

# Conversion of Latitude and Longitude to UTM Coordinates

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*The frame of reference is an important aspect of natural resource modeling. Two principal coordinate systems are encountered in resource analysis: latitude and longitude and universal transverse Mercator or UTM. Operations can also have their own local coordinate system that is defined within a specific lease area; however, these are typically just translated and/or rotated UTM coordinates. This paper reviews some of the basics behind these two coordinate systems and describes a program for conversion.*

## Introduction

Map projections are useful for presentation purposes and to simplify calculations of distances, areas, and volumes. In the earth's coordinate system, which is ellipsoidal, these computations can be cumbersome. The two coordinate systems that are explained here are the ellipsoidal coordinates defining the earth having longitude, latitude, and height axes, and universal transverse Mercator (UTM) coordinates which is a map projection to a cylindrical coordinate system that is discretized into a set of zones, each being an approximate Cartesian system with East and North coordinates.

Of course, coordinate systems require a point of reference or datum. Defining latitude and longitude from an ellipsoidal model of the earth is only possible by defining a point of reference on the ellipsoid. For the World Geodetic System of 1984 (WGS 84) defined principally for the global positioning system (GPS), the reference is a series of monitoring stations positioned on the earth with known coordinates. This provides an ellipsoid that fits the earth, or geoid, with minimal error in height between them. The ellipse is aligned with the poles of earth, therefore defining the equator from which latitude is measured. Lastly, a reference meridian must be chosen from which longitude is measured – the prime meridian located at Greenwich, UK.

This paper only briefly describes the WGS 84 and UTM coordinate systems. For much more detail on the subject, refer to Iliffe and Lott (2008) or Snyder (1987). A program for making the transformation is also provided. Source code for the transform was written by Chuck Gantz (chuck.gantz@globalstar.com) in C++. A simple interface was written for CCG to make the code accessible using typical executable and parameter file operation.

## WGS 84

The WGS 84 reference system is one of many ellipsoidal coordinate systems defined to model the earth. It is used as the reference system for GPS coordinates and is therefore of interest to the oil industry – many surveys are conducted using GPS technology. WGS 84 is a geodetic system: it is referenced to a geodetic datum for describing the relationship between the ellipsoidal model and the actual earth. Ellipsoidal coordinates are three dimensional and consist of latitude, longitude, and ellipsoidal height. Latitude ( $\phi$ ) is an angle measured north or south of the equatorial plane; longitude ( $\lambda$ ) is an angle measured east or west of the prime meridian; ellipsoidal height ( $h$ ) specifies the height above the ellipsoid in a direction normal to its surface, typically measured in meters. These measures are described by Figure 1, where the location  $p$  is defined with coordinates ( $\phi, \lambda, h$ ).

This ellipsoid is only an approximation to the actual earth's shape, referred to as the geoid. The shape is not the topography of the earth, but is an equipotential surface representing mean sea level – the direction normal to any point on the surface is parallel with the direction of gravity, which is the approximate shape sea level would follow without tides or currents. The difference between the geoid and the ellipsoid is the separation,  $N$ , which is positive where the geoid is above the ellipsoid as shown in Figure 2. Coordinates from GPS give the ellipsoidal height and to compute the actual height above the geoid the separation is needed. However, in most surveying applications the separation is not specifically required since relative coordinates are used. For example, the elevation of a well head is surveyed giving latitude, longitude and ellipsoidal height and from this, the well depth and trajectory can be computed.

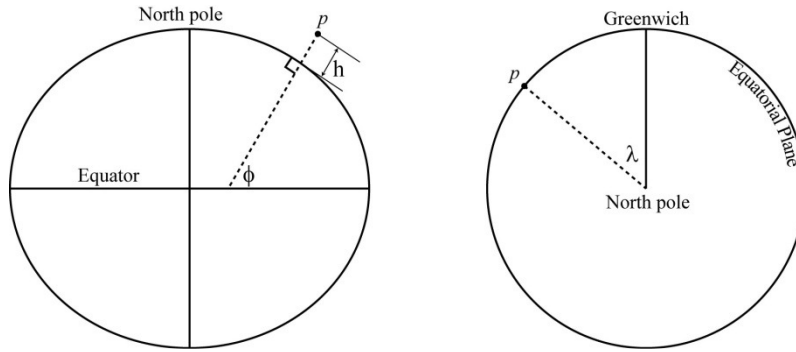


Figure 1: Ellipsoidal coordinates

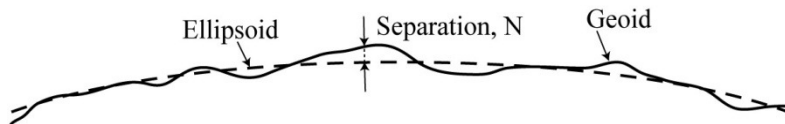


Figure 2: Geoid and ellipsoid separation

For purposes of earth models, ellipsoids are defined by two parameters: the semi-major axis,  $a$ , and flattening ratio,  $f$ . The semi-major axis runs from the center of the ellipsoid to the equator and the flattening parameter defines the ratio of the difference between the semi-major and semi-minor axes,  $b$ :  $f = (a - b) / a$ . From these two parameters, other constants are derived including the semi-minor axis and the eccentricity,  $e^2 = (a^2 - b^2) / a^2 = 2f - f^2$ . The parameters for the WGS 84 ellipsoid:

WGS 84 Parameter	Value
Semi-major axis, $a$	6,378,137 meters
Semi-minor axis, $b$	6,356,752 meters
Flattening, $f$	1 / 298.257223563
Eccentricity, $e$	0.00669438

**UTM Projection**

Transverse Mercator (TM) projections are formed by placing a cylinder in contact with a line of equal longitude also called a meridian (Figure 3) and projecting the earth’s surface onto it. Such projections are suited to regions of the Earth that are not adjacent to the Equator as with the standard Mercator projection which involved a cylinder in contact with the Equator. Because the earth is ellipsoidal, any projection onto a flat surface results in distortion, which is measured by a scale factor – the ratio of the distance on the projection to the distance on the ellipsoid. This ratio changes continuously with distance and is often non-linear. With TM, this distortion is only incurred between the earth and the cylinder. Unravelling the cylinder to a two dimensional map incurs no further distortion.

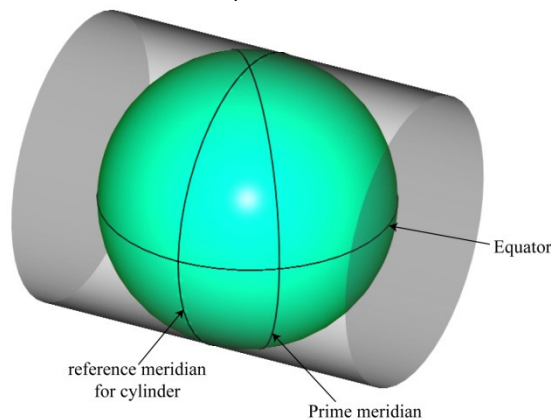


Figure 3: Transverse cylinder

Different types of projection methods are used to preserve different geometrical information such as areas or distances. The TM projection is conformal, that is it preserves the shape of features as well as angles. The scale factor,  $k$ , is defined by  $k = \sec \vartheta$ , where  $\vartheta$  is the angular distance from the reference meridian along which the scale factor is 1, meaning no distortion is realized. For this reason, transverse projections are ideal for regions having large north-south extent, but limited east-west extent. To limit the east-west extent the UTM system comprises 60 zones of longitude, each having a width of  $6^\circ$ . The first zone starts at  $180^\circ$ , with the reference or central meridian at  $177^\circ$ , the second at  $171^\circ$ , third at  $165^\circ$  and so forth. At  $3^\circ$ , the scale factor is approximately 1.0014. A scale shift is applied so that it is on average equal to 1. For UTM zones, a correction of 0.9996 is applied so that the scale factor ranges from 0.9996 to 1.0010. Therefore, distances computed from UTM coordinates within a particular zone will be correct to within 0.1 percent. The UTM is also constrained to a window of latitude from  $80^\circ$  S to  $84^\circ$  N. UTM coordinates do not have to be computed from these 60 zones. Any meridian can be chosen for the projection as the equations are quite general. The following equations taken from Snyder (1987, page 61) convert latitude ( $\phi$ ) / longitude ( $\lambda$ ) to UTM ( $x, y$ ) coordinates:

$$x = k_0 N \left[ A + (1 - T + C)A^3 / 6 + (5 - 18T + T^2 + 72C - 58e^{12})A^5 / 120 \right] \quad (1)$$

$$y = k_0 \left[ M - M_0 + N \tan \phi \left[ A^2 / 2 + (5 - T + 9C + 4C^2)A^4 / 24 + (61 - 58T + T^2 + 600C - 330e^{12})A^6 / 720 \right] \right] \quad (2)$$

$$k = k_0 \left[ 1 + (1 - C)A^2 / 2 + (5 - 4T + 42C + 13C^2 - 28e^{12})A^4 / 24 + (61 - 148T + 16T^2)A^6 / 720 \right] \quad (3)$$

Where

$$k_0 = 0.9996 \quad (4)$$

$$e^{12} = e^2 / (1 - e^2) \quad (5)$$

$$N = a / (1 - e^2 \sin^2 \phi)^{1/2} \quad (6)$$

$$T = \tan^2 \phi \quad (7)$$

$$C = e^{12} \cos^2 \phi \quad (8)$$

$$A = (\lambda - \lambda_0) \cos \phi \quad (9)$$

$$M = a \left[ (1 - e^2 / 4 - 3e^4 / 64 - 5e^6 / 256 - \dots) \phi - (3e^2 / 8 + 3e^4 / 32 + 45e^6 / 1024 + \dots) \sin^2 \phi + (15e^4 / 256 + 45e^6 / 1024 + \dots) \sin^4 \phi - (35e^6 / 3072 + \dots) \sin^6 \phi + \dots \right] \quad (10)$$

Latitude and longitude are expressed in radians,  $M$  is the true distance from the Equator to  $\phi$  along the central meridian, and  $M_0$  is computed using Equation 10 for  $\phi_0$ , which is the latitude crossing the central meridian at the origin of the ( $x, y$ ) coordinates. For these equations,  $k_0$  is specified for a  $6^\circ$  longitude window and will be different if a larger or smaller zone is transformed into transverse Mercator coordinates. It must be noted that windows extending beyond this will result in larger errors and more terms should be added to the above series approximation to compensate.

**Program and Parameters**

A program called *utmconv* that uses the typical GSLIB executable and parameter file usage has been written in C++. Transformation and reference ellipsoid code was written by Chuck Gantz who made the code available on <http://www.gpsy.com/gpsinfo/geotoutm/> (last accessed August 10, 2009). Code to read parameters and generate output was generated by the author. The program converts latitude and longitude to UTM coordinates and vice-versa. Parameters are as follows:

Line	Parameter
1	START OF PARAMETERS
2	data.dat            %file with input data
3	1 2                   % columns for lat,lon or x,y
4	0                    %0 - lat lon to UTM, 1 - UTM to lat lon

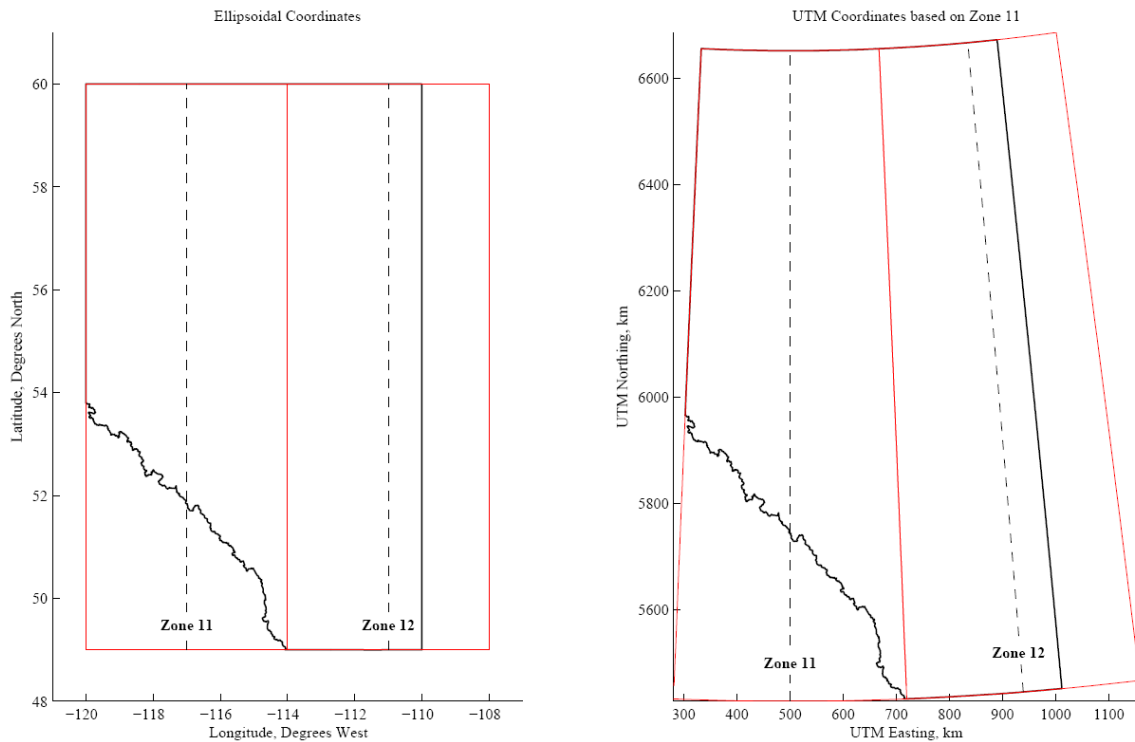
5	12	%UTM Zone: set to -1 for automatic
6	utmdata.out	%file for output

Line 1 is required for the program to find the actual start of the parameters. Comment text must be preceded by a percent sign – any other delimiter will not be recognized. Most other parameters are self explanatory. The output file is generated with two columns containing the transformed coordinates. Note that for larger areas that cross multiple UTM zones, the automatic setting will lead to a shift in the data and it is recommended that a zone be specified. This occurs because each zone is automatically assigned the associated longitude origin leading to different cylinders and an offset in the projection.

Executing the program is done from a command window using the parameter file as an input argument. The parameter file can have any name and if none is given it will be requested. If no parameter file is available, the program will generate one.

- The command from DOS, assuming everything is located on the C drive  
C:\>utmconv utmconv.par
- From Unix(Cygwin)  
\$ ./utmconv utmconv.par

An example using the province of Alberta is given in Figure 4. UTM coordinates were computed based on zone 11. Because of this, there will be more error in distances extending into zone 12 along the eastern portion of Alberta. Such large areas may warrant other transformations to reduce the level of distortion. For example, locating the central meridian with the center of a project’s area will reduce the overall distortion.



**Figure 4:** UTM conversion example using provincial boundary of Alberta

**References**

Iliffe J. and Lott R. (2008) Datums and map projections for remote sensing, GIS and surveying. Whittles Publishing, 208 pages  
 Snyder J.P. (1987) Map projections – a working manual. U.S. Geological Survey Professional Paper 1395, 385 pages