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# DEM INTRODUCTION

The Earth Science Information Center (ESIC) distributes digital cartographic/geographic data files produced by the U.S. Geological Survey (USGS) as part of the National Mapping Program. Digital cartographic data files may be grouped into four basic types. The first of these, called a Digital Line Graph (DLG), is the line map information in digital form. These data files include information on base data categories, such as transportation, hypsography, hydrography, and boundaries. The second type, called a Digital Elevation Model (DEM), consists of a sampled array of elevations for a number of ground positions at regularly spaced intervals. The third type is Land Use and Land Cover digital data which provides information on nine major classes of land use such as urban, agricultural, or forest as well as associated map data such as political units and Federal land ownership. The fourth type, the Geographic Names Information System, provides primary information for all known places, features, and areas in the United States identified by a proper name.

The digital cartographic data files from selected quadrangles currently available from ESIC include the following:

## Digital Line Graphs (DLG's)

1:24,000-scale

1:62,500-scale

1:63,360-scale

1:100,000-scale

1:2,000,000-scale

## Digital Elevation Models (DEM's)

7.5-minute

15-minute

30-minute

1-degree

## Land Use and Land Cover digital data

1:250,000- and 1:100,000-scale land use and land cover and associated maps

1:250,000-scale Alaska Interim Land Cover Maps

## Geographic Names

The digital data are useful for the production of cartographic products such as plotting base maps and for various kinds of spatial analysis. A major use of these digital cartographic/geographic data is to combine them with other geographically referenced data, enabling scientists to conduct automated analyses in support of various decision making processes.

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This document describes five distinct digital elevation products that are distributed by the USGS in the standard DEM format:

1) 7.5-Minute DEM (30- x 30-m data spacing, cast on Universal Transverse Mercator (UTM) projection). Provides coverage in 7.5- x 7.5-minute blocks. Each product pro-

vides the same coverage as a standard USGS 7.5-minute map series quadrangle.

2)1-Degree DEM (3- x 3-arc-second data spacing). Provides coverage in 1- x 1-degree blocks. Two products (three in some regions of Alaska) provide the same coverage as a standard USGS 1- x 2-degree map series quadrangle. The basic elevation model is produced by or for the National Imagery and Mapping Agency (NIMA), but is distributed by USGS in the DEM data record format.

3)30-Minute DEM (2- x 2-arc-second data spacing). Consists of four 15- x 15-minute DEM blocks. Two 30-minute DEM's provide the same coverage as a standard USGS 30- x 60-minute map series quadrangle. Saleable units will be 30- x 30-minute blocks, that is, four 15- x 15-minute DEM's representing one half of a 1:100,000-scale map (30- x 60-minute coverage).

4)15-minute Alaska DEM (2- x 3-arc-second data spacing, latitude by longitude). Provides coverage similar to a 15-minute DEM, except that the longitudinal cell limits vary from 20 minutes at the southernmost latitude of Alaska to 36 minutes at the northernmost latitude limits of Alaska. Coverage of one DEM will generally correspond to a 1:63,360-scale quadrangle.

5)7.5-minute Alaska DEM (1- x 2-arc-second data spacing, latitude by longitude). Provides coverage similar to a 7.5-minute DEM, except that the longitudinal cell limits vary from 10 minutes at the southernmost latitude of Alaska to 18-minutes at the northernmost latitude limits of Alaska.

The UTM-based DEM's (7.5-minute DEM) and the geographic-based DEM's (30-minute, Alaska, and 1-degree DEM's) are identical in logical data structure but differ in sampling interval, geographic reference system, areas covered, and horizontal and vertical accuracy. Knowledge of all of these properties is essential to ensure that the user does not exceed the useful limits of the data for required applications. The 7.5-minute UTM DEM's are available for selected quadrangles, which are indicated on a status graphic published biannually by USGS. The 1-degree DEM's are available for all of the contiguous United States, Hawaii, and portions of Alaska, Puerto Rico, and the Virgin Islands. Many of the original 1-degree DEM's are being replaced with more accurate digital models through a cooperative re-gridding project with NIMA, scheduled for completion in 1995. As they become available, these 1-degree DEM's will replace their corresponding product. The 30-minute and Alaska DEM's are new DEM series and are available on a limited basis as projects are completed.

## 7.5-MINUTE DIGITAL ELEVATION MODELS

### Characteristics

A 7.5-minute DEM has the following characteristics:

- 1)The data consist of a regular array of elevations referenced horizontally in the UTM coordinate system. The reference datum may be North American Datum of 1927 (AD 27), North American Datum of 1983 (NAD 83), Old Hawaiian Datum (OHD), or Puerto Rico Datum of 1940 (PRD).
- 2)The unit of coverage is the 7.5-minute quadrangle. Over edge coverage is not provided.
- 3)The data are ordered from south to north in profiles that are ordered from west to east.
- 4)The data are stored as profiles in which the spacing of the elevations along and between each profile is 30 m.
- 5)The profiles do not always have the same number of elevations because of the variable angle between the quadrangle's true north and the grid north of the UTM coordinate system.
- 6)Elevations for the continental U.S. are either meters or feet referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29). Elevations for Hawaii and Puerto Rico are either in meters or feet referenced to local mean sea level. DEM's of low-relief terrain or generated from contour maps with intervals of 10 ft (3 m) or less are generally recorded in feet. DEM's of moderate to high-relief terrain or generated from maps with terrain contour intervals greater than 10 ft are generally recorded in meters.

Profiles for 7.5-minute DEM's are generated by using a UTM Cartesian coordinate system as a base. The profiles are clipped to the straight-line intercept between the four geographic corners of the quadrangle--an approximation of the geographic map boundary (neatline) as shown in figure 1. The resulting area of coverage for the DEM is a quadrilateral, the opposite sides of which are not parallel.

The UTM coordinates of the four corners (bounds) of the DEM's are listed in the type A record, as shown in table 1, data element 11; the UTM coordinates of the starting points of each profile are listed in the type B record (profiles), table 2, data element 3. These coordinates describe the shape of the quadrilateral and the variable x, y starting position of each profile. Because of the variable orientation of the quadrilateral in relation to the UTM coordinate system, profiles intersect the east and west neatlines as well as the north and south neatlines as shown in figure 1. In addition, DEM's have profile easting values that are continuous from one DEM to the adjoining DEM only if the adjoining DEM is contained within the same UTM zone.

### Data Production

The 7.5-minute DEM data are produced in 7.5- x 7.5-minute blocks either from map contour overlays that have been digitized, or from automated or manual scanning of National Aerial Photography Program (NAPP) quarter quad-centered photographs or from the National High-Altitude Photography Program (NHAP) quad-centered photographs. The NHAP program was formally discontinued in 1988, however limited production using this scale source is permitted. The data are processed to produce a DEM having a 30-m sampling interval. The structure of a 7.5-minute DEM data file is shown in figure 1. (See tables for sample data records.)

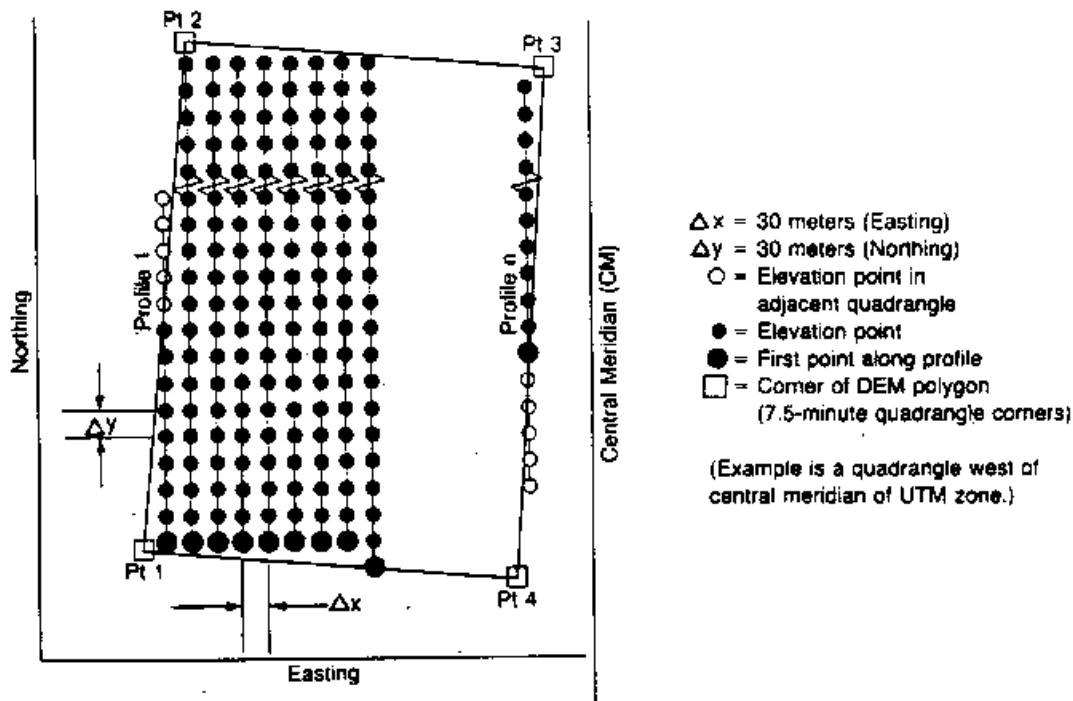


Figure 1.--Structure of a 7.5-minute Digital Elevation Model, UTM meter grid.

The USGS has used four processes to collect the digital elevation data for production of 7.5-minute DEM's: (1) the Gestalt Photo Mapper II (GPM2), (2) manual profiling from photogrammetric stereomodels, (3) stereomodel digitizing of contours, and (4) derivation from DLG hypsography and hydrography categories or pseudo-DLG's (tagged vector contours) .

The GPM2 (now discontinued) was an automated photogrammetric system designed to produce orthophotographs, digital terrain data, and contours. An electronic image correlation component of the GPM2 measured the parallax of 2,444 points within each 9- x 8-mm area of a photogrammetric stereomodel. Of these 2,444 correlated points, sub-units of 576, 1,024, or 1,600 points were collected for inclusion in the elevation model. These sub-units were called patches, and the patch size was selected to accommodate various terrain conditions. The horizontal (x and y) spacing of the elevation points within each patch was approximately 182 mm at photographic scale (equivalent to a ground distance of approximately 47 ft when using photographs at 1:80,000 scale). Each of the two NHAP stereomodels used to cover a standard 7.5-minute quadrangle contained over 500,000 correlated points; these were re-gridded to form a DEM in the standard format. Before discontinuance, approximately 15,000 DEM's were added to the NDCDB using this autocorrelation system.

The manual profiling process uses stereoplotters, equipped with three-axis electronic digital profile recording modules, for scanning of stereomodels along successive terrain profiles. High-altitude aerial photographs are used as source material. The scan speed and distance between profiles are selected by the operator to accommodate steepness in topographic slope. The most commonly used profile separation is approximately 90-m, with elevations normally recorded every 30 m along each profile. The profiled elevation data are reformatted and re-gridded using a weighted

four-nearest-neighbor interpolation to a regular 30-m UTM spacing, written in standard DEM format, and tested for vertical accuracy before placement in the National Digital Cartographic Data Base. Digital profile data of this type are collected as companion products during the production of orthophotographs.

For stereo model digitizing of contours (now deactivated), digital contours were acquired in digital form on stereoplotters equipped with three-axis digital recording modules. Digital data were acquired as the contours were stereocompiled for 7.5-minute quadrangle maps. The contours were assigned elevation values (attributes) during the acquisition phase. The contour data were processed into profile lines, and the elevation matrix was computed at a 30-m spacing using a bilinear interpolation.

Derivation of DEM's from DLG's or pseudo-DLG's is a process that involves the use of hardware such as scanners, manual digitizers, and (or) semi-automated line followers. The hypsography and hydrography categories of DLG or pseudo-DLG data are required as input to DEM processing. Contours and spot elevations in three-dimensional coordinates are required from the hypsographic category. Lake and shoreline data are required from the hydrographic category for water body flattening. Drainage data are also extracted from the hydrography file. Elevations are computed where contours merge with the hydrographic data. Ridge lines, the opposite of drainage lines, are normally interpolated automatically by computer programs using trends within the hypsographic overlay. If necessary, the delineation of ridge lines may be accomplished by manual inputs or sophisticated medial axis computation algorithms. The DLG or pseudo-DLG are reformatted as tagged vector line strings and are input to gridding software to interpolate gridded elevations for the DEM. A subsequent processing step involves trimming the grid along the quadrangle perimeter and formatting the data into a DEM file structure. The DEM is finally processed by the DEM Editing System to validate and test the accuracy before entry into the National Digital Cartographic Data Base.

# 1-DEGREE DIGITAL ELEVATION MODELS

## Characteristics

A 1-degree DEM has the following characteristics:

- 1) The product consists of a regular array of elevations referenced horizontally on the geographic (latitude/longitude) coordinate system of the World Geodetic System 1972 Datum (WGS 72) or the World Geodetic System of 1984 (WGS 84).
- 2) The unit of coverage is a 1- x 1-degree block. Elevation data on the integer degree lines (all four sides) correspond with the same profiles on the surrounding eight blocks.
- 3) Elevations are in meters relative to NGVD 29 in the continental U.S. and local mean sea level in Hawaii and Puerto Rico.
- 4) The data are ordered from south to north in profiles that are ordered from west to east.
- 5) Spacing of the elevations along each profile is 3 arc-seconds. The first and last data points are at the integer degrees of latitude. A profile will therefore contain 1,201 elevations.
- 6) Spacing between profiles varies by latitude; however, the first and last data points are at the integer degrees of longitude. North of 50° degrees N and south of 70° N, the spacing is 6 arc-seconds with 601 profiles per product. For the remainder of Alaska north of 70° N the spacing is 9 arc-seconds with 401 profiles per product.

## Data Production

The majority of the 1-degree Digital Elevation Models are produced by NIMA from cartographic and photographic sources. Under a cooperative agreement, selected 1-degree DEM's are being re-gridded by USGS from 7.5-minute DEM's and 30-minute DEM's. These data sets will be available upon completion of quality control and exchange between NIMA and USGS.

Elevation data from cartographic sources are collected from any map series 7.5 minute through 1 degree (1:24,000 scale through 1:250,000 scale). The hypsographic features (contours, drain lines, ridge lines, lakes, and spot elevations) are first digitized and then processed into the required matrix form and interval spacing. The structure of a 1-degree DEM data file is shown in figure 2 (see tables for sample data records).

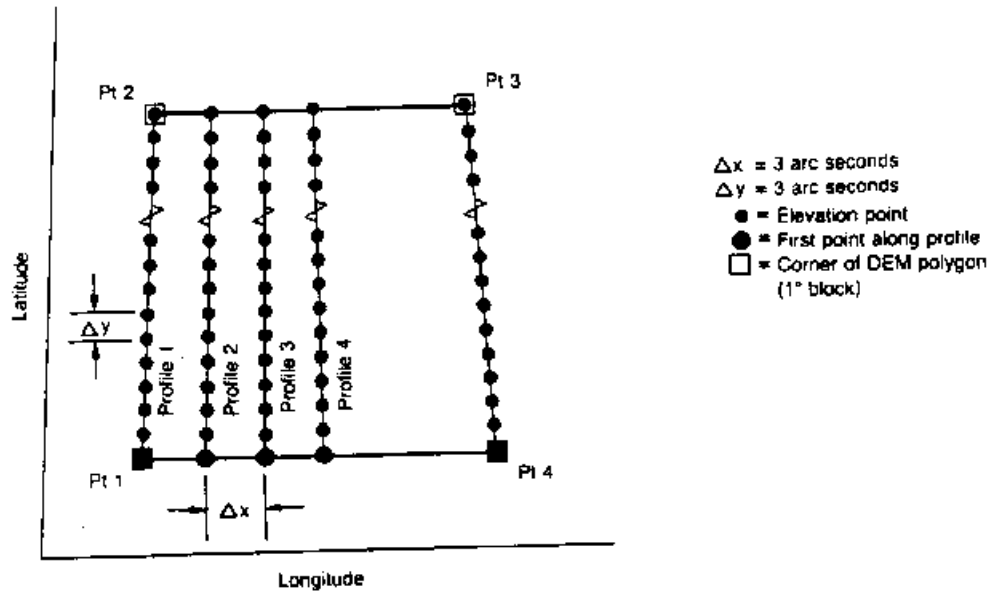


Figure 2.--Structure of a 1-degree Digital Elevation Model, arc-second grid.

Elevation data from photographic sources are collected by using manual and automated correlation techniques. Elevations along a profile are collected at 80 to 100 percent of the eventual point spacing. The raw elevations are weighted with additional information such as drain, ridge, water, and spot heights during the re-sampling process in which final elevations are determined for the required matrix form and interval spacing.

The digital elevation models distributed within the Department of Defense cover 1- x 1-degree blocks but are called Digital Terrain Elevation Data Level 1 (DTED-1). These blocks are referenced by their southwest corner coordinates rather than by the name of a corresponding map sheet. The header records and profile records are considerably different in their structure than those in the corresponding USGS-distributed version; however, in reformatting the product, the USGS does not change the basic elevation information.

The accuracy of the NIMA product, together with the data spacing, adequately support computer applications that analyze hypsographic features to a level of detail similar to manual interpretations of information as printed at map scales not larger than 1:250,000. The plotting of contours from the 1-degree DEM at scales larger than 1:250,000, or reliance on the elevation heights without incorporating the National Map Accuracy Standard (NMAS) horizontal error tolerance, will lead to less reliable results.

Note that NIMA 1-degree DTED-1 data and USGS-distributed 1-degree DEM's are gridded by using the WGS 72 or WGS 84 datum, which is significantly different than the NAD 27 datum used by the USGS for gridding 7.5-minute DEM's. At the present time, policy issues concerning the transformation algorithms and procedures to convert to or from NAD 27 and WGS 72 to WGS 84 and (or) NAD 83 are being developed. See appendix H for additional information related to these datums.

# 30-MINUTE DIGITAL ELEVATION MODELS

## Characteristics

A 30-minute DEM has the following characteristics:

- 1) The product consists of a regular array of elevations referenced horizontally to the geographic (latitude/longitude) coordinate system of NAD 27 or NAD 83.
- 2) The unit of coverage is a 30- x 30-minute block. Saleable units are four 15-minute DEM's covering a 30- x 30-minute area. Elevation data on the integer minute lines (all four sides) correspond to the same profiles on the surrounding eight blocks.
- 3) Elevations are in meters or feet relative to NGVD 29 in the continental U.S. and local mean sea level in Hawaii and Puerto Rico.
- 4) The data are ordered from south to north in profiles that are ordered from west to east.
- 5) Spacing of the elevations along each profile is 2 arc-seconds. The first and last data points are at the integer 15 minutes of latitude. A 15-minute profile will therefore contain 451 elevations.

## Data Production

The USGS uses two processes to collect the digital elevation data for production of 30-minute DEM's: (1) derivation from DLG contours of any map series 7.5 minute to 30 x 60 minute (1:24,000 scale to 1:100,000 scale), (2) re-sampling from digital elevation models with a source spacing equal to or less than 2-arc second sampling interval (if the data is re-sampled from preexisting DEM's, it is arbitrarily archived as level 1). DEM data for this series are tested according to level 2 (see Level 2, p. 14) accuracy specifications.

The accuracy of the DEM data, together with the data spacing, adequately support computer applications that analyze hypsographic features to a level of detail similar to manual interpretations of information as printed at map scales not larger than 1:100,000. The plotting of contours from 30-minute DEM data at scales larger than 1:100,000, or reliance on the elevation heights without incorporating the NMAS horizontal error tolerance, will lead to less reliable results.

# 15-MINUTE ALASKA DIGITAL ELEVATION MODELS

## Characteristics

15-minute Alaska DEM's have the following characteristics:

- 1) The product consists of a regular array of elevations referenced horizontally on to the geographic (latitude/longitude) coordinate system of NAD 27 or NAD 83.
- 2) The unit of coverage corresponds to four basic quadrangle sizes for 1:63,360-scale graphics (depending on latitude):
- 3) Cell size limits

15 x 36 minutes	State of Alaska north of 68° N latitude
15 x 30 minutes	Between 62° N and 68° N latitude
15 x 22.5 minutes	Between 59° N and 62° N latitude
15 x 20 minutes	State of Alaska south of 59° N latitude

- 4) The longitudinal limits of these cells are computed east and west of the -150 degree meridian. The north-south cell limits conform to even multiples of 15 minutes of latitude.
- 5) The data are collected with a 2- x 3-arc-second spacing in latitude, and longitude, respectively. The first and last data points along a profile are at the integer degrees of latitude. A profile will therefore contain 451 elevations.
- 6) Elevation data on the quadrangle neatlines (all four sides) share edge profiles with the surrounding eight quadrangles.
- 7) Elevations are in meters or feet relative to NGVD 29.
- 8) The data are ordered from south to north in profiles that are ordered from west to east.

## Data Production

The 15-minute Alaska DEM data are produced to match the spatial format of the 1:63,360-scale source contours. The primary process used for production of Alaska DEM's is to combine digitized hypsographic and hydrographic data from 1:63,360-scale graphics. Processing can include all of the scanning, re-sampling, and contour interpolation programs previously mentioned. Data production for this series, if derived from hypsography overlays, is classified according to level 2 specifications.

The accuracy of the DEM data, together with the data spacing, adequately support computer applications that analyze hypsographic features to a level of detail similar to manual interpretations of information as printed at map scales not larger than 1:63,360. The plotting of contours from the 15-minute Alaska DEM's at scales larger than 1:63,360, or reliance on the elevation heights without incorporating the NMAS horizontal error tolerance, will lead to less reliable results.

# 7.5-MINUTE ALASKA DIGITAL ELEVATION MODELS

## Characteristics

7.5-minute Alaska DEM's have the following characteristics:

- 1) The product consists of a regular array of elevations referenced horizontally to the geographic (latitude/longitude) coordinate system of NAD 27 or NAD 83.
- 2) The unit of coverage corresponds to four basic quadrangle sizes for 1:24,000- and 1:25,000-scale graphics (depending on latitude):
- 3) Cell size limits

7.5 x 18 minutes      State of Alaska north of 68° N latitude

7.5 x 15 minutes      Between 62° N and 68° N latitude

7.5 x 11.25 minute      Between 59° N and 62° N latitude

7.5 x 10 minutes      State of Alaska south of 59° N latitude

- 4) The longitudinal limits of these cells are computed east and west of the -150 degree meridian. The north-south cell limits conform to even multiples of 7.5 minutes of latitude.
- 5) The data are collected with a 1- x 2-arc-second spacing in latitude and longitude, respectively. The first and last data points along a profile are at the integer degrees of latitude. A profile will therefore contain 451 elevations.
- 6) Elevation data on the quadrangle neatlines (all four sides) share edge profiles with the surrounding eight quadrangles.
- 7) Elevations are in meters or feet relative to NGVD 29.
- 8) The data are ordered from south to north in profiles that are ordered from west to east.

## Data Production

The 7.5-minute Alaska DEM data are produced to match the spatial format of the 1:24,000- and 1:25,000-scale source contours. The collection of elevation data is primarily by raster-to-vector digitizing of map separates and gridding the resultant vectors. Data production for this series, if derived from hypsography overlays, is classified according to level 2 specifications.

The accuracy of the DEM data, together with the data spacing, adequately support computer applications that analyze hypsographic features to a level of detail similar to manual interpretations of information as printed at map scales not larger than 1:24,000. The plotting of the contours from the Alaska DEM's at scales larger than 1:24,000, or reliance on the elevation heights without incorporating the NMAS horizontal error tolerance will lead to less reliable results.

# GEOMETRY and ACCURACY

Profiles are the basic building blocks of DEM's and are defined as one-dimensional arrays, that is, arrays of dimension in  $m$  rows  $\times$  1 column, where  $m$  is the length of the profile (variable length for 7.5-minute DEM's or fixed length for 30-minute, Alaska, and 1-degree DEM's).

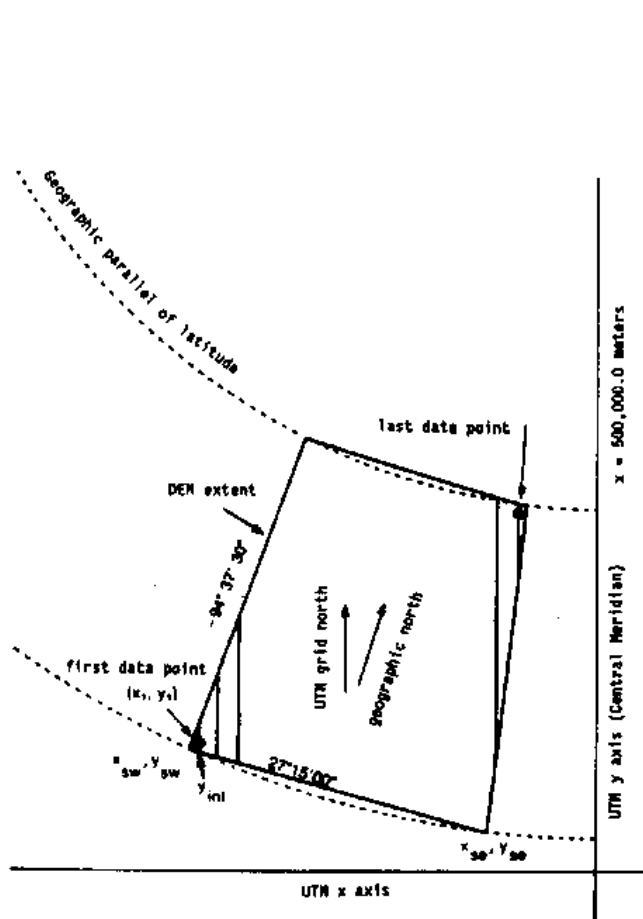
Figure 3 provides an example of the computation for the first data point inside the quadrilateral representing a 7.5-minute DEM west of the UTM central meridian. Figure 4 provides a similar example for a quadrangle east of the central meridian.

Figure 5, formula 1, illustrates the internal horizontal relationship ( $x_p$ ,  $y_p$ ) of elevations ordered as profiles in which the spacing of the elevations along each profile is  $\Delta y$  and the spacing between profiles is  $\Delta x$ . Figure 5, formula 2, relates the internal array structure to actual ground coordinates ( $x_{gp}$ ,  $y_{gp}$ ) based on an origin of the DEM at the lower left corner ( $x_{go}$ ,  $y_{go}$ ), and a rotation angle measured from quadrangle north, if any. The rotation angle of 7.5-minute DEM's is normally set to zero (see record A, element 13 in table 1). The rotation angle for a 1-degree DEM is always set to zero (see record A, element 13, in table 4). In general the mathematics is simpler for a 1-degree DEM. Each 1-degree DEM profile is composed of the same number of elevations per profile and the array is a square or rectangle. Therefore, the equations of figure 5 are greatly simplified.

The accuracy of a DEM is dependent upon the level of detail of the source and the grid spacing used to sample that source. The primary limiting factor for the level of detail of the source is the scale of the source materials. The proper selection of grid spacing determines the level of content that may be extracted from a given source during digitization. For example, 1:250,000-scale topographic maps are the primary source of 1-degree DEM's. Larger scale maps, such as 1:100,000 and 1:24,000, are used to generate higher accuracy DEM's. Scales smaller than 1:250,000 have not been used as a DEM source.

Another factor is the horizontal and vertical dimension of the DEM. Horizontal accuracy of DEM data depends on the horizontal spacing of the elevation matrix. Within a standard DEM, most terrain features are generalized by being reduced to grid nodes spaced at regular intersections in the horizontal plane (7.5-minute DEM interval is 30 m; 1-degree DEM interval is 3 arc-seconds). This generalization reduces the ability to recover positions of specific features less than the internal spacing during testing and results in a de facto filtering or smoothing of the surface during gridding.

Vertical accuracy of DEM data depends on the spatial resolution (horizontal grid spacing), quality of the source data, collection and processing procedures, and digitizing systems. As with horizontal accuracy, the entire process, beginning with project authorization, compilation of the source data sets, and the final gridding process, must satisfy accuracy criteria customarily applied to each system. Each source data set must qualify to be used in the next step of the process. Errors are compounded in each step of the process. For this reason, significant effort is expended in each phase of the production process to minimize errors.



Example computation of UTM coordinates  $(x_1, y_1)$  of the first data point in a 7.5-minute DEM west of the central meridian.

The southwest corner of the 7.5-minute DEM in this example is at latitude  $27^{\circ} 15' 00''$ , longitude  $-94^{\circ} 37' 30''$  ( $x_{sw} = 339117.761$ ,  $y_{sw} = 3015001.964$ ). The southeast corner is at latitude  $27^{\circ} 15' 00''$ , longitude  $-94^{\circ} 30' 00''$  ( $x_{se} = 351495.041$ ,  $y_{se} = 3014647.375$ ).

Compute  $x$  coordinate ( $x_1$ ) of the first profile. The first profile is offset to the next integer multiple of 30 m east of the southwest corner.

$$\begin{aligned} \frac{x_{sw}}{30m} &= \frac{339117.761m}{30m} \\ &= 11303.9 \text{ (round up)} \\ &= 11304 \\ x_1 &= 11304 (30m) \\ &= 339120m \end{aligned}$$

Compute  $y$  coordinate ( $y_1$ ) of the first data point on the first profile. The first data point is offset to the next integer multiple of 30 m north of the intercept ( $y_{int}$ ) of the first profile with the southern latitude line of the 7.5-minute quadrangle.

a) Use the slope intercept formula  $y = mx + b$  to compute  $y_{int}$ .

$$\begin{aligned} m &= \frac{(y_{se} - y_{sw})}{(x_{se} - x_{sw})} \\ &= \frac{-154.589}{12377.280} \\ &= -.0124897 \end{aligned}$$

$$\begin{aligned} b &= y_{sw} - mx_{sw} \\ &= 3015001.964 - (-.0124897)(339117.761) \\ &= 3019237.443 \end{aligned}$$

$$\begin{aligned} y_{int} &= b + mx_1 \\ &= (-.0124897)(339120) + 3019237.443 \\ &= 3015001.936m \end{aligned}$$

b) Compute  $y_1$ .

$$\begin{aligned} \frac{y_{int}}{30m} &= \frac{3015001.936m}{30m} \\ &= 100500.06 \text{ (round up)} \\ y_1 &= 100501 (30m) \\ &= 3015030m \end{aligned}$$

Figure 3.--Computation of first data point in a 7.5-minute Digital Elevation Model west of the central meridian.

Example computation of UTM coordinates  $(x_1, y_1)$  of the first data point in a 7.5-minute DEM east of the central meridian.

The southwest corner of the 7.5-minute DEM in this example is at latitude  $27^{\circ}07'34''$ , longitude  $-92^{\circ}34'08''$  ( $x_{sw} = 549553.918m$ ,  $y_{sw} = 3000211.822m$ ). The northwest corner is at latitude  $27^{\circ}15'00''$ , longitude  $-92^{\circ}35'00''$  ( $x_{nw} = 549498.713m$ ,  $y_{nw} = 3010026.068m$ ).

Compute x coordinate ( $x_1$ ) of the first profile. The first profile is offset to the next integer multiple of 30 m east of the northwest corner.

$$\begin{aligned} \frac{x_{nw}}{30m} &= \frac{549498.713m}{30m} \\ &= 18316.6 \text{ (round up)} \\ &= 18317 \\ x_1 &= 18317 (30m) \\ &= 549510m \end{aligned}$$

Compute y coordinate ( $y_1$ ) of the first data point on the first profile. The first data point is offset to the next integer multiple of 30 m north of the intercept ( $y_{int}$ ) of the first profile with the western longitude line of the 7.5-minute quadrangle.

(a) Use the slope intercept formula  $y = mx + b$  to compute  $y_{int}$ .

$$\begin{aligned} m &= (y_{nw} - y_{sw}) / (x_{nw} - x_{sw}) \\ &= 15845.816 / -55.285 \\ b &= y_{sw} - mx_{sw} \\ &= 3000211.822m - [(-258.79)(549553.919)] \\ &= 140822838.147m \\ y_{int} &= b + mx_1 \\ &= 140822838.147m + [(-258.79)(549510m)] \\ &= 3011225.247m \end{aligned}$$

(b) Compute  $y_1$

$$\begin{aligned} \frac{y_{int}}{30m} &= \frac{3011225.247m}{30m} \\ &= 100374.175 \text{ (round up)} \\ y_1 &= 100375 (30m) \\ &= 3011250m \end{aligned}$$

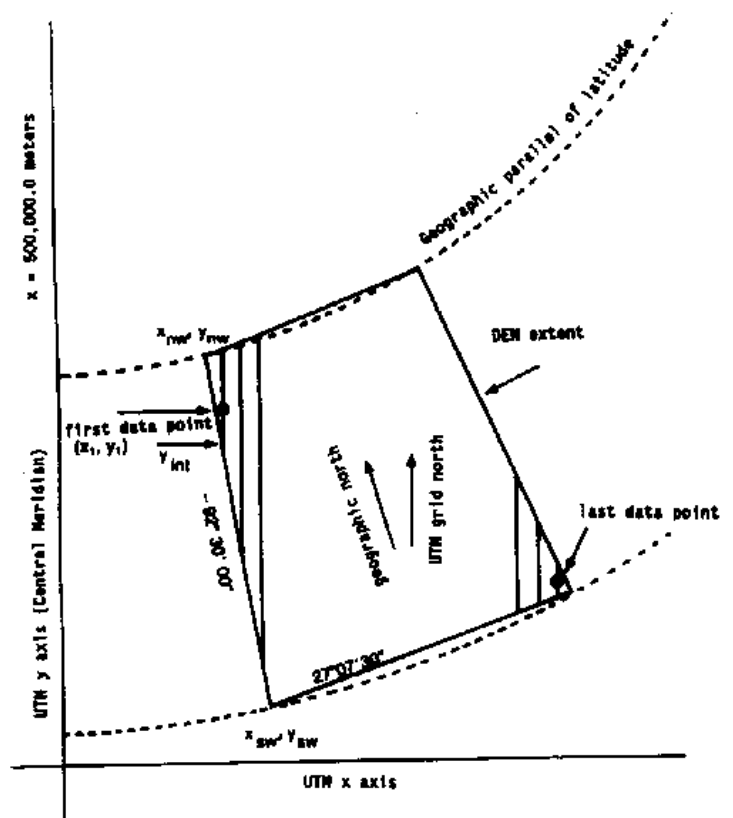


Figure 4.--Computation of first data point in a 7.5-minute Digital Elevation Model east of the central meridian.

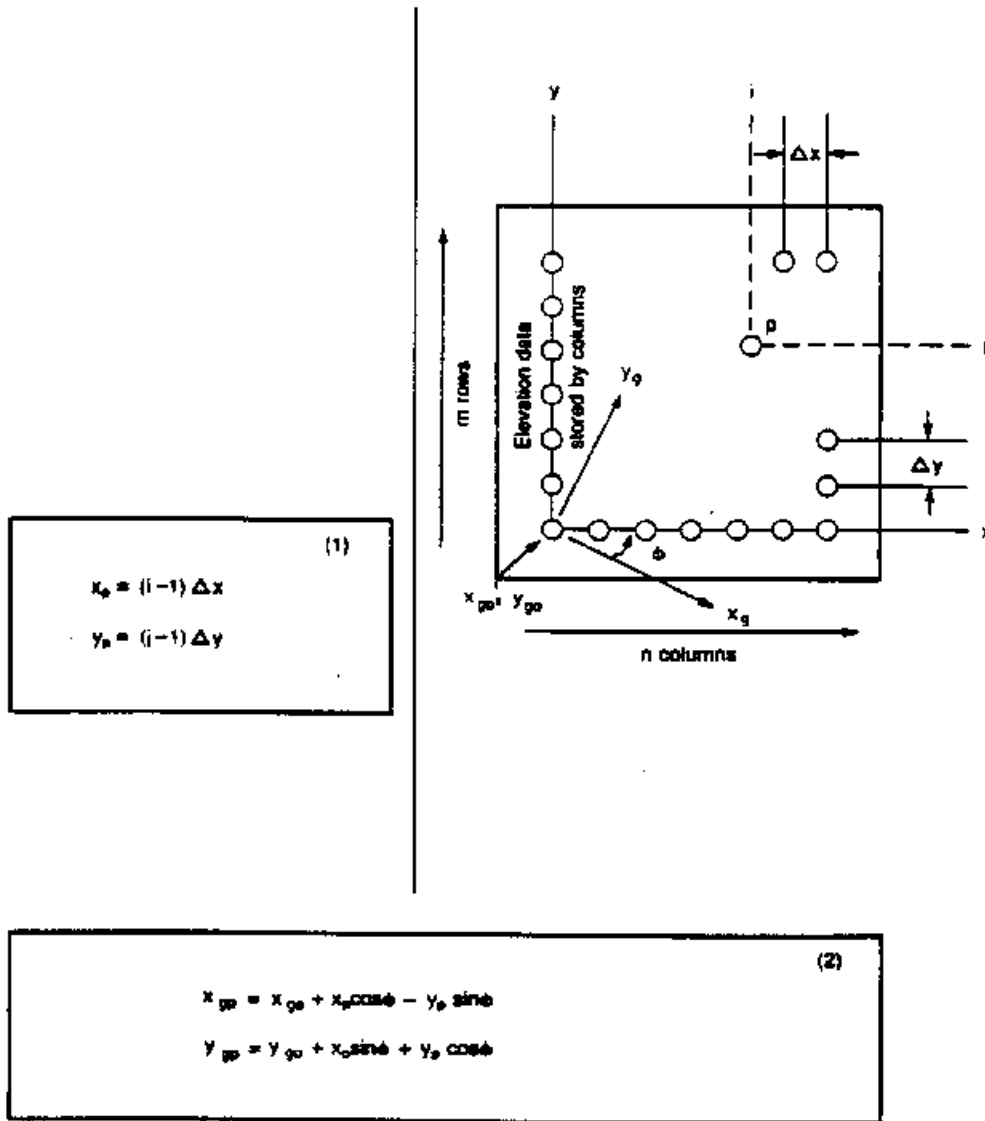


Figure 5.--Geometry and nomenclature of the 7.5-minute Digital Elevation Model file.

The method of determining 7.5-minute DEM accuracy involves computation of the root-mean-square error (RMSE) for linearly interpolated elevations in the DEM and corresponding "true" elevations from the published maps. Test points are well distributed, are representative of the terrain, and have "true" elevations well within the DEM accuracy criteria.

Test points are located on contour lines, bench marks, or spot elevations. A minimum of 28 test points per DEM is required (20 interior points and 8 edge points). Collection of test point data and comparison of the DEM to the quadrangle hypsography are conducted by the quality-control units within the USGS.

The broad NIMA production objective for a 1-degree DTED-1 is to satisfy an absolute horizontal accuracy (feature to datum) of 130 m, circular error at 90-percent probability; and an absolute vertical accuracy (feature to mean sea level) of  $\pm 30$  m, linear error at 90-percent probability. The rela-

tive horizontal and vertical accuracy (feature to feature on the surface of the elevation model), although not specified, will in many cases conform to the actual hypsographic features with higher integrity than indicated by the absolute accuracy.

# CLASSIFICATION LEVELS

The following is a description of the general data characteristics used to classify DEM's into one of three levels of quality. There are varying methods of data collection and degrees of editing available for DEM data. Classification levels are indicated in the DEM record A (appendix A).

## Level 1

Level 1 DEM's are elevation data sets in a standardized format. The intent is to reserve this level for 7.5-minute DEM's or equivalent that are derived from scanning National High-Altitude Photography Program, National Aerial Photography Program, or equivalent photography.

A vertical RMSE of 7 m is the desired accuracy standard. A RMSE of 15 m is the maximum permitted. The intent for 7.5-minute DEM data at this level is that an absolute elevation error tolerance of 50 m (approximately three times the 15-meter RMSE) be set for blunders for any grid node when compared to the true elevation, or that an array of points not encompass more than 49 contiguous elevations and be in error by more than 21 m (three times the 7-m RMSE). Systematic errors within the stated accuracy standards are tolerated at this level.

DEM data acquired photogrammetrically by using manual profiling or image correlation techniques are restricted to the level 1 category. DEM's with a RMSE of from 7 to 15 meters in elevation are being retained as an intermediate product and eventually will be replaced by higher accuracy DEM's. The DEM record C (appendix C) contains the RMSE accuracy statistics acquired during quality control.

A 30-minute DEM product has been produced by re-gridding level 1 or level 2 source 7.5-minute DEM data. These grid derivative DEM's are arbitrarily labeled as level 1 DEM's and carry a measured RMSE in record C. A tolerance has not been set for this RMSE, as a minimum level of accuracy has been satisfied previously with the data sets origin in the 7.5-minute DEM program. Alternatively, 30-minute DEM's are labeled as level 2 if gridded from 1:100,000-scale hypsography and hydrography stable base separates. The tolerance for level 2, 30-minute DEM's, is one-half contour interval (see level 2 specifications, below).

## Level 2

Level 2 DEM's are elevation data sets that have been processed or smoothed for consistency and edited to remove identifiable systematic errors. DEM data derived from hypsographic and hydrographic data digitizing, either photogrammetrically or from existing maps, are entered into the level 2 category after review on a DEM Editing System. An RMSE of one-half contour interval is the maximum permitted. There are no errors greater than one contour interval in magnitude. The DEM record C contains the accuracy statistics acquired during quality control.

## Level 3

Level 3 DEM's are derived from DLG data by using selected elements from both hypsography (contours, spot elevations) and hydrography (lakes, shorelines, drainage). If necessary, ridge lines and hypsographic effects of major transportation features are also included in the derivation. A RMSE of one-third of the contour interval is the maximum permitted. There are no errors greater than two-thirds contour interval in magnitude. The DEM record C contains the accuracy statistics acquired during quality control.

# DIGITAL ELEVATION MODEL CAVEATS

The majority of the 7.5-minute DEM's produced to date are level 1. The current priority for authorization of 7.5-minute DEM production is now oriented to level 2, interpolation from digital contours. The USGS does not currently produce level-3 DEM data.

All 30-minute DEM's derived from contours are level 2. All 30-minute DEM's derived from 7.5-minute DEM's are level 1.

All 1-degree NIMA DTED-I's have been classified as level 3 because the hypsographic information, when plotted at 1:250,000 scale is consistent with the planimetric features normally found on 1:250,000-scale topographic maps. Inconsistencies may exist, but these are regarded as isolated cases to be tempered by the 90-percent confidence level for the overall product. NOTE: The USGS classification of "level 3" for 1-degree DEM's is not to be confused with the NIMA'S "DTED level 1." In the NIMA, the term "level" is related to the spatial resolution of the data and not to the source of the data. For example, DTED level 2 (which the USGS does not distribute) would have an array spacing of 1 x 1 arc-second for latitudes south of 50° N.

# DATA RECORDS

A DEM file is organized into a series of three logical records are formatted as shown in

Record Definition A

Record Definition B

Record Definition C

Because of the restructuring of new elements within what was formerly defined as element 1, record type A, the element counts of old record type A elements 2-15 have been incremented by one to elements 3-16. A one-to-one correspondence still exists between the informational content of byte positions of elements in the old and new records. Therefore, DEM programs that expected elements 2-15 in specific byte positions in the DEM file will find the same information in those byte positions in the new files. In essence, this change is transparent to old DEM applications programs. Also, new data elements 17-29 have been appended to the end of the record A. These elements are contained in the end of the previously blank filled portion of the 1,024 byte record. This change is also expected to be transparent to existing DEM programs.

Appendixes D-G consist of code definitions that are needed to interpret various data elements in the three records. The type A record contains information defining the general characteristics of the DEM, including descriptive header information relating to the DEM's name, boundaries, units of measurement, minimum and maximum data values, number of type B records, and projection parameters. There is only one type A record for each DEM file, and it appears as the first record in the data file. The type B record contains elevation data and associated header information. All type B records of the DEM files are made up of data from one-dimensional arrays called profiles. The number of complete profiles covering the DEM area is synonymous with the number of type B records in the DEM. In a UTM structured DEM, an occasional profile that exists within the bounds of the DEM quadrilateral but is void of elevation grid points is not represented in the DEM. (This is called the "missing profile condition" and occurs occasionally as the first or last hypothetical profile of the DEM.) The type C record contains statistics on the accuracy of the data in the file.

The physical structure of the DEM distributed to the user is as follows:

- 1) Data recorded in fixed-block format on unlabeled or ANSI-labeled 9-track magnetic tape at 1,600 or 6,250 bpi density.
- 2) Logical record size of 1,024 bytes. No more than one logical record type (A, B, or C) recorded in any 1,024-byte record. However, more than one 1,024-byte record is usually required to store a single record type B. The logical record is padded with blanks if necessary to fill to the end of the logical record. Bytes 1,021-1,024 of each logical record are padded with blanks.
- 3) Physical record size of 4,096 bytes; that is, 4 logical records per physical record.
- 4) Data written as ANSI-standard ASCII characters.

## Sample Data Records

Example 7.5-minute DEM Record Type A

Example 7.5-minute DEM Record Type B

Example 7.5-minute DEM Record Type C

Example 1-degree DEM Record Type A

Example 1-degree DEM Record Type B

Included in these samples are literal ASCII listings of records directly from DEM distribution tapes. Following the literal listings are tabular explanations of each element in the type A, B, and C records. The tabular explanations may be used as direct references between the literal listings and the logical record type formats shown in Record Definitions A-C. Appendixes D-G consist of code definitions that are needed to interpret various data elements in the three records.

#### SAMPLE APPLICATIONS

The DEM files may be used in the generation of graphics such as isometric projections displaying slope, direction of slope, and terrain profiles between designated points. They may also be combined with other data types such as stream locations and weather data to plan forest fire control, or with remote sensing data to classify vegetation. Many non-graphic applications such as modeling terrain gravity data for use in locating energy resources, determining the volume of proposed reservoirs, calculating the amount of material removed during strip mining, and determining landslide probability have also been developed. Figures 6 and 7 show two graphic applications of DEM's.



Figure 6.--Pre-eruption isometric plot of Mount St. Helens

7.5-minute Digital Elevation Models generated from data obtained from July 15, 1979, photographs. View is from the northeast at a 45° altitude angle; vertical exaggeration is 3:1.



Figure 7.--Post-eruption isometric plot of Mount St. Helens

7.5-minute Digital Elevation Models generated from data obtained from September 6, 1980, photographs. View is from the northeast at a 45° altitude angle; vertical exaggeration is 3:1.



## Record Definition A

Data Element	Descriptor	Type	ASCII Format	First Byte	Last Byte	Comment
1	File name	ALPHA	A40	1	40	Authorized DEM quadrangle name
	Free Format Text	ALPHA	A40	41	80	Free format descriptor field, contains useful information related to digital process such as digitizing instrument, photo codes, slot widths, etc
	Filler			81	135	
	Process Code	ALPHA	A1	136		1=GPM 2=Manual Profile 3=DLG2DEM (includes any DLG type process such as CTOG or LINETRACE) 4=DCASS
	Filler			137		
	Sectional Indicator	ALPHA	A3	138	140	This code is specific to 30-minute DEM's. Identifies 1:100,000-scale sections. Formatted as XNN, where X is "s"=7.5-minute, "F"=15-minute, and NN is a two-digit sequence number
2	MC origin code	ALPHA	A4	141	144	Mapping Center origin Code. Valid codes are EMC, WMC, MCMC, RMMC, FS, GPM2
3	DEM level code	INTEGER*2	I6	145	150	1=DEM-1 2=DEM-2 3=DEM-3
4	Code defining elevation pattern (regular or random)	INTEGER*2	I6	151	156	1=regular 2=random is reserved for future use
5	Code defining ground planimetric reference system	INTEGER*2	I6	157	162	0=Geographic 1=UTM 2=State Plane Code 0 represents the geographic (latitude/longitude) system for 30-minute, 1-degree and Alaska DEM's. Code 1 represents the current use of the UTM coordinate system for 7.5-minute DEM's
6	Code defining zone in ground planimetric reference system	INTEGER*2	I6	163	168	Zero if element 5 is also set to zero defining data as geographic
7	Map projection parameters	REAL*8	15D24.15	169	528	All 15 fields of this element are set to zero and should be ignored when geographic, UTM, or State plane coordinates are coded in data element 5

8	Code defining unit of measure for ground planimetric coordinates throughout the file	INTEGER*2	I6	529	534	0=radians 1=feet 2=meters 3=arc-seconds Normally set to code 2 for 7.5-minute DEM's. Always set to code 3 for 30-minute, 1-degree, and Alaska DEM's.
9	Code defining unit of measure for elevation coordinates throughout the file	INTEGER*2	I6	535	540	1=feet 2=meters Normally code 2, meters, for 7.5-minute, 30-minute, 1-degree, and Alaska DEM's
10	Number (n) of sides in the polygon which defines the coverage	INTEGER*2	I6	541	546	n=4
11	A 4,2 array containing the ground coordinates of the four corners for the DEM	REAL*8	8D24.15	547	738	The coordinates of the quadrangle corners are ordered in a clockwise direction beginning with the southwest corner. The array is stored row-wise as pairs of eastings and northings.
12	A two element array containing minimum and maximum elevation for the DEM	REAL*8	2D24.15	739	786	The values are in the unit of measure given by data element 9 in this record.
13	Counterclockwise angle (in radians) from the primary axis of ground planimetric reference to the primary axis of the DEM local reference system	REAL*8	D24.15	787	810	See figure 5. Set to zero to align with the coordinate system specified in element
14	Accuracy code for elevations	INTEGER*2	I6	811	816	0=unknown accuracy 1=accuracy information is in logical record type C
15	A three element array of DEM spatial resolution for x, y, z. Units of measure are consistent with those indicated by data elements 8 and 9 in this record.	REAL*4	3E12.6	817	852	These elements are usually set to: 30, 30, 1 for 7.5-minute DEM's; 2, 2, 1 for 30-minute DEM's; 3, 3, 1 for 1-degree DEM's. 2, 1, 1 for high resolution DEM's in Alaska 3, 2, 1 for low resolution DEM's in Alaska. 7.5-minute DEM'S will eventually be converted to geographic, i.e., 1,1,1.
16	A two element array containing the number of rows and columns (m, n) of profiles in the DEM	INTEGER*2	2I6	853	864	When the row value m is set to 1 the n value describes the number of columns in the DEM file. Raw GPM data files are set to m=16, n=16.
Note, Old format stops here						
17	Largest primary contour interval	INTEGER*2	I5	865	869	Present only if two or more primary intervals exist.

18	Source contour	INTEGER*1	I1	870		Corresponds to the units of the map largest primary contour interval 0=N.A., 1=feet, 2=meters.
19	Smallest primary interval	INTEGER*2	I5	871	875	Smallest or only primary contour interval
20	Source contour interval units	INTEGER*1	I1	876		Corresponds to the units of the map largest primary contour interval 0=N.A., 1=feet, 2=meters.
21	Data source date in digit months	INTEGER*2	I4	877	880	YYMM two-digit year and two-digit month MM = 00 for source having year only.
22	Data inspection-revision date	INTEGER*2	I4	881	884	YYMM two-digit year and two-digit month.
23	Inspection-revision flag	ALPHA	A1	885		"I" or "R"
24	Data validation flag	INTEGER*1	I1	886		0= No validation performed  1=TESDEM (record C added) no qualitative test (no DEM Edit System review) 2=Water body edit and TESDEM run. 3=DES (includes water edit) no qualitative test (no TESDEM). 4=DES with record C added, qualitative and quantitative tests for level 1 DEM 5=DES and TESDEM qualitative and quantitative tests for levels 2 and 3 DEM's
25	Suspect and void area flag	INTEGER*1	I2	887	888	0=none  1=suspect areas 2=void areas 3=suspect and void areas
26	Vertical datum	INTEGER*1	I2	889	890	1=local mean sea level  2=National Geodetic Vertical Datum 1929 (NGVD 29) 3=North American Vertical Datum 1988 (NAVD 88)
27	Horizontal datum	INTEGER*1	I2	891	892	1=North American Datum 1927 (NAD 27)  2=World Geodetic System 1972 (WGS 72) 3=WGS 84 4=NAD 83 5=Old Hawaii Datum 6=Puerto Rico Datum 7=NAD 83 Provisional (shifts in horizontal coordinates are computed, but old DEM nodes are not re-sampled)
28	Data Edition	INTEGER*2	I4	893	896	01-99 Primarily a NIMA specific field.
29	Percent Void	INTEGER*2	I4	897	900	900 If element 25 indicates a void, this field (right justified) contains the percentage of nodes in the file set to void (-32,767).

## Record Definition B

Data Element	Descriptor	Type	ASCII Format	First Byte	Last Byte	Comment
1	A two element array containing the row and column identification number of the DEM profile contained in this record	INTEGER*2	2I6	1	12	See figure 5. The row/column numbers may range from 1 to m and 1 to n. The row number is normally set to 1. The column identification is the profile sequence number.
2	A two element array containing the number (m, n) of elevations in the DEM profile	INTEGER*2	2I6	13	24	See figure 5. The first element in the field corresponds to the number of rows and columns of nodes in this profile. The second element is set to 1, specifying 1 column per B record.
3	A two element array containing the ground planimetric coordinates (Xgo, Ygo) of the first elevation in the profile	REAL*8	2D24.15	25	72	See figure 5.
4	Elevation of local datum for the profile	REAL*8	D24.15	73	96	The values are in the units of measure given by data element 9, logical record type A.
5	A two element array of minimum and maximum elevations for the profile	REAL*8	2D24.15	97	144	
6	A m, n array of elevations for the profile. Elevations are expressed in units of resolution	INTEGER*2	m*n(I6)	6x(146 or 170) = max for first block, 170 = max for subsequent blocks		See data element 15 in appendix A. A value in this array would be multiplied by the spatial resolution value and added to the elevation of the local elevation datum for the element profile (data element 4 in this record) to obtain the elevation for the point. The planimetric ground coordinates of the point Xgp, Ygp are computed according to the formulas in figure 5.

## Record Definition C

<b>Data Element</b>	<b>Descriptor</b>	<b>Type</b>	<b>ASCII Format</b>	<b>First Byte</b>	<b>Last Byte</b>	<b>Comment</b>
1	Code indicating availability of statistics in data element 2	INTEGER*2	I6	1	6	Code 1=available 2=unavailable
2	RMSE of the file's datum relative to absolute datum (x ,y, z)	INTEGER*2	3I6	7	24	In same units as indicated by elements 8 and 9 of logical record type A
3	Sample size on which statistics in data element 2 are based	INTEGER*2	I6	25	30	If 0, then accuracy will be assumed to be estimated rather than computed
4	Code indicating availability of statistics in data element 5	INTEGER*2	I6	31	36	Code 1=available 2=unavailable
5	RMSE of DEM data relative to file's datum (x, y, z)	INTEGER*2	I6	37	54	In same units as indicated by elements 8 and 9 of logical record type A
6	Sample size on which statistics in element 5 are based	INTEGER*2	I6	55	60	If 0, then accuracy will be assumed to be estimated rather than computed

# National and International Datums Used for Digital Elevation Data

Two types of horizontal datums are presently in use for DEM data distributed by the USGS, the civilian North American Datum (NAD) and military World Geodetic System (WGS). The NAD 27 datum is currently used to define positions on USGS topographic maps and 7.5-minute DEM's. Plans are to convert to the new NAD 83 for these applications. The WGS 72 is currently used to define positions for 1-degree NIMA DEM's and DTED's. NIMA is converting these data to the new WGS 84. The NAD 83 and WGS 84 datums are being phased into the mapping community at different rates or where resources are available. For the conterminous United States these new datums are considered to be functionally the same; however, the two have been defined separately since they were designed to serve different segments of the mapping community, primarily civilian and military. The following information will help clarify the relationship between these datums.

## The Role of the Ellipsoid in Defining Datums

Unlike local surveys, which treat the Earth as a plane, the precise determination of the latitude and longitude of points over a broad area must take into account the actual shape of the Earth. To achieve the precision necessary for very accurate location, the Earth cannot simply be assumed to be a sphere. Rather, the Earth's shape more closely approximates an ellipsoid (oblate spheroid): flattened at the poles and bulging at the Equator. Thus the Earth's shape, when cut through its polar axis, approximates an ellipse.

Geodetic surveying, which takes into account variations in the shape of the Earth, is based on a reference ellipsoid to the geoid, the actual shape of the Earth, that is selected as a best fit over a limited area. The ellipsoid used to define a datum is a mathematical surface upon which computation of position can be based, as opposed to the actual surface of the Earth on which surveys are conducted. The geoid, which approximates the sea level surface, is an equipotential surface of the Earth's gravity field. It can be thought of as a continuous sea-level surface extended beneath the continents. It is the "level" surface of reference for astronomic observations and geodetic leveling, but because of undulations that respond to the Earth's mass distributions, it is not a useful computational surface for horizontal surveys.

## Horizontal Surveys -- Conversions

### NAD 27

The NAD 27 is defined with an initial point at Meades Ranch, Kansas, and by the parameters of the Clarke 1866 ellipsoid. The location of features on USGS topographic maps, including the definition of 7.5-minute quadrangle corners, are referenced to the NAD 27.

### NAD 83

Using recent measurements with modern geodetic, gravimetric, astrodynamical, and astronomic instruments, the Geodetic Reference System 1980 (GRS 80) ellipsoid has been defined as a best fit to the worldwide geoid. Unlike NAD 27, which is based on an initial point (Meades Ranch, Kansas), NAD 83 is an Earth-centered datum and uses the GRS 80 ellipsoid. Because the NAD 83 surface deviates from the NAD 27 surface, the position of a point based on the two reference datums will be different.

### WGS 72

The definition of NIMA DEM's, as presently stored in the USGS data base, references the WGS 72

datum. Like NAD 83, WGS 72 is an Earth-centered datum. The WGS 72 datum was the result of an extensive effort extending over approximately three years to collect selected satellite, surface gravity, and astrogeodetic data available through 1972. The combination of the data was performed using a unified WGS solution (a large-scale least squares adjustment). Such an adjustment was made possible in part because of the availability of adequate computers and software.

#### WGS 84

The WGS 84 datum was developed as a replacement for WGS 72 by the military mapping community as a result of newer, more accurate instrumentation and more comprehensive control networks. It is an improvement over WGS 72 in several respects. New and more extensive data sets and improved software were used in the development. A more extensive file of Doppler-derived station coordinates was available and for many more local geodetic systems; improved sets of ground-based Doppler and laser satellite-tracking data and surface gravity were available; and geoid heights were deduced from satellite radar altimetry (a new data type) for oceanic regions between 70° north and south latitude (approximately). This system is described in "World Geodetic System 1984," Department of Defense NIMA TR 8350.2, September 1987.

NIMA has recomputed the 1-degree DTED's for the contiguous United States and has made a copy of the data set available to the USGS.

#### NAD 27 - NAD 83

The methods available for transformation from NAD 27 to NAD 83 can result in inconsistencies. Therefore, a single method of conversion has been adopted by the USGS. The method involves the use of 7.5-minute grid intersection tables developed by the National Ocean Service and the software program NADCON, which is available as an interactive PC-based program or adapted to batch processing on PC or mainframe computers. Bilinear interpolation of the shifts derived for the four quadrangle corners results in a uniform horizontal translation of values which are applied to all points interior to and including the edges of the quadrangle.

#### WGS 72 - WGS 84

Table H-1 contains information on converting WGS 72 coordinates to WGS 84. There are no NIMA plans to develop WGS 72 coordinates of improved accuracy. However, if WGS 84 coordinates have been determined, the WGS 72-to-WGS 84 formulation in table H-1 can be reversed and used with the WGS 84 coordinates to obtain improved WGS 72 coordinates.

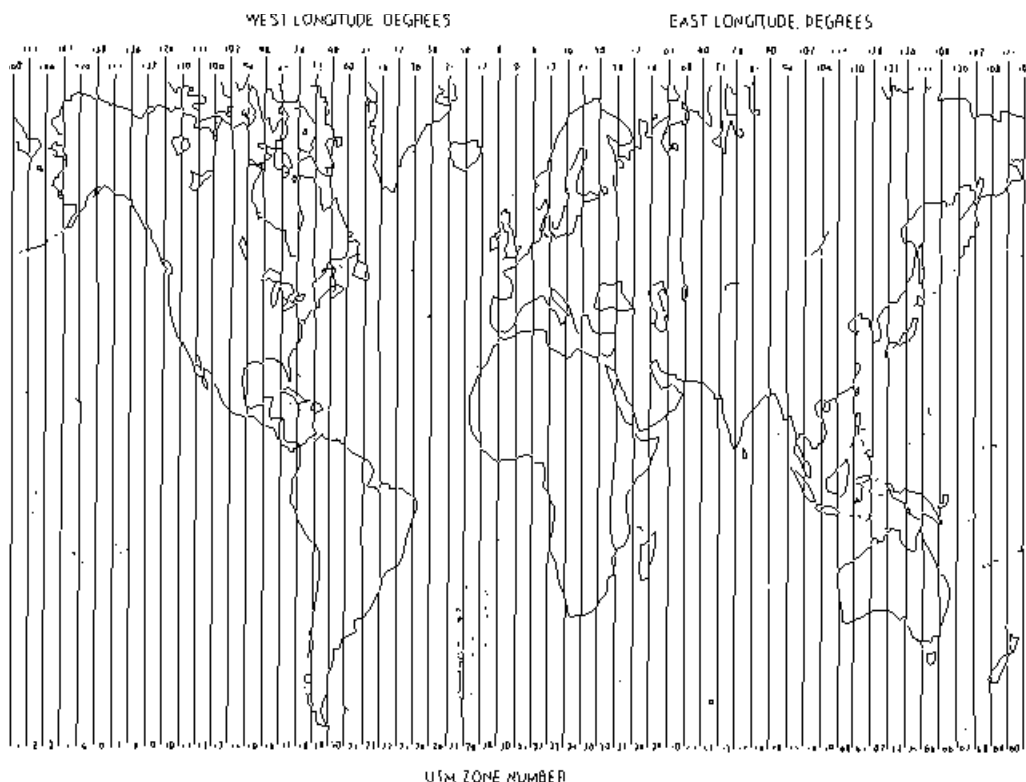
# UTM Coordinate System

The UTM (Universal Transverse Mercator) grid was devised as one way of solving the cartographer's dilemma: how to represent the (nearly) spherical earth's surface on a flat sheet of paper. Latitude and longitude coordinates are sufficient when long distances are to be covered. (Pilots and sailors use them almost exclusively.) However, for ground teams who cover only a few miles, latitude-longitude is much too cumbersome to be practical. For example, subdividing tic-marks for latitude-longitude are shown only in two places along the edge of a 7/2 minute quad map. Furthermore, the subdivisions of the units (minutes and seconds) are one-sixtieth of the larger unit. We are not accustomed to dividing lengths by sixtieths, as were the Babylonians who invented this system 4000 years ago. Another limitation is that a unit of longitude, a degree, represents less distance as one moves away from the equator. This complicates matters when one needs to calculate the distance or bearing from one point to another.

Spherical trigonometry or other complex mathematical methods must be used to make these calculations. These are not impossible of course, just inconvenient.

The UTM system was developed with guidelines that it would: (1) be a square grid; (2) have no negative numbers in the coordinates; (3) read left-to-right and bottom-to-top; and (4) be decimal-based.

To accomplish these goals, the UTM system divides the earth's sphere into 60 zones, each being six degrees of longitude wide. The zones are numbered I through 60, west-to-east, beginning at 180 degrees west longitude. **Figure 1** shows the zone numbering system on a continental outline map. Although not shown on this map, the zones cover only the area between 80 degrees south and 84 degrees north latitudes. Different grids (not described here) cover the polar areas.



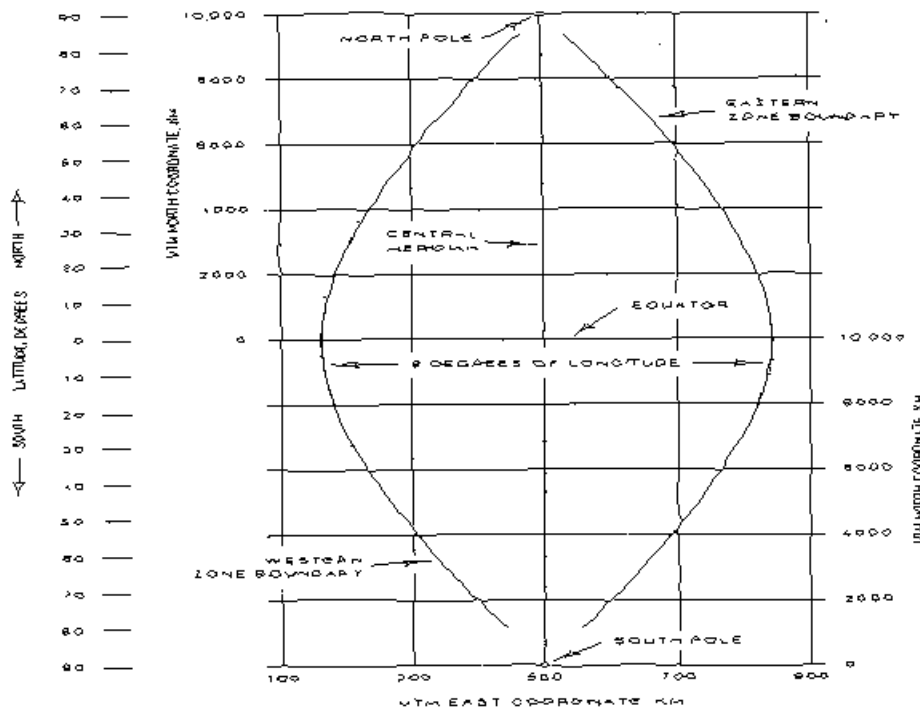
**Figure 1:** The numbering system for UTM zones. The zones extend from 80 degrees south to 84 degrees north latitudes.

The metric system is used as the units of the UTM coordinates. It may be convenient to remember (as a possible trivia answer) that the distance from the equator to either pole is 10,000,000 meters or 10,000kilometers. Tobe exact, a kilometer is equal to nearly 0.625 of a mile or 0.62137 miles.

A square grid is superimposed on each zone and aligned so its vertical lines are parallel to the center of the zone. This centerline is called the central meridian, and is three degrees of longitude from each zone boundary.

The UTM coordinates (measures of distance) are arranged so they always read from left-to-right and from bottom-to-top. This is done as follows. In the northern hemisphere the origin, or zero point, of the horizontal lines is at the equator, while in the southern hemisphere the origin is at the south pole.

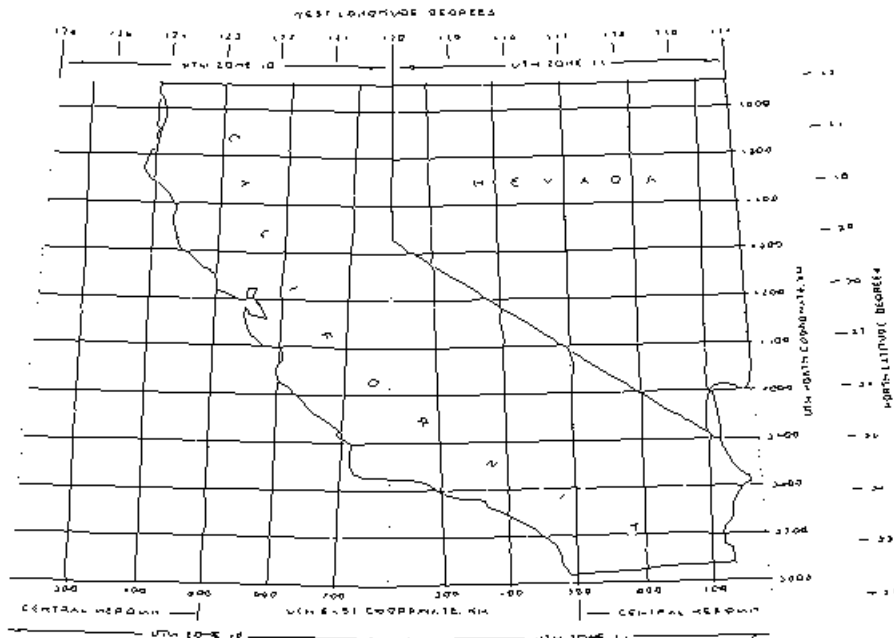
Establishing coordinates for the vertical lines was done differently. The vertical line at the center of each zone (central meridian) was arbitrarily assigned the value of 500 km to avoid having negative coordinate values. Assigning the value of 500 km to the center of each zone causes the zero point to fall in another zone - the one to its left (west). For this reason, you will never see a zero value for an east-west coordinate. The smallest value is 160 km and it is at the equator. As one moves away from the equator, the UTM east coordinate at the zone's western edge has larger and larger values. At 84 degrees north latitude it is 465 km. Likewise, the eastern (right) zone boundaries will have coordinates of 834 km at the equator and 515 km at 84 degrees north latitude. The way the square grid is placed on each zone is shown in **Figure 2**. Note that this drawing is not to scale; the horizontal axis is highly exaggerated.



**Figure 2:** The square UTM grid that is superimposed on each zone. This drawing is not to scale.

**Figure 3** shows a portion of zones 10 and 11 in the western U.S. Nevada, quite accidentally, lies totally in zone 11, while California falls in both zones 10 and 11. The latitude-longitude and UTM coordinates are both shown in this figure to illustrate their relationship. Note that the UTM lines at zone boundaries meet at slight angles, and the width (number of kilometers) of the zones is greater near the bottom (south) than at the top in this illustration. Observe also the square UTM

grid is parallel to the central meridian.



**Figure 3:** UTM zones 10 and 11 in California and Nevada.

Taking a closer look at the UTM grid, refer to **Figure 4**, which is a familiar 7.5 minute quad with emphasized UTM grid lines 1000 meters (1 kilometer) apart. All USCS topographic maps published in the last 30 years or so have this grid. Since about 1982, the grid lines have been printed on the map, while earlier maps show only the positions of the grid lines on the map's edges as blue tick-marks. A close-up view of a corner of a 7.5 minute quad is shown in Figure 5. On the lower right edge of the map is the notation 5095000mN. The numerals 5 and 7 are printed in larger type size than the others, but ignore the difference in type size. This number is the UTM coordinate of the black line just to its left. It is 5,095,000 meters (5095 kilometers) north of the equator and is called the UTM north coordinate. The other numbers along the edge are also UTM north coordinates but are expressed in kilometers. Again, ignoring type size, the next number up the map edge is 3958, one kilometer greater than the first one. Along the bottom of the map there is the notation 606000mE, a UTM east coordinate. The vertical line above it is 606 kilometers east (right) of the zone's zero point. Put another way it is 500 minus 606 or -106 kilometers east (right) of the central meridian.

**Figure 4:** UTM grid on a 7.5 minute USGS topographic map.

Locations between grid lines may be specified by dividing the space between them into tenths. For example, in the upper right-hand corner of **Figure 5** is the elevation notation 4180, printed in black. The digit 0 in this number is about four-tenths of the distance between the 605 and 606 vertical lines. The UTM east coordinate would then be 605.4 km. Likewise the 0 is about two-tenth of the distance up from the 5096 line and its UTM north coordinate is 5096.2 km. Just by giving these two numbers, 605.4 east and 5096.2 north, plus the zone number, you have uniquely specified this point on the earth's surface. And it was done just by looking at the map with no calculations or measurements needed. For more accurate subdivision between UTM grid lines, you can use a transparent overlay or the metric scale at the bottom of the map.

**Figure 5:** A corner of a 7.5 minute USCS topographic map showing UTM coordinates

As taught in the U.S. Army, it should be noted that some teams learn UTM coordinates as a six-digit number. This number is created using the two large, bold-type UTM numbers from the map, and the tenths from dividing the space between the grid lines. The decimal point is omitted. In addition, they learn to "read right up"; thus, presenting the number in the correct format. Therefore, the coordinates mentioned above would be transmitted as 054-962.

The UTM zone number will be found in the information printed on the lower left-hand corner of the map.

If you are plotting bearings very accurately, as you would during radio location of an ELT, one additional factor should be considered.

The only place where the UTM grid is aligned exactly true north is at the midpoint of a zone (at the central meridian). The grid will be rotated slightly counterclockwise for locations west (left) of the central meridian. This can be seen in Figure 4. Note how the UTM grid is not quite parallel to the edges of the map. Similarly, it will have a small clockwise rotation east of the central meridian. The amount of rotation increases as you move away from the central meridian and is maximized at the zone boundaries. This difference between true north and UTM grid north is called the convergence, so named because the meridians converge as they approach the poles. In the continental U.S. the convergence will never exceed 2.5 degrees. If you need to know the convergence, it is shown on a diagram on the map in Figure 6. The vertical line with the star at its end represents true north, while the line with the notation GN (abbreviation for grid north) at its end shows the angle (not to scale) of the UTM grid. The convergence for this map is shown as 0 degrees, 57 minutes, which is the same as 57 divided by 60 or 0.95 degrees. On this map grid north is counterclockwise from true north by 0.95 degrees.

**Figure 6** also shows the relation between true north and magnetic north. Note the legend below the figure gives a year associated with the magnetic declination. That's because declination is not a constant value - it changes with time. The change is slow; one degree every 10 years is common in parts of the U.S. But if you're using a 30-year-old map, the declination printed on it may be wrong by three degrees (in this case the 25 year difference is -2.6 degrees). On this map, the difference between magnetic north (in 1970) and UTM grid north is 21.0 degrees plus 0.95 degrees, or 21.95 degrees. Knowing the exact values of convergence and declination is not important unless you are doing precise navigation or making extremely accurate plots of bearings.

**Figure 6:** Diagram on USGS topographic maps that shows the angular relations among grid north, true north and magnetic north.

One further advantage the UTM system offers is its coordinates can be converted to latitude-longitude and vice versa. The mathematical equations for doing this are very complicated, but are easily handled by computers, including small hand held ones. Being able to make these conversions is quite useful when coordinating search operations involving both ground teams and air resources. If a ground team requests a victim evacuation by helicopter and gives its location in UTM coordinates, these can be converted to latitude-longitude. The aircraft crew can then use its on-board navigation equipment to locate the pickup site. Another use of the conversion process is in the plotting of locations on a map. In searches for missing aircraft, the FAA is sometimes able to furnish a record of the aircraft's flight path from its radar records (NTAP). These locations are always given in latitude-longitude coordinates. Plotting these on a map can be very time-consuming.

ing. But, if they are converted to UTM coordinates. they can be plotted very quickly.

These are the features of the UTM coordinate system that you need to use in the field. It provides a rapid, simple and accurate way to report your location. All that remains to be done is adding the UTM grid lines to your maps. Use a long straightedge to connect the blue tic-marks with a pencil or fine-point pen. This would be a good project for a cold winter night or at a team meeting when discussing map reading. Then, on your next mission, the UTM grid will be waiting for you to use it.

For those interested in more details about the UTM system. the following references are recommended:

*Maps for America*, by Morris M. Thompson, published by the United States Geological Survey, 1979. This is an excellent reference book that describes all the features on USGS maps. The appendix has a thorough description of the UTM coordinate system.

*United States Army Technical Manuals* TM 5-241-1, "Grids and Grid References", and TM 5-241-8, "Universal Transverse Macerator Grid". The first of these describes the way the UTM system forms the basis for the Military Grid Reference System. The latter provides the mathematical equations for converting UTM coordinates to latitude - longitude and vice versa.

# Geodetic Datums and Ellipsoids

Hundreds of geodetic datums are in use around the world. The Global Positioning system is based on the World Geodetic System 1984 (WGS-84). Parameters for simple XYZ conversion between many datums and WGS-84 are published by the Defense mapping Agency. Coordinate values resulting from interpreting latitude, longitude, and height values based on one datum as though they were based in another datum can cause position errors in three dimensions of up to one kilometer.

Datum conversions are accomplished by various methods. Complete datum conversion is based on seven parameter transformations that include three translation parameters, three rotation parameters and a scale parameter. Simple three parameter conversion between latitude, longitude, and height in different datums can be accomplished by conversion through Earth-Centered, Earth Fixed XYZ Cartesian coordinates in one reference datum and three origin offsets that approximate differences in rotation, translation and scale. GeoMag uses the Standard Molodensky formulas to convert latitude, longitude, and ellipsoid height in one datum to another datum.

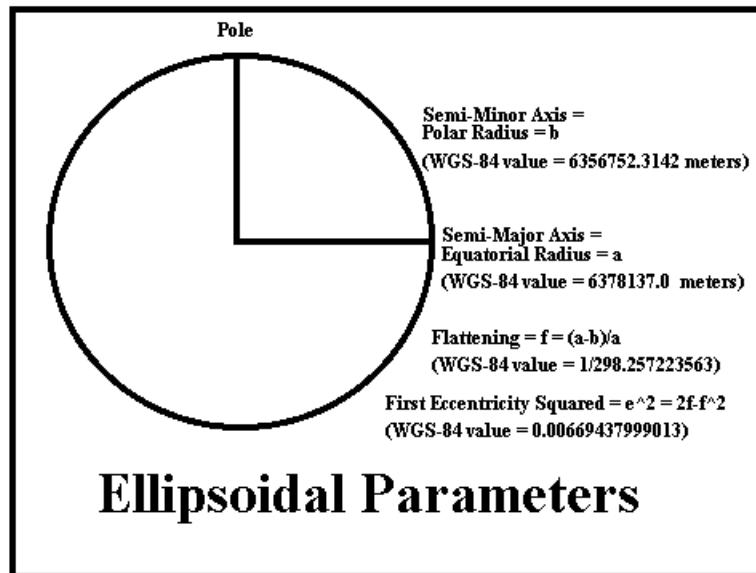
Datums and their Parameters Available with GeoMag

Datum	Ellipsoid	DX	DY	DZ
Adindan	Clarke 1880	-162.0	-12.0	206.0
Arc 1950	Clarke 1880	-143.0	-90.0	-294.0
Arc 1960	Clarke 1880	-160.0	-8.0	-300.0
Australian 1966	Australian National	-133.0	-48.0	148.0
Australian 1984	Australian National	-134.0	-48.0	149.0
Camp Area Astro	International 1909	-104.0	-129.0	230.0
Cape	Clarke 1880	-136.0	-108.0	-292.0
European 1950	International 1909	-87.0	-98.0	-121.0
European 1979	International 1967	-86.0	-98.0	-119.0
Geodetic 1949	International 1967	84.0	-22.0	209.0
Hong Kong 1963	International 1967	-156.0	-271.0	-189.0
Hu Tzu Shan	International 1967	-634.0	-549.0	-201.0
Indian	Everest	289.0	734.0	257.0
North American 1927	Clarke 1866	-8.0	160.0	176.0
North American 1983	GRS 80	0.0	0.0	0.0
Oman	Clarke 1880	-346.0	-1.0	224.0

Ordnance Survey 1936	Airy	375.0	-111.0	431.0
Pulkovo 1942	Krassovsky 1942	27.0	-135.0	-89.0
South American 1956	International 1967	-288.0	175.0	-376.0
South American 1969	South American 1969	-57.0	1.0	-41.0
Tokyo	Bessel 1841	-128.0	481.0	664.0
WGS 1972	WGS 72	0.0	0.0	-4.5
WGS 1984	WGS 84	0.0	0.0	0.0

Early ideas of the figure of the Earth resulted in descriptions of the Earth as an oyster (The Babylonians before 3000 B.C.), a rectangular box, a circular disk, a cylindrical column, a spherical ball, and a very round pear (Columbus in the last years of his life). Flat Earth models are still used for plane surveying, over distances short enough so that Earth curvature is insignificant (less than 10 kms).

Spherical Earth models represent the shape of the Earth with a sphere of a specified radius. Spherical Earth models are often used for short range navigation (VOR-DME) and for global distance approximations. Spherical models fail to model the actual shape of the Earth. The slight flattening of the Earth at the poles results in about a twenty kilometer difference at the poles between an average spherical radius and the measured polar radius of the Earth.



Ellipsoidal Earth models are required for accurate range and bearing calculations over long distances. Loran-C, and GPS navigation receivers use ellipsoidal Earth models to compute position and waypoint information. Ellipsoidal models define an ellipsoid with an equatorial radius and a

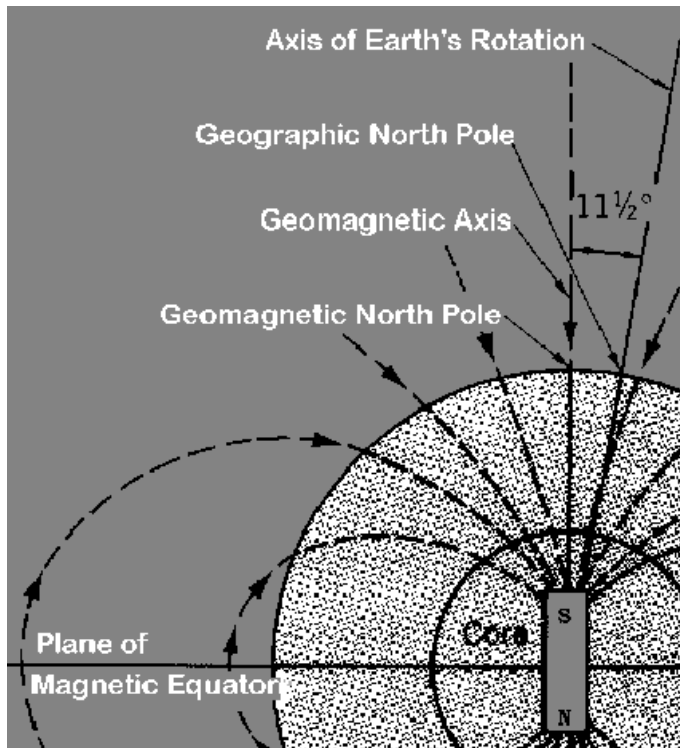
polar radius. The best of these models can represent the shape of the Earth over the smoothed, averaged sea-surface to within about one-hundred meters.

#### Ellipsoids and their Parameters Available with GeoMag

Ellipsoid	Semi-Major Axis	Semi-Minor Axis	1/f
Clarke 1866	6378206.4	6356583.8	294.979
Clarke 1880	6378249.145	6356514.86955	293.465
Australian National	6378160.0	6356774.719	298.240
International 1909	6378388.0	6356911.94613	297.000
International 1967	6378157.5	6356772.2	298.250
Everest	6377276.3452	6356075.4133	300.802
GRS 80	6378137.0	6356752.31414	298.257
Airy	6377563.396	6356256.91	299.325
Krassovsky 1942	6378245.0	6356863.0188	298.300
South American 1969	6378160.0	6356774.7192	298.250
Bessel 1841	6377397.155	6356078.96284	299.153
WGS 72	6378135.0	6356750.519915	298.260
WGS 84	6378137.0	6356752.31414	298.257

# A Brief Introduction to Geomagnetism

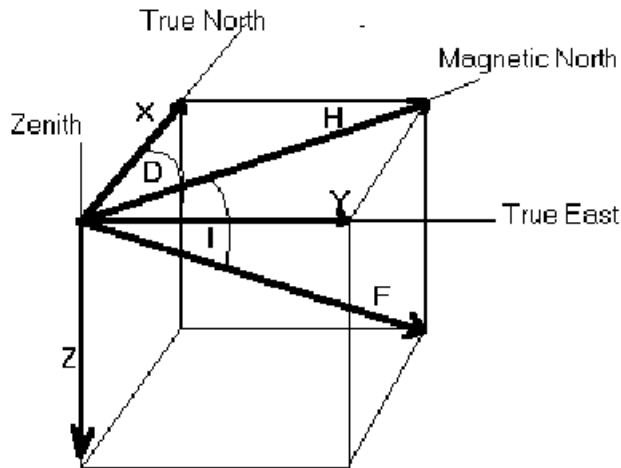
The following is intended to give those users unfamiliar with Earth magnetism an introduction to the various parameters calculated by the GeoMag program and an understanding of the changing nature of the Earth's magnetic field. If you are interested in pursuing the subject further, some references are listed at the end of this section.



The Earth's magnetic field resembles, in general, the field generated by a dipole magnet (i.e., a straight magnet with a north and south pole) located at the center of the Earth. The axis of the dipole is offset from the axis of the Earth's rotation by approximately 11 degrees. This means that the north and south geographic poles and the north and south magnetic poles are not located in the same place. At any point, the magnetic field is characterized by a direction and intensity which can be measured. The geomagnetic poles are located in the area where the lines of force are perpendicular to the Earth's surface and are sometimes referred to as the dip poles (dip = 90 degrees). The physical location of the magnetic pole is actually an area rather than a single point. Because of the changing nature of Earth's magnetic field, the location of the magnetic poles also changes. The current location of the magnetic poles are approximately:

North Pole: 78.5 N and 103.4 W degrees, near Ellef Ringnes Island, Canada

South Pole: 65 S and 139 W degrees, in Commonwealth Bay, Antarctica

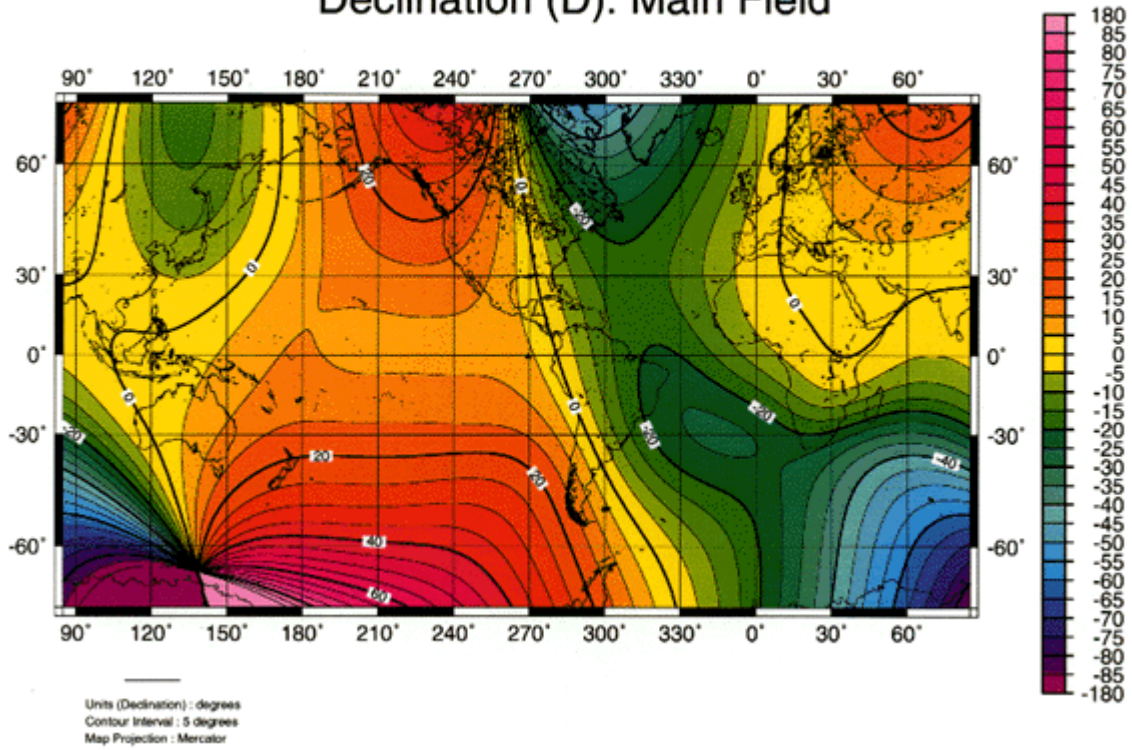


The Earth's magnetic field is described by seven parameters. These are declination (**D**), inclination (**I**), horizontal intensity (**H**), vertical intensity (**Z**), total intensity (**F**) and the north (**X**) and east (**Y**) components of the horizontal intensity. The parameter most frequently requested and most often misunderstood is magnetic declination or variation, *D*. This is the angle made between the trace of the total magnetic field in the horizontal plane, *H*, and true north. *D* is considered positive when the angle measured is east of true north and negative when west. The inclination or dip, *I*, is the angle between the horizontal plane and the total magnetic field. Inclination, also called magnetic dip, is considered positive when downward pointing. These elements, *D*, *I* and *H* give a full vector representation of the magnetic field, *F*. Vertical intensity is the trace of the total intensity in the vertical plane and is considered positive when *I* is positive, that is downward pointing. The east component, *Y*, is considered positive when pointing east and the north component, *X*, is positive when pointing towards geographic north.

At any specific point, the values of the magnetic elements are changing. The changes are not uniform over area or time. Some types of change are distinguishable. Three important, classifiable changes are the diurnal, secular and storm variations. The small regular fluctuations in the magnetic field that occur more or less regularly every 24 hours are called diurnal variations. Secular changes extend over years with generally smooth increases or decreases in the field. Magnetic storms are sudden and potentially large disturbances in the magnetic field which may last hours or days. Of these changes, the least understood is the long-term change that occurs over years in the main magnetic field. The magnetic field can be approximated by mathematical models over short periods of time, but because the secular change is not predictable, the potential for error increases the further in time from the base epoch the calculations are. For this reason, it is important to use the most current accepted models of the magnetic field. These models are produced about every 5 years and are available from NGDC and the World Data Centres.

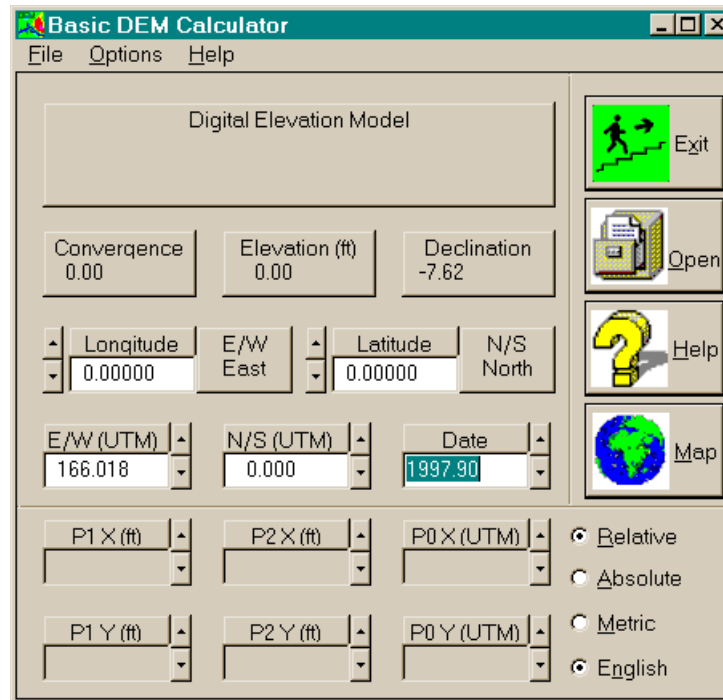
# DOD World Magnetic Chart -- 1995

## Declination (D): Main Field



# Using BasicDEM

Click the mouse above any box to learn its function. The Menu Items include additional controls.



BasicDEM is a very simple program to use. Data items can be directly typed into any of the white fields. For each of the data fields, the up/down arrow on their sides will increment or decrement the value in the field. Whenever a data item changes, the dependant fields will change according to the parameters of the conversion. For example, changing a Longitude will change the X/Y UTM coordinates and zone, based on the new Longitude and the old Latitude. The UTM Convergence and Magnetic Declination will always be updated for changes in position and time.

The valid ranges for each data field is determined by the coverage of the DEM. It is possible to calculate Long/Lat to UTM and magnetic declinations without reading a DEM across the entire Earth. However, once a DEM is loaded, the coordinates will be restricted to values described by the DEM.

## Drawing the Map

Once a DEM has been loaded, pressing the Map button or selecting Map from the Options pull-down menu will create a second window displaying a graphic representation of the region. Moving the mouse over the map window will cause the coordinate information to track the mouse's position and calculate the elevation and magnetic declination. The pixels set in the map correspond to the elevations read from the DEM, in a one to one placement. This means the representation of the DEM is **NOT** a correct geographic projection of the region. For example, for 1-Degree DEM's,

each pixel represents an angular measurement and the map will be increasingly compressed in the vertical dimension at higher latitudes. For 7.5-Degree DEM's, each pixel represents a square in UTM coordinates and while the map is proportionally correct, it is not aligned to true north.

## Making a Selection

Once the map is displayed, a sub-region may be selected for export as a DXF object. Click the mouse at one corner of the sub-region and drag the mouse diagonally to the opposite corner while depressing the left button. This action will draw a selection box around the sub-region (on color maps, it may be difficult to see and switching to a black and white map will help). The dialog boxes P1(x,y) and P2(x,y) will now display the coordinates of the sub-region. By clicking on the up/down arrows, the sub-region can be fine tuned to exact coordinates. If the Relative radio button is selected, then the dialog box for P0 will also be enabled, initially set to the center of the sub-region. The up/down arrows can be used to position P0 anywhere within the sub-region. When the sub-region is exported, the x, y and z location of P0 will be subtracted from the location, effectively making in the origin in the exported region.

## Garmin Track Files

BasicDEM can import and export Garmin "Track" files, as created by their PCX software. A track file, which lies within the DEM's region, is drawing on the map by importing the file. If any portion of the track is outside the region, a warning will be issued. The track file must be generated in either Degrees or Degrees-Decimal Minute format and can be specified in a limited number of datums. One problem with GPS coordinates is their poor or non-existent elevation coordinate. By exporting the track, BasicDEM will calculate the correct elevation for each location along the track. More than one track file can be imported at a time, each subsequent file is added to the existing total track. Tracks can also be exported as a Tape and Compass survey (.SUR).

Follow these links to learn more about the Digital Elevation Models, UTM coordinate system and Geomagnetism.

# Menu Items

BasicDEM has the following pull-down menu choices

## File

Open

Select a DEM file from a dialog box. Opened files will be added to a list of recently used files. Same has the Open button along the right edge of the window.

Close

Close the current DEM, including the Map window if displayed. Opening a second DEM will automatically close the first file.

Save

Save the current DEM under a new name.

Import

Import a Garmin track (.TRK) file and display it if the Map window is open and contains the track.

Export

Export either a Garmin track, AutoDesk Drawing Exchange Format (.DXF) or WinKarst tape and compass survey (.SUR). The track and survey exports are only available if a previous track has been import. The DXF export is only available if a Selection Box has been draw in the Map Window.

(recent file list)

Displays four of the most recently used DEM's. Selecting one will open the file.

Exit

Close all windows and exit BasicDEM. Same has the Exit button along the right edge of the window.

## Options

Map

If a DEM has been opened, draw its elevation representation in an adjacent window.

Save Preferences

Save the display choices made by the radio buttons in the main window and the options pull-down menu in the map window.

## Help

Contents

Start the Help system.

About

Display the how to contact the author and the version number of the application.

About DEM

Display the parameters of the DEM file.

About Projection

Display the parameters of the projection used by the DEM file.

## Register

Bring up a dialog box to allow the user to enter their unique User Code and register the application.

When a map is displayed, it has the following pull-down choices

## File

Export Bitmap

The entire window has displayed, with any imported tracks and contours, will be exported as a bitmap. An exported black and white (gray scale) bitmap will be a true 256 shaded in gray bitmap, slightly different than the displayed window which may contain colors from the windows operating environment.

Close Window

Close the map window, the DEM will remained loaded.

Exit

Close all windows and exit BasicDEM.

### **Options**

Full Scale

Draw the map in full scale, one pixel for every elevation number in the DEM.

Half Scale

Draw the map at half scale, one pixel for every other elevation number in the DEM.

Quarter Scale

Draw the map at quarter scale, one pixel for every four elevation numbers in the DEM.

Color Map

Draw the map with a rainbow coloring scheme indicating elevation, red highest and violet the lowest elevations.

B/W Map

Draw the map with a gray scale coloring scheme indicating elevation, white highest and black the lowest elevations.

Contours

Draw elevation contours on the map. If the metric radio button has been selected, then the contour interval is 100 meters. If the english radio button has been selected, then the contour interval is 200 feet.

Only Contours

Draw only the elevation contours and do not color the regions between the contours.



## About BasicDEM

BasicDEM is a shareware program and is copyrighted.

If you like the program or want to register your copy to unlock its export functions, write

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503-690-5465 evenings

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