Developing and Adopting a Single Zone State Plane Coordinate System for Kentucky

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Abstract

In an effort to better meet the growing needs of statewide surveying, mapping, and geospatial interests, the Commonwealth of Kentucky has addressed the difficulties associated with multiple zone partitioning within the national State Plane Coordinate System (SPCS) by developing and adopting a statewide single zone projection. Although the SPCS has been around for several decades, it has just recently gained widespread use and mainstream popularity over the past few years due mainly to advances in surveying, global positioning, digital mapping, and geographic information technologies. These advances have not only brought about increased use of the SPCS, but have also facilitated a growing need to reevaluate the original strategy of partitioning states into multiple zones based on considerations no longer applicable to current surveying and mapping endeavors.

SPCS Background

The National State Plane Coordinate System (SPCS) was originally established in the 1930's to provide land surveyors and engineers a means of georeferencing projects in standardized coordinate systems defined on a common datum that could incorporate control established by the United States Coast and Geodetic Survey (National Geodetic Survey). The most common early use of this system in Kentucky were public sector projects that covered large geographic regions or spanned long distances such as highway corridors. Due to recent advances in surveying, mapping, and computational technologies, the SPCS has gained widespread acceptance, and at times, has become an essential requirement.

The science of modern geodesy focuses, in part, on measuring and defining the size and shape of the earth as accurately as possible. Since the topographic surface of the earth is dynamic and non-mathematical in nature, any attempt to define it in mathematical terms will result, at best, in an approximation. Although the simplest way to model the earth's geometry is with a sphere of constant radius, a more accurate approximation of its general size and shape due to equatorial bulging and polar flattening is achieved by an *oblate* ellipsoid whose semimajor equatorial axis is slightly larger than its semiminor polar axis.

Throughout modern history, there have been a variety of geodetic ellipsoids developed to approximate the earth. The most well known in the United States are the Clarke ellipsoid of 1866, which is the basis of the North American Datum of 1927 (NAD27), the Geodetic Reference System ellipsoid of 1980 (GRS80) which is the basis of the North American Datum of 1983 (NAD83), and the World Geodetic System ellipsoid of 1984 (WGS84) which is the basis of the Global Positioning System developed, operated, and maintained by the United States Department of Defense. The Clarke ellipsoid of 1866 was developed to best fit the North American continent, while GRS80 and WGS84 represent progressive refinements of globally defined datums whose origins were intended to coincide with the earth's center of mass based on the accuracy of positional data and computational capabilities available at the time of their development.

The desire to model the size and shape of the earth mathematically is further complicated by the practical need to represent all or a portion of its surface on a planar map or grid. Although it is impossible to achieve an exact representation of the curved earth on a flat map without introducing distortions, there are ways to mathematically control how distortions in angular relationships, areas, and shapes are manifest through the projection process. One such approach, classified as a *conformal* projection, maintains angular relationships for infinitesimally small distances about a position. This type of projection is well suited for surveying and engineering applications because it preserves shapes for reasonably small areas by confining grid scale factors to be equal in all directions infinitesimally constrained about a given point.

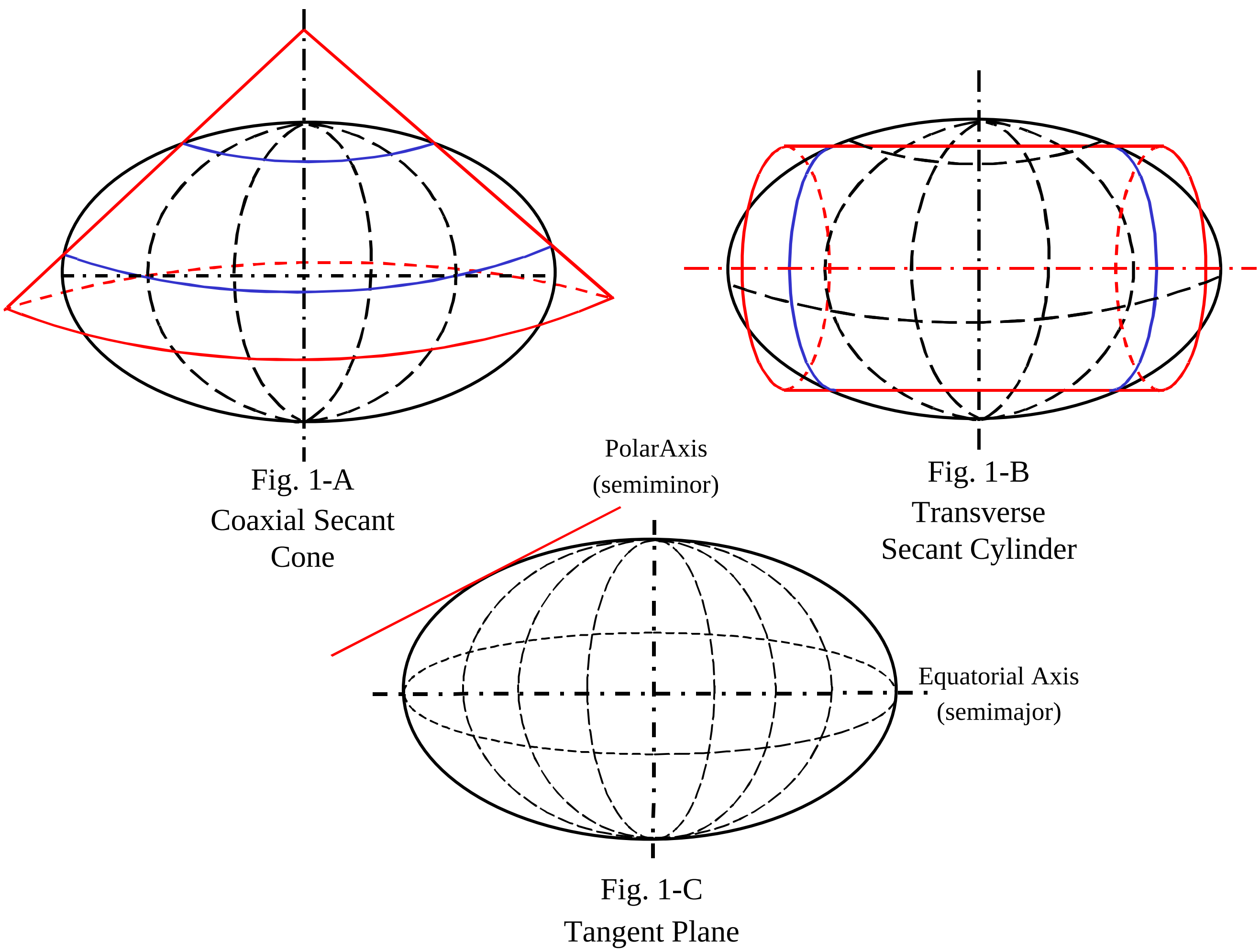

Figure 1. Mapping Projection Schemes

The SPCS implements three types of conformal projection schemes. One method, introduced in 1772 by Johann Heinrich Lambert (1728-1777), utilizes a cone as the projection surface while the other two are based on an approach developed in 1569 by Gerardus Mercator (1512-1594) in which a cylinder provides the basis of the projection surface. The cone and cylinder are commonly employed in projection schemes because they form a *developable* surface that is first geometrically defined relative to the ellipsoid, then ‘sliced’ and ‘rolled out’ to form a planar surface capable of accommodating a rectangular grid while mathematically preserving key geometric relationships to the reference ellipsoid. Figure 2 demonstrates how a Lambert projection surface is developed onto the projection grid.

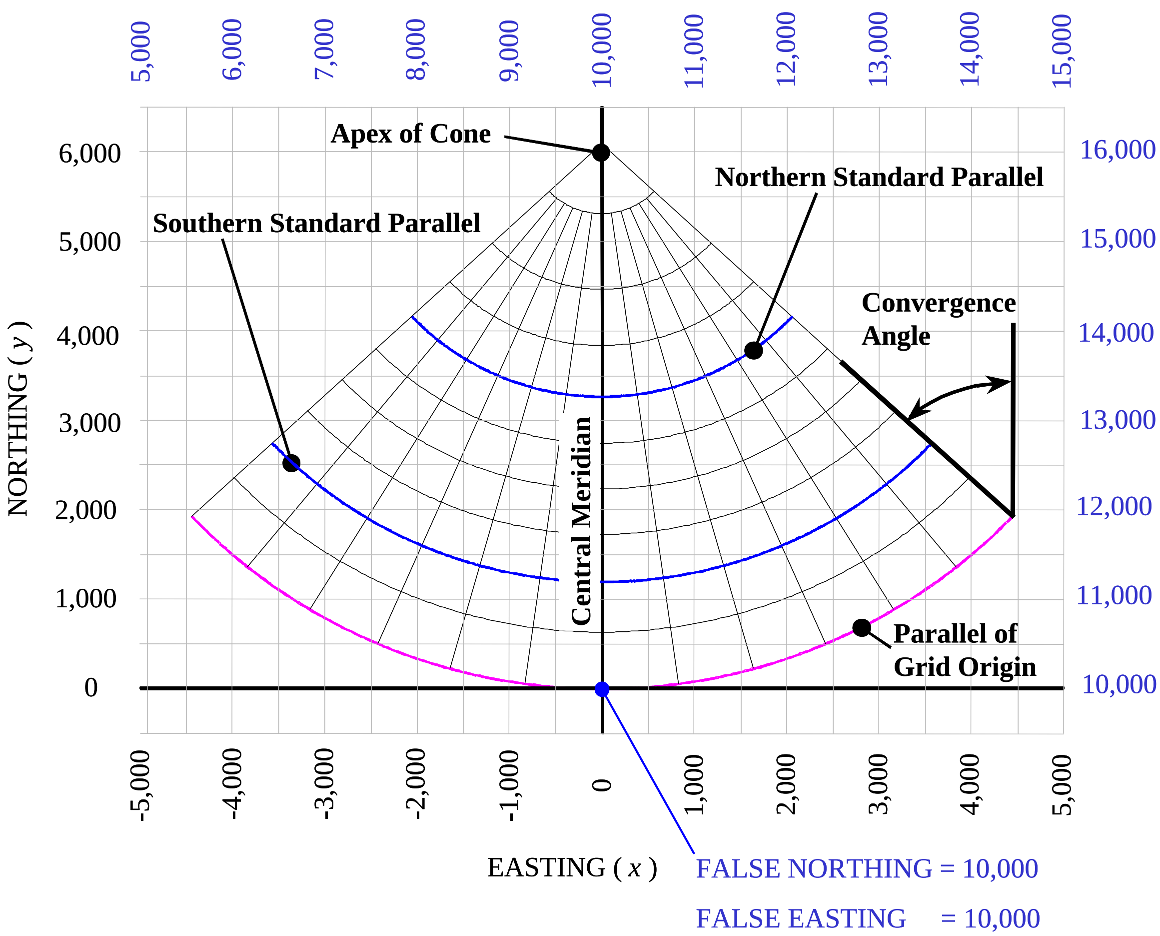

Figure 2. Lambert Conic Projection and Grid Surface

In the general case of Lambert conic projections, the cone is oriented to the ellipsoid such that the axis of the cone coincides with the polar axis of the ellipsoid. The surface of the cone is then defined to either just touch or pierce through the ellipsoid. In all but one of the SPCS zones implementing the Mercator method, a cylinder is oriented to the ellipsoid such that the axis of the cylinder lies in the equatorial plane perpendicular to the polar axis of the ellipsoid. This method is known as a *Transverse* Mercator projection and is the basis of the *Universal Transversal Mercator Coordinate System*. One SPCS zone in Alaska implements an *Oblique* Mercator projection in which the axis of the projection cylinder coincides with a pre-determined non-orthogonal azimuth referenced from the polar axis of the ellipsoid. In the general case of Mercator projections, the radius of the cylinder is defined to achieve a surface that either just touches or pierces through the surface of the ellipsoid.

The Lambert and Mercator methods as implemented by the SPCS are *secant* projections (Figs. 1-A and 1-B respectively) in that their respective surfaces are designed to pierce the reference ellipsoid at two locations. This approach is preferred over a *tangential* arrangement in which the projection surface only touches the ellipsoid at a single set of all points forming a closed loop around the surface of the ellipsoid. The secant arrangement allows the projection to cover a slightly larger region on the earth's surface while limiting mapping distortions to a reasonable and quantifiable maximum value. Nonetheless, both methods are still limited in their range of applicability across larger regions due to the increased rate of distortion experienced as the projection plane is extended outward and away from the curved surface of the ellipsoid.

Given the surveying and computational tools available at the time of its inception, the SPCS was originally designed to achieve ellipsoid to grid distortions no greater than one part in ten thousand (1:10,000) so that ignoring ellipsoid based grid scale factors would not degrade positional accuracies more than was considered practical for common field surveys of the day. As a result of this 1:10,000 constraint, many states were divided into two or more projection zones that have been defined along county boundaries. Nonetheless, in 1986 when the NAD27 horizontal datum was officially superceded by NAD83, Montana, Nebraska, and South Carolina all revised their SPC systems by dropping multiple zone schemes in favor of single zone projections.

The SPCS in Kentucky

Kentucky's oblong shape and east-west orientation renders it well suited for a Lambert conic conformal mapping projection. However, due to the 1:10,000 constraint placed on allowable SPCS ellipsoid to grid distortions, it has been divided into two separate North and South coordinate zones defined along county boundaries. These zones have also been designed to achieve a reasonable overlap region to allow projects and areas of interest spanning these boundaries to be represented entirely within one projection zone or the other.

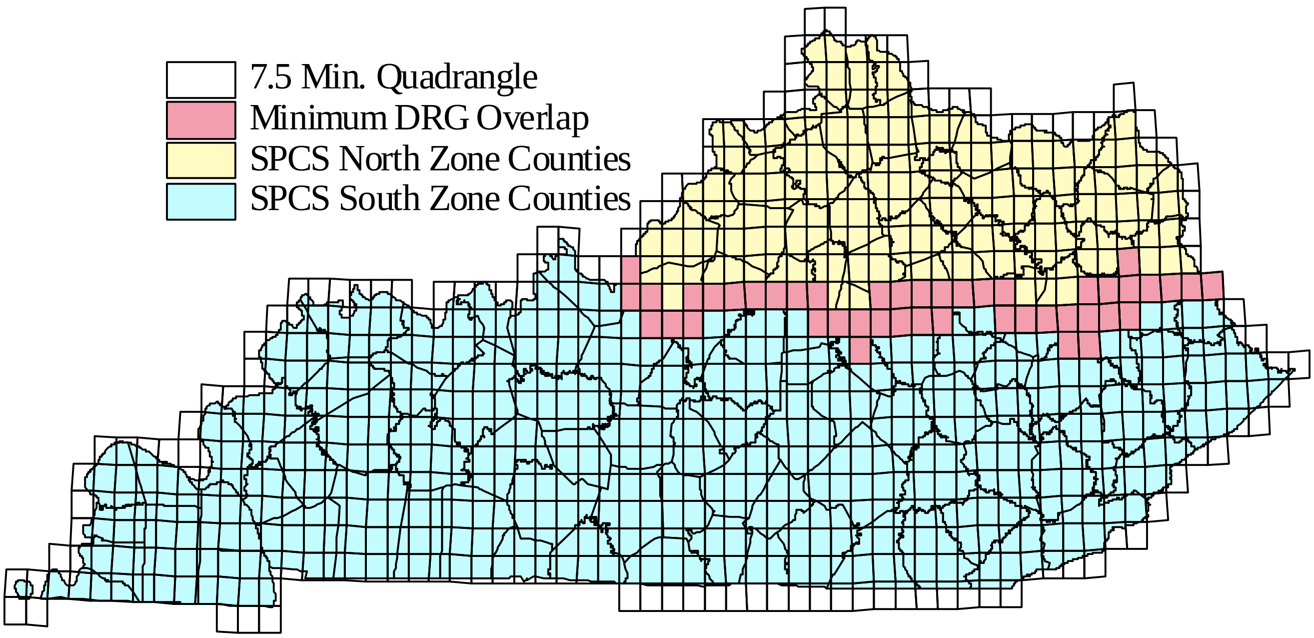

Figure 3. Kentucky SPCS Zones with 7.5 Minute Quadrangle Tiles

In past decades when surveying, mapping, and engineering applications were stored graphically on sheet media, division of the state into two separate SPCS zones was generally not a problem for those who utilized the system. Also, most applications of the SPCS in Kentucky were limited to isolated projects and jurisdictions that were completely contained within a particular zone. The few exceptions were transportation and utility projects that spanned from one zone into another, or statewide agencies and regional development districts whose jurisdictions included areas lying in both zones. In those cases, the multiple zone problem was solved by either extending one zone beyond its originally intended coverage area, or creating two separate datasets with duplication of data existing in an overlap buffer between the two zones. Figure 3 illustrates this situation for statewide coverage of USGS 7.5 minute topographic quadrangle maps. Since each DRG overlap quadrangle contains areas in both North and South Zone counties, they must be duplicated and projected for each zone.

The advent of semiconductor and computer technology has spawned the development of automated surveying, design, and mapping equipment, including digital geodetic total stations, global positioning systems (GPS), digital aerial photogrammetry and remote sensing, as well as computer aided design (CAD) and geographic information system (GIS) software. These technologies have made it feasible to create, manage, access, view, query, and analyze high-resolution datasets covering large geographic regions which may include more than one state plane projection zone. As a result of these capabilities, analyzing raster and non-vector datasets on a statewide basis or over large geographic regions is practical only when all data is presented in the same mapping projection or reference frame.

As GIS and digital mapping technologies have gained popularity and are applied to large regions across the state, the need for a unified single state plane projection has become very clear. One mitigating aspect of the Single Zone issue is that the very technologies that resulted in the need for a single zone have essentially rendered the original considerations that necessitated multiple SPCS zones obsolete.

Thus, the time had come to develop and adopt a single SPCS zone that would better meet the needs of a broader spectrum of geospatial and positioning professionals, including the land surveying and engineering communities.

Developing a Single Zone SPCS Projection

The process of developing and adopting a single zone projection was greatly facilitated by a 1994 Kentucky Act establishing the Geographic Information Advisory Council, which is an advisory body comprised of membership from all cabinets within state government, as well as major statewide agencies and organizations including the Kentucky Geological Survey, the Kentucky League of Cities, the Kentucky Associations of Counties, and private organizations such as the Kentucky Association of Professional Surveyors, the Kentucky Society of Professional Engineers, and the Kentucky Society of Professional Geologists. The Kentucky GIAC was established in 1994 by the passage of KRS 61.958 (now KRS 11.515) and has played a vital role in the formulation of policies and standards concerning statewide GIS and other geospatial endeavors.

As concerns regarding the SPCS issue in Kentucky became more prevalent, the GIAC established the Single Zone Subcommittee and charged it with the task of reviewing existing SPCS legislation and working with statewide GIS and other geospatial interests to formulate a solution that would address these concerns. The subcommittee was comprised of representatives from the Kentucky Natural Resources and Environmental Protection Cabinet, Kentucky Office of Geographic Information, Kentucky Geological Survey, Kentucky Department for Fish and Wildlife, the Mid-America Remote Sensing Center at Murray State University, the Kentucky Association of Professional Land Surveyors, and the National Geodetic Survey through the participation of the Kentucky Geodetic Advisor. The subcommittee met several times during the last half of 2000 and presented its recommendations and solution to the full council in December.

The need to develop and adopt a single zone SPCS projection for Kentucky was unanimously agreed upon by the subcommittee during its first meeting in August of 2000. It was evident from the onset that the current two-zone system failed to meet the growing needs of many state agencies and other interests, and that the bulk of the subcommittee's work would focus on developing a reasonable scope and specifications for a single zone projection. As a result, the following goals were established:

1. The Single Zone must be centered on the entire state to minimize distortions in a balanced manner and result in a projection suitable for land surveying and civil engineering endeavors located anywhere in the state (Fig. 4).
2. The goal of minimizing distortions would focus on those experienced between the ground and the grid as opposed to the ellipsoid and grid (Fig. 5).
3. The Single Zone projection would occupy a region in coordinate space such that any single zone position in Kentucky would result in a unique (x, y) coordinate pair not reproducible in any other zone for positions lying within the state boundary (Fig. 6).
4. The process must include not only adoption by the GIAC, but also the promulgation of an administrative regulation establishing and adopting the Single Zone projection as an official means of

representing spatial data and positions located within and reasonably near the Kentucky state boundary.

5. The Single Zone must be adopted and supported by the National Geodetic Survey and the United States Geological Survey through their line of products and services. It became clear that successful implementation and widespread acceptance of a new SPCS zone would require coordinates in the new zone for National Spatial Reference System monuments be published by the National Geodetic Survey.
6. The GIAC, through the Single Zone Subcommittee, would attempt to notify the surveying, engineering, geopositioning, and GIS communities through professional media outlets, as well as notify major relevant software developers.
7. Continuing education opportunities focusing on the SPCS in general and the Kentucky Single Zone in particular would be developed and presented to foster and encourage proper utilization of both.
8. The GIAC should encourage revision of existing SPCS legislation to include adoption of the Single Zone projection.

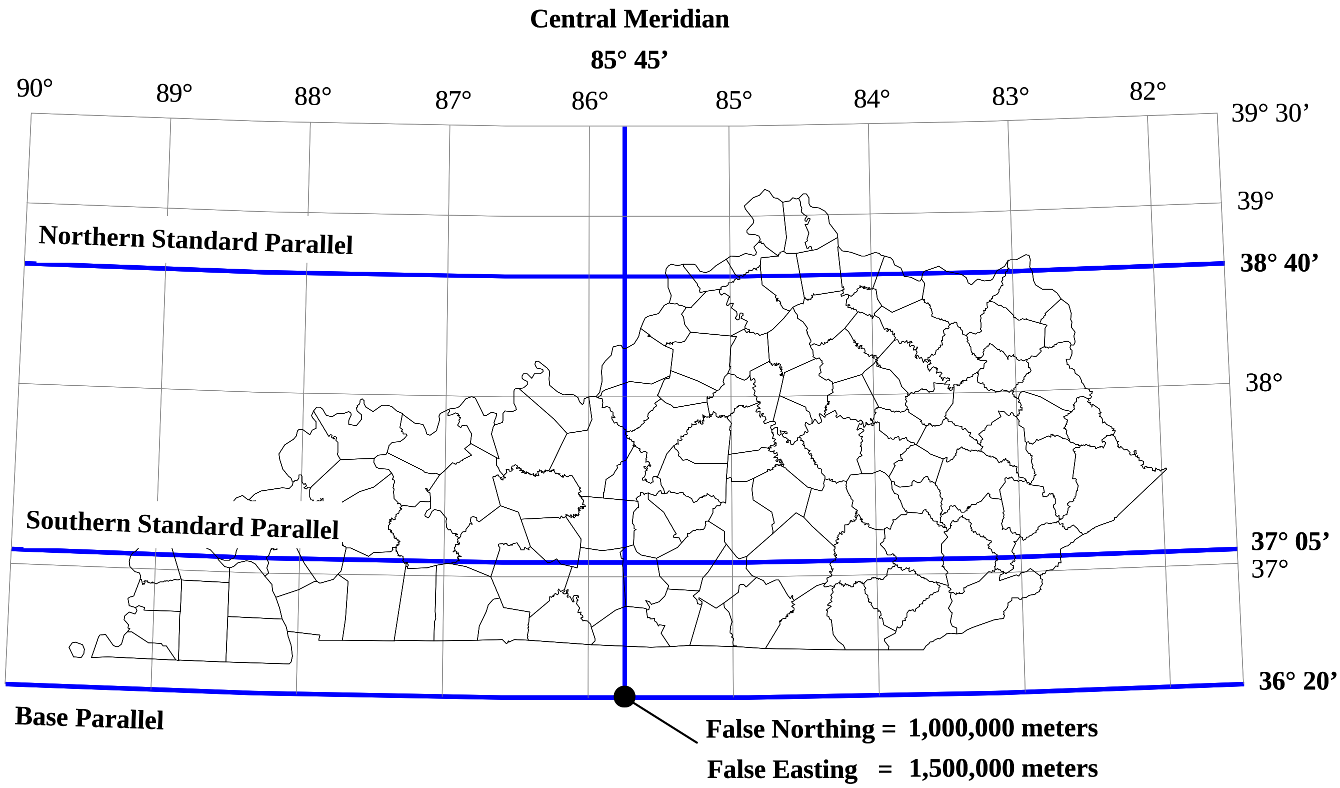

Figure 4. Kentucky Single Zone Parameters

The task of achieving the first two goals was approached by developing a custom computer program that could analyze the distribution of grid scale factors across the state for a given set of Lambert projection parameters. It was also necessary to identify an appropriate dataset that would yield a reasonable estimate of ground to grid distortions across the entire state based on position and elevation. The Kentucky Geological Survey provided a previously developed coarse dataset that identified the center coordinates for each 7.5 minute topographic quadrangle map with the highest and lowest elevation occurring within that quad. Since Kentucky is covered by 779 quadrangles, it was decided that the projection analysis program could easily be modified to read this dataset and output a ground to grid distortion table that would indicate the worst case distortion scenario as applied to the center of each quadrangle. This made it possible to quickly create a variety of scenarios based on varying the projection parameters. These scenarios were then compared to identify a projection scheme that covered the state in a balanced manner while attempting to minimize ground to grid distortions.

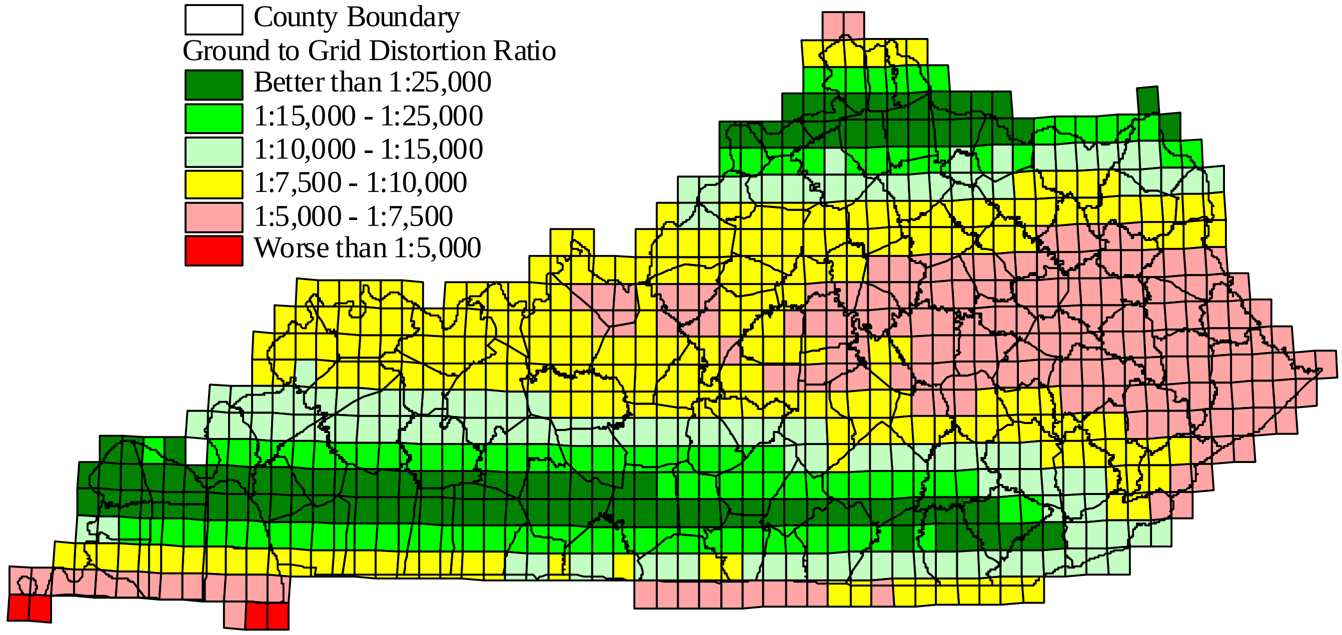

Figure 5. Single Zone Ground to Grid Distortion Ratios

The final projection scheme resulted in a coordinate zone that achieved a worst-case ground to grid distortion ratio less than one part in five thousand (approximately 1:5,200). This was considered to be acceptable for land surveying and civil engineering applications since 1:5,000 was the minimum standard error of closure for rural Class B surveys as defined by administrative regulations governing the practice of land surveying in Kentucky. Although projection distortions and traverse closure errors are technically different quantities, the comparison was considered to be appropriate in this situation because mapping distortions would have a commensurate effect on the computation and reporting of parcel areas. Nonetheless, mapping distortions can be fully accounted for by direct geometric relationships while random errors are generally accounted for through statistical analysis and adjustment.

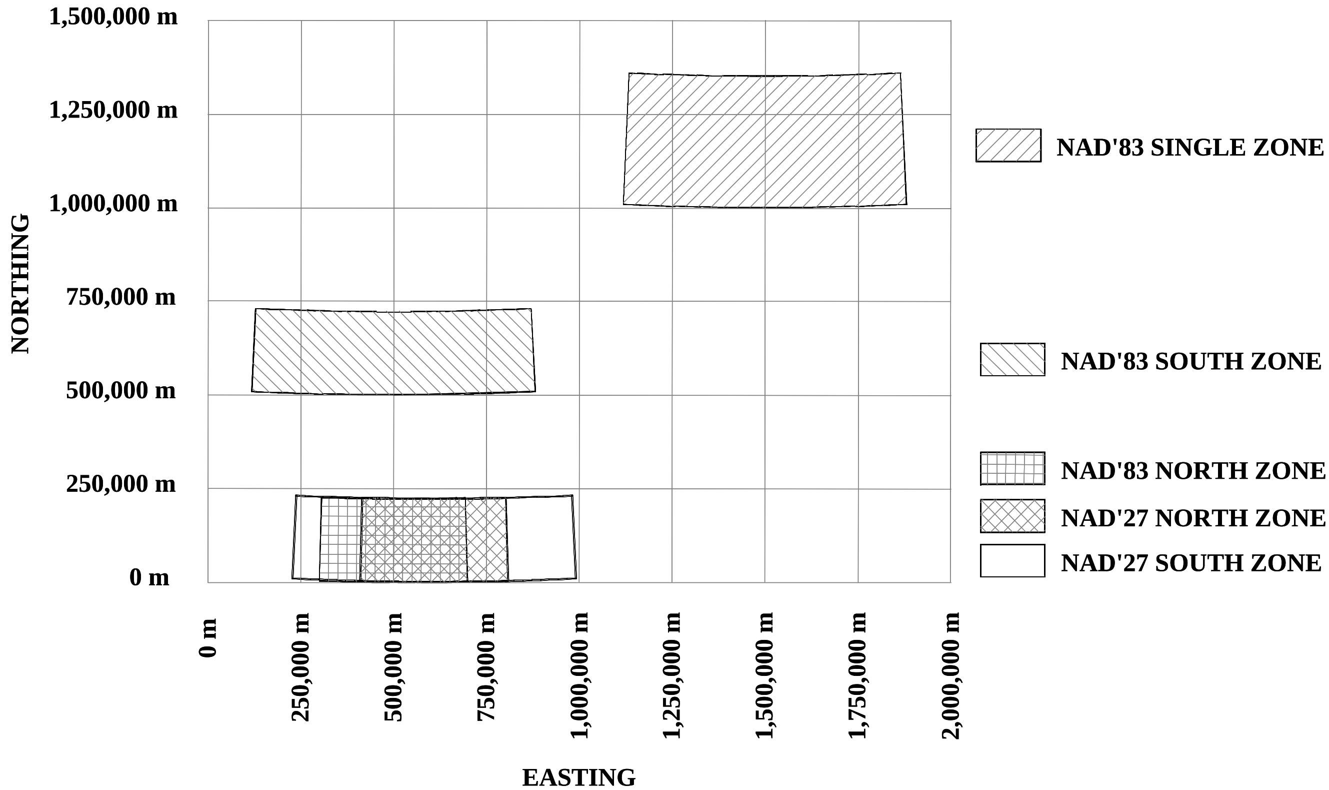

Figure 6. Spatial Distribution and Nominal Ranges for SPCS Zones in Kentucky

The Single Zone projection was presented to and unanimously adopted by the GIAC in December of 2000. This essentially completed the first stage of creating a single zone projection for Kentucky. The next step, that of developing an administrative regulation to be promulgated in accordance with legislative guidelines, was carried out by the continuing work of the subcommittee over the months that followed. During this process, it became important to realize that the current Kentucky Coordinate System of 1983 as established by KRS 1.020 only recognized the North and South zones as defined on the GRS80 ellipsoid. Thus, the definition of a new zone through administrative regulation would have to be established and adopted in *addition* to the existing SPCS zones, rather than in place of them. Also, even though use of the new system would be declared preferred for future applications and upgrading existing datasets, it would also have to be declared voluntary to ensure compatibility and consistency with existing laws.

The Kentucky Single Zone Coordinate System of 1983 officially became effective on August 15, 2001 through the promulgation of Kentucky Administrative Regulation 10 KAR 5.010, which now recognizes the valid implementation of a unified coordinate system covering the entire Commonwealth of Kentucky regardless of project size, scope, and location. In an ongoing effort to assure that the Single Zone is properly supported, the GIAC also requested in writing that the National Geodetic Survey and the United States Geological Survey adopt this new zone into their current line of products and services. In response, the National Geodetic Survey has accepted and now publishes Kentucky Single Zone coordinate values as SPCS Zone 1600 (KY1Z) on all pertinent data sheets, assuring that the Kentucky

Single Zone projection has taken its official place in the ranks of the National State Plane Coordinate System.

Projection Scheme	Lambert Conformal Conic with Two Standard Parallels
Datum	NAD83 / GRS80 Ellipsoid
Linear Unit of Measure	U.S. Survey Foot (1 USFt = 1200 / 3937 meter)
Central Meridian	85° 45' West (-85.75°)
Northern Standard Parallel	38° 40' North (38.666666666667°)
Southern Standard Parallel	37° 05' North (37.083333333333°)
Base Parallel	36° 20' North (36.333333333333°)
False Northing	1,000,000 meters (3,280,833.33333 USFt)
False Easting	1,500,000 meters (4,921,250.00000 USFt)

Table 1. Kentucky Single Zone Projection Parameters

Acknowledgements

The author wishes to thank David Doyle and Jim Stem of the National Geodetic Survey for discussing and answering many questions regarding SPCS history, NGS related policies, and the technical aspects of geodesy and mapping projections in general. The time they took from their busy schedules provided the author with otherwise unattainable information and insights. Jack Sergeant of the Kentucky Geological Survey, Ted Stumbur of the Kentucky Office of Geographic Information, and Ross MacKay, Kentucky Geodetic Advisor, all provided valuable review and suggestions, many of which were incorporated into the final development of this article.

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