FieldGenius Technical Notes
GPS – Coordinate Systems

Definition of a Datum

A datum is a reference coordinate system which is defined by an origin, orientation and is physically tied to the surface of the earth with control stations. Datums will have an associated reference ellipsoid which closely approximates the shape of the earth's geoid. The ellipsoid (an ellipse of revolution) provides a reference surface for defining three dimensional geodetic or curvilinear coordinates and a foundation for map projections.

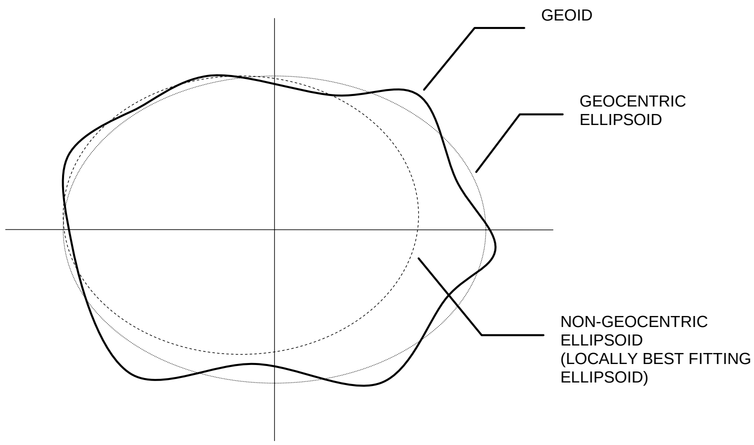

Figure 1. Geocentric and Non-Geocentric Ellipsoids.

Coordinate Types

Coordinates representing positions on the earth can be given in two formats, curvilinear or cartesian. Curvilinear or geodetic coordinates are three dimensional with the components of latitude (φ), longitude (λ) and height above ellipsoid (h). With two of the components being non-linear with angular units, computations are more complex for coordinate geometry problems.

Alternatively, cartesian coordinates are entirely linear and provide for an excellent platform for mathematics. The origin and orientation of the coordinate frame are dependant on the user's application and many well defined systems already exist. Map projections, which are discussed later in this document, will orientate the frame so it is more meaningful with respect to the user's perspective. For global applications the system known as earth centered - earth fixed (ECEF) is preferred. Figure 2 illustrates the relationship between curvilinear coordinates (φ_P, λ_P, h_P) and cartesian ECEF coordinates (X_P, Y_P, Z_P) with respect to a reference ellipsoid.

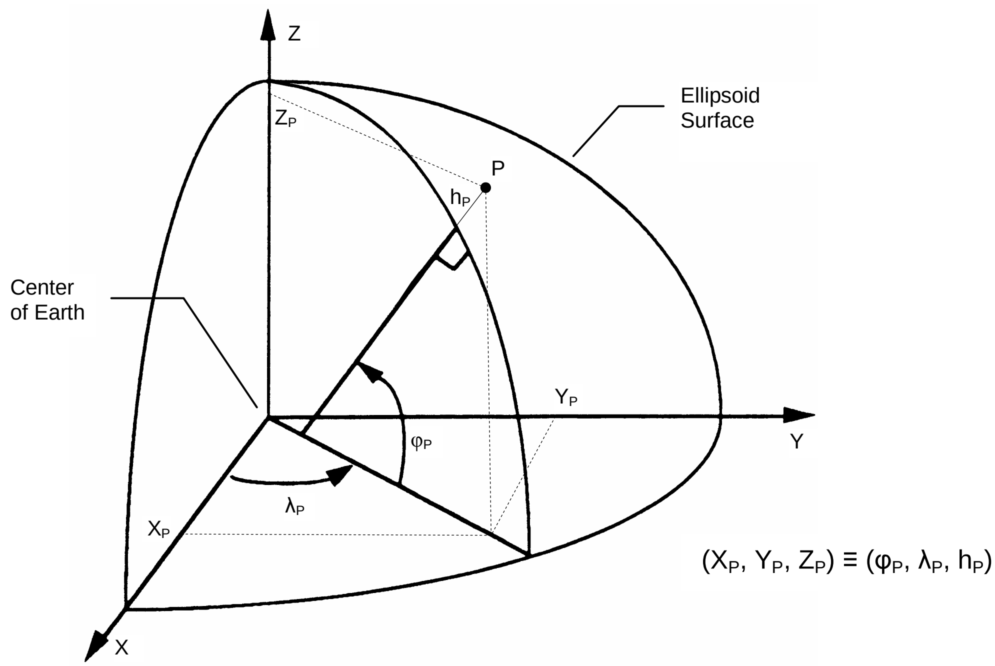

Figure 2. Geodetic Reference System.

The origin of the system is located at the center of earth's mass, the Z axis runs along earth's mean spin axis, the X axis intersects the mean equator plane and the mean meridian plane of Greenwich and the Y axis completes the right handed coordinate system. Coordinate conversions from curvilinear to cartesian can be computed with knowledge of the ellipsoidal parameters, semi-major axis (a) and semi-minor axis (b).

Early Datums

Prior to the advent of satellite positioning, national geodetic organizations would derive their own locally best fitting datums without global considerations and the applied ellipsoid generally would be non-geocentric and rather unique. The establishment of control networks were done with terrestrial observations and commonly resulted in distortions due to inappropriate models. An example of an early datum is the North American Datum of 1927 (NAD27) where the origin was located at Meades Ranch in Kansas and coincided with the surface of the Clarke 1866 ellipsoid.

Modern Datums

The Global Positioning System (GPS) is based on the World Geodetic System of 1984 (WGS84) datum. WGS84 is a geocentric system which provides an excellent mathematical representation in relation to the orbiting satellite constellation. Upon the introduction of satellite navigation, several national geodetic organizations immediately grasped the technology to update their datums with modernized geocentric ellipsoids and to reduce existing distortions. Extending on the previous example of NAD27, the new modernized datum became the North America Datum of 1983 (NAD83). NAD83 is associated with the Geodetic Reference System of 1980 (GRS80) ellipsoid. NAD83 has been through several re-adjustments since its beginning with the densification of more accurate observations.

The International Earth Rotation Service (IERS) maintains a global datum called the International Terrestrial Reference Frame (ITRF). Using GPS observations and very long baseline interferometry (VLBI) observations, the IERS routinely updates station positions worldwide. The precision of the coordinates are at the level where tectonic plate motion is detectable and in addition to coordinates being published, velocities are also published so that positions can be interpolated between published epochs. Most of today's modern national datums are referenced to a specific ITRF epoch. Table 1 lists several regional datums developed before and after the establishment of satellite positioning.

Datum	**Region**	**Reference Ellipsoid**	**GPS Compatible**
WGS84	International	WGS84	Yes
ITRF	International	N/A	Yes
ETRS89	Europe	GRS80	Yes
NAD83	North America	GRS80	Yes
NAD27	North America	Clarke 1866	No
GDA94	Australia	GRS80	Yes
AGD66	Australia	ANS	No
NZGD2000	New Zealand	GRS80	Yes
NZGD49	New Zealand	Hayford	No

Table 1. Examples of Datums and Ellipsoids.

GPS and Datums

Autonomous or absolute GPS position solutions will be referenced to the WGS84 datum due to the broadcast ephemerides (satellite positions) being in the same reference system. Positions derived from differential corrections will be in the datum to which the reference station coordinates were constrained. Forcing the reference station to use a non-geocentric datum will result in significant distortions of computed positions at the rover station. The datum restrictions of GPS do not all together ignore the application of non-geocentric datums such as NAD27. It is possible to use a seven parameter transformation (three translations, three rotations and scale) to convert GPS obtained NAD83 coordinates into NAD27 coordinates but due to localized distortions as discussed previously, there is no single set of parameters to apply to the entire of North America which will produce acceptable residuals. The simplest and most rigorous solution to transforming coordinates is to use a look up table or grid which covers the datum region. These tables are published by national geodetic organizations and consist of horizontally grided values that describe the required translation to convert coordinates from one datum to another. A third order interpolation method is used to determine the horizontal translation for points which fall between the grid points. Figure 3 graphically illustrates how the datum transformation tables are employed, where each arrow denotes the direction and magnitude of a two dimensional shift at each location on the grid.

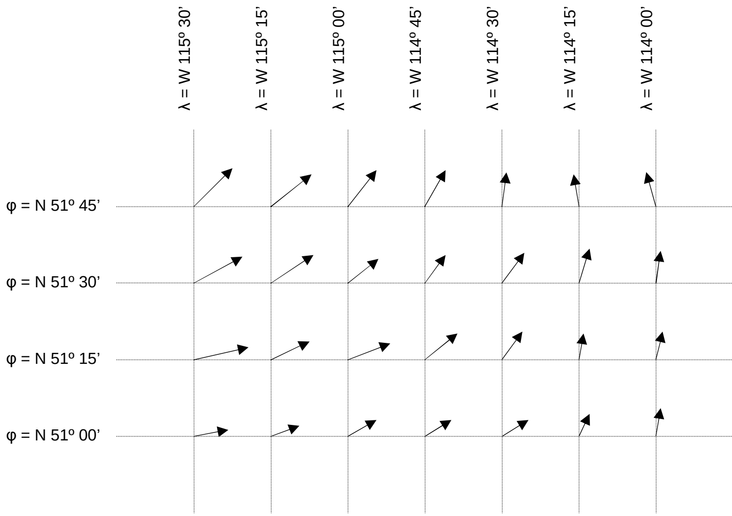

Figure 3. Example of Datum Transformation Table.

Vertical Datums

Previous discussions of datums in this document have primarily focused on what are commonly known as horizontal datums. Vertical datums can refer to either a surface such as a geoid or the surface of a reference ellipsoid. Orthometric heights (H) are referenced to the geoid which is a surface of equipotential gravity and considered an idealized surface of the oceans. Orthometric datums are established on the ocean coast with respect to the mean sea level and transferred inland by means of spirit leveling.

Ellipsoidal heights (h) have become more established and measurable with the use of satellite positioning. The ellipsoid surface represents a simple mathematical model of the geoid surface and therefore is the only reference surface upon which GPS heights can be directly measured. The relationship between the geoid and ellipsoid is shown in Figure 4 and the algebraic difference between the two is known as the geoidal undulation (N). Knowledge of the geoidal undulation of a particular position, allows the orthometric height to be derived from GPS measured ellipsoidal heights.

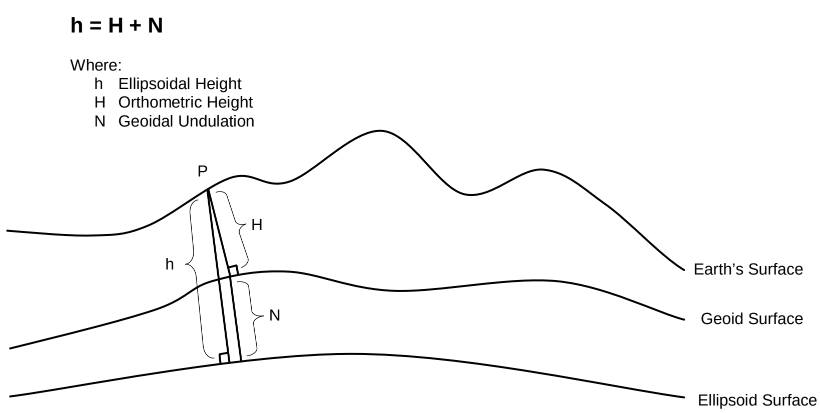

Figure 4. Ellipsoid Height and Geoid Height Relationship.

Representing geoidal undulations for a relatively large area with a mathematical model becomes difficult due to high frequency spherical harmonics. To overcome the problem of irregular geoidal undulations, an identical approach to the horizontal datum transformations can be done with the use of two dimensional data grids. Each node on the grid has a geoidal undulation (N) value and intermediate locations are interpolated.

Map Projections

Maps and survey plans are customarily presented on a two dimensional medium such as a sheet of paper or a computer display. This two dimensional plane represents the approximate local level horizontal X axis and Y axis and the vertical axis of Z, representing height, being normal to the plane and positive towards the viewer. The earth is a three dimensional curved surface and provides difficult approach to compute and conceptualize distances and directions with curvilinear or ECEF coordinates. A map projection is the mathematical process of transferring the curved surface of the earth (or any spherical object) onto a flat surface as illustrated in Figure 5 with the process being reversible.

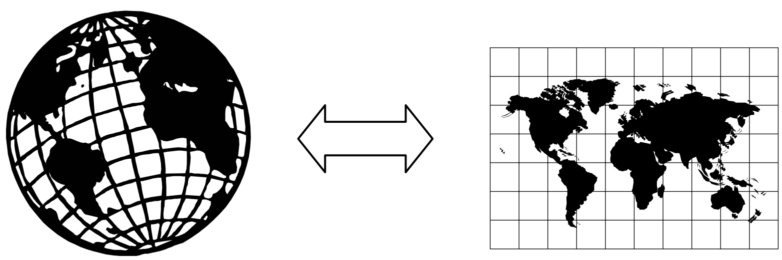

Figure 5. The Concept of Map Projections.

Various techniques have been developed for specific applications to preserve equal areas, preserve shape, preserve directions and minimize scale distortions. Examples of two common projection methods using simple geometric shapes such as cylinders and cones are shown in Figure 6.

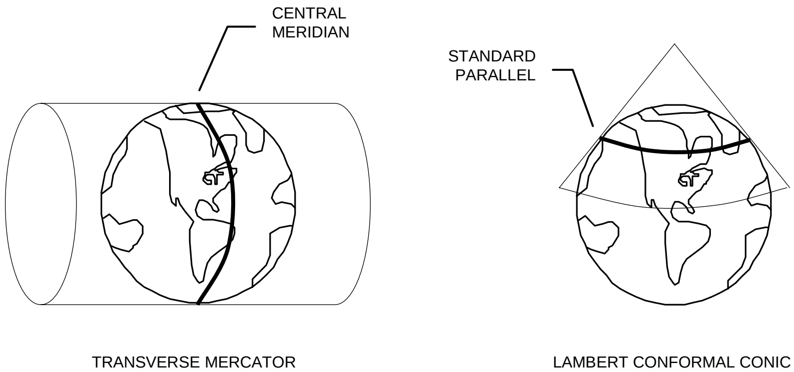

Figure 6. Examples of Transverse Mercator and Lambert Map Projections.

When these geometric shapes such as the cylinder or cone are unwrapped from the ellipsoid, they will describe the projected objects on a two dimensional plane surface. The bold line for each of the projections in Figure 6 represents the intersection between the geometric shape and the ellipsoidal surface. Positions deviating from the central meridian or standard parallel will increase the scale factor distortion as the separation between the ellipsoidal surface and geometric shape increases.

National geodetic authorities will carefully select map projections to define grid systems which encompass their area with minimal distortions. Examples of various grid systems used world wide are shown in Table 2. The Universal Transverse Mercator (UTM) grid system was developed by the United States Army for large scale military maps of the world and has been adopted by many other organizations. UTM zones extend in a north to south direction from pole to pole and are evenly spaced in a west to east direction with meridian separations of six degrees. The State Plane Coordinate System (SPCS) used by the United States takes advantage of both the Transverse Mercator projection and Lambert Conic Conformal projection for states which have a longer north to south extent and a longer west to east extent respectively. Each state may have multiple map projection zones defining individual central meridians or parallel to minimize scale distortions. The United States has two different SPCS's with each being related to the NAD27 datum and NAD83 datum respectively. It must be noted that the difference between SPCS27 and SPCS83 extends beyond their related datums and can include differences in map projection parameters. Canada makes extensive use of the UTM grid system and has further densified it with a system called Modified Transverse Mercator (MTM) which consists of three degree zone spacing compared to the six degree spacing of UTM. The MTM grid system is also frequently called Three Degree Transverse Mercator (3TM).

Grid System	**Region**	**Number of Zones**	**Projection Type**	**Reference Ellipsoid**
Universal Transverse Mercator (UTM)	International	60	Transverse Mercator	Varies
State Plane Coordinate System 1927 (SPCS27)	United States	133	Transverse Mercator, Lambert Conformal Conic, Oblique Mercator	Clarke 1866
State Plane Coordinate System 1983 (SPCS83)	United States	133	Transverse Mercator, Lambert Conformal Conic, Oblique Mercator	GRS80
Modified Transverse Mercator (MTM)	Canada	32	Transverse Mercator	GRS80
New Zealand Map Grid (NZMG)	New Zealand	1	Transverse Mercator	GRS80
National Grid	Great Britain	1	Transverse Mercator	GRS80

Table 2. Examples of Grid Systems.

Zone	**West Bdry**	**East Bdry**	**Zone**	**West Bdry**	**East Bdry**	**Zone**	**West Bdry**	**East Bdry**
1	W 180º	W 174º	21	W 60º	W 54º	41	E 60º	E 66º
2	W 174º	W 168º	22	W 54º	W 48º	42	E 66º	E 72º
3	W 168º	W 162º	23	W 48º	W 42º	43	E 72º	E 78º
4	W 162º	W 156º	24	W 42º	W 36º	44	E 78º	E 84º
5	W 156º	W 150º	25	W 36º	W 30º	45	E 84º	E 90º
6	W 150º	W 144º	26	W 30º	W 24º	46	E 90º	E 96º
7	W 144º	W 138º	27	W 24º	W 18º	47	E 96º	E 102º
8	W 138º	W 132º	28	W 18º	W 12º	48	E 102º	E 108º
9	W 132º	W 126º	29	W 12º	W 6º	49	E 108º	E 114º
10	W 126º	W 120º	30	W 6º	W 0º	50	E 114º	E 120º
11	W 120º	W 114º	31	E 0º	E 6º	51	E 120º	E 126º
12	W 114º	W 108º	32	E 6º	E 12º	52	E 126º	E 132º
13	W 108º	W 102º	33	E 12º	E 18º	53	E 132º	E 138º
14	W 102º	W 96º	34	E 18º	E 24º	54	E 138º	E 144º
15	W 96º	W 90º	35	E 24º	E 30º	55	E 144º	E 150º
16	W 90º	W 84º	36	E 30º	E 36º	56	E 150º	E 156º
17	W 84º	W 78º	37	E 36º	E 42º	57	E 156º	E 162º
18	W 78º	W 72º	38	E 42º	E 48º	58	E 162º	E 168º
19	W 72º	W 66º	39	E 48º	E 54º	59	E 168º	E 174º
20	W 66º	W 60º	40	E 54º	E 60º	60	E 174º	E 180º

Table 3. Universal Transverse Mercator (UTM) Zones.

FieldGenius Datum Parameters

An understanding of the previous sections on datums and map projections will provide the reader with an ability to make correct datum selections within FieldGenius.

Depending on the chosen horizontal or vertical datum, a horizontal transformation grid file or geoid grid file may be required for coordinate computations. Table 4 lists selectable datums for North America and related grid files if required. FieldGenius is supplied with an accompanying utility called the Datum Grid Editor for selecting the required transformations and producing data grid files which are manageable in size for data collectors.

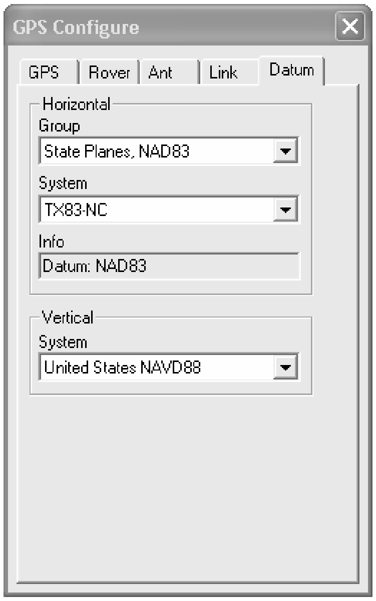

Figure 10. GPS Configure – Datum.

FieldGenius provides for a variety of international datums and map projection. Setup can be broken into two sections of horizontal and vertical components. Discussion will primarily focus on the coordinate systems of Canada and the United States.

1. Horizontal
   The group option provides for the selection of regional coordinate systems. The selection of a group then drives the options available for the system which can be considered zones within a group. The combinations of available groups and systems for both the United States and Canada are shown in Table 4. If differential positioning is to be done with respect to the datums of NAD83, NAD83(HARN), WGS84 or ITRF, the recommended procedure is to use one of the listed groups based on NAD83 and configure the coordinates at the reference station with respect to the desired datum. The selection of a NAD83 datum will not apply a horizontal transformation. Alternatively if positioning is to be done with respect to the NAD27 datum, the reference station coordinates must be configured with a NAD83 based coordinate and the appropriate NAD27 horizontal group chosen for the rover stations so that the necessary transformation can take place.

2. Vertical
   Ellipsoidal heights with respect to the datum ellipsoid are always available. If a particular horizontal group has additional associated vertical system, they will be

available and typically represent an orthometric height datum. As seen in Table 5, grid data files are not required for ellipsoidal heights but are necessary for orthometric heights derived from GPS observations.

Region	**Group**	**System**	**Required Grid Data**	**Notes**
North America	UTM Zones, NAD27	Zones 1-23 and 58-60	NADCON or NTv2	
	UTM Zones, NAD83	Zones 1-22 and 58-60	None	
	UTM Zones, HARN	Zones 10-18	NADCON-HPGN	United States only
United States	State Planes, NAD27	All 133 zones	NADCON	
	State Planes, NAD83	All 133 zones	None	
	State Planes, HARN	108 zones	NADCON-HPGN	
Canada	Canadian Systems	MTM-NAD27, zones 1-17	NTv2	
		MTM-NAD83, zones 1-17	None	
		Canada-LLC	None	
		British Columbia Polyconic	None	
		New Brunswick – NAD83	None	
		Nova Scotia – NAD83, zones 4 and 5	None	
		Prince Edward Island – NAD83	None	

Table 4. FieldGenius Supported Horizontal Datums for North America.

Region	**System**	**Grid Data**	**Note**
United States	Ellipsoidal	None	GRS80 ellipsoid
	NGVD29	GEOID99 and VERTCON	
	NAVD88	GEOID99	
Canada	Ellipsoidal	None	GRS80 ellipsoid
	CGVD28	HTv2.0	

Table 5. FieldGenius Supported Vertical Datums for North America.