a single flightline of collection. *See* flightline.

V

vector One of the fundamental types of geospatial data (others being raster and point cloud), vectors include a variety of data structures that are geometrically described by x and y coordinates*,* and potentially z values. Vector data subtypes include points, lines, and polygons. *See* point cloud, raster.

void area (data void) In lidar, a gap in the point cloud coverage, caused by surface nonreflectance of the lidar pulse, instrument or processing anomalies or failure, obstruction of the lidar pulse, or improper collection flight planning. Any area greater than or equal to four times the aggregate nominal pulse spacing squared, measured using first returns only, is considered to be a data void.

vegetated vertical accuracy (VVA) Replaces supplemental vertical accuracy (SVA) and consolidated vertical accuracy (CVA). An estimate of the vertical accuracy, based on the 95th percentile, in vegetated terrain where errors do not necessarily approximate a normal distribution. *See* percentile, nonvegetated vertical accuracy.

W

withheld Within the LAS file specification, a single bit flag indicating that the associated lidar point is geometrically anomalous or unreliable and should be ignored for all normal processes. These points are retained because of their value in specialized analysis. Withheld points typically are identified and tagged during preprocessing or through the use of automatic classification routines. Examples of points typically tagged as withheld are listed below:

- spatial outliers in either the horizontal or vertical domains, and
- geometrically unreliable points near the edge of a swath.

Appendixes

Appendix 1. 1-Meter Digital Elevation Model Metadata Example

Note: This metadata example refers to the legacy National Elevation Dataset (NED) terminology, which is in the process, as of August 2015, of being rebranded under The National Map.


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   <abstract>This is a tile of the National Elevation Dataset (NED) and is
    one meter resolution. Data in this layer represent a bare earth surface.
    The National Elevation Dataset (NED) serves as the elevation layer of
    The National Map, and provides basic elevation information for Earth
    science studies and mapping applications in the United States. Scientists
    and resource managers use NED data for global change research, hydrologic
    modeling, resource monitoring, mapping and visualization, and many other
    applications. The NED is an elevation dataset that consists of seamless
    layers and non-seamless high resolution layers.  Each of the seamless
    layers are composed of the best available raster elevation data of the
    conterminous United States, Alaska, Hawaii, territorial islands, Mexico
    and Canada.  The NED is updated continually as new data become available.
    All NED data are in the public domain. The NED is derived from diverse
    source data that are processed to a common coordinate system and unit of
    vertical measure.  The spatial reference used for tiles of the one meter
    layer within the conterminous United States is Universal
    Transverse Mercator (UTM) in units of meters, and in conformance with the
    North American Datum of 1983 (NAD83).  All bare earth elevation values
    are in meters and are referenced to the North American Vertical Datum of
    1988 (NAVD88).  Each tile is distributed in the UTM Zone in which it lies.
    If a tile crosses two UTM Zones, it is delivered in both zones.  Only
    source data of one meter resolution or finer are used to produce the NED
    standard one meter layer
   </abstract>
   <purpose>The NED serves as the elevation layer of The National Map, and
    provides basic elevation information for Earth science studies and mapping
    applications in the United States. The data are utilized by the
    scientific and resource management communities for global change research,
    hydrologic modeling, resource monitoring, mapping and visualization, and
    many other applications.
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   <supplinf>This is a 10,000 meter by 10,000 meter tile. The geographic area
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    information for the NED may be found on http://ned.usgs.gov/. Data may
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         applications without a full awareness of its limitations. Acknowledgement
         of the originating agencies would be appreciated in products derived from
         these data. Any user who modifies the data is obligated to describe the
         types of modifications they perform. User specifically agrees not to
         misrepresent the data, nor to imply that changes made were approved or
         endorsed by the USGS. Please refer to http://www.usgs.gov/privacy.html
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         warranty the delivery of this product in computer-readable format and will
         offer appropriate adjustment of credit when the product is determined
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Appendix 2. 1-Meter Digital Elevation Model Spatial Metadata Data Dictionary

PMETHOD

Production Method (short integer)

The method used to compile or capture the source digital elevation model (DEM).

Valid codes are:

0	Unknown
1	Electronic Image Correlation (specifically GPM II)
2	Manual Profiling
3	DLG2DEM
4	DCASS
5	LT4X
6	Complex polynomial interpolation, such as ANUDEM
7	Lidar
8	Photogrammetric mass points and breaklines
9	Digital camera correlation
10	Ifsar
11	Topobathy
12	Other remote sensing technique

S_DATE

Data Source Date (short integer)

For DEMs derived from standard U.S. Geological Survey paper map series, this field is data element 21 in the source DEMs Type A record, the date of original photography from which the DEM was compiled. For more information consult “Standards for Digital Elevation Models” (U.S. Geological Survey, 1997). This information was not provided with some standard DEMs with a native resolution of 30 meters.

In the case of high-resolution source data, this field reflects the year that the base elevation data was collected, as in the case of lidar derived DEMs. For projects whose collection spanned more than one calendar year, this is the earliest acquisition year.

Format: YYYY

ZUNIT

Elevation Unit (short integer)

This code represents the unit of elevation values in source DEM.

Valid values:

0	International Feet
1	Meters
2	U.S. Survey Feet
3	Decimal degrees

4	Centimeters
5	Inches
99	Other reference system

HORIZRES

Horizontal Resolution (floating point)

The horizontal resolution (x, y) of the original project resolution DEM.

The value is reported in the units recorded in the HORIZUNIT field.

HORIZUNIT

Horizontal Resolution Units (short integer)

The unit in which the horizontal resolution, HORIZRES, is reported.

Valid values:

0	International Feet
1	Meters
2	U.S. Survey Feet
3	Decimal Degrees
4	Centimeters
5	Inches
99	Unknown

HORIZRES_M

Horizontal Resolution Expressed in Meters (floating point)

The horizontal resolution (x, y) of the Original Project Resolution DEM expressed in meters.

This field is provided for easy comparison of and sorting of horizontal resolutions, regardless of the horizontal units of the actual DEM.

PROJ_NAME

Project name (text)

This field is the name of the original project that was adapted for incorporation into the 1/9 arc-second layer. The format of this field will most commonly be three parts separated by underscores: PRIMARYSTATE, BRIEF-PROJECT-DESCRIPTION, YEAR.

This is a new field introduced into the 1/9 arc-second spatial metadata for DEMs introduced into The National Map after April 1, 2014. This field is not populated for DEMs incorporated into The National Map before March 31, 2014.

QUADDATE

Date the data were incorporated into The National Map (long integer)

The date on which the source DEM was first processed into The National Map. This field is particularly useful in the identification of new elevation data coverage areas. Format: YYYYMMDDva_unit

VA_UNIT

Vertical Accuracy Unit (short integer) The units in which the vertical accuracy statistics are reported.

Valid values:

0	International Feet
1	Meters
2	US Survey Feet
3	decimal degrees
4	centimeters
5	inches
99	unknown

S_FVA

Source DEM fundamental vertical accuracy (FVA) (floating point)

This is the tested FVA of the source resolution DEM. FVA, or $accuracy_z$, is based only on points in clear and open terrain. The fundamental accuracy is the value by which vertical accuracy can be equitably assessed and compared between datasets. The S_FVA is calculated at the 95-percent confidence level as a function of vertical root mean square error (RMSE) (that is, $accuracy_z = RMSE_z \times 1.96$).

S_FVA is expressed in the units reported in the VA_UNIT field.

S_CVA

Source DEM consolidated vertical accuracy (CVA) (floating point)

This is the tested CVA of the source resolution DEM. CVA is based on checkpoints in all land cover categories combined. Error distribution for points in vegetated areas does not have a normal distribution; therefore, S_CVA is reported as the 95th percentile.

S_CVA is expressed in the units reported in the VA_UNIT field.

S_NVA

nonvegetated vertical accuracy (floating point)

This field is reserved for future use.

Current valid value: -1

S_VVA

vegetated vertical accuracy (floating point)

This field is reserved for future use.

Current valid value: -1

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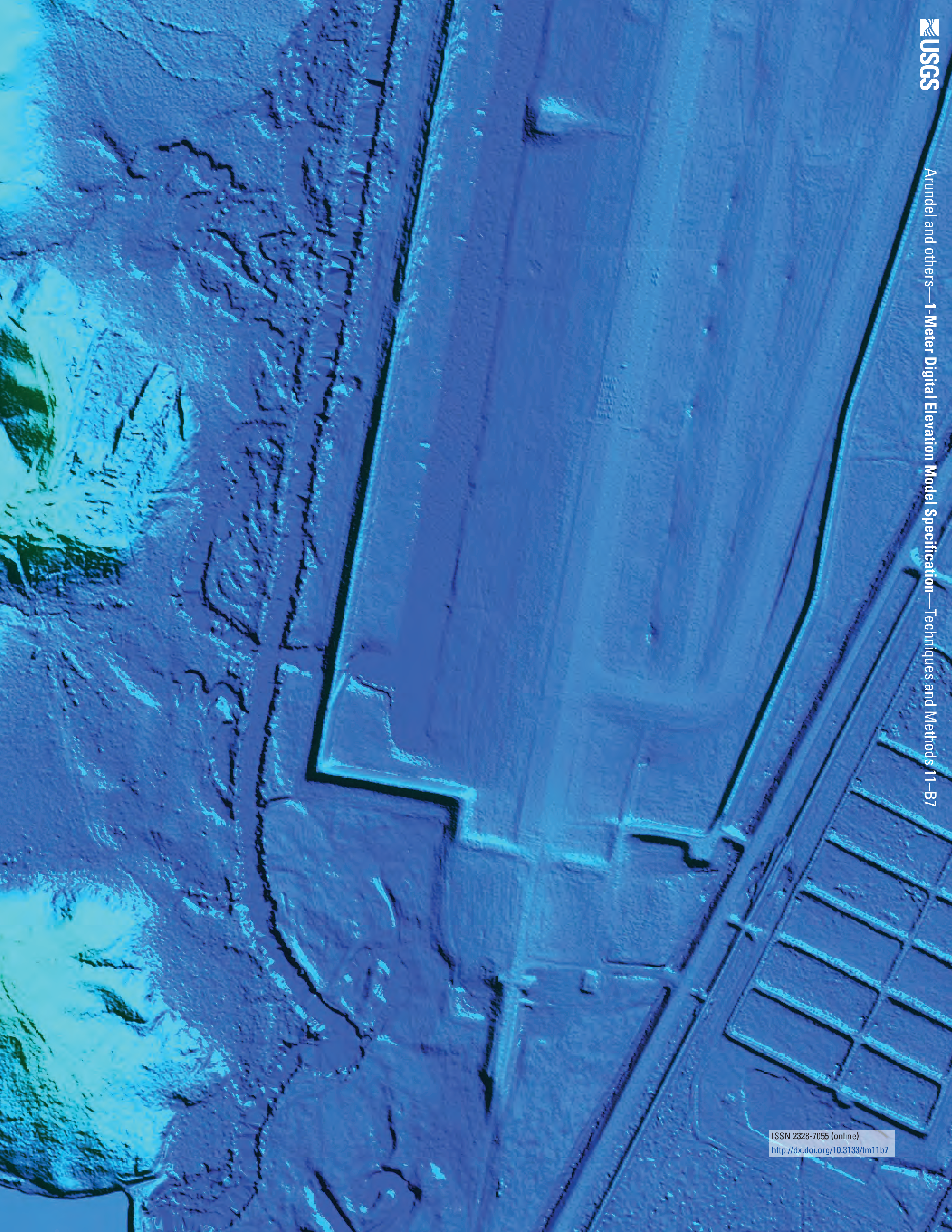
Rolla, Missouri 65401–2602
or
PO Box 25046, MS 510
Denver, Colorado 80225–004
or email nmpstds@usgs.gov

Or visit the The National Geospatial Technical Operations Center Standards and Specifications Web site at:
http://nationalmap.gov/standards



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