

SEDRIS Geospatial Reference Model

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1. Introduction

1.1 Purpose

This document serves to fully define the specification of coordinates, datums, projections, and a variety of geo- and non-geo-referenced spatial reference systems as used in SEDRIS. In particular, the Location_3D object of the SEDRIS Data Model is dependent upon these definitions. Proper understanding of coordinate systems is critical to ensuring that data transmitted in SEDRIS is correctly interpreted and used by both the transmitter and receiver of SEDRIS data. The “where” in a transmittal is just as important as the “what”; this document addresses how SEDRIS supports the specification of “where”.

1.2 References

The SEDRIS Geospatial Reference Model, and this document, makes liberal use of existing standards in the commercial, military, and government civilian sectors. The following documents were used heavily in the preparation of this specification, and should serve as the basis for possible future extensions to the SEDRIS Geospatial Reference Model.

- Bhavnani, K.H. and Vancour, R.P.; Coordinate Systems for Space and Geophysical Applications; USAF Phillips Laboratory Scientific Report No. 9 (PL-TR-91-2296); Hanscom Air Force Base, Massachusetts; 11 December 1991
- Buehler, Kurt A. (Ed.); The Open Geodata Interoperability Specification – Draft Base Document; OGIS Project Document 94-025R2; Champaign, Illinois; 22 December 1994
- DMA Technical Manual 8358.1
- DMA Technical Manual 8358.2
- DMA Technical Report 80-003; Geodesy for the Layman; Defense Mapping Agency, Edition 5, December 1983
- DMA Technical Report 8350.2; Department of Defense World Geodetic System 1984 – Its Relationships with Local Geodetic Systems; Defense Mapping Agency, 2nd Edition, 4 June 1992
- Federal Geospatial Data Committee; Draft Geospatial Positioning Accuracy Standards; Reston, Virginia; 2 January, 1997
- Ritter, Niles and Ruth, Mike; GeoTIFF Format Specification – GeoTIFF Revision 1.0; Version 1.8.1; 31 October, 1995

- Snyder, John P.; Map Projections – A Working Manual (USGS Professional Paper 1395); US Government Printing Office, Washington, DC; 1987

2. General Notion of a Geospatial Reference Model

2.1 Interoperability of Geospatial Information

Geospatial information processing requires a robust capability to describe location, or position. Generally, this is accomplished through the use of coordinate locations. Interoperability of geospatial data is facilitated through the adoption of a common and well-known geospatial reference model (GRM) that allows coordinate locations to be known succinctly, and transformed accurately into multiple definitions of geo- and non-geo-referenced space. Interoperability of geospatial information requires that:

- Coordinate systems can be defined such that coordinates describe location uniquely.
- A mechanism exists for data to be transferred to alternative coordinate systems, should this be required.

A GRM serves to define coordinate systems, and forward and reverse transformations of geospatial measurements taken in relation to different coordinate systems.

2.2 Spatial Addressing and Geospatial Systems

Spatial addresses can consist of a wide variety of measurements and data types. Classical navigation employed a method of describing georeferenced location through a coordinate tuple based on the Earth-centered angular measurements of longitude and latitude. Modern geographic information processing generally uses a tuple of easting and northing, possibly with an elevation measurement. In SEDRIS, all location specifications are triplets, including an elevation (or altitude) measurement (which may be explicitly marked as “unknown”).

But other types of spatial addressing are possible. For example, a postal zip code can have a spatial address, which can be georeferenced if a relationship is known between the postal code address and the geographic properties related to the postal district location. A telephone number can be georeferenced, for example, if a relationship is known between the phone number and the geographic location of the end-user’s telephone, or of the geographic coordinates of switches and routes used in delivery of the telephone signal. A heuristic description such as a set of instructions from one position to another (“go south on Route 722 from the intersection of Route 7 for about 1.7 miles until you see a stone house on the right”) also can represent a spatial address, provided that some starting point of the description (“intersection of Rt. 7 and route 722”) can be georeferenced to a known coordinate in a GRM. More formally, a surveyor and theodolite are used to make precise measurements of angle, distance, and plumb lines from well known, highly accurate benchmarks and the geoid, in order to locate and assign coordinate positions to locate boundaries, monuments, or other features.

SEDRIS uses an analogous concept when “planting” a 3D Model one or more times into an Earth-referenced transmittal – specific transformation information is required to orient and position the 3D Model, and given that transformation information all locations in the 3D Model can be exactly converted into geo-referenced locations.

The above examples describe locations which may be georeferenced, or not. That is, the locations being described may be defined in terms of an Earth-referenced coordinate system, or they may exist as non-georeferenced descriptions relative to non-Earth origins (e.g. in Local Space Rectangular). The GRM must be capable of registering non-georeferenced data, provided that spatial relationships are known from the data to geodetic or projected coordinate systems which conform to the requirements of the GRM.

Geographers commonly express positions as spatial addresses in “easting” and “northing” tuplet values and their (implied) units of measurement. The tuplet may be a “doublet,” which cites only horizontal planimetric position, or a triplet, in which the third coordinate is an elevation (Z) value. Easting and northing are coordinate terms used to describe a features’ position, as a distance from a point of projection origin. The projection origin, scale, orientation and other properties are unique to the instantiation of the particular coordinate transformation (and its parameters) in which the coordinates are defined. An example of the use of a coordinate triplet would be “the building center is located at easting, northing coordinate position *Xxxxxxx*, *Yyyyyyy* with an elevation of *ZZZ* meters above sea level.” The precision of the measurement of this position must also be known to conform to mapping requirements.

Coordinate positions based on local references may be extended to global or international use only if the positions can be related precisely to a geodetic reference model. Geographic information expressed in any of the ways above is interoperable only if the values of easting and northing (and elevation) can be related with known precision to the algorithm of cartographic transformation, and thus to an underlying geospatial reference model. SEDRIS specifies not only how coordinate positions may be expressed, but also supplies a standard set of transformation algorithms for interconverting coordinate positions among a well-defined set of standard geospatial reference frames.

2.3 Spatial Addressing and Other Reference Systems

All of the preceding discussion takes not only an Earth-centric view in describing spatial locations, but also an Earth-*surface* view. That is, spatial locations are not only *geospatial*, but also assume a fixed reference frame that rotates with the Earth; they are *geographic* or *geodetic*. These assumptions are common given the wealth of immediately-accessible environmental descriptions readily available and in common usage (e.g. maps). However, there exists a significant variety of spatial data which is described in Earth-centered (and non-Earth-centered) reference frames which are unconcerned with the exact location of the Earth’s surface. These data include astronomical, orbital, geomagnetic, and local observations whose reference frame may be fixed with respect to observer, solar, celestial, or other positional standards (rather than, e.g., a prime meridian on the Earth’s surface).

This family of reference frames can be divided into the following categories; those twelve appearing in underlined print (and followed by their code in **bold**) are currently supported in SEDRIS:

- Non-Cartesian
 - Geodetic (**GDC**)
- Cartesian (right-handed)
- Earth Center (or near Earth Center) Origin

- Earth Fixed (Rotating)
 - Geocentric (GCC)
 - Others (Centered Dipole, Magnetic, Dipole Meridian)
- Inertial
 - Geocentric Equatorial Inertial (GEI)
 - Geocentric Solar Ecliptic (GSE)
 - Geocentric Solar Magnetospheric (GSM)
 - Solar Magnetic (SM)
 - Others (ATS-1, Geocentric Solar Equatorial, PQW, Solar Wind Magnetospheric, Solar Wind)
- Earth Surface Origin
 - Global Coordinate System (GCS)
 - Others (Topocentric Equator, Topocentric Horizon)
 - Projected Coordinate Systems
 - Polar Stereographic PCS (PS)
 - Lambert Conformal Conic PCS (LCC)
 - Transverse Mercator PCS (TM)
 - Universal Transverse Mercator PCS (UTM)
- Center of Gravity Origin – used for orbiting bodies (Body Axis, Look Angle, Local Vertical/Local Horizontal, Local Orbital)
- Arbitrary (“point-of-interest”) Origin
 - Local Space Rectangular (LST)
 - Others (Magnetic Field, VDH, Sensor, Plasma)

While not all of these reference frames are immediately required to support SEDRIS transmittals, they need to be accommodated by the SEDRIS Geospatial Reference Model.

2.4 GRM Requirements

The GRM should have the following characteristics:

- The GRM should allow a definition of coordinate systems such that coordinates are unambiguous and the accuracy of the coordinates can be described succinctly.
- The GRM should allow transformation of coordinates from one system to another.
- The GRM should employ a hierarchy of data abstractions, ranging from the most primitive elements (such as the measurements of the shape of the planet) to derived elements (such as a three-dimensional or two-dimensional coordinate system imposed on a localized measurement of the planetary shape).
- The GRM should be capable of explicit, complete, succinct, and international (multilingual) coding of fields, properties, and variables. (This may imply a numerical encoding system, or, alternatively, a defined character string and associated aliases for multi-language support, or other mechanism to prevent ambiguity.)

- The GRM should be sufficiently extensible to encompass any well known mapping reference system in common (well known, documented) usage.
- The GRM should allow extension into private, or secret, or non-standard domains within the theoretical constructs of the GRM.
- The GRM should be capable of describing transformations between and among coordinate systems with definable precision.
- The GRM should be accompanied by parameters defining coordinate system components and transformations.

3. Geodetic Coordinate System (GDC)

GeoDetic Coordinate (GDC) systems are based on approximations of the shape of the Earth. The shape of the Earth was defined by classical navigators as a spherical body, but more accurate geodetic coordinates require that the Earth be modeled instead as an oblate spheroid, or ellipsoid-of-rotation. The term “ellipsoid” is preferred, for the purposes of this document, over the approximately equivalent term “spheroid” of former usage.

Many GDC’s include localized gravity measurements, and continue to have relevance to geodetic coordinate measurements taken locally. Modern GDC’s have been derived using satellite data which provide geodesists with measurements to define Earth-fitting ellipsoids which are global in significance and accuracy. World Geodetic System 1984 (WGS-84) defines the current US DoD standard ellipsoid (see DMA, TR 8350.2).

Geodetic Coordinate Systems are those that relate Earth-centered angular latitude and longitude (and optionally height) to an actual point near or on the Earth’s surface.

Latitude¹ is defined to be the angle subtended with the ellipsoid's equatorial plane by a perpendicular through the surface of the ellipsoid from a point. Latitude is positive if north of the equator, negative if south.

Longitude is defined to be the angle measured about the minor (polar) axis of the ellipsoid from a prime meridian to the meridian through a point, positive if east of the prime meridian and negative if west. Unlike latitude, which has a natural origin at the equator, there is no feature on the ellipsoid which forms a natural origin for the measurement of longitude. The zero longitude can be any defined meridian. Historically, nations have used the meridian through their national astronomical observatories, giving rise to several prime meridians. By international convention, the meridian through Greenwich, England is the standard prime meridian. Longitude is only unambiguous if the longitude of its prime meridian relative to Greenwich is given. Prime meridians other than Greenwich are sometimes used for Earth mapping. In a hierarchy of geodetic information, the citation of prime meridian may be considered either as a property of the datum or as a separate element in the definition of the GDC.

There are two major components of a GDC: the ellipsoid, and the datum. There are many ellipsoids in use to model the Earth and any one particular ellipsoid can have its location and orientation relative to the Earth defined in different ways. The location and orientation of the

¹ Note that we are using the **Geodetic Latitude**, which is not to be confused with the **Astronomic Latitude**. The Astronomic Latitude is based on the perpendicular to the geoid, rather than the ellipsoid.

ellipsoid with respect to the Earth is defined by the datum. World Geodetic System 1984 (WGS-84) defines the current US DoD standard datum (see DMA, TR 8350.2).

Geodetic coordinates describe locations of features on the surface of the Earth model (ellipsoid) and are commonly expressed in longitude/latitude tuples (optionally including height). A longitude/latitude tuple may only describe a position on the Earth model uniquely if the position and orientation of the ellipsoid are defined with respect to the Earth. It follows that if the ellipsoid model is changed, or if the location or orientation of the ellipsoid is changed with respect to the Earth, then the latitude and longitude coordinates of a position will also be changed. A point located on a specific longitude and latitude in a datum "N" which is a localization of ellipsoid "O" will have a different value for longitude/latitude if mapped on datum "P" even if datum "P" also uses ellipsoid "O" as its Earth reference model. Hence the term "datum shift" to describe the relative displacement of the (same) geodetic point between the two different datum-based GDC.

An interoperable GRM standard must include a list of frequently used geodetic coordinate systems and their component ellipsoids, geodetic datums and prime meridians. The interoperability of geodetic data requires that the GRM be capable of accommodating transformations between and among GDC's with known accuracy. GDC's use either two-dimensional or three-dimensional geodetic coordinates to express position. These coordinates are only unique if qualified by the definition of the geodetic coordinate system to which they belong.

3.1 The Geoid

The geoid is a physical surface of equi-gravitational potential corresponding to mean sea-level. It extends into landforms through an approximation of mean sea level in inland areas. The geoid can be observed by measurement of mean sea level, and as such, it represents a fundamental surface from which elevations can be measured directly. Although it is difficult to observe mean sea level in the central areas of land masses, the fact exists that the geoid is physically measurable, and therefore most common mapping measurements can be related easily to the geoid. World Geodetic System 1984 (WGS-84) defines the current US DoD standard geoid (see DMA, TR 8350.2), and is the only geoid used in SEDRIS.

3.2 The Ellipsoid

Because it is related to the Earth's gravity field, the geoid is a very complex surface. At a detailed level its description is not well known. The geoid is therefore not used in some aspects of mapping in which a modeled surface is required. It has been found that an oblate spheroid can be modeled as an ellipse rotated about its minor axis. The ellipsoid is a good approximation to the geoid and therefore a good model of the Earth for many mapping applications. Many approximations exist of the ellipsoid: several hundred ellipsoids have been defined for scientific purposes and about 30 are in use today for mapping.

To define an ellipsoid, the shape and size must be described. There are many ellipsoid parameters. Only two are needed to describe both shape and size, but at least one of these must be linear, to define a dimension. It is common in classical geodesy to define the ellipsoid based on:

- the semi-major axis: a
- the semi-minor axis: b

There are other parameters of the ellipsoid which can be derived from the axes, such as inverse flattening ($1/f = a/(a-b)$). In general, the semi-major axis and inverse flattening are meaningful and sufficient to define the ellipsoid, and the remaining parameters are derivative and interconvertible (see Figure 3-1). In addition, some geodesists use a triaxial definition of ellipsoid, which accounts for two equatorial perpendicular axes and one polar axis. The GRM, as defined in this document, only requires a biaxial ellipsoid (consistent with the WGS-84 specification).

Appendix A lists the 21 standard reference ellipsoids used in SEDRIS together with their unique code, name, semi-major axis diameter, and their inverse flattening.

Historical models exist which use a spherical approximation; such models are not recommended for modern applications, but if needed the size of a model sphere may be defined by specifying identical values for the semi-major and semi-minor axes; the inverse flattening cannot be used as it becomes infinite for perfect spheres.

Other ellipsoid parameters needed for mapping applications, for example the square of the eccentricity, can easily be calculated by an application from the two defining parameters. Numeric codes for ellipsoids regularly used for Earth-mapping are tabulated in standard reference lists.

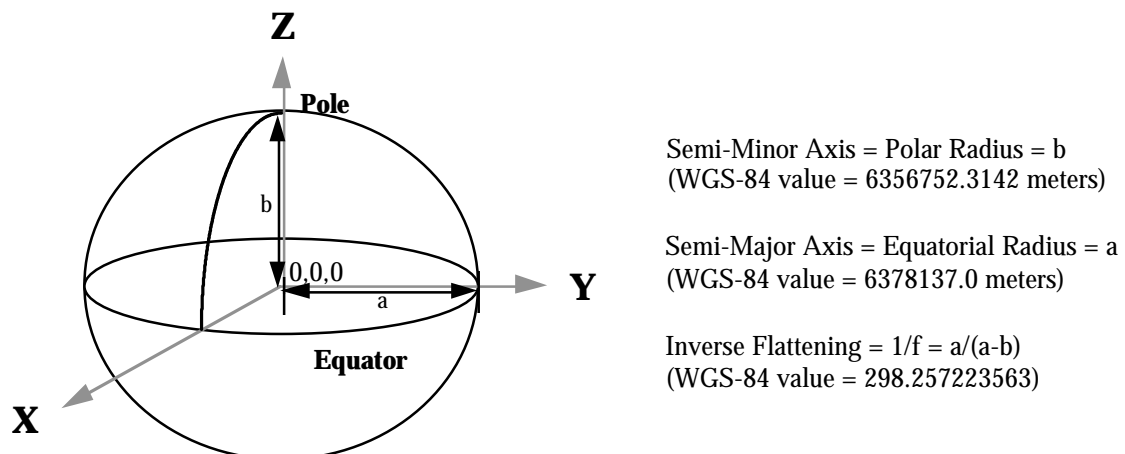


Figure 3-1: The relationship between the ellipsoid properties

3.3 The Horizontal Datum

The horizontal, or geodetic, datum defines the relationship between the ellipsoid adopted as the model of the Earth's shape, and the Earth itself. As such, it is a localization of the ellipsoid, which is derived from the measurement of Earth properties at a fundamental point which has a

well known position with respect to the ellipsoid measured. For the intentions of most mapping applications, it is sufficient to refer to the datum using a label. Labels in common use include “World Geodetic System, 1984,” “North American Datum of 1927,” and “Nouvelle Triangulation Francaise.” Public tables available provide several hundreds of geodetic datums in common mapping usage. World Geodetic System 1984 (WGS-84) defines the current US DoD standard datum (see DMA, TR 8350.2).

It is beyond the scope of this document to attempt a complete definition of the datum and the observations and properties used to define it, and the GRM requires only the label of the datum to be defined uniquely. The definition must allow explicit citation of the prime meridian upon which a datum is based, or, alternatively, the definition of the relationship between a prime meridian and the Greenwich meridian (0.0 degrees longitude).

Quantification of the datum is achieved through application of transformation algorithms to and from other datums. Commonly, the WGS-84 datum is used as a “master” since it results from the compilation of satellite gravity measurements and is generally considered to be the most accurate datum in common usage. Some datums require only three parameters to effect a transformation, while others may require many more variables - in some cases hundreds of parameters may be necessary. Commonly used transformations, such as the Molodensky Method (DMA, TM 8358.1) and Helmert Transformation are described in geodetic technical literature and beyond the scope of this document.

Appendix B lists the 181 standard horizontal datums used in SEDRIS together with their unique code, name, reference ellipsoid, Molodensky transformation parameters to the WGS-84 datum, and applicable extents. The Prime Meridian for all listed datums is Greenwich.

3.4 The Vertical Datum

Longitude and latitude values are part of a two-dimensional coordinate system. The GRM needs to supplement these horizontal locations with the third, vertical dimension. In common mapping usage, vertical coordinates belong to a one-dimensional vertical coordinate system (VCS).

The geoid is a fundamental reference surface for measurement of height. The geoid, as observed from mean sea level and other gravitational field measurements, is a “real surface” which forms the basis of topographical mapping applications. Many common mapping measurements of elevation in practical usage are related to the geoid, expressed as “elevation from mean sea level” or similar basis. Elevations are typically recorded in units of feet or meters.

Geodesists recognize height relative to an ellipsoidal surface as “ellipsoidal height.” Heights relative to the gravitational surface closely approximating to sea level (the geoid), and measured with respect to the gravity of the Earth, are recognized as “orthometric height.” The separation between ellipsoid and geoid surfaces in the vertical plane defines “geoid height” or “geoidal separation”.

Height coordinate systems are either ellipsoidal (in which the two-dimensional geodetic coordinate system becomes three-dimensional) or orthometric (relative to the geoid). Latitude, longitude, and orthometric height is the usual way of describing a location on or near the

surface of the Earth. However, the two-dimensional geodetic coordinate system and the one-dimensional vertical coordinate system are independent coordinate systems.

Often a datum for a georeferenced VCS is directly related to the surface of the Earth. However, it can sometimes be related to the surface of the ellipsoid instead. In this special case, ellipsoidal height together with longitude and latitude form a *different* three-dimensional coordinate system.

Many geospatial information products represent elevation as a value above mean sea level (MSL; as in all modern NIMA digital terrain data products) or height above low water (as in some hydrographical products) and as such take the geoid into account as the reference elevation surface. In marked distinction to most DoD digital terrain data products, the Global Positioning System (GPS) reports elevations with respect to the WGS-84 *ellipsoid*, and therefore the reported ellipsoidal height must be corrected to orthometric height by applying the local geoidal separation (see DMA TR 8350.2) before being compared to digital terrain data.

3.5 Summary

In SEDRIS, a Geodetic Coordinate System (GDC) is defined by the following parameters:

- **Horizontal Datum** (selected from datum enumeration in Appendix B. The standard reference ellipsoid associated with the specified Horizontal Datum as listed in Appendix B will be used as required.)
- **Horizontal Units** (fixed as degrees)
- **Vertical Datum** (selected from the ellipsoid enumeration in Appendix A, extended with the code **GD** if using the WGS-84 Geoid (i.e. MSL))
- **Vertical Units** (feet | meters)

In SEDRIS, a GDC coordinate is defined by:

- **Longitude** (decimal degrees)
- **Latitude** (decimal degrees)
- **z – Elevation/Height** (in specified units)

4. Cartesian Earth Center Origin Coordinate Systems

4.1 Earth Fixed (Rotating)

4.1.1 Geocentric (GCC)

The GeoCentric Coordinate (GCC) System is based on a Cartesian coordinate system with three orthogonal axes with an origin at the center of the Earth. The x axis is defined as pointing to the Prime (Greenwich) Meridian in the Equatorial plane. The z axis is defined as the semi-minor (polar) axis (coincident with the Earth's rotational axis) and pointing North. The y axis is defined as orthogonal to the other two (and in the Equatorial plane) such as to form a right-handed orthogonal set (see Figure 4-1). Locations are defined as $\{x, y, z\}$ triplets in meters from the origin (Earth center).

GCC is thus fixed to the Earth's surface, and is therefore independent of Earth's rotation. This provides a convenient system for defining the positions of objects; as such, it is used in Distributed Interactive Simulation (DIS) to define the position of all simulated entities. It also provides a convenient system for relating the coordinate system of a rotating Earth to a variety of Earth-centered Inertial Coordinate Systems.

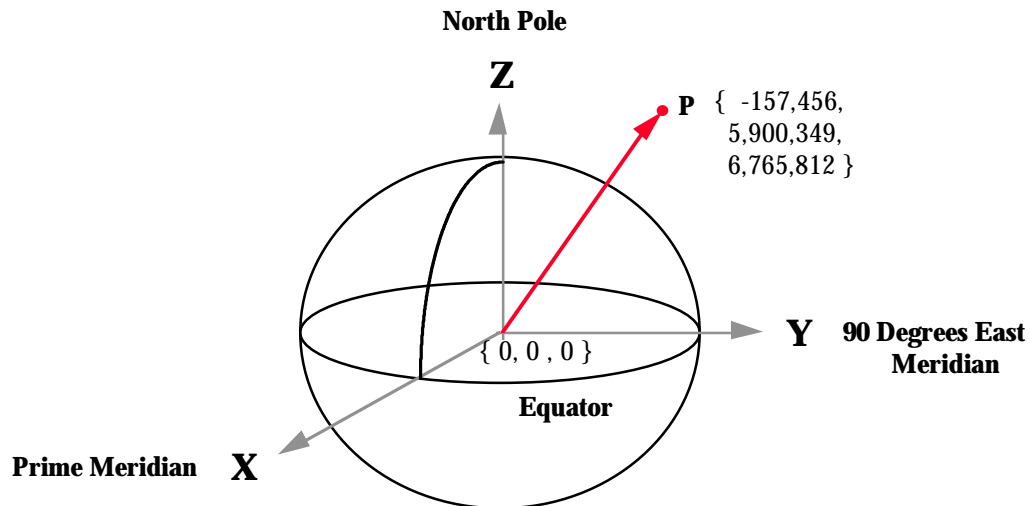


Figure 4-1: The Geocentric Coordinate System

In SEDRIS, the Geocentric Coordinate System (GCC) is defined by the following parameters:

- None

In SEDRIS, a GCC coordinate is defined by:

- x (meters)
- y (meters)
- z (meters)

4.1.2 Other Earth Centered and Fixed Coordinate Systems

There exist other Earth centered and fixed coordinate systems which are similar to the Geocentric Coordinate System, except that they define their z axis in terms of the Magnetic Dipole (instead of the rotational pole) and their x and y axes in terms of the Geomagnetic Equator (instead of the rotational Equator). These include the: Centered Dipole (D), the Magnetic Eccentric Dipole (MAG), and the Dipole Meridian (DM). For Epoch 1990 the north magnetic dipole has geodetic coordinates 79.19 degrees North and 289.02 degrees East (70.98 degrees West), and the south magnetic dipole has the geodetic coordinates of 79.19 degrees South and 109.02 degrees East.

These coordinate systems are generally of use in studying the geomagnetic field in close proximity to Earth (including magnetic observations and navigation), or in studying the dipole

magnetic field at somewhat higher altitudes in those locations where the solar wind interaction with the magnetosphere is weak.

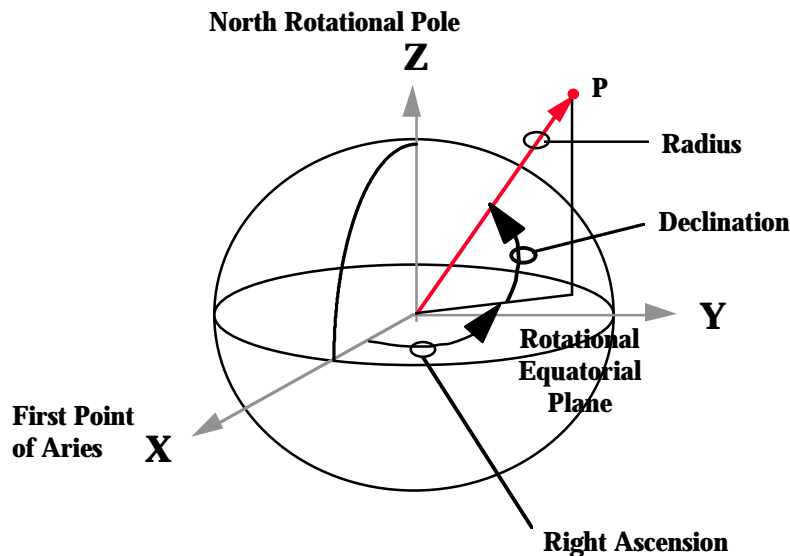
4.2 Inertial and Quasi-Inertial

4.2.1 Geocentric Equatorial Inertial (GEI) Coordinate System

The Geocentric Equatorial Inertial (GEI) Coordinate System, also known as Earth Centered Inertial (ECI) or Geocentric Celestial Inertial (GCI), is based on a Cartesian coordinate system with three orthogonal axes with an origin at the center of the Earth. The x axis is defined as pointing in the direction of the first point in Aries² (vernal equinox³) in the Rotational Equatorial and Ecliptic⁴ planes. The z axis is defined as the semi-minor (polar) axis (coincident with the Earth's rotational axis) and pointing North. The y axis is defined as orthogonal to the other two (and in the Equatorial plane) such as to form a right-handed orthogonal set (see Figure 4-2).

Locations are defined as $\{ra, dec, r\}$ triplets from the origin (Earth center). Right Ascension (ra) is defined as the geocentric angle between the projection of the radius vector onto the rotational equatorial plane and the vernal equinox; it is positive towards the East. Declination (dec) is defined as the geocentric angle between the radius vector and the Equatorial plane; it is positive towards the North. R is the magnitude of the radius vector.

GEI is thus independent of the Earth's surface, and the Earth's position with respect to the Sun – it is fully inertial. This provides a convenient system for defining the positions of orbital satellites and space vehicle dynamics, as well as various astronomic data.



² The epoch establishing the direction for the Vernal Equinox must be defined; one of: Aries-True-of-Date (ATD), Aries-Mean-of-1950 (M50), or Aries-Mean-of-2000 (FK5/J2000). See Bhavnani, 1991, for details.

³ Vernal Equinox – The point on the Celestial Sphere at the intersection of the Celestial Equator and the Ecliptic, where the Sun crosses the Equator from south to north in its apparent annual motion along the Ecliptic.

⁴ Ecliptic – Plane defined by the apparent annual path of the Sun around the Earth.

Figure 4-2: The Geocentric Equatorial Inertial Coordinate System

In SEDRIS, a Geocentric Equatorial Inertial (GEI) Coordinate System is defined by the following parameters:

- **Epoch** (Aries-True-of-Date (ATD) |
Aries-Mean-of-1950 (M50) |
Aries-Mean-of-2000 (FK5/J2000)

In SEDRIS, a GEI coordinate is defined by:

- **Right Ascension** (decimal degrees)
- **Declination** (decimal degrees)
- **Radius** (meters)

4.2.2 Geocentric Solar Ecliptic (GSE) Coordinate System

The Geocentric Solar Ecliptic (GSE) Coordinate System, also known as Ecliptic (ECL) or Solar Ecliptic (SE), is based on a Cartesian coordinate system with three orthogonal axes with an origin at the center of the Earth. The x axis is defined as pointing in the direction of the Sun (noon meridian) and is in the Rotational Equatorial plane. The z axis is defined as perpendicular to the ecliptic plane (parallel to the ecliptic pole) and pointing North. The y axis is defined as orthogonal to the other two (and in the Ecliptic plane) such as to form a right-handed orthogonal set (see Figure 4-3).

Locations are defined as $\{lon, lat, r\}$ triplets from the origin (Earth center). Longitude (lon) is defined as the geocentric angle measured eastward along the intersection of the ecliptic plane with the Earth's surface from the noon meridian to the local meridian containing the radius vector. Latitude (lat) is defined as the geocentric angle between the radius vector and the ecliptic plane; it is positive towards the North. R is the magnitude of the radius vector.

GSE is quasi-inertial in that it has a yearly rotation. This provides a convenient system for interplanetary magnetic field observations and solar wind velocity data, as well as displaying satellite trajectories.

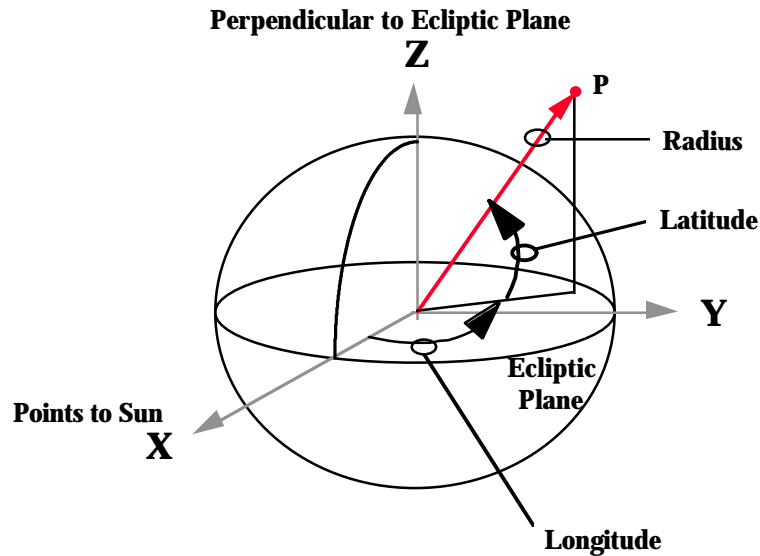


Figure 4-3: The Geocentric Solar Ecliptic Coordinate System

In SEDRIS, the Geocentric Solar Ecliptic (GSE) Coordinate System is defined by the following parameters:

- **None**

In SEDRIS, a GSE coordinate is defined by:

- **Right Ascension** (decimal degrees)
- **Declination** (decimal degrees)
- **Radius** (meters)

4.2.3 Geocentric Solar Magnetospheric (GSM) Coordinate System

The Geocentric Solar Magnetospheric (GSM) Coordinate System, also known as Solar Magnetospheric (SMC), is based on a Cartesian coordinate system with three orthogonal axes with an origin at the center of the Earth. The x axis is defined as pointing in the direction of the Sun and is in the Geomagnetic Equatorial plane. The z axis is defined as perpendicular to the x axis, in the plane containing the x axis and the Geomagnetic dipole (axis), and pointing North. The y axis is defined as orthogonal to the other two (and in the Geomagnetic Equatorial plane) such as to form a right-handed orthogonal set (see Figure 4-4).

Locations are defined as $\{lon, lat, r\}$ triplets from the origin (Earth center). Longitude (lon) is defined as the geocentric angle measured eastward along the intersection of the Geomagnetic Equatorial plane with the Earth's surface from the noon meridian to the local meridian containing the radius vector. Latitude (lat) is defined as the geocentric angle between the radius vector and the Geomagnetic Equatorial plane; it is positive towards the North. R is the magnitude of the radius vector.

GSM is quasi-inertial in that it rocks about the solar direction on both yearly (23.4 degrees +/- 11.2 degrees) and 24 hour (+/- 11.2 degree) cycles. This provides a convenient system for displaying magnetopause and shock boundary positions, magnetosheath and magnetotail fields and magnetosheath solar wind velocities (since the orientation of the magnetic dipole axis alters the otherwise cylindrical symmetry of the solar wind flow).

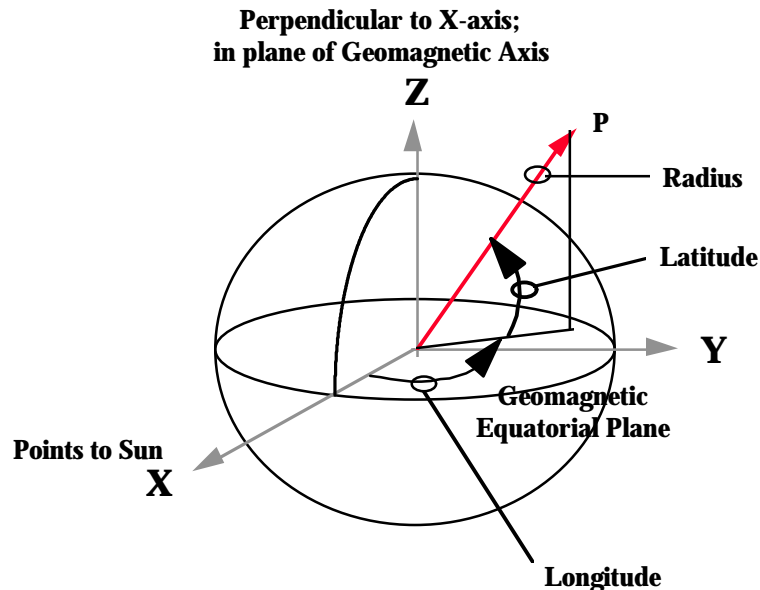


Figure 4-4: The Geocentric Solar Magnetospheric Coordinate System

In SEDRIS, the Geocentric Solar Magnetospheric (GSM) Coordinate System is defined by the following parameters:

- **None**

In SEDRIS, a GSM coordinate is defined by:

- **Longitude** (decimal degrees)
- **Latitude** (decimal degrees)
- **Radius** (meters)

4.2.4 Solar Magnetic (SM) Coordinate System

The Solar Magnetic (SM) Coordinate System, also known as Solar Geomagnetic (SG), is based on a Cartesian coordinate system with three orthogonal axes with an origin at the center of the Earth. The z axis is defined as coincident with the geomagnetic (magnetic dipole) axis and is positive towards North. The y axis is defined as perpendicular to the Earth-Sun line (positive towards dusk) and lies in the Geomagnetic Equatorial plane. The x axis is defined as

orthogonal to the other two (and in the Geomagnetic Equatorial plane, although it does not necessarily point to the Sun) such as to form a right-handed orthogonal set (see Figure 4-5).

Locations are defined as $\{lon, lat, r\}$ triplets from the origin (Earth center). Longitude (lon) is defined as the geocentric angle in the Geomagnetic Equatorial plane from the Geomagnetic meridian containing the Earth-Sun line to the Geomagnetic meridian containing the radius vector (and positive towards the East). Latitude (lat) is defined as the geocentric angle between the radius vector and the Geomagnetic Equatorial plane; it is positive towards the North. R is the magnitude of the radius vector.

SM is quasi-inertial in that it rotates with both a yearly and daily period. This provides a convenient system for ordering data controlled more strongly by the Earth's dipole field than by the solar wind. It has been used for magnetopause cross-sections and magnetospheric magnetic fields.

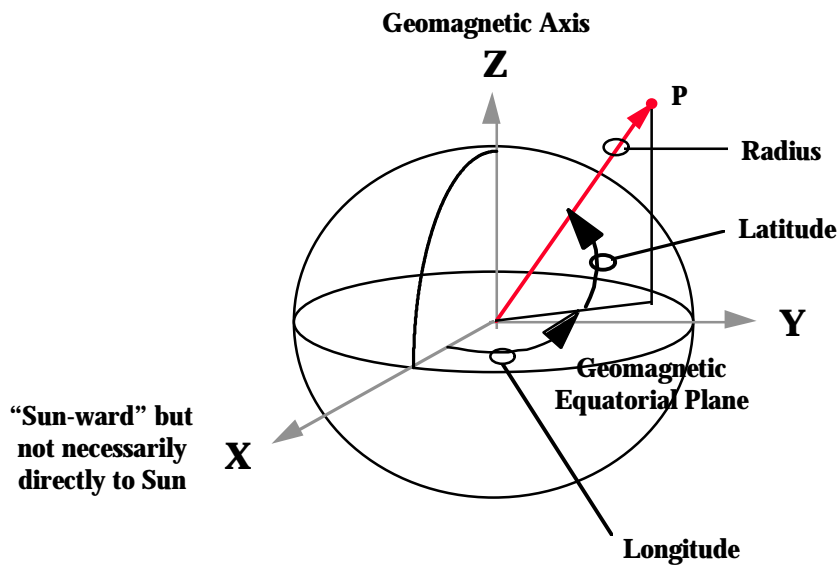


Figure 4-5: The Solar Magnetic Coordinate System

In SEDRIS, the Solar Magnetic (SM) Coordinate System is defined by the following parameters:

- **None**

In SEDRIS, a SM coordinate is defined by:

- **Longitude** (decimal degrees)
- **Latitude** (decimal degrees)
- **Radius** (meters)

4.2.5 Other Earth Centered Inertial Coordinate Systems

There exist other Earth centered inertial coordinate systems which are similar to the Geocentric Equatorial Inertial (GEI) Coordinate System. These include:

- ATS-1 – Based on the z axis passing through the polar axis, and the x and y axes on the Equatorial Plane, however the y axis is defined as perpendicular to the Earth-Sun line (and the x axis defined to create a right-handed orthogonal set). Quasi-inertial in that it rotates with a yearly period. Used extensively in the analysis of magnetometer data from the Applications Technology Satellite-1 (ATS-1) satellite.
- Geocentric Solar Equatorial (GSEQ) – Based on the x axis pointing toward the sun and in the ecliptic plane, with the z axis defined in terms of the Sun's rotational axis, and the y axis parallel to the Solar Equatorial Plane. Quasi-inertial in that it rotates with a yearly period. Used to display the interplanetary magnetic field.
- PQW – A specialty right-handed Cartesian coordinate system where the x and y axes (also known as p and q) are defined in terms of the orbital plane of a selected satellite. z (or w) is defined as the positive orbital plane normal. Quasi-inertial. Used for many orbit-related calculations such as eclipsing and station viewing.

There also exist other Earth centered inertial coordinate systems which are similar to the Geocentric Solar Magnetospheric (GSM) Coordinate System. These include:

- Solar Wind Magnetospheric (SWM) – Based on the x axis pointing into the solar wind, with the z axis perpendicular to the x axis and containing both the x axis and the geomagnetic (dipole) axis and positive towards South. The y axis is defined accordingly to create a right-handed Cartesian coordinate system. Useful in studying the effects of the solar wind on the magnetosphere.
- Solar Wind (SW) – Based on the x axis pointing into the solar wind, with the z axis perpendicular to the ecliptic plane and positive towards North. The y axis is defined accordingly to create a right-handed Cartesian coordinate system. Useful in studying the impact of the solar wind on hemispheric events.

5. Cartesian Earth Surface Origin Coordinate Systems

5.1 Global Coordinate System (GCS)

The Global Coordinate System (GCS) defines multiple local Cartesian coordinate systems with origins at multiple locations on the WGS-84 reference ellipsoid. Each local Cartesian coordinate system is referred to as a "cell"; the Earth's surface is completely tiled by GCS cells.

For much of the Earth's surface, each cell covers one degree of latitude by one degree of longitude (see Figure 5-1). However, near the poles many degrees of longitude are grouped together, since a degree of longitude becomes arbitrarily small near the poles. In all cases, cells are defined at least every 112 km in latitude and longitude. (The side dimension of 112 km is based on the side dimension of the largest 1-degree by 1-degree cell at the equator.) The maximum number of integer longitude degrees that fit within 112 km are included in a single cell. The final cell at each latitude may have less longitude degrees since the number of longitude degrees in each of the other cells in that row are rounded up to include an integer number of degrees. Cells are always one degree of latitude high. GCS defines 49778 cells, with

cell number one defined at -90.0 degrees latitude, -180 degrees longitude (South Pole, International Date Line). Cell numbers increase to the East and then North (row major).

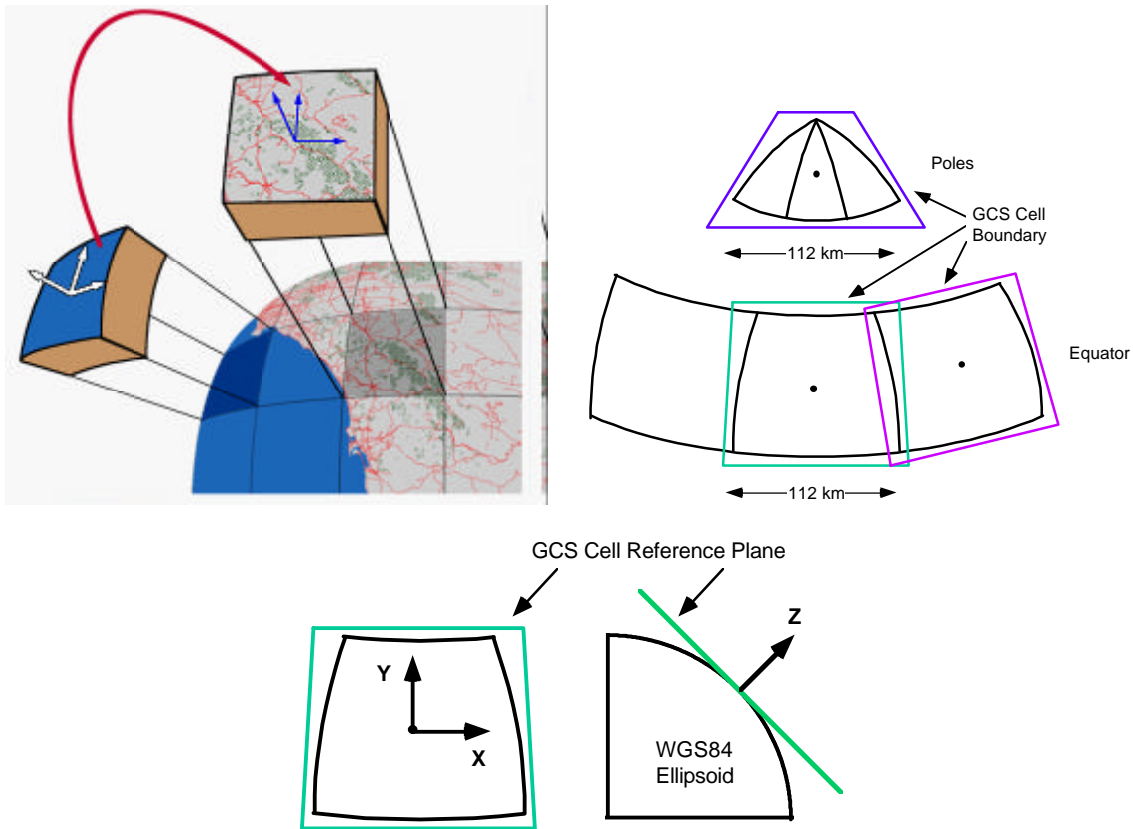


Figure 5-1: Graphic representation of the Global Coordinate System

Within each cell, a local Cartesian frame of reference is defined (see Figure 5-1). The origin of the Cartesian coordinate system is the point of tangency of the reference surface with the WGS-84 ellipsoid. The point of tangency is at the center of the rectangular cell, even if more than one degree of longitude fits in a cell. The x axis points East, the y axis points North, and the z axis is an outward normal vector from the reference ellipsoid at the point of tangency. The local Cartesian coordinate system for each cell can be extended arbitrarily in all directions, although by convention every georeferenced location has a “preferred” cell to which it is referenced (by *Cell ID*).

Cells are defined to be rectangular, so there is necessarily an overlap between adjacent cells (see Figure 5-2). The amount of overlap increases nearer the poles. The overlap regions are defined in order to provide potential “hysteresis” to a vehicle-based simulation application, so that vehicles that are operating on the boundaries between cells are not constantly changing frames of reference. Cells overlap neighboring cells by at least 250 meters.

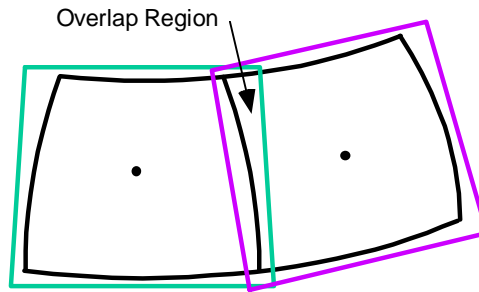


Figure 5-2: GCS Cell Overlap

Applications can use GCS in the same way they have been using projected “flat Earth” Cartesian coordinate systems (e.g. the Transverse Mercator Projected Coordinate System), with a few differences (see Figure 5-3). One difference is that the z vector in GCS is not the same as the gravity vector. However, the size of the GCS cells was chosen to keep the difference between these vectors small. Also, since the shape of the Earth is intended to be retained in the terrain data, i.e. it is not projected onto a flat plane, there is a slight slope introduced by GCS, especially towards the edges of the terrain database in each cell. The extents of the terrain databases in each cell were chosen to keep this apparent slope very small.

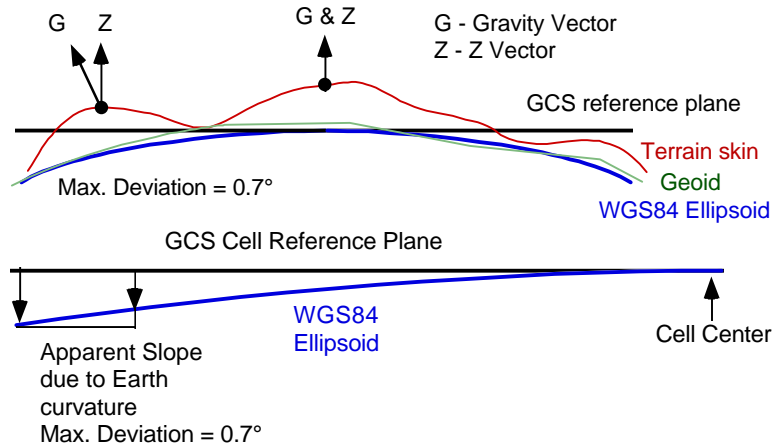


Figure 5-3: GCS differences from “flat Earth”

GCS, when used to georeference terrain data, maps digital terrain data into specific GCS cells, based on its specified latitude and longitude. In areas where GCS cells overlap, the terrain data would be mapped into all overlapping cells (e.g., in the ModSAF/JointSAF implementation of GCS in the Compact Terrain Data Base - CTDB). The geodetic coordinates of the terrain data are converted to the appropriate GCS coordinates for the mapped cells, which are x and y meters from the point of tangency of the reference plane with the WGS-84 ellipsoid, and z

meters above/below the reference plane. The digital terrain data are then stored in these GCS coordinates (see Figure 5-4).

In the areas where GCS cells overlap, the terrain data is duplicated in each overlapping GCS cell, in the local frame of reference for each cell (2, 3 or 4 of them). In all cases, the shape of the underlying terrain does not change during the GCS cell “filling” process (only the frame of reference that is used to provide spatial locations for the terrain data changes).

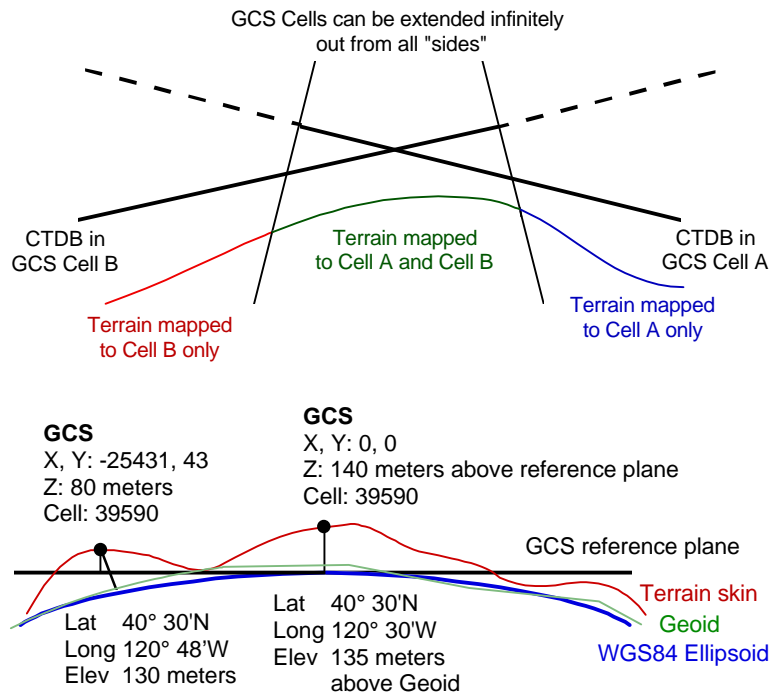


Figure 5-4: Representing the Earth’s surface in a GCS Cell

In SEDRIS, the Global Coordinate System (GCS) is defined by the following fixed parameters:

- **Horizontal Datum** (fixed as WGS-84, including the associated ellipsoid)
- **Horizontal Units** (fixed as meters)
- **Vertical Datum** (fixed as WGS-84 Ellipsoid)
- **Vertical Units** (fixed as meters)

In SEDRIS, a GCS coordinate is defined by:

- **Cell ID** (1 ... 49778)
- **x** (meters; positive Eastward)
- **y** (meters; positive Northward)
- **z** – **Elevation/Height** (meters; positive along *xy* surface normal)

5.2 Other Earth Surface Origin Coordinate Systems

There exist other Earth surface origin coordinate systems which are similar to a cell in the Global Coordinate System (GCS). These include:

- Topocentric Equator (TE) – The origin is a point on the Earth’s surface (not necessarily the geoid) and is based on an xy plane parallel to the celestial equator that contains the origin (the equatorial reference plane). The x axis lies along the line of intersection of a reference vertical plane, containing either the vernal equinox of epoch, the observers’ meridian, or the Greenwich meridian, with the equatorial reference plane. The z axis is perpendicular to the equatorial reference plane and is positive upward. Used for making local observations.
- Topocentric Horizon (TH) – The origin is a point on the Earth’s surface (not necessarily the geoid) and is based on an xy plane parallel to the horizon. The x axis lies along the line of intersection of a reference vertical plane (usually containing local north) with the horizon reference plane. The z axis is perpendicular to the horizon reference plane and is positive upward. Used for making experimental measurements.

5.3 Projected Coordinate Systems

Geographers have commonly used the term "projection" to describe the representation of a three-dimensional spatial object, or “globe” on a two dimensional plane surface, or “map.” Many algorithms for transforming geodetic measurements and positions from globe to map have been known and developed for hundreds of years. Each type of algorithm is termed a “coordinate transformation type”, which defines a projection function to change input coordinate tuples (x,y) to output tuples (x', y') .

Several hundred coordinate transformation types have been catalogued formally, and there exist, theoretically, an infinite number which could be devised. Only a small subset of the possible range of coordinate transformation types is used for most mapping applications, the others being “rarely used novelties” (Snyder, 1987). Coordinate transformations from the globe to the map are themselves varied by the choice of parameters, such as meridians and parallels of origin, scale factors, and others particular to each coordinate transformation algorithm. The result is an infinite set of possible ways to represent the globe on a two-dimensional planar display such as a paper map, or a video display screen.

A *Coordinate Transformation* (CT) provides the frame of reference in which coordinate positions of geographical features and related geodetic measurements are meaningful. The description of position typically cites an easting and northing value of a feature (or object being described), in reference to the origin of the coordinate transformation in which the easting and northing are measured. “False easting” and “false northing” are conventions which allow the limitation of the coordinate position values of the geographic features into range of values suitable to the mapping application.

Each CT type creates distortions in the projection of coordinates from a three-dimensional ellipsoid (or spheroid) to a two-dimensional plane representation. (See Snyder, 1987, p. 4 for a summary of projection properties and attendant distortions.) The projection algorithms

commonly use the concept of a “developable surface” to define the geometric equations between the ellipsoid and the map. A *developable surface* is a shape that can be transformed to a plane without distortion (Snyder, 1987). Three types of developable surfaces are used as the basis of many common map projections: the planar, conic, and cylindrical. Variations of these three types include map projection methods such as Polar Stereographic (PS; a planar type), Lambert Conformal Conic (LCC; a conic type), and Transverse Mercator (TM; a cylindrical type).

But the ellipsoid is not a developable surface, therefore, distortions caused by projection are inevitable. For this reason, many projections from ellipsoid to plane have been developed. A catalogue of the types of coordinate transformations, their distortions and properties, parameters, and limitations can be found in Snyder, 1987. For most common mapping applications, the transformation algorithms and their attendant distortions are well known.

There are many examples of each type of developable surface, and, as well, many projections which rely only partially on a developable surface, such as Sinusoidal, Bonne, and others. Users can select which CT and parameters are most appropriate to a mapping application, based on the characteristics and implications of projection distortions, the ability to know fully the parameters of the CT, and the ease of calculation or conversion from sources of mapping data. The resulting “map projection” thus represents an instantiated coordinate transformation in which the CT algorithm and a set of defining parameters is populated by real-world values that fully define the equations which effect the coordinate transformation. The CT and parameters are not sufficient to describe a coordinate address completely, since the underlying Earth shape, or geodetic reference model, must also be understood.

When the Coordinate Transformation equations are known, and the parameters are populated with valid values, and the underlying geodetic coordinate system (in ellipsoidal space) is completely characterized, then a "projection" is implemented as a *Projected Coordinate System* (PCS). A PCS is thus an instantiation of a CT which also embeds a geodetic coordinate system (GDC).

Projected coordinate systems are an important and popular way for geographers to use a geodetic reference model to describe location. For example, a geographer may cite a particular coordinate measurement (easting and northing) in relation to *Universal Transverse Mercator Zone 18 on the NAD 1927 Datum*.⁵ The italicized material in the prior sentence is sufficient to describe completely the cartographic and geodetic information that relates the easting and northing to a GRM. Through transformations of the GRM, the easting and northing can thus be related to any other PCS which fulfills the requirements of the GRM.

A *Projected Coordinate System* (PCS) is a planar, right-handed Cartesian coordinate set which, for a specific map projection, has a single and unambiguous transformation to a geodetic coordinate system, based on an ellipsoid. The relationship to the ellipsoid is unambiguous for geodetic measurements of the Earth’s surface because the ellipsoid is a convex surface. To be unambiguous, a projected coordinate system requires that the related geodetic coordinate system, the projection algorithm and the projection defining parameters are understood. Figure

⁵ Since the NAD 1927 Datum is already associated with a specific standard Ellipsoid, this specification is complete with respect to horizontal measurements.

5-5 outlines the parameters, and steps, required to convert from locations from a GDC to a PCS. Appendix C further elaborates this specification process by example.

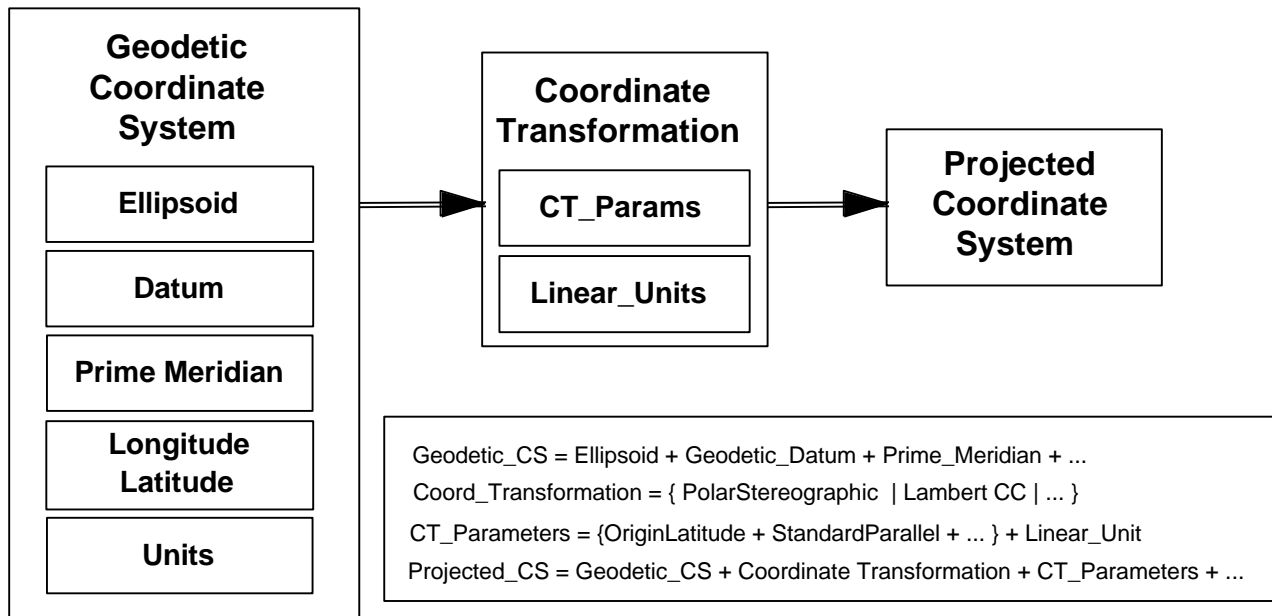


Figure 5-5: Transforming from a Geodetic to a Projected Coordinate System

See Appendix D for a summary of the critical characteristics of the Projected Coordinate Systems supported by SEDRIS.

5.3.1 Polar Stereographic (PS) Projected Coordinate System

The Stereographic Projection is a true perspective projection which is also conformal (relative local angles around every point on the map are correct -- although a large area must still be distorted in shape, the small features are shaped essentially correctly -- lines of latitude and longitude always meet at 90 degree angles). Its point of projection is on the surface of the sphere at a point just opposite the point of tangency of the plane (the center point of the projected map). Thus if the North Pole is the center of the map, the projection is from the South Pole -- hence the name Polar Stereographic for this specific variant. The Polar Stereographic projection is the most common scientific projection in use for Earth polar areas. Because of the conformality of the projection, a Stereographic map may be given, instead of a "standard point" (the point of tangency of the plane), a "standard circle" (or, in the polar aspect, a "standard parallel") with an appropriate radius from the center, balancing the scale error throughout the map.

The Polar Stereographic Projection, a conformal azimuthal projection, is similar in both the northern and southern polar regions. The projection is developed on a plane tangent at a pole with the projection lines originating from the opposite pole. The plane is perpendicular to the semi-minor axis (the line from North to South Pole; polar axis) of the ellipsoid (see Figure 5-6). Meridians appear as straight lines radiating from the point of tangency (the pole). Parallels are

concentric circles. Directions from the pole are true, and scale monotonically increases with distance from the pole.



Figure 5-6: Graphic representation of the Polar Stereographic Projection

For use with the Universal Polar Stereographic (UPS) grid, a scale factor of 0.994 is applied at the origin (pole) to lower the plane of projection to intersect the sphere at approximately 81.11667 degrees (81 degrees 07 minutes) latitude. This arbitrary geometry is applied to reduce the maximum scale distortion of the tangent projection. While the scale is exact (unity scale factor) at approximately 81.11667 degrees (81 degrees 07 minutes) latitude, the scale factor decreases to 0.994 at the pole and increases to 1.0016076 at 80.0 degrees latitude. The scale factor attains its maximum value of 1.0023916 at 79.50 degrees (79 degrees 30 minutes) latitude (the maximal limit of the UPS grid extent). The scale factor is constant along any given parallel.

Coordinates are referenced to the pole, with a specified meridian defining the positive y axis of a right-handed coordinate system, with numbers increasing toward the east and north

In SEDRIS, a Polar Stereographic (PS) Projected Coordinate System is defined by the following parameters:

- **Horizontal Datum** (selected from datum enumeration in Appendix B. The standard reference ellipsoid associated with the specified Horizontal Datum as listed in Appendix B will be used as required.)
- **Vertical Datum** (selected from the ellipsoid enumeration in Appendix A, extended with the code **GD** if using the WGS-84 Geoid (i.e. MSL))
- **Vertical Units** (feet | meters)
- **Origin of Rectangular Coordinates (center):**
 - Latitude: (North_Pole | South_Pole)
 - Longitude: (decimal degrees; the meridian which specifies the positive y axis)
- **Central scale factor** (unitless; scale at pole)

In SEDRIS, a PS PCS coordinate is defined by:

- x (meters; positive Eastward)
- y (meters; positive Northward along meridian defined above)
- z – **Elevation/Height** (in specified units; positive along xy surface normal)

5.3.2 Lambert Conformal Conic (LCC) Projected Coordinate System

The Lambert Conformal Conic Projection, like the Stereographic Projection, preserves local angles (and shapes), and can be visualized as the projection of the ellipsoid onto a cone whose axis coincides with the semi-minor (polar) axis of the ellipsoid (see Figure 5-7). Usually the cone is secant to the ellipsoid, intersecting along two parallels of latitude known as its "standard parallels". The two parallels may be made true to scale, as well as conformal. Thus neither of the parallels appear in exactly the projected positions; they are mathematically adjusted to produce the property of conformity; this adjustment is slight if the standard parallels are sufficiently close together.

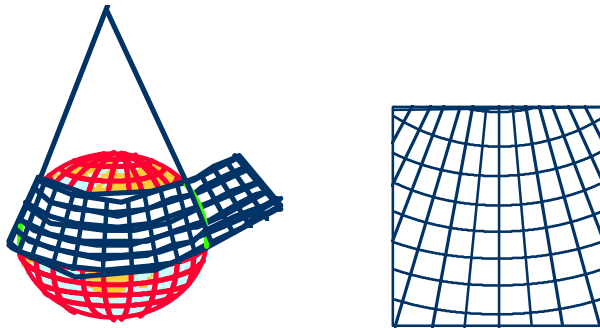


Figure 5-7: Graphic representation of the Lambert Conformal Conic Projection

The resulting scale is less than unity between the standard parallels and larger than unity outside them (and applies to the scale along the meridians, as well as along the parallels, or in any other direction, since they are equal at any given point). Meridians appear as straight lines radiating from a point beyond the mapped area. Parallels appear as arcs of concentric circles which are centered at the point from which the meridians radiate.

For example, when used for maps of the contiguous United States (or individual states) standard parallels are located at 33.0 degrees and 45.0 degrees North. While the scale is exact (unity scale factor) along those two parallels, the scale factor decreases to 0.99454 at 39.0 degrees North and increases to 1.02215 at 52.0 degrees latitude. The scale factor attains its maximum value of 1.03692 at 22.0 degrees North (the normal use limit for this specific projection). The scale factor is constant along any given parallel.

The Lambert Conformal Conic Projection is often used for State Plane Coordinate Systems (SPCS), in particular those not exhibiting pronounced north-south extent (in which case the Transverse Mercator is used), and is generally used at scales of 1:500,000 or larger.

Coordinates are referenced to a specified meridian (x), and parallel (y), with numbers increasing toward the East and North.

In SEDRIS, a Lambert Conformal Conic (LCC) Projected Coordinate System is defined by the following parameters:

- **Horizontal Datum** (selected from datum enumeration in Appendix B. The standard reference ellipsoid associated with the specified Horizontal Datum as listed in Appendix B will be used as required.)
- **Horizontal Units** (feet | meters)
- **Vertical Datum** (selected from the ellipsoid enumeration in Appendix A, extended with the code **GD** if using the WGS-84 Geoid (i.e. MSL))
- **Vertical Units** (feet | meters)
- **Standard Parallels:**
 - North_Latitude (decimal degrees)
 - South_Latitude (decimal degrees)
- **Origin of Rectangular Coordinates:**
 - Latitude (decimal degrees)
 - Longitude (decimal degrees; meridian along positive y axis)

In SEDRIS, a LCC PCS coordinate is defined by:

- x (meters; positive Eastward)
- y (meters; positive Northward along meridian defined above)
- z – **Elevation/Height** (in specified units; positive along xy surface normal)

5.3.3 Transverse Mercator (TM) Projected Coordinate System

The Mercator Projection can be visualized as an ellipsoid projected onto a cylinder with tangency established at the Equator, and with the minor (polar) axis of the ellipsoid in coincidence with the cylinder axis (see Figure 5-8). The origins of the projection lines vary, and are about three-quarters of the way back along the diameters of the equatorial plane. When the cylinder is opened and flattened, a distortion appears in the polar regions, in as much as the line representing the Equator is the true distance and each parallel is represented by a line as long as the equator. The poles are infinitely distant from the Equator and can not be shown in this projection. Distortion becomes more pronounced as the distance north and south of the Equator increases (i.e. the map scale at 60 degrees latitude is about twice that at the Equator). The meridians of longitude are vertical parallel equally spaced lines, cut at right angles by horizontal straight parallels which are increasingly spaced toward each pole so that conformality exists. The spacing of parallels at a given latitude is proportional to the secant of the latitude. Since the regular Mercator Projection has little error close to the Equator (the scale 10 degrees poleward is only 1.015), it has been found very useful in the transverse form.

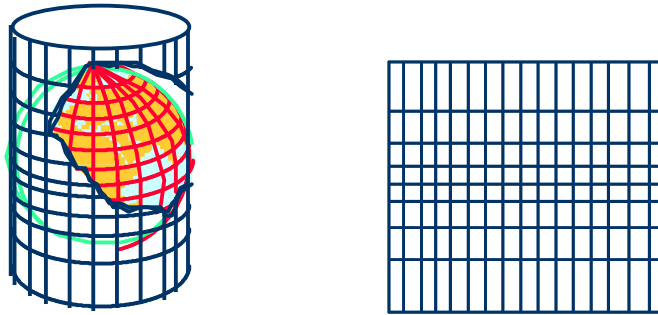


Figure 5-8: Graphic representation of the Mercator Projection

The Transverse Mercator Projection is a Mercator Projection where the cylinder has been rotated, or transversed, 90 degrees. The ellipsoid and cylinder are thus tangent along a meridian, termed the “central meridian”. By projecting the surface of the ellipsoid onto the cylinder in the same manner as for the Mercator Projection, the Transverse Mercator Projection is developed on the surface of the cylinder, which is then opened and flattened (see Figure 5-9). The central meridian is then true to scale no matter how far north or south the map extends, and regions near it are mapped with low distortion. Like the regular Mercator Projection, the map is conformal.

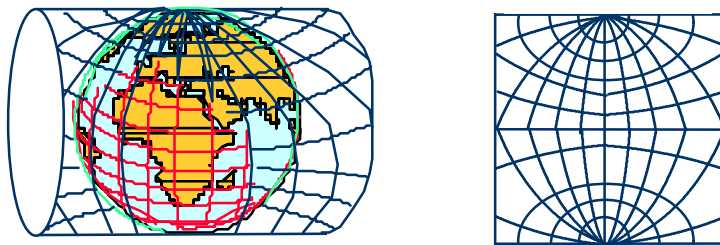


Figure 5-9: Graphic representation of the Transverse Mercator Projection

The meridians and parallels of the Transverse Mercator Projection are no longer the straight lines they are on the regular Mercator Projection, except for the Equator and the central meridian. Other meridians and parallels are complex curves. However, the resulting map is exactly conformal, and scale error is primarily a function of the distance from the central meridian (plus ellipsoidal related factors). The scale along the central meridian may be made true to scale, or deliberately reduced to a slightly smaller constant scale, so that the mean scale of the entire map is more nearly correct. If the central meridian is mapped at a reduced scale (e.g. 0.9996 is often used), two nominally straight lines parallel to it and equally spaced from it, one on either side, become true to scale on the ellipsoid (these lines are not perfectly straight

due to deviations from the sphere). Equivalently, the cylinder of projection can be modified by reducing its elliptical dimension and making it secant to the ellipsoid, intersecting the ellipsoid along two lines parallel to the central meridian.

The Transverse Mercator Projection is often used for State Plane Coordinate Systems (SPCS), in particular those exhibiting pronounced north-south extent. Except for narrow states, all states using the Transverse Mercator Projection are divided into two to eight zones, each with its own central meridian, along which the scale is slightly reduced to balance the scale throughout the map.

Coordinates are referenced to the central meridian (x), and a specified parallel (y), with numbers increasing toward the East and North.

In SEDRIS, a Transverse Mercator (TM) Projected Coordinate System is defined by the following parameters:

- **Horizontal Datum** (selected from datum enumeration in Appendix B. The standard reference ellipsoid associated with the specified Horizontal Datum as listed in Appendix B will be used as required.)
- **Horizontal Units** (feet | meters)
- **Vertical Datum** (selected from the ellipsoid enumeration in Appendix A, extended with the code **GD** if using the WGS-84 Geoid (i.e. MSL))
- **Vertical Units** (feet | meters)
- **Origin of Rectangular Coordinates:**
 - Latitude (decimal degrees)
 - Longitude (decimal degrees; meridian along positive y axis)
- **Central Scale Factor** (unitless)

In SEDRIS, a TM PCS coordinate is defined by:

- x (in specified units; positive Eastward)
- y (in specified units; positive Northward along meridian defined above)
- z – **Elevation/Height** (in specified units; positive along xy surface normal)

5.3.4 Universal Transverse Mercator (UTM) Projected Coordinate System

The Universal Transverse Mercator (UTM) Projection was adopted by the U.S. Army in 1947 for designating rectangular coordinates on large-scale military maps of the entire world (1:250,000 and smaller). The UTM Projection is the ellipsoidal Transverse Mercator Projection to which specific parameters, such as central meridians, have been applied. The Earth, between latitudes 84.0 degrees North and 80.0 degrees South, is divided into 60 zones each generally 6 degrees wide in longitude (an exception occurs in Southern Norway; refer to NIMA TM 8358.1).

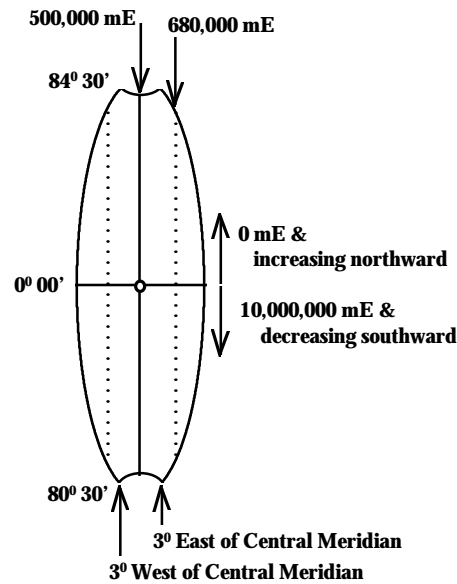
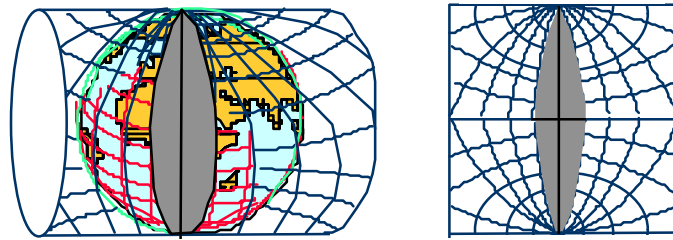


Figure 5-10: Graphic representation of the Universal Transverse Mercator Projection

Within a 6 degree zone, the scale along the central meridian is 0.9996, increasing to 1.0 at the two lines of secancy (roughly 180,000 meters east and west of the central meridian), and increasing outward to about 1.0010 near the zone boundaries at the equator (see Figure 5-10). These lines of secancy allow a more congruous relationship between ellipsoidal and map distances than that of the central meridian tangency. Map and ground distances can thus be assumed to be equivalent for most military operations (excepting geodetic and artillery operations). If required, zones can be “range extended” by 3 degrees Eastward and Westward for a total span of 12 degrees, with concomitantly increased scale (and decreased congruency) as the Eastern and Western edges are approached.

Bounding meridians are evenly divisible by 6 degrees, and zones are numbered from 1 to 60 proceeding eastwards from the 180 degrees West meridian (e.g. Zone 1 extends from 180 to 174 degrees West, and Zone 31 extends from 0 to 6 degrees East), with minor exceptions.

Above 84 degrees North latitude and below 80 degrees South latitude, up to and including the respective poles, the Universal Polar Stereographic (UPS) projection is used instead.

In the Northern Hemisphere, the Equator at the central meridian is considered the origin, with an x coordinate of 500,000 meters and a y of 0 meters. For the Southern Hemisphere, the same point is the origin, but, while x remains 500,000 meters, y is 10,000,000 meters. In each case, numbers increase toward the east and north. Negative coordinates are thus avoided.

In SEDRIS, a Universal Transverse Mercator (UTM) Projected Coordinate System is defined by the following parameters:

- **Horizontal Datum** (selected from datum enumeration in Appendix B. The standard reference ellipsoid associated with the specified Horizontal Datum as listed in Appendix B will be used as required.)
- **Vertical Datum** (selected from the ellipsoid enumeration in Appendix A, extended with the code **GD** if using the WGS-84 Geoid (i.e. MSL))
- **Vertical Units** (feet | meters)

In SEDRIS, a UTM PCS coordinate is defined by:

- **Zone** (1 ... 60)
- x (meters; positive Eastward)
- y (meters; positive Northward)
- z – **Elevation/Height** (in specified units; positive along xy surface normal)

6. Center of Gravity Origin Coordinate Systems

Some center of gravity origin coordinate systems are similar to Earth-centered Cartesian coordinate systems like GCC in that they define a right-handed Cartesian coordinate space centered on the body, e.g. Body Axis (BA) and Look Angle (LA). They can also be considered as variant of Local Space Rectangular (LST) in which a well-defined origin relative to the body has been specified.

Others differ from Earth-centered Cartesian coordinate systems in that, while they define a right-handed Cartesian coordinate space centered on the body, the z axis lies along the geocentric radius vector to the vehicle and is positive towards the center of the Earth and the x axis lies in the orbital plane and is perpendicular to the z axis, pointing forward. The y axis is defined as orthogonal to the other two (and in the orbital plane) such as to form a right-handed orthogonal set. These coordinate systems include Local Vertical/Local Horizontal (LVLH), and Local Orbital (LO).

Center of gravity origin coordinate systems are often used for measurements collected from, or radiation-distribution patterns of, orbiting and other bodies in motion.

7. Arbitrary (“point-of-interest”) Origin Coordinate Systems

7.1 Local Space Rectangular (LST)

The Local Space Rectangular (LST) coordinate system is a right-handed Cartesian coordinate system without a specified origin. Used for SEDRIS models, generally the origin is located on or within the volume of the described data (e.g. a vehicle or structure). The relationship (if any) between the origin and the spatial feature described must be determined by inspection.

In SEDRIS, a Local Space Rectangular (LST) Coordinate System is defined by the following parameters:

- **Units** (feet | meters)

In SEDRIS, an LST coordinate is defined by:

- x (in specified units)
- y (in specified units)
- z (in specified units; positive along xy surface normal)

7.2 Other Point-of-Interest Origin Coordinate Systems

There exist other “point-of-interest” coordinate systems which are similar to the Local Space Rectangular (LST) Coordinate System, generally varying according to specific constraints on two of the coordinate axes and the choice of angular vs. Cartesian coordinates.

- **Magnetic Field (MFD)** – Used in (nearly) Earth-surface measurements of components of the geomagnetic field, the x axis points North, the y axis points East, and the z axis corresponding points downwards. Coordinates are specified in terms of the inclination (or dip) angle downwards from the xy plane, and the declination angle from North (positive Eastwards), and the magnitude of the magnetic field vector.
- **VDH** – Also used in analysis of geomagnetic field data, the z axis is parallel to the Magnetic Dipole axis, and the y axis is defined as perpendicular to the geocentric radius vector, pointing Eastwards.
- **Sensor (S)** – Used as a foundation for converting measured sensor data to other coordinate systems, the x and y axes are aligned with the sensor plane and form a right-handed orthogonal system with the z axis, which is usually the line of sight.
- **Plasma (P)** – Used to study wave propagation in plasmas, the z axis is parallel to the magnetic field and is positive in the same sense as the magnetic field, while the x axis is perpendicular to the z axis, lying in a plane defined by the z axis and the propagation vector (termed w). The y axis completes a right-handed orthogonal set.

Appendix A: SEDRIS Ellipsoids

The following table delineates the ellipsoid names and constants used for defining Geodetic Coordinate Systems (GDC) in SEDRIS (see DMA TR 8350.2, Appendix A.1).

Reference Ellipsoid		Semi-major Axis	Inverse Flattening
Code	Name	a (meters)	f^{-1} (unitless)
AA	Airy 1830	6377563.396	299.3249646
AM	Modified Airy	6377340.189	299.3249646
AN	Australian National	6378160	298.25
BN	Bessel 1841 (Namibia)	6377483.865	299.1528128
BR	Bessel 1841 (Ethiopia Indonesia Japan Korea)	6377397.155	299.1528128
CC	Clarke 1866	6378206.4	294.9786982
CD	Clarke 1880	6378249.145	293.465
EA	Everest (India 1830)	6377276.345	300.8017
EB	Everest (Sabah & Sarawak)	6377298.556	300.8017
EC	Everest (India 1956)	6377301.243	300.8017
ED	Everest (W. Malaysia 1969)	6377295.664	300.8017
EE	Everest (W. Malaysia & Singapore 1948)	6377304.063	300.8017
FA	Modified Fischer 1960	6378155	298.3
HE	Helmert 1906	6378200	298.3
HO	Hough 1960	6378270	297
IN	International 1924	6378388	297
KA	Krassovsky 1940	6378245	298.3
RF	Geodetic Reference System 1980 (GRS 80)	6378137	298.257222101
SA	South American 1969	6378160	298.25
WD	WGS 72	6378135	298.26
WE	WGS 84	6378137	298.257223563

Appendix B: SEDRIS Datums

The following table delineates the geodetic datums used for defining Geodetic Coordinate Systems (GDC) in SEDRIS, and their reference ellipsoids, transformation parameters to the WGS-84 datum, and applicable extents (see DMA TR 8350.2, Appendix B.2).

Geodetic Datums		Reference Ellipsoid	Transformation Parameters			Applicable Extent of Datum
Code	Name		delta X (meters)	delta Y (meters)	delta Z (meters)	
ADI-A	Adindan	CD	-165	-11	206	Ethiopia
ADI-B	Adindan	CD	-161	-14	205	Sudan
ADI-C	Adindan	CD	-123	-20	220	Mali
ADI-D	Adindan	CD	-128	-18	224	Senegal
ADI-E	Adindan	CD	-118	-14	218	Burkina Faso
ADI-F	Adindan	CD	-134	-2	210	Cameroon
ADI-M	Adindan	CD	-166	-15	204	MEAN FOR Ethiopia, Sudan
AFG	Afgooye	KA	-43	-163	45	Somalia
AIA	Antigua Island Astro 1943	CD	-270	13	62	Antigua (Leeward Islands)
AIN-A	Ainel Abd 1970	IN	-150	-250	-1	Bahrain
AIN-B	Ainel Abd 1970	IN	-143	-236	7	Saudi Arabia
ANO	Anna1 Astro 1965	AN	-491	-22	435	Cocos Islands
ARF-A	Arc 1950	CD	-138	-105	-289	Botswana
ARF-B	Arc 1950	CD	-125	-108	-295	Lesotho
ARF-C	Arc 1950	CD	-161	-73	-317	Malawi
ARF-D	Arc 1950	CD	-134	-105	-295	Swaziland
ARF-E	Arc 1950	CD	-169	-19	-278	Zaire
ARF-F	Arc 1950	CD	-147	-74	-283	Zambia
ARF-G	Arc 1950	CD	-142	-96	-293	Zimbabwe
ARF-H	Arc 1950	CD	-153	-5	-292	Burundi
ARF-M	Arc 1950	CD	-143	-90	-294	MEAN FOR Botswana, Lesotho, Malawi,

						Swaziland, Zaire Zambia, Zimbabwe
ARS	Arc 1960	CD	-160	-6	-302	MEAN FOR Kenya, Tanzania
ASC	Ascension Island 1958	IN	-205	107	53	Ascension Island
ASM	Montserrat Island Astro 1958	CD	174	359	365	Montserrat (Leeward Islands)
ASQ	Astronomical Station 1952	IN	124	-234	-25	Marcus Island
ATF	Astro Beacon E 1945	IN	145	75	-272	Iwo Jima
AUA	Australian Geodetic 1966	AN	-133	-48	148	Australia & Tasmania
AUG	Australian Geodetic 1984	AN	-134	-48	149	Australia & Tasmania
BAT	Djakarta (Batavia)	BR	-377	681	-50	Indonesia (Sumatra)
BER	Bermuda 1957	CC	-73	213	296	Bermuda
BID	Bissau	IN	-173	253	27	Guinea-Bissau
BOO	Bogota Observatory	IN	307	304	-318	Colombia
BUR	Bukit Rimpah	BR	-384	664	-48	Indonesia (Bangka Belitung Islands)
CAC	Cape Canaveral	CC	-2	151	181	Bahamas, Florida
CAI	Campo Inchauspe	IN	-148	136	90	Argentina
CAO	Canton Astro 1966	IN	298	-304	-375	Phoenix Islands
CAP	Cape	CD	-136	-108	-292	South Africa
CAZ	Camp Area Astro	IN	-104	-129	239	Antarctica (McMurdo Camp Area)
CGE	Carthage	CD	-263	6	431	Tunisia
CHI	Chatham Island Astro 1971	IN	175	-38	113	New Zealand (Chatham Island)
CHU	Chua Astro	IN	-134	229	-29	Paraguay
COA	Corrego Alegre	IN	-206	172	-6	Brazil
DAL	Dabola	CD	-83	37	124	Guinea
DOB	GUX1 Astro	IN	252	-209	-751	Guadalcanal Island
EAS	Easter Island 1967	IN	211	147	111	Easter Island
ENW	Wake-Eniwetok 1960	HO	102	52	-38	Marshall Islands

EUR-A	European 1950	IN	-87	-96	-120	MEAN FOR Austria, Denmark, France, West Germany, Netherlands, Switzerland
EUR-B	European 1950	IN	-84	-95	-130	Greece
EUR-C	European 1950	IN	-87	-95	-120	Finland, Norway
EUR-D	European 1950	IN	-84	-107	-120	Portugal, Spain
EUR-E	European 1950	IN	-104	-101	-140	Cyprus
EUR-F	European 1950	IN	-130	-117	-151	Egypt
EUR-G	European 1950	IN	-86	-96	-120	England, Channel Islands, Scotland, Shetland Islands
EUR-H	European 1950	IN	-117	-132	-164	Iran
EUR-I	European 1950	IN	-97	-103	-120	Italy (Sardinia)
EUR-J	European 1950	IN	-97	-88	-135	Italy (Sicily)
EUR-K	European 1950	IN	-86	-96	-120	England, Ireland, Scotland, Shetland Islands
EUR-L	European 1950	IN	-107	-88	-149	Malta
EUR-M	European 1950	IN	-87	-98	-121	MEAN FOR Austria, Belgium, Denmark, Finland, France, West Germany, Gibraltar, Greece, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland
EUR-S	European 1950	IN	-103	-106	-141	MEAN FOR Iraq, Israel, Jordan, Lebanon, Kuwait, Saudi Arabia, Syria
EUS	European 1979	IN	-86	-98	-119	MEAN FOR Austria, Finland, Netherlands, Norway, Spain, Sweden, Switzerland
FAH	Oman	CD	-346	-1	224	Oman
FLO	Observatorio Meteorologico 1939	IN	-425	-169	81	Azores (Corvo Flores Islands)
FOT	Fort Thomas 1955	CD	-7	215	225	Nevis, St. Kitts (Leeward

						Islands)
GAA	Gan 1970	IN	-133	-321	50	Republic of Maldives
GEO	Geodetic Datum 1949	IN	84	-22	209	New Zealand
GIZ	DOS 1968	IN	230	-199	-752	New Georgia Islands (Gizo Island)
GRA	Graciosa Base SW 1948	IN	-104	167	-38	Azores (Faial, Graciosa, Pico, Sao Jorge, Terceira)
GSE	GunungSegara	BR	-403	684	41	Indonesia (Kalimantan)
GUA	Guam 1963	CC	-100	-248	259	Guam
HEN	Herat North	IN	-333	-222	114	Afghanistan
HIT	Provisional South Chilean 1963	IN	16	196	93	South Chile (Near 53 ⁰ S) (HitoXVIII)
HJO	Hjorsey 1955	IN	-73	46	-86	Iceland
HKD	HongKong 1963	IN	-156	-271	-189	Hong Kong
HTN	Hu-Tzu-Shan	IN	-637	-549	-203	Taiwan
IBE	Bellevue (IGN)	IN	-127	-769	472	Efate & Erromango Islands
IND-B	Indian	EA	282	726	254	Bangladesh
IND-I	Indian	EC	295	736	257	India, Nepal
INF-A	Indian 1954	EA	218	816	297	Thailand, Vietnam
INH-A	Indian 1975	EA	209	818	290	Thailand
IRL	Ireland 1965	AM	506	-122	611	Ireland
ISG	ISTS061 Astro 1968	IN	-794	119	-298	Sout Georgi Islands
IST	ISTS073 Astro 1969	IN	208	-435	-229	Dieg Garcia
JOH	Johnston Island 1961	IN	189	-79	-202	Johnston Island
KAN	Kandawala	EA	-97	787	86	Sri Lanka
KEA	Kertau 1948	EE	-11	851	5	West Malaysia & Singapore
KEG	KerguelenIsland 1949	IN	145	-187	103	Kerguelen Island
KUS	Kusaie Astro 1951	IN	647	1777	-1124	Caroline Islands
LCF	L.C.5 Astro 1961	CC	42	124	147	Cayman Brac Island
LEH	Leigon	CD	-130	29	364	Ghana

LIB	Liberia 1964	CD	-90	40	88	Liberia
LUZ-A	Luzon	CC	-133	-77	-51	Philippines (Excluding Mindanao)
LUZ-B	Luzon	CC	-133	-79	-72	Philippines (Mindanao)
MAS	Massawa	BR	639	405	60	Ethiopia (Eritrea)
MER	Merchich	CD	31	146	47	Morocco
MID	Midway Astro 1961	IN	912	-58	1227	Midway Islands
MIK	Mahe 1971	CD	41	-220	-134	Mahe Island
MIN-A	Minna	CD	-81	-84	115	Cameroon
MIN-B	Minna	CD	-92	-93	122	Nigeria
MOD	Rome 1940	IN	-225	-65	9	Italy (Sardinia)
MPO	M'Poraloko	CD	-74	-130	42	Gabon
MVS	Viti Levu 1916	CD	51	391	-36	Fiji (Viti Levu Island)
NAH-A	Nahrwan	CD	-247	-148	369	Oman (Masirah Island)
NAH-B	Nahrwan	CD	-249	-156	381	United Arab Emirates
NAH-C	Nahrwan	CD	-243	-192	477	Saudi Arabia
NAP	Naparima BWI	IN	-10	375	165	Trinidad & Tobago
NAR-A	North American 1983	RF	0	0	0	Alaska
NAR-B	North American 1983	RF	0	0	0	Canada
NAR-C	North American 1983	RF	0	0	0	CONUS
NAR-D	North American 1983	RF	0	0	0	Mexico, Central America
NAS-A	North American 1927	CC	-9	161	179	MEAN FOR CONUS (East of Mississippi River) including Louisiana, Missouri, Minnesota
NAS-B	North American 1927	CC	-8	159	175	MEAN FOR CONUS (West of Mississippi River) excluding Louisiana, Missouri, Minnesota
NAS-C	North American 1927	CC	-8	160	176	MEAN FOR CONUS
NAS-D	North American 1927	CC	-5	135	172	Alaska
NAS-E	North American 1927	CC	-10	158	187	MEAN FOR Canada

NAS-F	North American 1927	CC	-7	162	188	Canada (Alberta, British Columbia)
NAS-G	North American 1927	CC	-22	160	190	Canada (New Brunswick, Newfoundland, Nova Scotia, Quebec)
NAS-H	North American 1927	CC	-9	157	184	Canada (Manitoba, Ontario)
NAS-I	North American 1927	CC	4	159	188	Canada (Northwest Territories, Saskatchewan)
NAS-J	North American 1927	CC	-7	139	181	Canada (Yukon)
NAS-L	North American 1927	CC	-12	130	190	Mexico
NAS-N	North American 1927	CC	0	125	194	MEAN FOR Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua
NAS-O	North American 1927	CC	0	125	201	Canal Zone
NAS-P	North American 1927	CC	-3	142	183	MEAN FOR Antigua, Barbados, Barbuda, Caicos Islands, Cuba, Dominican Republic, Grand Cayman, Jamaica, Turks Islands
NAS-Q	North American 1927	CC	-4	154	178	Bahamas (Except San Salvador Island)
NAS-R	North American 1927	CC	1	140	165	Bahamas (San Salvador Island)
NAS-T	North American 1927	CC	-9	152	178	Cuba
NAS-U	North American 1927	CC	11	114	195	Greenland (Hayes Peninsula)
OEG	Old Egyptian 1907	HE	-130	110	-13	Egypt
OGB-A	Ordnance Survey Great Britain 1936	AA	371	-112	434	England
OGB-B	Ordnance Survey Great Britain 1936	AA	371	-111	434	England Isle of Man, Wales
OGB-C	Ordnance Survey Great Britain 1936	AA	384	-111	425	Scotland, Shetland, Islands

OGB-D	Ordnance Survey Great Britain 1936	AA	370	-108	434	Wales
OGB-M	Ordnance Survey Great Britain 1936	AA	375	111	431	MEAN FOR England, Isle of Man, Scotland, Shetland Islands, Wales
OHA-A	Old Hawaiian	CC	89	-279	-183	Hawaii
OHA-B	Old Hawaiian	CC	45	-290	-172	Kauai
OHA-C	Old Hawaiian	CC	65	-290	-190	Maui
OHA-D	Old Hawaiian	CC	58	-283	-182	Oahu
OHA-M	Old Hawaiian	CC	61	-285	-181	MEAN FOR Hawaii, Kauai, Maui, Oahu
PHA	Ayabelle Lighthouse	CD	-79	-129	145	Djibouti
PIT	Pitcairn Astro 1967	IN	185	165	42	Pitcairn Island
PLN	Picodelas Nieves	IN	-307	-92	127	Canary Islands
POS	PortoSanto1936	IN	-499	-249	314	Porto Santo, Madeira Islands
PRP-A	Provisional South American 1956	IN	-270	188	-388	Bolivia
PRP-B	Provisional South American 1956	IN	-270	183	-390	Northern Chile (Near 19 ⁰ S)
PRP-C	Provisional South American 1956	IN	-305	243	-442	Southern Chile (Near 43 ⁰ S)
PRP-D	Provisional South American 1956	IN	-282	169	-371	Colombia
PRP-E	Provisional South American 1956	IN	-278	171	-367	Ecuador
PRP-F	Provisional South American 1956	IN	-298	159	-369	Guyana
PRP-G	Provisional South American 1956	IN	-279	175	-379	Peru
PRP-H	Provisional South American 1956	IN	-295	173	-371	Venezuela
PRP-M	Provisional South American 1956	IN	-288	175	-376	MEAN FOR Bolivia, Chile, Colombia, Ecuador, Guyana, Peru, Venezuela

PTB	Point 58	CD	-106	-129	165	MEAN FOR Burkina Faso & Niger
PTN	Pointe Noire 1948	CD	-148	51	-291	Congo
PUR	Puerto Rico	CC	11	72	-101	Puerto Rico Virgin Islands
QAT	Qatar National	IN	-128	-283	22	Qatar
QUO	Qornoq	IN	164	138	-189	Greenland(South)
REU	Reunion	IN	94	-948	-1262	Mascarene Islands
SAE	Santo (DOS) 1965	IN	170	42	84	Espirito Santo Island
SAN-A	South American 1969	SA	-62	-1	-37	Argentina
SAN-B	South American 1969	SA	-61	2	-48	Bolivia
SAN-C	South American 1969	SA	-60	-2	-41	Brazil
SAN-D	South American 1969	SA	-75	-1	-44	Chile
SAN-E	South American 1969	SA	-44	6	-36	Colombia
SAN-F	South American 1969	SA	-48	3	-44	Ecuador (excluding Galapagos Islands)
SAN-G	South American 1969	SA	-53	3	-47	Guyana
SAN-H	South American 1969	SA	-61	2	-33	Paraguay
SAN-I	South American 1969	SA	-58	0	-44	Peru
SAN-J	South American 1969	SA	-47	26	-42	Ecuador (Baltra, Galapagos Islands)
SAN-K	South American 1969	SA	-45	12	-33	Trinidad & Tobago
SAN-L	South American 1969	SA	-45	8	-33	Venezuela
SAN-M	South American 1969	SA	-57	1	-41	MEAN FOR Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Trinidad & Tobago, Venezuela
SAO	Sao Braz	IN	-203	141	53	Azores (Sao Miguel, Santa Maria Islands)
SAP	Sapper Hill 1943	IN	-355	21	72	East Falkland Island
SCK	Schwarzeck	BN	616	97	-251	Namibia
SGM	Selvagem Grande 1938	IN	-289	-124	60	Salvage Islands

SHB	Astro DOS 71/4	IN	-320	550	-494	St. Helena Island
SOA	South Asia	FA	7	-10	-26	Singapore
TAN	Tananarive Observatory 1925	IN	-189	-242	-91	Madagascar
TDC	Tristan Astro 1968	IN	-632	438	-609	Tristanda Cunha
TIL	Timbalai 1948	EB	-679	669	-48	Brunei, East Malaysia (Sabah, Sarawak)
TOY-A	Tokyo	BR	-148	507	685	Japan
TOY-B	Tokyo	BR	-146	507	687	Korea
TOY-C	Tokyo	BR	-158	507	676	Okinawa
TOY-M	Tokyo	BR	-148	507	685	MEAN FOR Japan, Korea, Okinawa
TRN	Astro Tern Island (FRIG) 1961	IN	114	-116	-333	Tern Island
W72	WGS 1972	WD	0	0	0	Global Definition
W84	WGS 1984	WE	0	0	0	Global Definition
WAK	Wake Island Astro 1952	IN	276	-57	149	Wake Atoll
YAC	Yacare	IN	-155	171	37	Uruguay
ZAN	Zanderij	IN	-265	120	-358	Suriname

Appendix C: Hierarchy of a Geodetic Reference Model (GeoRM)

Geodetic and projected coordinates are both imposed on models of the Earth. To describe a location uniquely, a coordinate set must be referenced to an adequately defined coordinate system. Using a GeoRM hierarchy, a coordinate system from the tabulated standard definitions requires only the reference to the standard coordinate system code/name. If the coordinate system is non-standard, it may be “user-defined” through use of a GeoRM, following the workflow described below.

The following methods of describing spatial model locations are recognized in a GeoRM. These comprise a hierarchy, as follows:

- Basic units of measurement (such as meters, radians, feet, etc.)
- Ellipsoidal approximations of the Earth shape (including datums and prime meridians)
- Geodetic coordinates (based on ellipsoid and/or datum and a prime meridian)
- Projected coordinates (transformations of longitude/latitude tuples through a CT)
- Projected Coordinate System coordinates (instantiation of a CT and GDC, often zoned).

Within the hierarchy, each successive layer embeds the definitions inherited from the prior layer. Thus, a PCS (most derivative in the hierarchy) embeds the properties of the coordinate transformation method (CT and associated parameters), the geodetic reference system which expresses the longitude and latitude values, the ellipsoid and datum (GDC) which allow unambiguous meaning of the lon/lat tuples, and the units of measurement of the axes of the ellipsoid.

The hierarchy also allows, in reverse order, a workflow in which a user can define units for measurement of the Earth model properties, then a “user defined” ellipsoid can be constructed, and localized through definition of a prime meridian to allow lon/lat tuples to describe geodetic coordinates for any position (GDC); the geodetic coordinates can be transformed through any of an infinite set of coordinate transformations and their parameters (CT’s), to result in projected coordinates which describe a position in linear units (PCS). Using this workflow, a user can describe any position on the Earth model surface using entirely user-defined properties.

Users may also choose to accept some levels of the hierarchy and “user define” the others. This is commonly performed by, for example, users who accept a GDC from the public tabulation, but modify the CT to create a map which has properties (and distortions) specific to the mapping application. A GeoRM thus serves as a means of linking together unsubstantiated “fields” of a model, which the user can populate, either with publicly tabulated values, or with user-defined values.

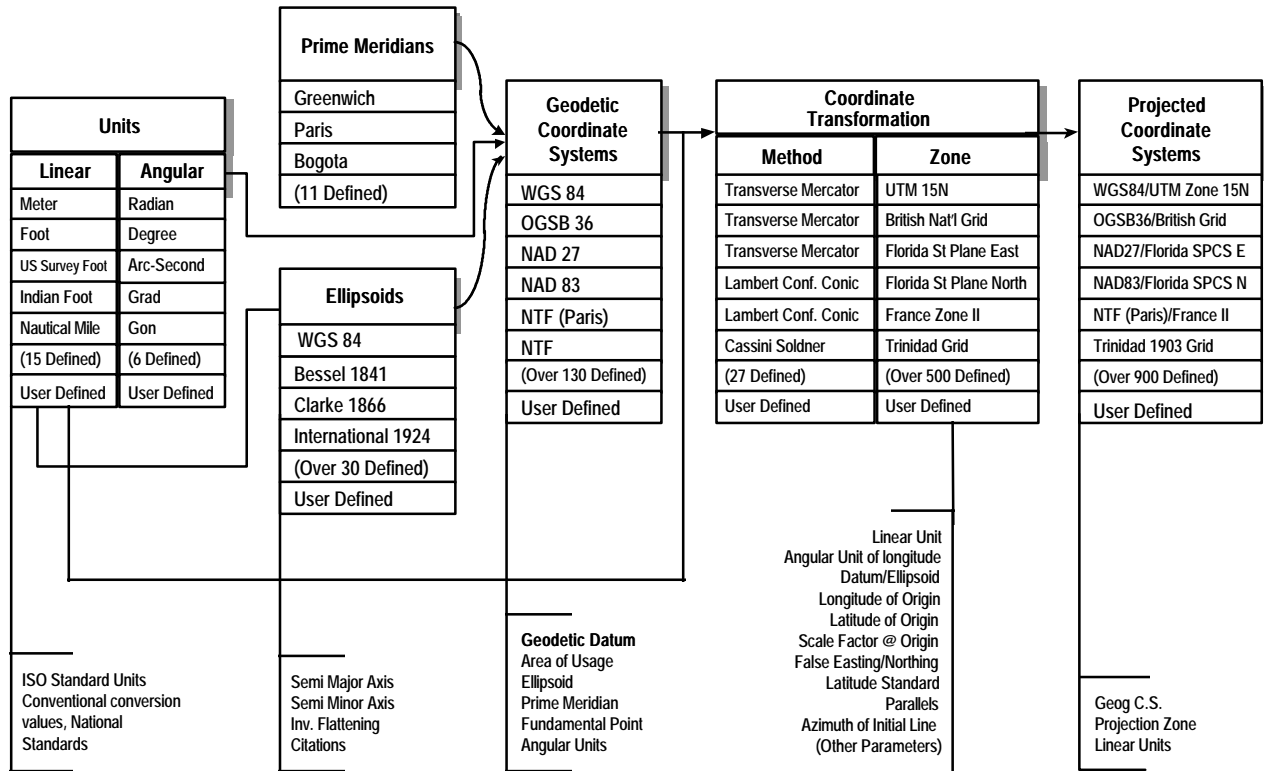
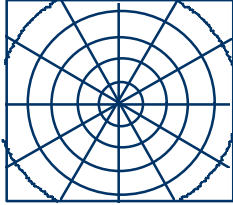
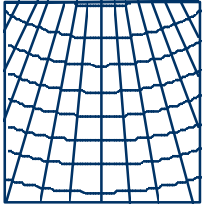
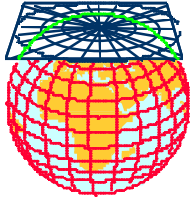



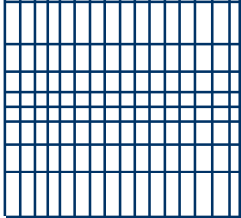
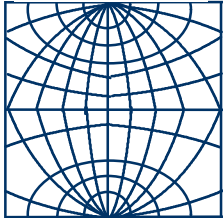
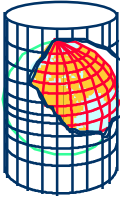
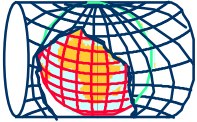
Figure C-1: Graphic representation of cartographic hierarchy as implemented in GeoTIFF.⁶

Vertical coordinates are outside of this particular example hierarchy, and instead are considered as a second one-dimensional vertical coordinate system, used in conjunction with the two-dimensional horizontal coordinate system. Horizontal coordinates and vertical coordinates complement one another to give a three dimensional description of location.

⁶ Examples are shown for each class of variables, and available parameter fields are shown at the bottom. Read left to right to “compose” from fundamental elements (Units) to derivative elements (PCS). Parameters by EPSG (European Petroleum Survey Group), and data model by POSC (Petrotechnical Open Software Corp.). Vertical dimensions not shown.

Appendix D: Summary of Projections Supported by SEDRIS

		POLAR	LAMBERT
CHARACTERISTICS OF THE PROJECTION	CONFORMALITY	CONFORMAL	CONFORMAL
	DISTANCE SCALE	NEARLY CONSTANT EXCEPT ON SMALL-SCALE CHARTS	NEARLY CONSTANT
	DISTORTION OF SHAPES & AREAS	INCREASES AWAY FROM POLE	VERY LITTLE
	ANGLE BETWEEN PARALLELS & MERIDIANS	90° ANGLE	90° ANGLE
	APPEARANCE OF PARALLELS	CONCENTRIC CIRCLES UNEQUALLY SPACED	ARCS OF CONCENTRIC CIRCLES NEARLY EQUALLY SPACED
	APPEARANCE OF MERIDIANS	STRAIGHT LINES RADIATING FROM THE POLE	STRAIGHT LINES CONVERGING AT THE POLE
APPEARANCE OF PROJECTIO			
GRAPHI ILLUSTRATIO			
PRODUCTION	METHOD OF PRODUCTION	GRAPHIC OR MATHEMATICAL	MATHEMATICAL
	ORIGIN OF PROJECTORS	FROM OPPOSITE POLE	FROM CENTER OF SPHERE (for illustration only)
	POINT OF TANGENCY	POLE	TWO STANDARD PARALLELS
APPEARANCE OF LINES ON CHARTS	STRAIGHT LINE CROSSES MERIDIANS	VARIABLE ANGLE (approximates Great Circle)	VARIABLE ANGLE (approximates Great Circle)
	GREAT CIRCLE	APPROXIMATED BY STRAIGHT LINE	APPROXIMATED BY STRAIGHT LINE
	RHUMB LINE	CURVED LINE	CURVED LINE
NAVIGATIONAL USES	ALL TYPES OF POLAR NAVIGATION	PILOTAGE AND RADIO (suitable for all types)	

		MERCATOR	TRANSVERSE MERCATOR
CHARACTERISTICS OF THE PROJECTION	CONFORMALITY	CONFORMAL	CONFORMAL
	DISTANCE SCALE	VARIABLE (measure at mid-latitude)	NEARLY CONSTANT (near meridian of true scale)
	DISTORTION OF SHAPES & AREAS	INCREASES AWAY FROM EQUATOR	INCREASES AWAY FROM TANGENT MERIDIAN
	ANGLE BETWEEN PARALLELS & MERIDIANS	90° ANGLE	90° ANGLE
	APPEARANCE OF PARALLELS	PARALLEL STRAIGHT LINES UNEQUALLY SPACED	CURVES CONCAVE TOWARD NEAREST POLE
	APPEARANCE OF MERIDIANS	PARALLEL STRAIGHT LINES EQUALLY SPACED	COMPLEX CURVES CONCAVE TOWARD CENTRAL MERIDIAN
APPEARANCE OF PROJECTION			
GRAPHIC ILLUSTRATION			
PRODUCTION	METHOD OF PRODUCTION	MATHEMATICAL	MATHEMATICAL
	ORIGIN OF PROJECTORS	FROM CENTER OF SPHERE (for illustration only)	FROM CENTER OF SPHERE (for illustration only)
	POINT OF TANGENCY	EQUATOR	GREAT CIRCLE THROUGH THE POLES
APPEARANCE OF LINES ON CHARTS	STRAIGHT LINE CROSSES MERIDIANS	CONSTANT ANGLE (Rhumb line)	VARIABLE ANGLE (approximates Great Circle)
	GREAT CIRCLE	CURVED LINE (except Equator and meridians)	APPROXIMATED BY STRAIGHT LINE
	RHUMB LINE	STRAIGHT LINE	CURVED LINE
NAVIGATIONAL USES		DEAD RECKONING AND CELESTIAL (suitable for all types)	GRID NAVIGATION IN POLAR AREAS