Part 5: Chart Projections (2)

Practical Geodesy

In the previous article the importance of chart projections was described. An important aspect of projecting information from an ellipsoid on a flat surface is that the information will be distorted. In this article some of these distortions and their effect on calculations will be described.

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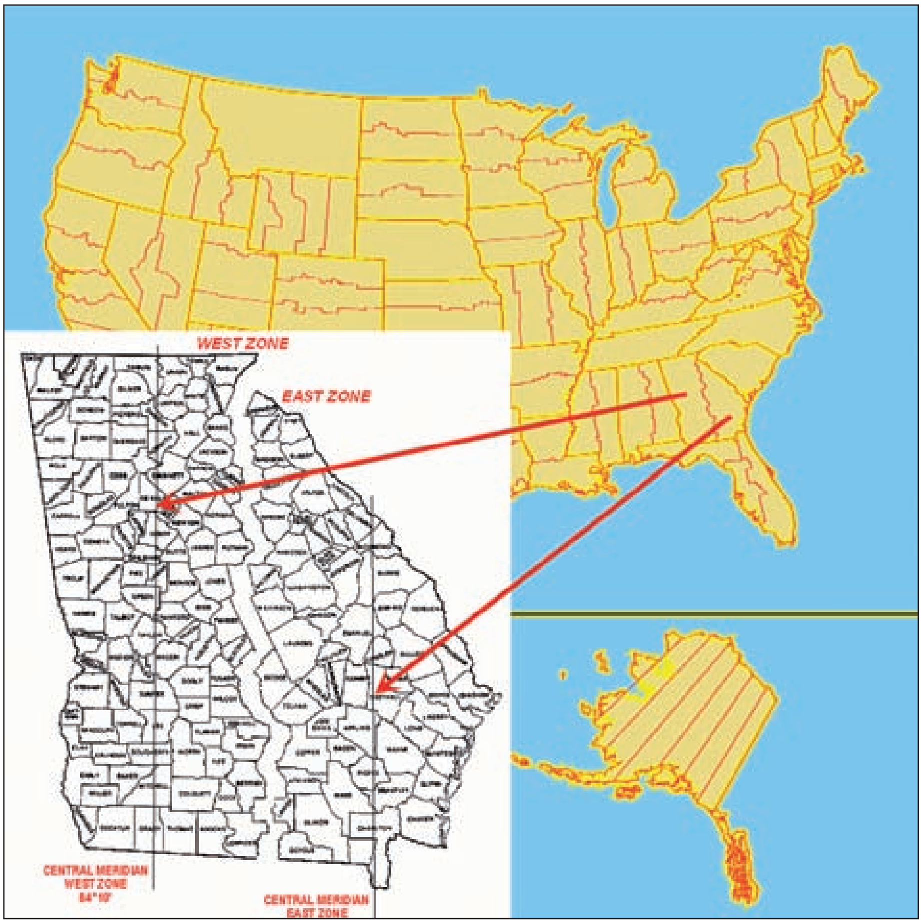


State plane coordinate system for the state of Georgia (2 TM zones).

We have already seen that the major distortions take place in distance and direction. Especially for land survey work, these are important parameters. When working on smaller projects distance or scale distortion will not pose a great problem and can generally be ignored. On larger scale projects, such as the laying of a pipeline or construction of a road, scale distortion will pose a problem. Heading or direction distortion is important for all types of projects.

Within every chart projection there are one or more points where the distortion will be non-existent. This is the point or line where the projection intersects with the ellipsoid. For the longitudinal Mercator this is the equator, while for the UTM projection it is the central meridian.

UTM Projection

A commonly used projection is the Universal Transverse Mercator or UTM projection. There is no geodetic datum associated with the UTM projection, so whenever it is used the geodetic datum from which the coordinates were projected has to be stated as well. A UTM projection can, for example, be based on WGS84 or ED50.

The UTM projection is derived from the Transverse Mercator or TM projection. A number of countries use the TM projection with an underlying geodetic datum. This combination is identified by name. Examples include the German Gauss-Kruger projection and the American State Plane Coordinate System (SPCS).

State Plane Coordinate System (SPCS)

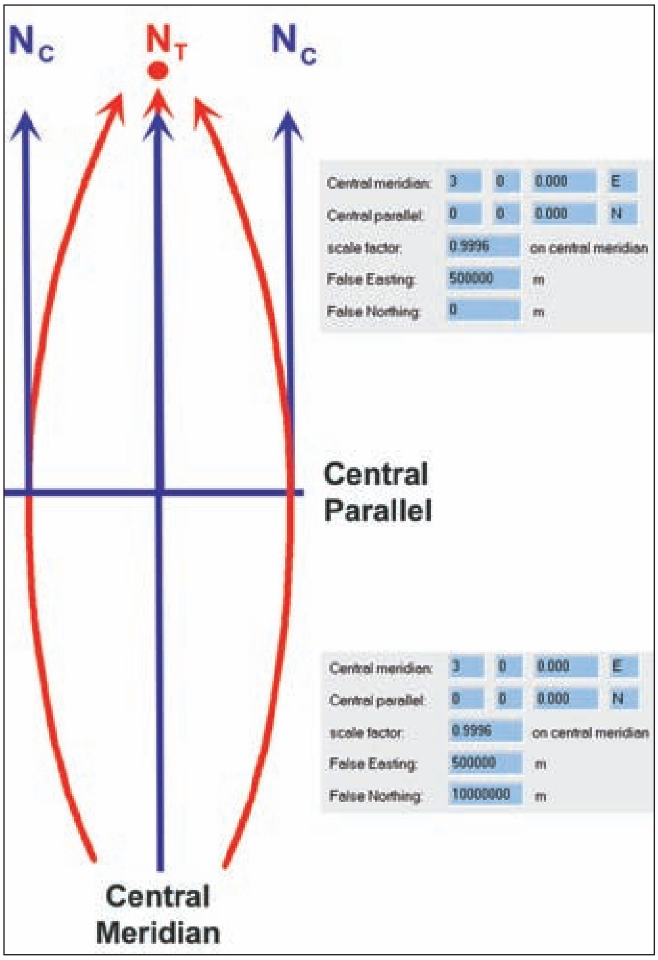
The SPCS is a somewhat peculiar system since it uses three different projections depending on which state is selected. For east-west lying states the Lambert conformal projection is used; for states lying generally north-south the Transverse Mercator is used; and for the Alaska panhandle the Oblique Mercator projection is used.

Most states are further divided into Federal Information Processing Standard (FIPS) zones that minimize distortion even further. The aim of the SPCS is to minimize scale distortion to a maximum of 1:10000, which at the time of design in the 1930s was supposed to be the maximum survey accuracy. The geodetic

North Directions

Headings are always referenced to north. This however is an ambiguous reference since there are a number of 'norths'. The following north references are in common use:

- True or geodetic north: this is the northern location of the axis that the earth revolves around.
- Magnetic north: the location of the magnetic North Pole. The latter slowly moves around true north.
- Chart north: the direction on a chart indicated by the northing or Y-axis. This axis is by definition at right angles to the easting or X-axis.



Single UTM zone with parameters showing as well the difference between chart north (N_C) and true north (N_T)

datum underlying the SPCS is always North American Datum 1983 (NAD1983).

Origin of the UTM System

As discussed in the previous article, UTM divides the world into strips or zones that are 6° wide. The line where the projection touches the earth runs north-south and is called the Central Meridian or CM. Since both a north/south and an east/west reference are needed for a position, an additional reference line is necessary. With UTM this is the equator. Therefore all positions in UTM are calculated referenced to the intersection point of the CM and the equator.

With the selected intersection point, negative coordinates (south, east) would exist. Since the minus sign is a common source of error when noting coordinates, a solution was found using a so-called false easting and northing. The rules are simple: to all computed easting from the projection formula 500,000 meters are added. For the northing it is slightly more complicated: if the positions are to the north of the equator then no false northing is added, but if the positions are to the south then 10,000,000 is added to the coordinates found from the projection. In other words, for positions in the southern hemisphere the equator has a northing of 10,000,000, while for positions in the northern hemisphere it has a northing of 0.

Scale Factor

In the origin of the projection the so-called scale factor equals exactly 1. One meter in reality will show as 1 projected meter. As we move out from the origin (line) the scale factor will increase. This effect is most evident in the longitudinal Mercator projection where the distance between the parallels increases from the equator towards either the North or the South Pole.

Since the distortion near the edges of the projection will become disproportionate with respect to the origin, the scale factor in the origin is decreased.

The actual result is that the projection no longer touches the ellipsoid but rather intersects it. As a result the line(s) where the scale factor equals exactly 1 will shift outward. When this shift is well selected, the result will be that the scale factor is equally divided across the projection.

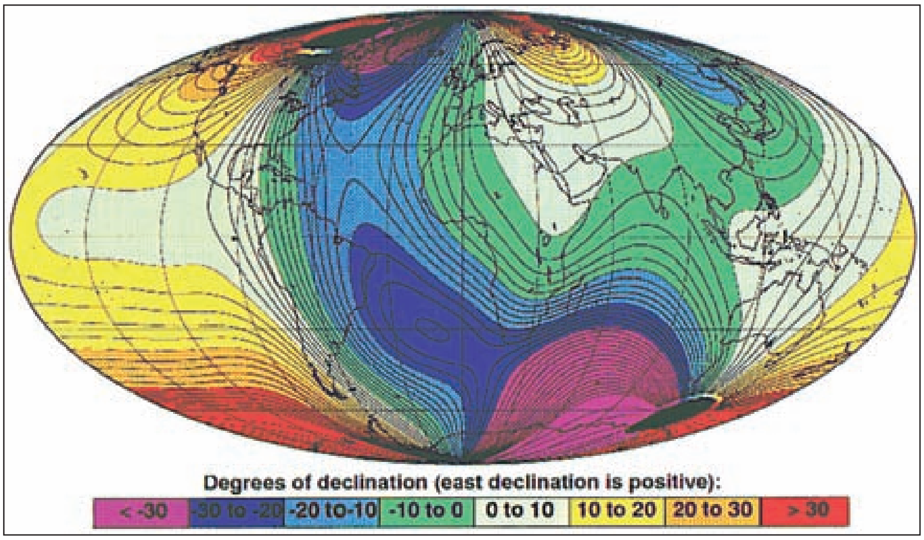
The UTM projection has, for example, a scale factor of 0.9996 at the Central Meridian. The result is that every kilometer on the CM is portrayed with a length of 999.6 meters. For every kilometer we calculate the distance to be 40 centimeters too short. As we move east or west from the CM, the scale factor will increase until it becomes 1 again. If we go even further east or west the distortion will increase again until it reaches a maximum of 1.000981 or almost a meter per kilometer too long at the edges of the projection.

Convergence

In the previous article it was mentioned that, as a rule, a single aspect of reality is projected, relatively undistorted, in the chart projection. For a UTM projection these are the angles measured. This is an advantage on larger-scale construction jobs.

A common mistake, though, is that people think that since angles are undistorted, measured headings are also identical to the true heading. This is simply not true (with the exception of the CM). Headings on the chart cannot be transferred to the real world without some sort of correction.

The main reason is that headings in reality are always referenced to true north while headings on the chart are always referenced to chart north (see cadre). The difference between these two 'norths' depends on the position with respect to the origin of the projection and is therefore a variable. The difference between chart north and true north, namely the meridian convergence, varies between 0° and ± 3° for the UTM projection.



Worldwide magnetic variation or declination for the epoch 1995-2000 (source: www.gly.fsu.edu)

Variation and Deviation

Historically headings are set out using a magnetic compass. With these not only the convergence is important, but the difference between magnetic north and true north, also called the variation or declination, is important as well. This difference is not a constant but will, due to the shifting of the magnetic Poles, vary slowly. Depending on the location, the variation can be several times larger than the convergence.

Another factor that influences magnetic heading measurements is the deviation. This is the effect of local magnetic disturbances on the compass heading. Depending on the amount of (magnetized) iron in the neighbourhood of the compass, the deviation error can be as much as tens of degrees. The deviation is one of the reasons why compasses are mainly built of copper or, nowadays, plastic since these materials cannot be magnetized.

Setting out Headings

For every projection and project one needs to determine how much the effect of scale factor and convergence will influence project results. Even if the local effect is small, however, reading headings from the chart and setting them out in reality will probably result in an error.

A single GPS receiver cannot be used for setting out headings. It is, of course, possible to measure two positions and compute the heading between them. Depending of whether one works with projected positions or geographic positions, the answer will be referenced to chart north or true north.

There are special GPS compasses (having two or more antennas) that will indicate heading referenced to true north. When using such a system for setting out headings, one needs to take the convergence into account whenever a heading from the chart is set out. For a small area this error can be assumed constant.

When using a magnetic compass, one needs to correct for variation and deviation as well as convergence. As a result, a magnetic heading can differ several degrees from the true heading.

Setting out Distances

Depending on the projection selected, the scale factor usually does not pose a problem in small projects. With UTM, the effect will become readily noticeable over distances of just a few kilometers. Other projections such as the stereographic RD projection in the Netherlands have much smaller scale factors (RD: 0.999079), resulting in errors that are much smaller. As a result the scale factor can be ignored for much greater distances.

Conclusion

In general one may assume the distortions mentioned (with the exception of deviation) to be constant over an area of a few square kilometers. Since a constant error is not identical to having no error at all, one needs to determine the convergence and scale factor (and variation if applicable) for every single project.

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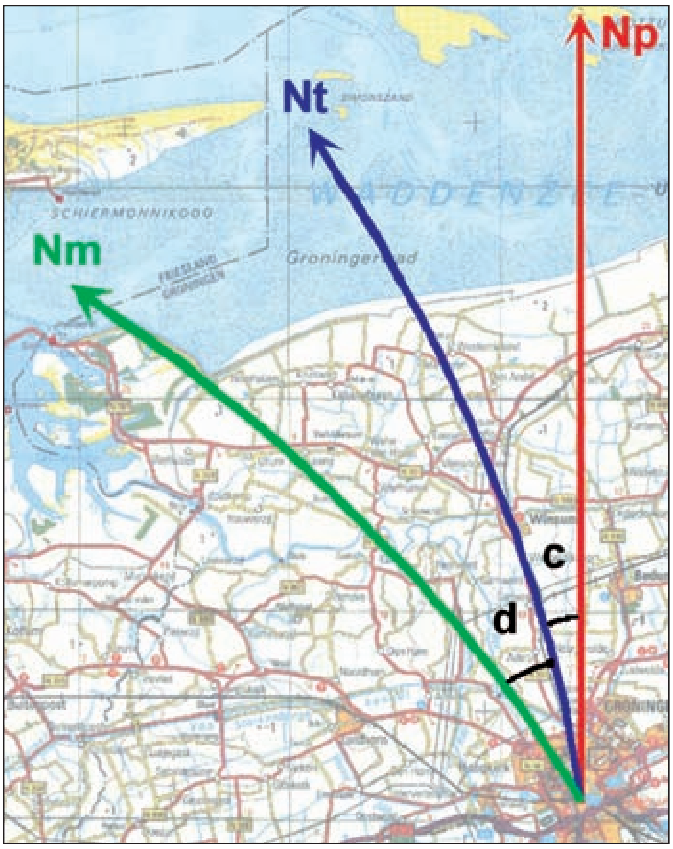

Applying convergence and variation when determining directions from a chart.
- Np = projection or chart north
- Nt = true north
- Nm = magnetic north
- c = convergence
- d = declination / variation