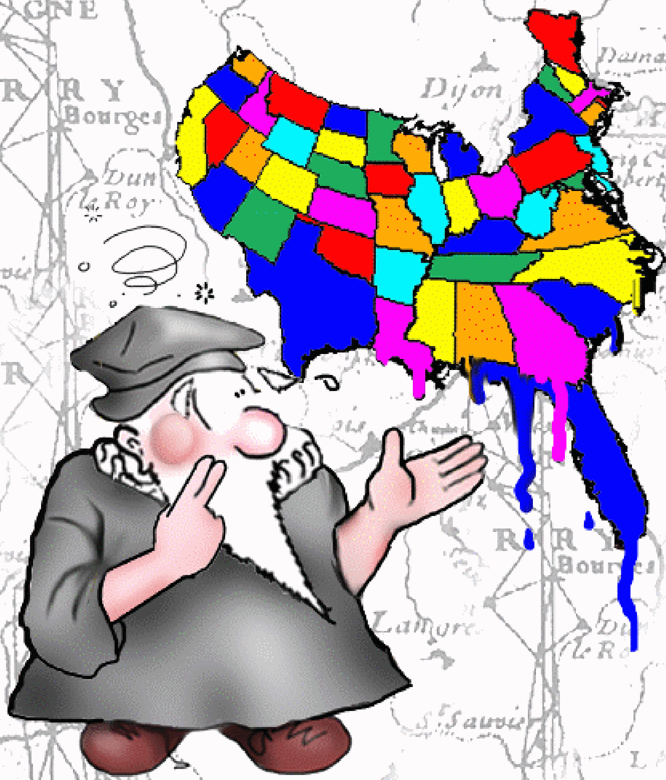
P R O J E C T I O N S

Introduction to

Map Projections



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TNTmips®

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Before Getting Started

Positions in a georeferenced spatial object must refer to a particular coordinate reference system. Many standard reference systems locate positions in a two-dimensional (planar) coordinate system. Such a system must use a map projection to translate positions from the Earth's nearly spherical surface to a hypothetical mapping plane. Although the projection procedure inevitably introduces systematic spatial distortions, particular types of distortion can be minimized to suit the geographic scope and intended use of the map data. This booklet provides a conceptual introduction to map projections and geographic reference systems.

Prerequisite Skills This booklet assumes that you have completed the exercises in the tutorial booklets *Displaying Geospatial Data* and *Navigating*. Those exercises introduce essential skills and basic techniques that are not covered again here. Please consult those booklets for any review you need.

Sample Data This booklet does not use exercises with specific sample data to develop the topics presented. You can, however, use the sample data that is distributed with the TNT products to explore the ideas discussed on these pages. If you do not have access to a TNT products DVD, you can download the data from MicroImages' web site. Make a read-write copy on your hard drive of the data sets you want to use so changes can be saved.

More Documentation This booklet is intended only as an introduction to concepts of map projections and spatial reference systems. Consult the tutorial booklet entitled *Coordinate Reference Systems* for more information about how these concepts are implemented in TNTmips.

TNTmips® Pro and TNTmips Free TNTmips (the Map and Image Processing System) comes in three versions: the professional version of TNTmips (TNTmips Pro), the low-cost TNTmips Basic version, and the TNTmips Free version. All versions run exactly the same code from the TNT products DVD and have nearly the same features. If you did not purchase the professional version (which requires a software license key) or TNTmips Basic, then TNTmips operates in TNTmips Free mode.

Randall B. Smith, Ph.D., 27 September 2011

You can print or read this booklet in color from MicroImages' web site. The web site is also your source for the newest tutorial booklets on other topics. You can download an installation guide, sample data, and the latest version of TNTmips.

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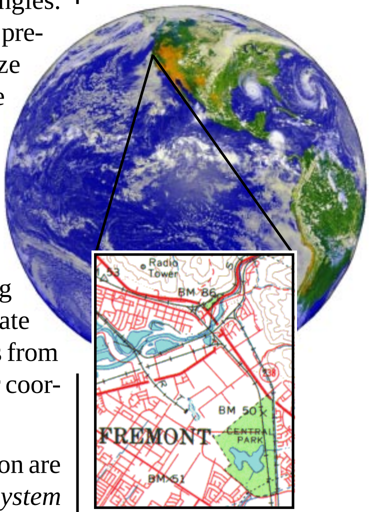
Introduction to Map Projections

Although Earth images and map data that you use are typically rendered onto flat surfaces (such as your computer screen or a sheet of paper), the Earth's surface obviously is not flat. Because Earth has a curving, not-quite sphericial shape, planar maps of all but the smallest areas contain significant geometric distortions of shapes, areas, distances, or angles. In order to produce two-dimensional maps that preserve geographic relationships and minimize particular types of distortion, several steps are required. We must choose a geometric model (known as a *geodetic datum*) that closely approximates the shape of the Earth, yet can be described in simple mathematical terms. We must also adopt a *coordinate system* for referencing geographic locations in the mapping plane. Finally we must choose an appropriate mathematical method of transferring locations from the idealized Earth model to the chosen planar coordinate system: a *map projection*.



A coordinate system, datum, and map projection are all components of the *coordinate reference system* for a spatial object. You can choose coordinate reference system parameters in TNTmips when you establish georeference control for your project materials, when you import georeferenced data, or when you warp or resample georeferenced objects to a new projection. In addition, the Spatial Data Display process in all TNT products allows you to change the coordinate reference system for the layers in a group, either to control the display geometry or to provide coordinate readouts.

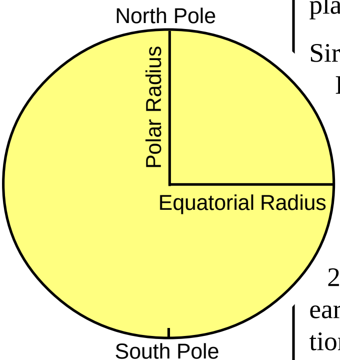
The tutorial booklet entitled *Coordinate Reference Systems* introduces the mechanics of selecting coordinate reference system components. The present booklet provides a conceptual introduction to map projections, coordinate systems, and geodetic datums. We will begin with the latter concept.

The shape of the Earth and the geodetic datum concept are covered on pages 4-6. Page 7-9 discuss map scale and the basics of coordinate systems. Map projections are introduced on pages 10-12, and pages 13-19 present some widely used examples. Several common projected coordinate systems are discussed on pages 20-21. Page 22 covers use of map projections in group display. Resources for further study are presented on page 23.

The Shape of the Earth

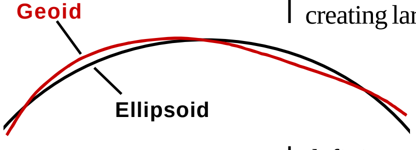
Geodesy is the branch of science concerned with measuring the size and shape of the Earth.

The Earth Ellipsoid
(flattening exaggerated)



From our traditional human vantage point on the ground, the Earth's surface appears rough and irregular. But spacecraft images show that on a planetary scale, the Earth has a regular geometric shape with a very smooth surface. Knowledge of this shape is a prerequisite if we are to accurately transform geographic coordinates through a map projection to a planar coordinate system.

Sir Isaac Newton was the first to suggest that the Earth, because it rotates on its polar axis, is not quite spherical, but bulges outward slightly at the equator. The polar radius is thus slightly shorter than the equatorial radius. If expressed as a fraction of the equatorial radius, the difference according to current measurements is about 1/298.257, a value known as polar flattening. The earth thus appears slightly elliptical in a cross section through the poles. Rotating this ellipse about the polar axis results in a three-dimensional shape known as an *ellipsoid*. It is this geometric shape that cartographers use as the reference surface for creating large-scale maps (such as topographic maps).



While cartographers need a simple geometric representation of the Earth's shape, geodesists are also interested in defining a level surface to provide a basis for land surveys. A level surface at any point is the plane perpendicular to the local direction of gravity (the direction in which the surveyor's plumb bob points). Because of local topography and the irregular distribution of mass within the Earth, the local direction of gravity may not be exactly perpendicular to the ideal ellipsoidal surface. Hence the *geoid* (the level surface on which gravity is everywhere equal to its strength at mean sea level) is not perfectly ellipsoidal in shape. Instead it has smooth, irregular undulations that depart from the ideal ellipsoid by as much as 100 meters.

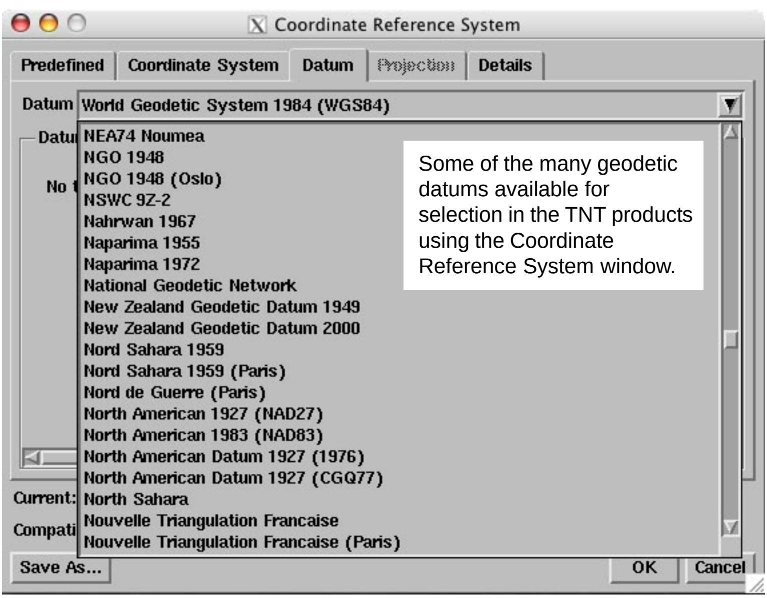
The geographic positions of survey benchmarks are either measured or adjusted to conform to an ideal ellipsoidal surface. The elevations shown on topographic maps, however, are expressed relative to the mean sea level geoid.

Geodetic Datums

Many different reference ellipsoids have been used by cartographers over the years. Estimates of the ellipsoid dimensions that best fit the overall shape of the Earth have changed as new technologies have permitted increasingly refined measurements of the planet. In addition, any global best-fit ellipsoid does not fit all parts of the surface equally well because of the irregular undulations of the geoid. For this reason many additional reference ellipsoids have been defined for surveying and mapping in different countries. Each regionally-defined ellipsoid has been chosen to conform as closely as possible to the local geoid shape over that specific region. The resulting ellipsoids differ in their dimensions, the location of their centers, and the orientation of their polar axes.

A *horizontal geodetic datum* specifies an ellipsoidal surface used as a reference for mapping horizontal positions. The definition includes the dimensions and position of the reference ellipsoid. Planar coordinates used to express positions for georeferenced data always refer to a specific geodetic datum (usually that of the map from which the data were abstracted).

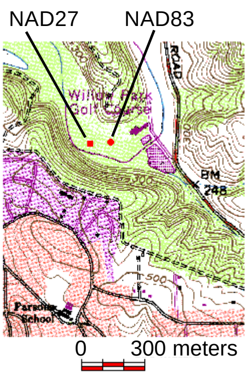
The TNT products include specifications for a great many geodetic datums. When you georeference new data, be sure to check the datum specification. (You may need to consult the documentation or metadata that accompanies the data). *Referencing map coordinates to the wrong datum can lead to positioning errors of tens to hundreds of meters!*



Some of the many geodetic datums available for selection in the TNT products using the Coordinate Reference System window.

North American Datums

The position of a given set of geodetic latitude and longitude coordinates in North America can shift up to 300 meters with the change from NAD27 to NAD83. The amount of the shift varies from place to place. The illustration shows position N 37° 43' 31.84", W 122° 05' 01.03" in the Hayward, California quadrangle plotted with respect to both datums.



The U.S. Geological Survey has begun converting its primary series of topographic maps (1:24,000 scale 7.5-minute quadrangles) to NAD83 as part of the periodic revision process.

The World Geodetic System 1984 (WGS84) datum, developed by the U.S. Department of Defense, is almost identical to NAD83. Positions in the two systems agree to within about 0.1 millimeter. WGS84 is the reference used for positions determined from the Global Positioning System satellites.

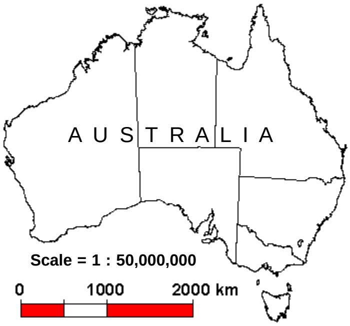
There are two geodetic datums in common use in North America. The North American Datum of 1927 (NAD27) is an example of a regional datum, in which the ellipsoid (Clarke 1866) is tied to an initial point of reference on the surface. NAD27 was developed in conjunction with the adjustment of a number of independent geodetic survey networks to form a single integrated network originating at Meades Ranch, Kansas. The ellipsoid's position is specified relative to the Meades Ranch survey station, with the result that the ellipsoid is not earth-centered.

The vast majority of U.S. Geological Survey topographic maps have been produced using NAD27. Over the years, however, it has become clear that the accuracy of the survey network associated with this datum is not sufficient for many modern needs. Surveying errors, destruction of survey monuments, and horizontal movements of the Earth's crust have led to horizontal errors in control point positions as large as 1 part in 15,000. The creation of satellite-based positioning systems also now requires the use of a global best-fit ellipsoid centered on the Earth's center of mass (termed a *geocentric* ellipsoid).

As a result of these problems, the U.S. National Geodetic Survey has introduced a new datum, the North American Datum of 1983 (NAD83). The reference ellipsoid used is that of the International Union of Geodesy and Geophysics Geographic Reference System 1980 (GRS 1980), which is geocentric, and thus has no single initial reference point on the surface. New latitude and longitude coordinates were computed for geodetic control points by least-squares adjustment. The calculations included over 1.75 million positions obtained by traditional survey and satellite observations, using sites throughout North America, Greenland, and the Caribbean.

Map Scale

Globes and traditional paper maps depict scaled-down versions of surface features. *Map scale* is defined mathematically as the ratio between a unit distance on the map and the actual distance (in the same units) that it represents in the real area depicted on the map. A map scale can then be represented as a fraction with 1 in the numerator (as in 1 / 250,000), but map scale is more commonly printed on maps using a colon as a separator (as in 1: 250,000).



Example of a small-scale map

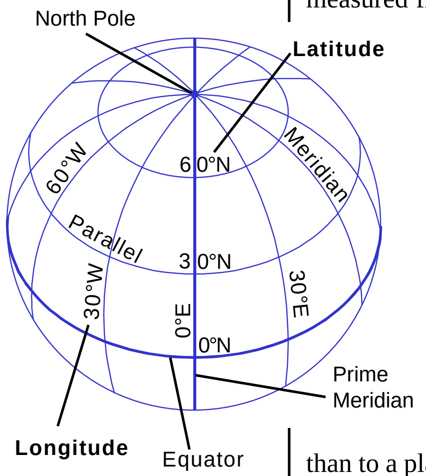
Maps are can be roughly categorized by their scale. A small map that depicts a large area has a small scale fraction (large number in the denominator), and can be termed a *small-scale map*. Examples include the small map of Australia shown on this page (scale of 1: 50,000,000) and the page-size maps shown in printed atlases. A map of the same size that showed a much smaller area of the world would have a larger scale fraction (smaller number in the denominator), and could be called a *large-scale map*. Topographic quadrangle maps (such as the excerpt on the preceding page), which typically have map scales between 1: 24,000 and 1: 100,000, are examples of large-scale maps. Large-scale maps can depict more map features more accurately than can small-scale maps.

The Scale field at the bottom of TNT View windows shows the map scale (at the current zoom level) for the georeferenced data you are viewing.

Once map data have been converted to electronic form, they can be displayed at any scale. In the TNT products the current view scale is shown in the Scale field at the bottom of View windows (see the bottom illustration). While exercising the freedom to view your map data at any scale, you should not lose sight of the fact that the map features were originally created at a particular map scale. The detail and level of accuracy of the map features are commensurate with that original map scale regardless of the current scale at which you are viewing them.

Latitude / Longitude Coordinates

The spherical latitude/ longitude coordinate system has been adapted mathematically to account for Earth's ellipsoidal shape, yielding *geodetic latitude and longitude* values.



Latitude / Longitude is used as the native coordinate system for several widely available forms of spatial data (including the U.S. Census Bureau's TIGER / Line data, the Digital Chart of the World, and some types of USGS Digital Elevation Models and Digital Line Graphs).

The oldest global coordinate system is the Latitude/ Longitude system (also referred to as *Geographic* coordinates). It is the primary system used for determining positions in surveying and navigation. A grid of east-west latitude lines (parallels) and north-south longitude lines (meridians) represent angles relative to standard reference planes. Latitude is measured from 0 to 90 degrees north and south of the equator. Longitude values range from 0 to 180 degrees east or west of the Prime Meridian, which by international convention passes through the Royal Observatory at Greenwich, England. (South latitude and west longitude coordinates are treated as negative values in the TNT products, but you can use the standard directional notation and omit the minus sign when entering values in process dialogs.)

Because the Latitude/Longitude system references locations to a spheroid rather than to a plane, it is not associated with a map projection. Use of latitude/longitude coordinates can complicate data display and spatial analysis. One degree of latitude represents the same horizontal distance anywhere on the Earth's surface. However, because lines of longitude are farthest apart at the equator and converge to single points at the poles, the horizontal distance equivalent to one degree of longitude varies with latitude. Many TNTmips processes adjust distance and area calculations for objects with latitude/longitude coordinates to compensate for this effect, but these approximations are less accurate than calculations with data projected to a planar coordinate system. If you have data of regional or smaller extent with Geographic coordinates, you will achieve better results by warping or resampling the data to a planar coordinate system.

Planar Coordinate Systems

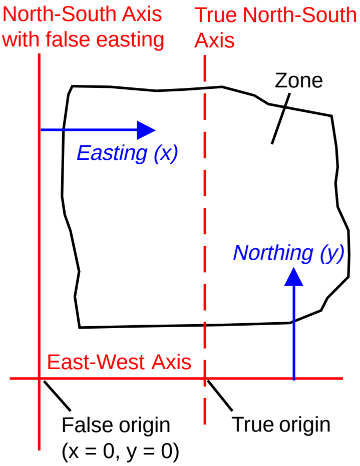
Portion of a color orthophoto overlaid with a map grid with 200 meter spacing between the grid lines.

A large-scale map represents a small portion of the Earth's surface as a plane using a rectilinear grid coordinate system to designate location coordinates. A planar *Cartesian coordinate system* has an origin set by the intersection of two perpendicular coordinate axes and tied to a known location. The coordinate axes are normally oriented so that the x-axis is east-west and the y-axis is north-south. Grid coordinates are customarily referred to as *easting* (distance from the north-south axis) and *northing* (distance from the east-west axis). The definition of a Cartesian coordinate system also includes the units used to measure distances relative to these axes (such as meters or feet).

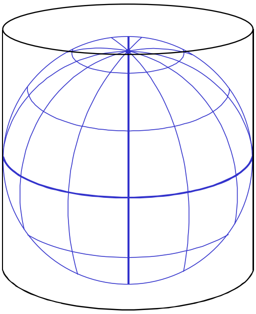
For very small areas (such as a building construction site) the curvature of Earth's surface is so slight that ground locations can be referenced directly to an arbitrary planar Cartesian coordinate system without introducing significant positional errors. For areas larger than a few square kilometers, however, the difference between a planar and curving surface becomes important when relating ground and map locations. A map projection must then be selected to relate surface and map coordinates to reduce undesirable distortions in the map. In the TNT products a Cartesian coordinate system that is related to the Earth via a map projection is termed a *projected coordinate system*.

A number of projected coordinate systems have been set up to represent large areas (states, countries, or larger areas) by subdividing the coverage area into geographic zones, each of which has its own origin. To minimize variations in scale associated with the map projection, one of the coordinate axes (sometimes both) typically bisects the zone. In that case, in order to force all locations within the zone to have positive coordinate values, a large number is added to one or both coordinates of the origin, termed *false easting* and *false northing*. This procedure moves the 0,0 position of the coordinate system outside the zone to create a *false origin*, as illustrated to the right.

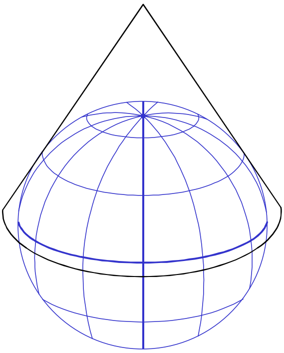
Planar Coordinate System with false easting



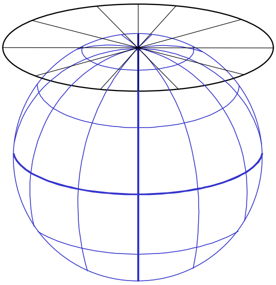
Map Projections



Cylindrical Projection



Conic Projection



Azimuthal Projection

A map projection can be thought of as a process or as the output of the process. For example, a map projection can be described as a systematic representation of all or part of the Earth's surface on a plane. But this representation is the result of a complex transformation process. The input for the map projection process is a set of horizontal positions on the surface of a reference ellipsoid. The output is a corresponding set of positions in a reference plane at a reduced scale. In this sense, a map projection is a complex mathematical formula that produces the desired coordinate transformations. However, a mathematical approach is not required for understanding the basic concepts surrounding the map projection process.

Transforming coordinates from the Earth ellipsoid to a map involves projection to a simple geometric surface that can be flattened to a plane without further distortion (such as stretching or shearing). Such a surface is called a *developable surface*. Three types of developable surfaces form the basis of most common map projections: a cylinder, a cone, or the plane itself.

Simple *cylindrical projections* are constructed using a cylinder that has its entire circumference tangent to the Earth's surface along a great circle, such as the equator. Simple *conic projections* use a cone that is tangent to the surface along a small circle, such as a parallel of latitude. Projecting positions directly to a plane tangent to the Earth's surface creates an *azimuthal projection*.

Regular cylindrical and conic projections orient the axis of the cylinder or cone parallel to the Earth's axis. If the axes are not parallel, the result is a transverse (perpendicular axes) or oblique projection. Additional variants involve the cylinder, cone, or plane cutting through the globe rather than being merely tangent to the surface.

Map Distortions

Projecting the Earth's curving surface to a mapping plane cannot be done without distorting the surface features in some way. Therefore all maps include some type of distortion. When selecting a map projection, cartographers must decide which characteristic (or combination thereof) should be shown accurately at the expense of the others. The map properties that enter into this choice are *scale*, *area*, *shape*, and *direction*.

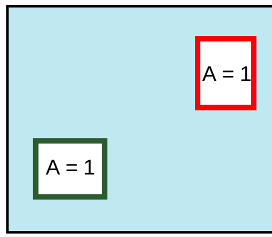
All maps are scaled representations of the Earth's surface. Measuring exact distances from any map features in any direction would require constant scale throughout the map, but no map projection can achieve this. In most projections scale remains constant along one or more standard lines, and careful positioning of these lines can minimize scale variations elsewhere in the map. Specialized *equidistant* map projections maintain constant scale in all directions from one or two standard points.

In many types of spatial analysis it is important to compare the areas of different features. Such comparisons require that surface features with equal areas are represented by the same map area regardless of where they occur. An *equal-area* map projection conserves area but distorts the shapes of features.

A map projection is *conformal* if the shapes of small surface features are shown without distortion. This property is the result of correctly representing local angles around each point, and maintaining constant local scale in all directions. Conformality is a local property; while small features are shown correctly, large shapes must be distorted. A map projection cannot be both conformal and equal-area.

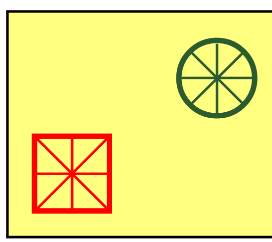
No map projection can represent all great circle directions as straight lines. *Azimuthal* projections show all great circles passing through the projection center as straight lines.

Due to the projection from a curving surface to a plane, map scale varies from place to place and for different directions on maps. The *scale factor* in any map location is the actual map scale at that location divided by the nominal map scale. For those special locations where the actual map scale equales the nominal scale, the scale factor equals 1.0.



Equal-Area Projection

Shapes are distorted, but all map features are shown with the correct relative areas.



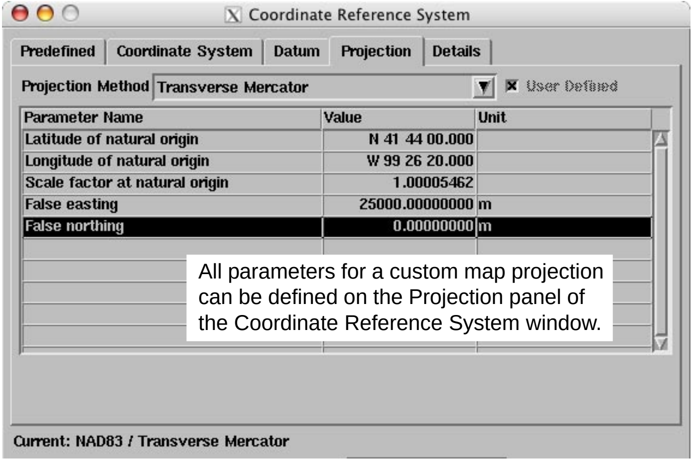
Conformal Projection

Small shapes maintain correct proportions, as local scale and angles are constant around each point. Relative area of features varies throughout the map.

Using Map Projections

The TNT products provide built-in support for hundreds of projected coordinate systems whose definitions include all parameters for the required map projection. So when you import or georeference new geodata, or reproject existing geodata, in most cases you do not need to select or set up a map projection directly. You merely select the predefined coordinate reference system or projected coordinate system that matches your data. (Several of the commonly-used projected coordinate systems are described later in this booklet.)

In some cases you may need to import or georeference spatial data referenced to a projected coordinate system that is not among the predefined choices. Or you may want to define your own projected coordinate system for a project. For these cases, the Coordinate Reference System window in TNTmips allows you to set up and save a custom coordinate reference system with your choice of map projection and projection parameters. The required procedures are introduced in the tutorial booklet entitled *Coordinate Reference Systems*.



All parameters for a custom map projection can be defined on the Projection panel of the Coordinate Reference System window.

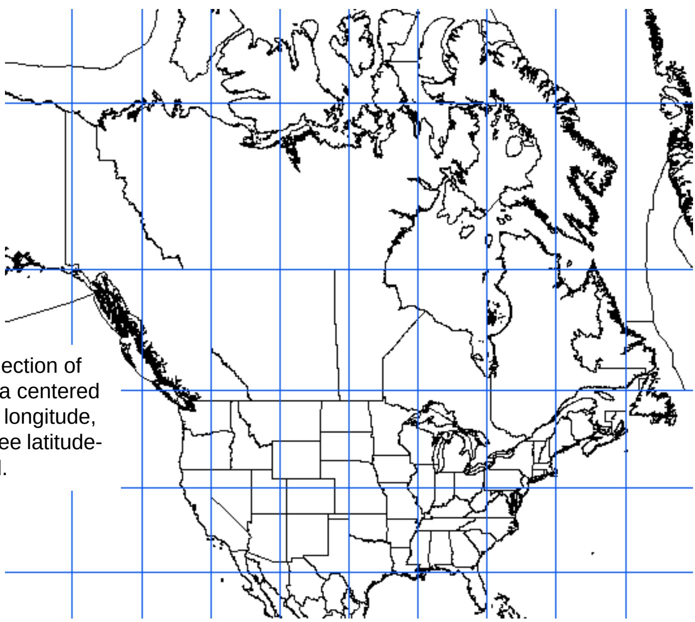
A particular projection can be centered on the project area by choosing appropriate projection parameters. Because of varying patterns of distortion, some projections are better for areas elongate in an east-west direction and others for areas elongate north-south. Large-scale maps used to determine or plot directions, such as navigational charts or topographic maps, should use a conformal map projection. Equal-area projections are appropriate for smaller-scale thematic maps and maps that show spatial distributions. The following pages discuss some of the projections that are commonly used on paper maps and in the projected coordinate systems used with digital geodata.

Mercator Projection

One of the best known map projections, the Mercator projection was devised specifically as an aid to navigation. A ship's course can be plotted easily with the Mercator projection because a course with constant azimuth (compass direction) is shown as a straight line.

The Mercator is a regular cylindrical projection (the cylinder axis passes through the north and south poles). Meridians of longitude are shown as equally spaced vertical lines, intersected at right angles by straight horizontal parallels. The spacing between parallels increases away from the Equator to produce a conformal projection. The scale is true along the equator for a tangent Mercator projection, which has a natural origin at the equator. Assigning a different latitude of natural origin produces an intersecting cylindrical projection with two standard parallels (with true scale) equidistant from the equator.

The poleward increase in spacing of parallels produces great distortions of area in high-latitude regions. In fact, the *y* coordinate for the poles is infinity, so maps using the Mercator projection rarely extend poleward of 75 degrees latitude. The Mercator projection remains in common use on nautical charts. Because scale distorion is minor near the equator, it also is a suitable conformal projection for equatorial regions.



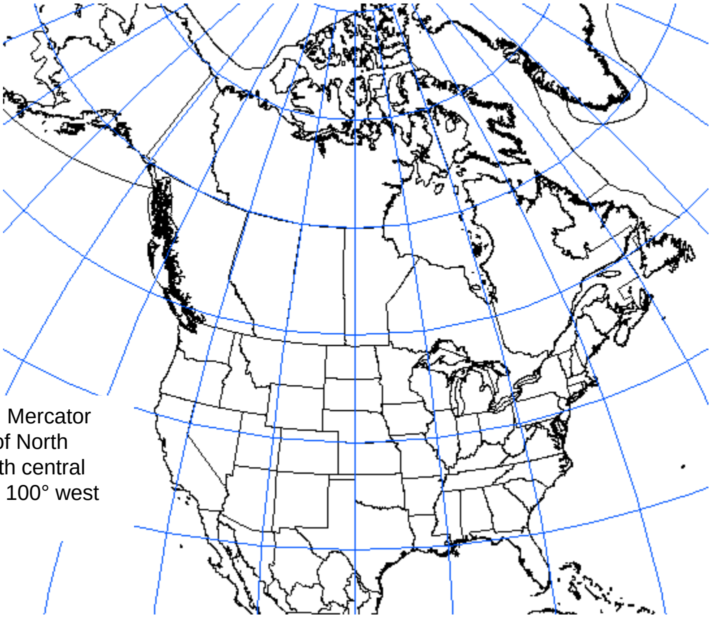
Mercator projection of North America centered on 100° west longitude, with ten-degree latitude-longitude grid.

Transverse Mercator Projection

The Transverse Mercator projection is a conformal cylindrical projection with the cylinder rotated 90 degrees with respect to the regular Mercator projection. The cylinder is tangent to a central meridian of longitude around its entire circumference. The central meridian and equator are straight lines, but all other meridians and parallels are complex curves.

Scale is constant along any meridian. Scale change along parallels is insignificant near the central meridian, but increases rapidly away from it, so the Transverse Mercator projection is useful only for narrow bands along the central meridian. It forms the basis for the Universal Transverse Mercator Coordinate System, and is primarily used for large-scale (1:24,000 to 1:250,000) quadrangle maps. The central meridian can be mapped at true scale (Central Scale parameter = 1.0), or at a slightly reduced constant scale (for example, the value 0.9996 used in the UTM system). In the latter case a pair of meridians bracketing the central one maintain true scale, and the mean scale for the entire map is closer to the true scale.

In the United States the Transverse Mercator projection is also used in the State Plane Coordinate System for states (or individual state zones) which are more elongate in the north-south direction. Gauss Conformal and Gauss-Kruger are European names for the Transverse Mercator projection.



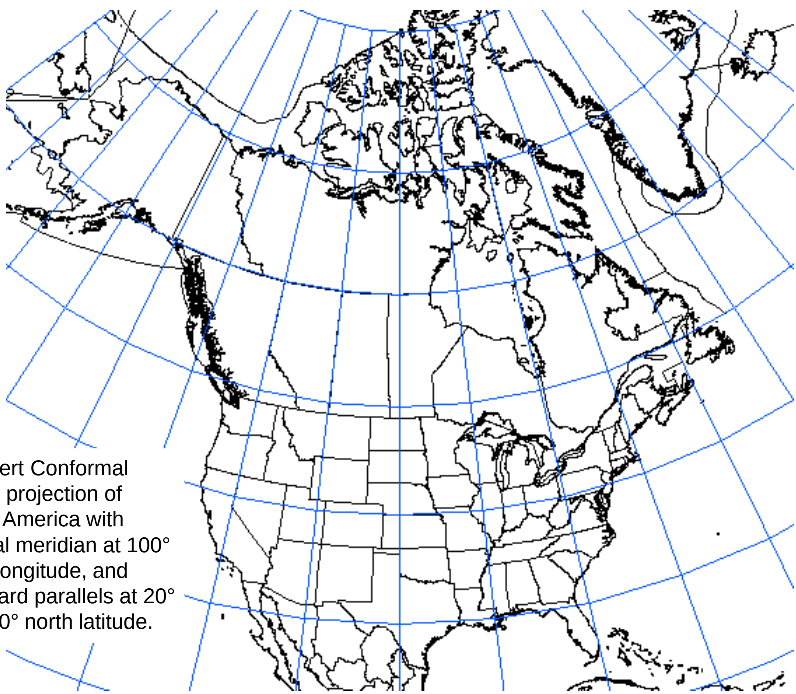
Transverse Mercator projection of North America with central meridian at 100° west longitude.

Lambert Conformal Conic Projection

The Lambert Conformal Conic projection is normally constructed with a developable surface that intersects the globe along two standard parallels. You must specify the latitude for each standard parallel when setting up the projection, as well as the latitude to use as the origin for northing coordinates. Scale is true along the standard parallels, smaller between them, and larger outside them. Area distortion is also relatively small between and near the standard parallels. This projection therefore is particularly useful for mid-latitude regions which are elongate in the east-west direction.

The parallels in the Lambert Conformal Conic projection are concentric circles, while the meridians are equally-spaced straight radii of these circles. The meridians intersect parallels at right angles (as expected in a conformal projection). Spacing of the parallels increases north and south from the band defined by the standard parallels.

In the United States the Lambert Conformal Conic projection (also known as Conical Orthomorphic) is used in the State Plane Coordinate System for state zones with greater east-west than north-south extent. It is also used for regional world aeronautical charts and for topographic maps in some countries.



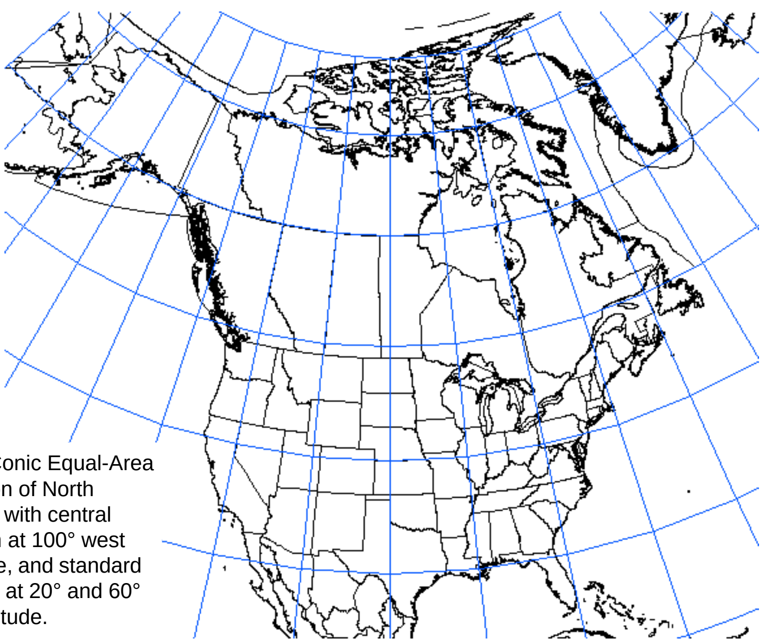
Lambert Conformal Conic projection of North America with central meridian at 100° west longitude, and standard parallels at 20° and 60° north latitude.

Albers Conic Equal-Area Projection

The Albers Conic Equal-Area Projection is commonly used to map large areas in the mid-latitudes, such as the entire "lower 48" United States. In this normal application there are two standard parallels. Like other conic projections, the parallels are concentric circular arcs with equally-spaced meridians intersecting them at right angles. The change in spacing between parallels is opposite from the Lambert Conformal Conic projection; parallels are more widely spaced between the standard parallels, and more closely spaced outside them.

Each parallel has a constant scale, with true scale along the standard parallels, smaller scale between them, and larger scale outside them. To maintain equal area, scale variations along the meridians show a reciprocal pattern; the increase in east-west scale outside the standard parallels is balanced by a decrease in north-south scale.

The Albers Conic Equal-Area projection has been used by the U.S. Geological Survey for a number of small-scale maps of the United States, using latitude 29.5º and 45.5º north as standard parallels. Mid-latitude distortion is minor for most normal conic projections, so that differences between them become obvious only when the region mapped extends to higher or lower latitudes.



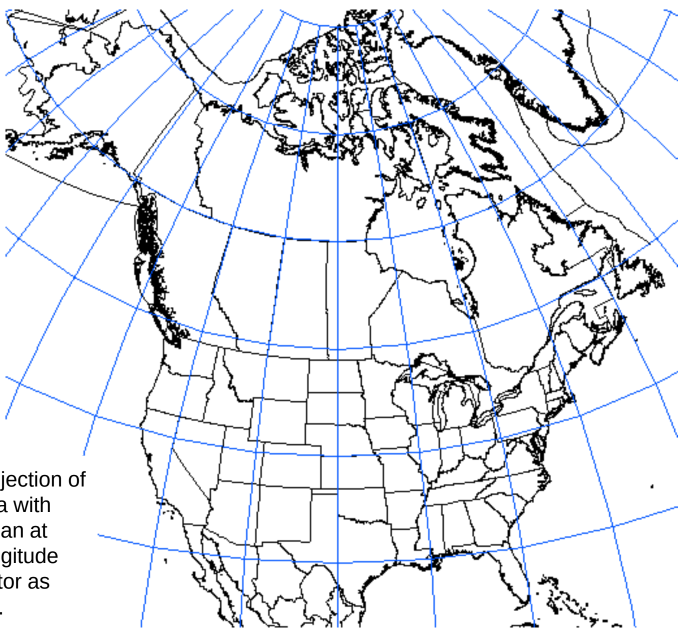
Albers Conic Equal-Area projection of North America with central meridian at 100° west longitude, and standard parallels at 20° and 60° north latitude.

Polyconic Projection

The Polyconic projection was devised in the early days of U.S. government surveying and was used until the 1950's for all large-scale U.S. Geological Survey quadrangle maps (now superceded for most revised maps by Universal Transverse Mercator). The Polyconic projection produces extremely small distortion over small areas near the central meridian, despite being neither conformal nor equal-area.

Parallels in the Polyconic projection are circular arcs, but are not concentric. Each parallel is the trace of a unique cone tangent to the globe at that latitude. The name thus refers to the fact that there are many cones involved in creating the projection, rather than a single conic developable surface. When chosen as the origin latitude, the equator is a straight line. The central meridian is also a straight line, but all other meridians are complex curves that are not exactly perpendicular to the parallels.

Scale is true along each parallel and along the central meridian. When the central meridian is chosen to lie within a large-scale map quadrangle, scale distortion is almost neglible for the map. Because polyconic quadrangle maps are not precisely rectangular, they cannot be mosaicked in both north-south and east-west directions without gaps or overlaps.



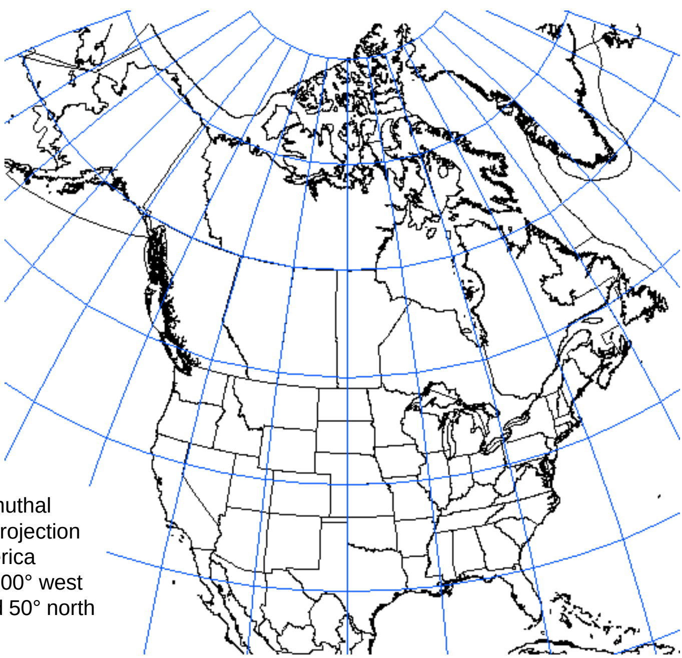
Polyconic projection of North America with central meridian at 100° west longitude and the equator as origin latitude.

Lambert Azimuthal Equal-Area Projection

The Lambert Azimuthal Equal-Area projection transforms surface coordinates directly to a plane tangent to the surface. The point of tangency forms the center of the projection, and is specified by the longitude and latitude of natural origin. In general, the projection center should coincide with the center of the area to be mapped. Scale is true only at the center point, but deviation from true scale for other points on the map is less than for other forms of azimuthal projection.

Scale in the radial direction decreases away from the center. Scale perpendicular to a radius increases with distance from the center, as required to produce the equal-area property. Distortion is symmetric about the central point, so this projection is appropriate for areas that have nearly equal north-south and east-west extents.

The pattern of meridians and parallels depends on the choice of central point. If the projection is centered at a pole, meridians are straight radii and parallels are concentric circles. In an oblique projection, such as the example illustrated below, only the central meridian is straight, and other meridians and parallels are complex curves. The Lambert Azimuthal Equal-Area projection has been used commonly for small-scale maps of the polar regions, ocean basins, and continents.

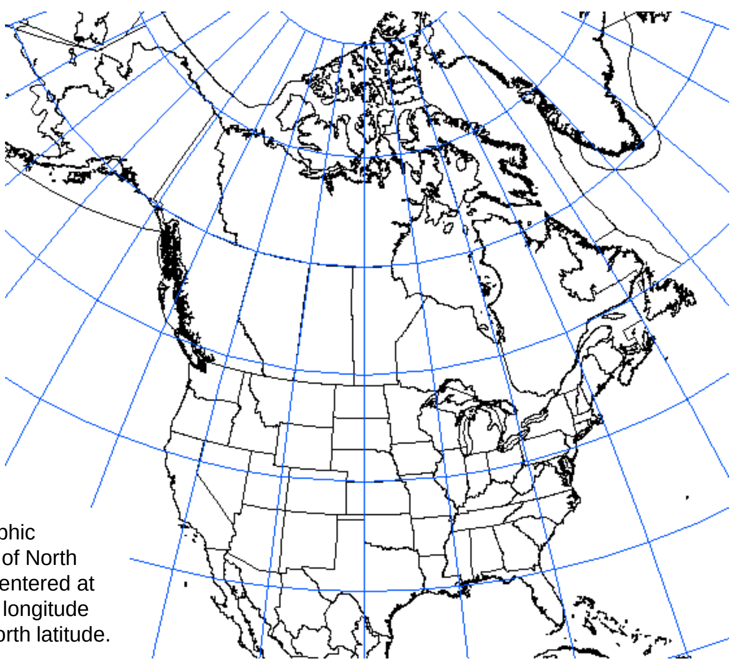


Lambert Azimuthal Equal-Area projection of North America centered at 100° west longitude and 50° north latitude.

Stereographic Projection

The Stereographic projection is a conformal azimuthal projection. When used for large areas, so that the spherical Earth model can be used, it is also a true perspective projection, unlike most map projections. Surface locations are projected to a tangent plane using a single projection point on the surface of the sphere exactly opposite the center of the projection. When used to map smaller areas, so that the ellipsoidal Earth model is used, the projection is not perspective, and, in order to maintain conformality, is not truly azimuthal.

The Stereographic projection is most commonly used to map polar regions, in which case the pole is chosen as the center point. (The Universal Polar Sterographic coordinate system is an adjunct to the Universal Transverse Mercator system, extending this universal system to polar regions.) In this form, the map shows meridians as straight radii of concentric circles representing parallels. In an oblique Stereographic projection, such as the illustration below, only the central meridian is straight. All other meridians and parallels are circular arcs intersecting at right angles. Scale increases away from the central point, which normally has true scale (scale factor at natural origin = 1.0). Reducing the scale value produces an intersecting rather than tangential plane. Scale is then true along an ellipse centered on the projection center, and the mean scale for the entire map is closer to the true scale.



Stereographic projection of North America centered at 100° west longitude and 50° north latitude.

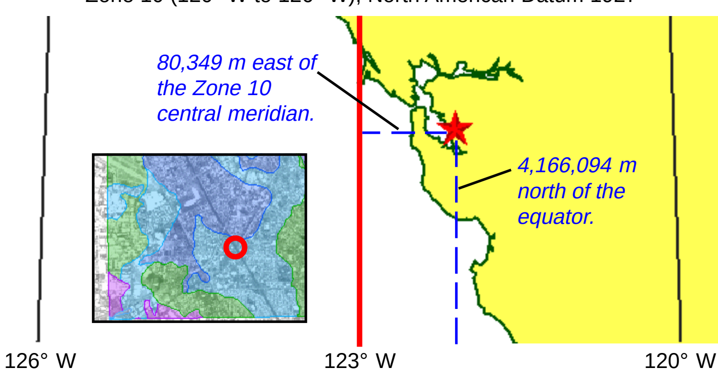
Universal Transverse Mercator System

The next two pages discuss several of the formally-defined projected coordinate systems that are in widespread use in the United States and throughout the world.

The Universal Transverse Mercator (UTM) system is a global set of coordinate systems commonly used in the United States on topographic maps and for large-scale digital cartographic data. The UTM system divides the world into uniform zones with a width of 6 degrees of longitude. The zones are numbered from 1 to 60 eastward, beginning at 180 degrees. Easting is measured from a zone's central meridian, which is assigned a false easting of 500,000 meters. Northing is measured relative to the equator, which has a value of 0 meters for coordinates in the northern hemisphere. Northing values in the southern hemisphere decrease southward from a false northing of 10,000,000 meters at the equator. (You must choose either northern or southern hemisphere coordinates when choosing a UTM zone.) The scale factor at the central meridian is 0.9996. The illustration below shows a sample location in UTM zone 10, a highway intersection in the Hayward Quadrangle, California (USA).

The UTM coordinate system uses the Transverse Mercator map projection, which minimizes shape distortions for small geographic features. The inherent accuracy of distance measurements (related to scale variations) is one part in 2500. The Gauss-Kruger zonation system is very similar to UTM, except for a scale factor of 1.000 at the central meridian. Variants of the Gauss-Kruger zonation use either 6-degree or 3-degree geographic zones, and in some versions the zone number is added to the beginning of the 500,000 meter false easting value at each central meridian (e.g. 4,500,000 meter false easting for Zone 4 central meridian).

Hayward Quadrangle Highway Intersection UTM Coordinates
Easting 580,349 m, Northing 4,166,094 m
Zone 10 (120° W to 126° W), North American Datum 1927

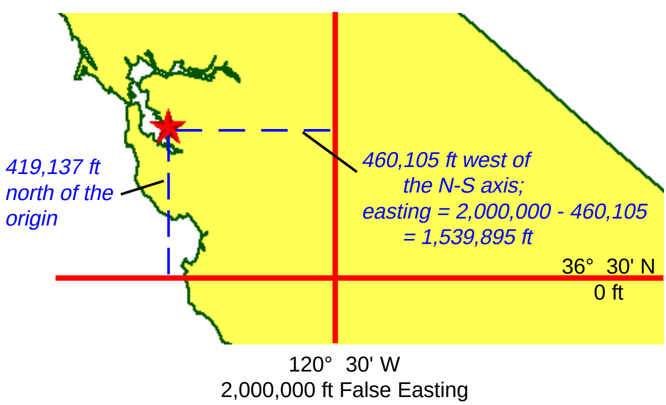


U.S. State Plane Coordinate System

The United States State Plane Coordinate System (SPCS) has been widely used as a grid system for land surveys. It was devised to provide each state with rectangular coordinates that could be tied to locations in the national geodetic survey system. The original system, based on the North American Datum 1927, uses coordinates in feet. Most states are divided into two or more overlapping state plane zones, each with its own coordinate system and projection. A few smaller states use a single zone. The Lambert Conformal Conic projection is used for zones with a larger east-west than north-south extent. Zones that are more elongate in the north-south direction are mapped using the Transverse Mercator projection. Scale variations are minimized to provide an accuracy of one part in 10,000 for distance measurements. State Plane Coordinate tick marks and zone information can be found on U.S. Geological Survey topographic maps.

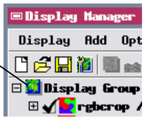
With the development of the North American Datum 1983, a revised version of the State Plane Coordinate System based on that datum was also developed. Zones were redefined for some states, and northing and easting coordinates are nominally in meters. However, some state and local governments require the use of feet as a measurement unit with SPCS83. To cover these variations, the TNT products provide two versions of each SPCS27 and SPCS83 zone, one in meters and one in US feet.

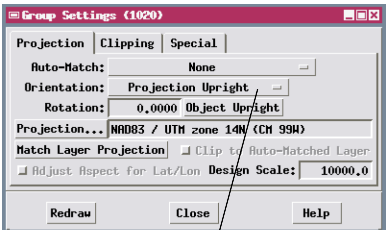
Hayward Quadrangle Highway Intersection
State Plane Coordinates
Easting 1,539,895 ft, Northing 419,137 ft
California Zone III, North American Datum 1927

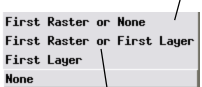


Using Map Projections in Group Display

In Display, open the Group Settings window for the desired group by left-clicking on its Settings icon button in the Display Manager window





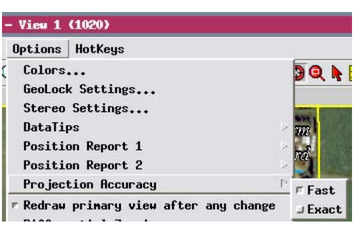


The [First Raster or First Layer] and [First Layer] options always use the object coordinates of the indicated layer to control the group orientation and projection. "First" refers to the lowest layer in the layer list.

If a geospatial object has been created in or reprojected to a specific map projection, the object's coordinate system coincides with the map coordinate system. For many georeferenced objects, however, this is not the case. The Orientation / Projection Options controls in the Group Settings window determine whether a display group is oriented relative to object coordinates or to a specific map coordinate system.

The Auto-Match option determines whether object coordinates are used or not, and, for multiple layers, which object provides the basis for the group projection. To orient the group to a map projection, choose [None] (or [First Raster or None] if there is no raster layer in the group). The Match Layer Projection button then becomes active; press it and then the Redraw button to redraw the view using the Coordinate Reference System of the layer that is currently active.

A vector, CAD, shape or TIN object in the display group is projected precisely to the selected map coordinates, subject to the inherent accuracy of the element coordinates. Reorientation of a raster object is governed by the Positional Accuracy option in the View window's Option menu. The Fast option changes the orientation and scale in a uniform manner to approximately match the output projection. The Exact option provides an exact resampling to the projection, but can take slightly longer to redisplay the view.



As you gather spatial data from different sources for a project, you will probably end up with data in a number of different coordinate systems and projections. The Display process can overlay layers with different coordinate reference systems with reasonable registration, but for maximum efficiency materials that will be used together routinely should be reprojected to a common coordinate reference system. For raster images, choose Image / Resample and Reproject / Automatic from the TNTmips menu. For geometric objects (vector, CAD, or TIN), choose Geometric / Reproject.

Looking Further

References

Langley, Richard B. (February, 1992). Basic geodesy for GPS. *GPS World, 3,* 44-49.

A valuable introduction to geodetic concepts, including the geoid, the ellipsoid, and geodetic datums.

Maling, D. H., (1992). *Coordinate Systems and Map Projections*. Oxford: Pergamon Press. 255 pp.

Robinson, A. H., Morrison, J. L., Muehrcke, P. C., Kimerling, A. J., and Guptill, S. C. (1995). *Elements of Cartography* (6th ed.). New York: John Wiley & Sons, Inc. 674 pp.

Contains excellent chapters on Geodesy, Map Projections, and Reference and Coordinate Systems.

Snyder, John P. (1987). *Map Projections -- A Working Manual*. U.S. Geological Survey Professional Paper 1395. Washington, D.C.: U.S. Government Printing Office. 383 pp.

An exhaustive description and history of map projections and related concepts, including the mathematical details.

Snyder, John P., and Voxland, Philip M. (1989). *An Album of Map Projections*. U.S. Geological Survey Professional Paper 1453. Washington, D.C.: U.S. Government Printing Office. 249 pp.

Internet Resources

Map Projection Overview, *Coordinate Systems Overview*, and *Geodetic Datum Overview*:

http://www.colorado.edu/geography/gcraft/notes/mapproj/mapproj.html

These web pages by Peter H. Dana (part of The Geographer's Craft Project) provide an illustrated discussion of each topic.

NGA Geospatial Sciences Publications:

http://earth-info.nga.mil/GandG/publications/index.html

This page at the U.S. National Geospatial Intelligence Agency website provides links to a number of online documents on geodesy and mapping science (in PDF or HTML format), including *Geodesy for the Layman* and *All You Ever Wanted to Know and Couldn't Find Out About Precise Positioning...(In Plain English)*.

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