The Future is Here: Introducing the State Plane Coordinate System of 2022

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SUMMARY

Fundamental changes are coming soon to coordinate reference systems in the United States. In 2025, NOAA's National Geodetic Survey (NGS) will complete its modernization of the National Spatial Reference System (NSRS), the basis for U.S. surveying and mapping. That includes an update of the State Plane Coordinate System (SPCS) as the State Plane Coordinate System of 2022 (SPCS2022), a projected coordinate reference system with multiple zones covering all 56 U.S. states and territories. SPCS was originally established by NGS in the 1930s and was redefined in the 1980s as part of changing the national reference frame. SPCS2022 is the third generation of SPCS, developed to accompany the new terrestrial reference frames of the modernized NSRS. Like its predecessors, SPCS2022 consists of the three following conformal map projections: Lambert Conformal Conic, Transverse Mercator, and Hotine Oblique Mercator.

An overview of SPCS2022 is provided, along with key innovations and changes from existing and previous versions of SPCS. The main change is that linear distortion (scale error) is minimized at the topographic surface rather than the reference ellipsoid surface (to reduce the difference between "grid" and "ground" distances). To further decrease distortion in areas of high usage, population distribution was accounted for in the design process, using data from the U.S. Census Bureau. Another change is that states can have zone "layers." Every state and territory has a statewide zone to provide complete coverage with a single geometry, particularly useful for statewide Geographic Information Systems. Most states also have either one or two multiple-zone layers, each covering all or part of a state with less distortion than the statewide zone. To reduce distortion even further, 28 states designed their own SPCS2022 zones as so-called "low distortion projections" (LDPs). These LDP zones support surveying and engineering applications by making the difference between "grid" and "ground" essentially negligible. By incorporating zone layers and allowing state contributions, SPCS2022 represents a customer-driven evolution of SPCS, one that is intended to meet the wide-ranging needs of the nation's diverse geospatial community.

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INTRODUCTION AND BACKGROUND

The U.S. National Geodetic Survey (NGS) is currently in the process of modernizing the National Spatial Reference System (NSRS), as described in NGS (2021a) and NGS (2021b). This will include replacing the North American Datum of 1983 (NAD 83) with four new terrestrial reference frames (TRFs). The existing NAD 83-based State Plane Coordinate System of 1983 (SPCS 83) will also be replaced by the State Plane Coordinate System of 2022 (SPCS2022). SPCS2022 will reference the new TRFs and provide coverage for all 50 U.S. states and six territories. SPCS2022 is the third projected coordinate reference system (PCRS) created by NGS, which began with SPCS 27 in 1934 and was followed by SPCS 83 in 1986. The purpose of SPCS is to support engineering, surveying, and mapping referenced to the NSRS. Details on the history of SPCS are given by Dennis (2018a).

This paper gives an overview of SPCS2022 characteristics, describes the approach used by NGS for zone design, gives preliminary results, and includes comparisons with SPCS 83. Additional details on how SPCS2022 is defined are given in the associated NGS policy and procedures (NGS, 2019a and 2019b).

1.1 Linear Distortion and the Projection Axis

The same three conformal projection types are used for all three versions of SPCS: Lambert Conformal Conic (LCC), Transverse Mercator (TM), and Hotine Oblique Mercator (HOM). But the design process for SPCS2022 differs from SPCS 83 and 27 in that *linear distortion* is minimized at the topographic surface (rather than *scale error* at the reference ellipsoid surface). The term “linear distortion” is taken from Stem (1990, p. 18). Snyder (1987) also frequently uses “distortion” in a similar context for conformal projections. It is similar (and related to) “scale error” and the “combined factor.” Linear distortion is the difference in horizontal distance represented by a map projection (“grid”) versus its actual value on the topographic surface of the Earth (“ground”) and is computed at a point as

$$\delta = k\left(\frac{R_G}{R_G + h}\right) - 1 \qquad (1)$$

where h is the ellipsoidal height in the reference frame of the PCRS and k is the projection grid point (scale) factor, which is a function of horizontal position only. For conformal projections, k is the same in all directions from a point (although it generally differs with location). The term in parentheses is the height (or “elevation”) factor and gives distortion due to ellipsoidal height. R_G is the geometric mean (or Gaussian) radius of curvature,

$$R_G = \frac{a\sqrt{1-e^2}}{1 - e^2 \sin^2 \varphi} \qquad (2)$$

where, for a given reference ellipsoid, φ is the geodetic latitude, a is the semimajor axis, and e^2 is first eccentricity squared. The GRS 80 ellipsoid is used for both SPCS 83 and SPCS2022, with a = 6,378,137 m (exact) and e^2 = 0.006 694 380 022 90.

In this paper, the term "scale error" refers to the ellipsoid, and "linear distortion" to the topographic surface, i.e., scale error = $k - 1$. The combined factor is similar to linear distortion in that it is evaluated at ground, but it differs numerically. The combined factor = $\delta + 1$, so linear distortion of $\delta = 0$ corresponds to a combined factor of exactly 1. Linear distortion is given here in parts per million (ppm), which is mm per km, as a convenience for dealing with small numbers. Table 1 gives examples of four typical distortion values in ppm, along with commonly encountered numerical equivalents. The largest value (±400 ppm) is the scale error limit for zones of the Universal Transverse Mercator (UTM) system.

Table 1. Typical linear distortion design values in ppm and numerical equivalents.

Parts per million (mm/km)	Feet per mile	Dimensionless ratio (absolute value)	Grid point scale factor or combined factor range	Comments and example applications
±20	±0.11	1 : 50,000	0.99998–1.00002	Common design criterion for low distortion projection (LDPs)
±50	±0.26	1 : 20,000	0.99995–1.00005	Nominal minimum design criterion for SPCS2022 zones designed by NGS
±100	±0.53	1 : 10,000	0.9999–1.0001	Typical scale error limit for SPCS 83 and 27 zones (with respect to ellipsoid)
±400	±2.11	1: 2,500	0.9996–1.0004	Scale error limit for UTM zones (with respect to ellipsoid)

A zone is designed by selecting the appropriate projection type and specifying its *projection axis* location and scale (and orientation for the HOM) to achieve optimal performance. The term "projection axis" is taken from the phrase "axis of the projection" as used by Stem (1990). This axis is the horizontal line or curve along which projection scale error is minimum and constant. It is the central meridian for the TM, the central parallel for the LCC, and the skew axis for the HOM, although scale error is not quite constant along the skew axis but changes slowly with distance from its local origin (Snyder, 1987, p. 70).

1.2 Related Work and Justification

The approach for designing SPCS2022 zones is to determine map projection parameters that optimally minimize linear distortion for LCC, TM, and HOM projections. This allows use of existing algorithms, making it possible to quickly deploy the modified projections. For this paper, the equations of Stem (1990) were used, with some modifications (described later).

Determining parameters that minimize linear distortion for existing map projections has been explored by others, often referred to as "low distortion projections" (LDPs), e.g., Gillins et al. (2022, Chapter 3). LDPs are typically designed to achieve distortion low enough that the difference between "grid" and "ground" is negligible, such as ±20 ppm (see Table 1). There are three reasons for designing zones that reduce linear distortion at the topographic surface: (1) mapping activities are performed on the ground, not on the ellipsoid; (2) engineering and surveying applications often require ground distances; and (3) the ground surface can be far above the ellipsoid, resulting in greater distortion magnitudes. The mean topographic ellipsoidal height of the conterminous U.S. (CONUS) is ~750 m, causing distortion of about -120 ppm (more negative with increasing height). The mean total SPCS 83 distortion for CONUS is -178 ppm at ground, and for 20% of CONUS it exceeds -300 ppm. This substantially exceeds the nominal ±100 ppm limit used for SPCS 83 and 27.

SPCS2022 CHARACTERISTICS

Although SPCS2022 uses the same reference ellipsoid and projection types as SPCS 83, SPCS2022 characteristics and performance will differ significantly in most states. The main differences are described in the following five sections.

2.1 Minimize linear distortion at the topographic surface

As mentioned above, the main difference between SPCS2022 and existing SPCSs is that SPCS2022 zones are designed to minimize linear distortion at the topographic rather than the ellipsoid surface. The basic approach is to define the projection axis scale and location such that the total linear distortion is minimized for a zone. NGS also takes into account population distribution, so that distortion can be further reduced in populated areas. This has a particularly significant effect on designs in the western U.S., where population is often irregularly distributed and concentrated in lower elevation areas. Details of the SPCS2022 design methodology used by NGS are given in Section 3.

2.2 Zone layers

In SPCS2022, a state can have up to three co-existing "layers" of zones. In a state with multiple layers, zones in one layer will overlap some or all zones in another layer, as already done for SPCS 83 in Kentucky (covered by both a statewide zone layer and a two-zone layer). Every state and territory will have a statewide zone designed by NGS. One will cover both Puerto Rico and the U.S. Virgin Islands (as done for SPCS 83), and one will cover both Guam and the Commonwealth of the Northern Mariana Islands, for a total of 54 statewide zones.

States may also have one or two multiple-zone layers. If a state has two multiple-zone layers, one must completely cover the entire state, and the other must cover only part of the state. Partial coverage layers were intended for mountainous regions, so that zones can be designed for limited areas where low distortion is desired (such as in valleys where most of the population is typically located). The top map in Fig. 1 shows the preliminary number of zone layers in each state. Most states (28) will have two layers: a statewide zone and a complete-coverage multiple-zone layer. States with a partial coverage layer are mainly in mountainous western states, as intended, with some exceptions (most notably Florida). Hawaii will have two layers on only its two largest islands, Hawaii and Maui.

2.3 Large increase in the number of zones

SPCS2022 will have more zones than either SPCS 83 (125 zones) or SPCS 27 (131 zones), but the number of SPCS2022 zones varies greatly between states. The preliminary number of zones by state is shown in the bottom map of Fig. 1, which varies from one statewide zone only (12 states and 6 territories) to a maximum of 91 in three layers (Utah), for a total of 967 zones. Of these, 165 zones were designed by NGS, including the 54 statewide zones plus three special use zones (described in the next section). The remaining 802 zones were designed by state stakeholders, and most of these zones are LDPs, as discussed in Section 2.5.

2.4 Special use zones

NGS SPCS2022 Policy allows zones for well-defined geographic regions that fall within two or more states. Because they are not in a single state, they cannot "belong" to any state and are called Special Use zones. Three special use zones are included in SPCS2022, as shown in the bottom map of Fig. 1: the Gulf of Mexico (labeled "GULF"), the Navajo Nation ("NAVA"), and the Kansas City ("KANC") zones. The GULF zone replaces the Louisiana Offshore Zone used in SPCS 83 and 27. It was designated a special use zone because it includes offshore waters of five states and most of its coverage area is not within any state. The NAVA zone covers the entire Navajo Nation, which falls within three states (Arizona, New Mexico, and Utah) and spans five SPCS 83 and 27 zones. The KANC zone covers the Kanas City metropolitan area in both Kansas and Missouri. Notably, the stakeholders of these two states collaborated in its design to provide a uniform PCRS for their mutual benefit.

2.5 Stakeholder involvement in the design process

Groups identified as SPCS2022 stakeholders were an integral part of the design process. These groups consist of the following state-based organizations: departments of transportation, GIS or cartographer offices, professional surveying, engineering, and other geospatial organizations; and universities or colleges with a geospatial curriculum. A formal process was established for stakeholders to make requests and proposals. Requests were for zones designed by NGS, and proposals were for zones designed by stakeholders themselves. A total 38 requests and 30 proposals were submitted by stakeholder groups in 41 states and the Navajo Nation. Once the proposals were reviewed and approved by NGS, 28 states submitted their own designs, which were reviewed for acceptance as part of SPSC2022.

As shown in Fig. 2, the number of zones designed by state stakeholders ranged from one for Florida and Wyoming to 88 for Ohio (one per county), for a total of 802 zones in SPCS2022. The reason for the large number of zones designed by stakeholders is that most are LDPs. NGS does not have the resources to design such a large number of zones, so a lower limit of ±50 ppm was set as the objective for zones designed by NGS, corresponding to a zone width of 180 km (if there is no topographic relief), or to an ellipsoidal height range of 637 m. In contrast, a typical LDP design objective is ±20 ppm, corresponding to a zone width of 114 km, or to a height range of 255 m (which can occur over very short distances in mountainous regions). Consequently, covering an entire state with LDPs can require many zones. Although NGS designed some zones with LDP performance, this typically occurred only in cases where the state or the existing SPCS 83 zone was small (e.g., Rhode Island, New York Long Island), and it was simply a result of the small size of those zones.

ZONE DESIGN METHODOLOGY

The NGS design process for SPCS2022 minimizes linear distortion and consists of the steps described in the following four sections (3.1 through 3.4).

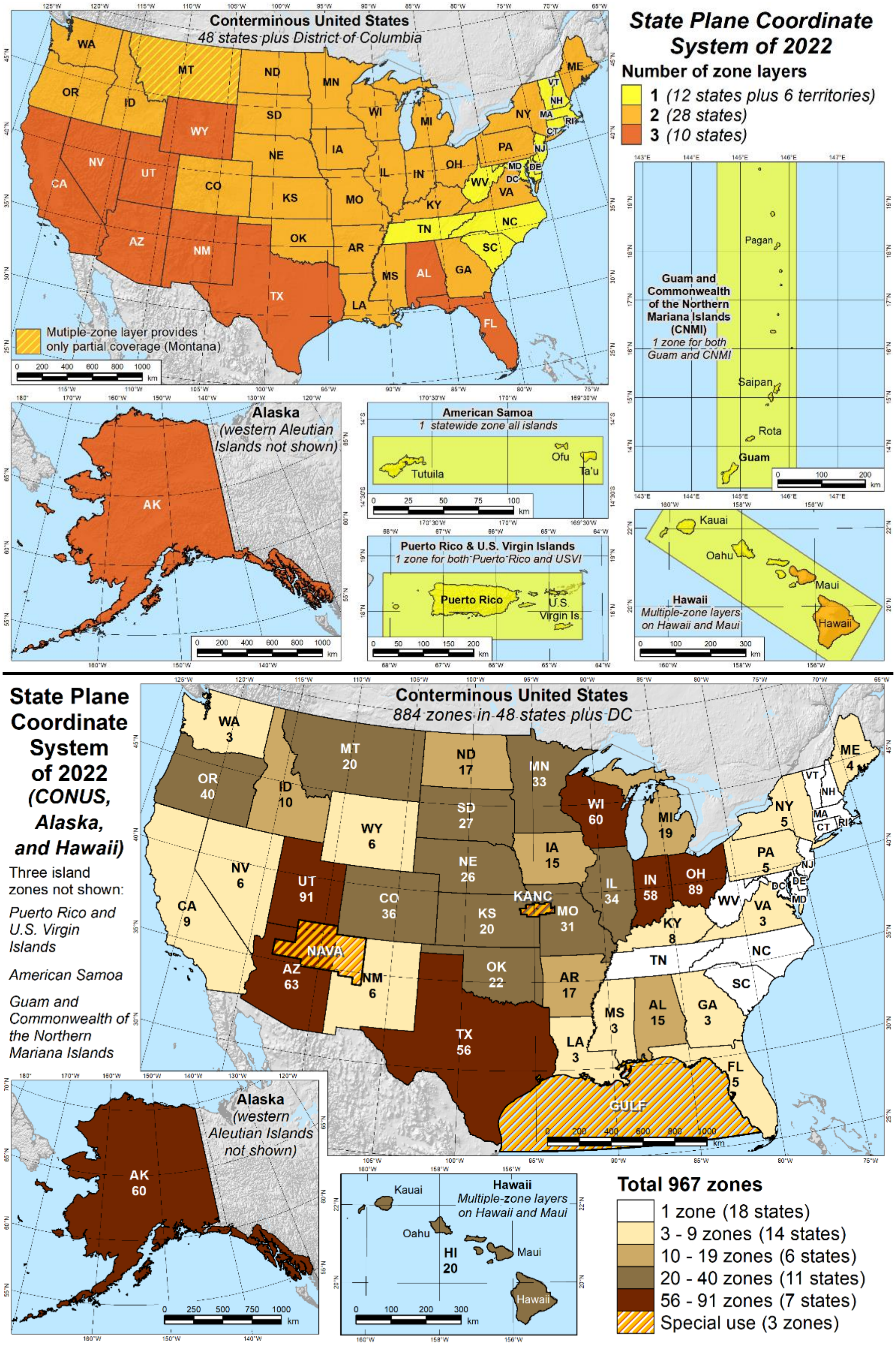

Figure 1. Preliminary number of SPCS2022 zone layers (top) and zones (bottom).

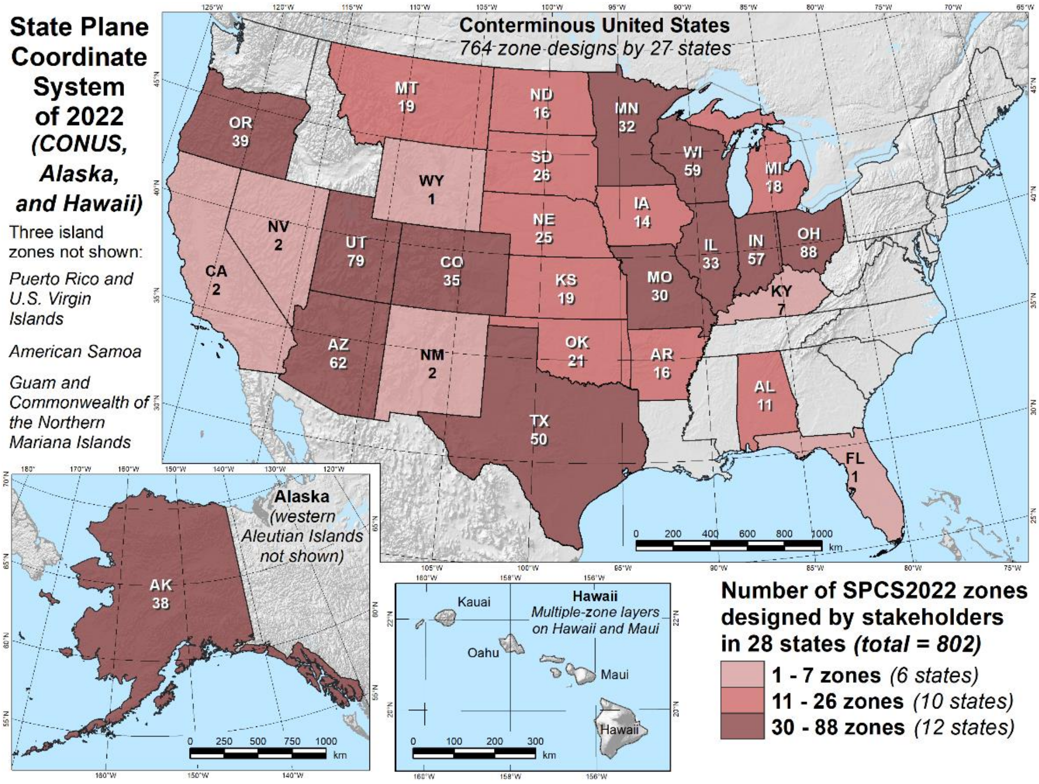

Figure 2. Number of SPCS2022 zones designed by state stakeholders (preliminary).

Datasets of topographic ellipsoidal heights for computing distortion were created from U.S. Geological Survey (USGS) 3D Elevation Program (3DEP) digital elevation model (DEM) rasters for CONUS (1 arcsecond resolution) and Alaska (2 arcsecond resolution), and from the NASA Shuttle Radar Topography Mission (SRTM) DEMs for Pacific and Caribbean islands (3 arcsecond resolution). The estimated root mean square errors of the DEMs for CONUS and Alaska are 2 and 5 m, respectively (Gesch et al. 2014), and for the SRTM DEMs is 10 m (Mukul et al. 2015). These accuracies were considered sufficient for design, since an error of 6 m causes only about 1 ppm error in linear distortion.

Ellipsoidal heights from the CONUS DEMs were computed using NGS hybrid geoid model GEOID18 transformed to ITRF2014 at epoch 2020.0 so that they are consistent with the forthcoming NSRS TRFs. The U.S. National Geospatial-Intelligence Agency Earth Gravitational Model 2008 was used for computing all other ellipsoidal heights, including in Alaska; the NGS hybrid geoid model for Alaska was not used because of known bias and tilt errors (NGS, 2021b). Point grids were generated using equal area PCRSs at spacings of 1, 2, 3, and 5 km for CONUS and Alaska, and 500 m for islands. That allowed performing area calculations by simply counting points, since each point represents a constant area.

3.1 Select a projection type and establish a distortion design criterion

The design process begins with selection of a projection type. Below are the parameters that affect linear distortion for the three projections used for SPCS2022, where origin latitude and longitude and projection axis scale are represented as φ_0, λ_0, and k_0, respectively.

- **Transverse Mercator (TM).** <u>2 parameters</u>: λ_0 and k_0, where λ_0 is the central meridian. For SPCS2022, the Gauss-Krüger form of the TM is used. The φ_0 parameter has no effect on linear distortion and can be set to any value for design.
- **Lambert Conformal Conic (LCC).** <u>2 parameters</u>: φ_0 and k_0, where φ_0 is the central parallel. Only the 1-parallel version of the LCC can be used in SPCS2022, to allow for "non-intersecting" LCCs (i.e., $k_0 > 1$). In such situations a 2-parallel (secant) LCC does not make sense, and its behavior can be duplicated with a 1-parallel LCC simply by using $k_0 < 1$ (i.e., any 2-parallel LCC can be converted into an equivalent 1-parallel). The λ_0 value has no effect on linear distortion, although it does affect convergence angles.
- **Hotine Oblique Mercator (HOM).** <u>4 parameters</u>: φ_0, λ_0, and k_0 all affect linear distortion, as does the orientation of the projection axis at the origin (the skew azimuth), α_0. For SPCS2022, these parameters refer specifically to the center (local) version of the HOM with a defined azimuth (Snyder, 1987, p. 74). It differs from the "natural" version used for SPCS 83 and 27 only by where the grid origin is defined. Although all four parameters affect distortion, φ_0, λ_0, and α_0 are not independent of one another. Thus, the projection origin can be moved along the skew axis with negligible effect on distortion, allowing change of λ_0 to minimize convergence angles.

For "large" zones (short dimension greater than about 100 km), the projection type is usually dictated by the orientation of the long axis of the zone. As zones become smaller, the effect of topographic relief increases, and situations can occur where the best-performing projection type is not the one corresponding to the zone's long dimension.

Once the projection type is known, a linear *distortion design criterion*, δ_0, is determined. This criterion is based on the minimum amount of distortion that can be achieved for a zone of a given width. It is desirable to have a simple method for estimating a δ_0 value that is suitable for any of the three projection types used for design, anywhere on Earth. To that end, the following simple equation for δ_0 was derived for the TM projection,

$$\delta_0 = \pm\left(\frac{w}{4R}\right)^2 = \pm(0.001540\ \text{ppm})w^2 \tag{3}$$

where w is the zone width perpendicular to the projection axis, R = 6371 km is the mean radius of the GRS 80 ellipsoid, and δ_0 is multiplied by 1 million to give the distortion range in ppm. Although derived for the TM projection, it is suitable for the LCC and HOM as well (with w perpendicular to their projection axes). The maximum error of Eq. 3 for all three projection types is less than 1% for zone widths up to 1200 km, between latitudes ±70°. See Dennis (2018b, Chapter 3) for the derivation.

A distortion range based on Eq. 3 gives the performance for the ideal case where ellipsoidal height is constant over the entire zone. While this is never actually true, it provides a useful basis for establishing a design criterion. For SPCS2022, the following distortion design criteria categories were used: ±5, ±10, ±20, ±30, ±40, ±50, ±75, ±100, ±150, ±200, ±300, ±400, and ±500 ppm. Greater design criteria of ±1000 and ±5000 ppm were used for the statewide zones of Texas and Alaska, respectively, due to their large size.

3.2 Determine projection axis location and scale based on topography

The projection axis location is determined mainly by minimizing the range of linear distortion over the entire zone. The scale can initially be set to $k_0 = 1$ or some other reasonable value, such as one that gives a mean distortion of zero. The initial value used is not of much importance, since the distortion range is very insensitive to k_0 and will be refined later.

For TM and LCC projections, the projection axis can initially be set to the mid-longitude or mid-latitude of the zone, respectively. The midpoint is used rather than the centroid so that the positive scale error is balanced (equal) in the parts of the zone most distant from the projection axis. For the HOM, an initial axis location and orientation can be found by determining the narrowest rectangle that completely encloses the zone. The axis origin is at the center of the rectangle and α_0 is parallel to the long side of the rectangle. Both the zone and its minimum bounding rectangle must be defined in the same conformal PCRS. Since the actual PCRS is not yet known, a TM or LCC projection with the axis passing through the midpoint of the zone can be used. For constant topographic height, this method yields φ_0, λ_0, and α_0 values that (very nearly) minimize distortion.

The initial location of the projection axis is then modified to minimize distortion range due to topographic relief. This can be determined quickly by iteration for TM and LCC zones, since the range minimum is well-defined and unique. Systematic variation in topographic height will cause the range minimum to occur at a location other than the zone midpoint. This concept is illustrated schematically in Fig. 3, which shows how the variability in distortion over an area with topographic slope can be decreased by moving the projection axis. Although the range of linear distortion is minimized in the right diagram of Fig. 3, the ellipsoidal heights are not constant (which is true for the left diagram as well). This shows that a single ellipsoidal height should not be used for design, especially for large areas.

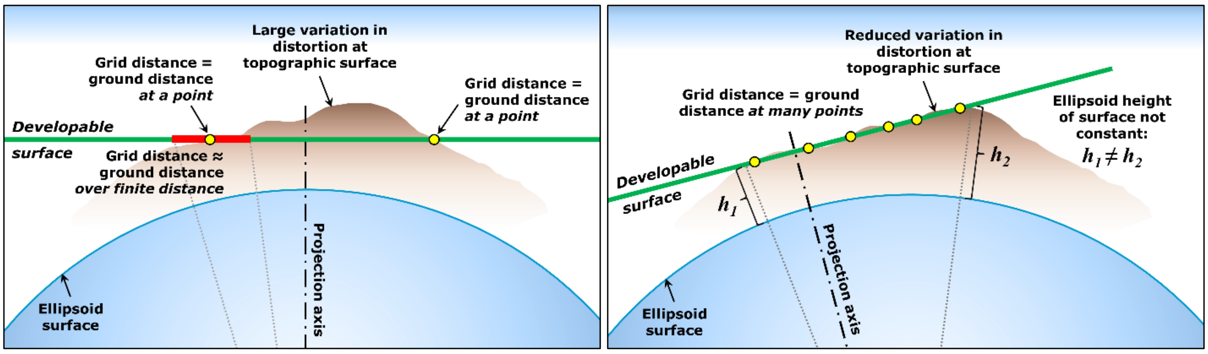

Figure 3. Reduction of linear distortion by changing projection axis location.

The procedure for HOM is more complex, because the distortion range is a function of three variables (φ_0, λ_0, and α_0), rather than only one for TM and LCC. The initial estimate of location and orientation based on the minimum bounding rectangle by width will typically provide a good start, especially for large zones. Then α_0 can be iterated to find a value that gives the lowest distortion range. The process can be simplified by then choosing λ_0 on the skew axis to minimize convergence angles, so that only φ_0 and α_0 need further iteration to find the minimum distortion range.

3.3 Modify projection axis scale based on linear distortion design criterion

Once the projection axis location (and orientation for HOM) is selected, k_0 is refined using the linear distortion design criterion. This is done by considering population, to optimize design for areas where most people live and work. To avoid biasing the design to favor large cities at the expense of smaller ones, the distortion at all cities and towns is also considered, irrespective of population. Distortion magnitude is also evaluated everywhere in the zone, because not all surveying and mapping work or geospatial analysis occurs in populated areas.

To accommodate these divergent objectives, k_0 is selected (and other parameters refined) to achieve the smallest distortion design criterion that satisfies the following three conditions: at least (1) 90% of the zone population, (2) 75% of all cities and towns (by location only), and (3) 50% of the total zone area all fall within the distortion design criterion. Although admittedly somewhat arbitrary, these thresholds for design performance are reasonable and practical, and they are based on preliminary designs of a large number of widely distributed SPCS2022 zones. An additional metric for analysis is reducing the mean distortion weighted by population, along with the unweighted mean for the entire zone.

Population distribution for computing weighted mean distortion and percent of population within the design criterion was determined using 2010 U.S. Census data (U.S. Census, 2023). The highest-resolution (block level) U.S. Census data were used. The blocks are polygons, each of which has a population determined in the decennial census. There were 11,166,336 blocks in the 56 U.S. states and territories of the 2010 Census. For SPCS2022 zone design, the population of each census block was assigned to its centroid point. These points were projected to an equal area PCRS and then used to create a raster for each state with cell dimensions of 1 km (in CONUS and Alaska) and 500 m (for all islands). The population assigned to each cell is the sum of the population of all points within the cell, so that the population raster for each state exactly equals that of the 2010 Census. The non-zero raster cells were then converted to points with the same grid spacing. An ellipsoidal height was assigned to each point using the DEMs and geoid models mentioned previously. This created a set of points with population, latitude, longitude, and ellipsoidal height that could be used in design and analysis. Excluding points with zero population had no effect on computations and greatly reduced the number of points (from 9,414,068 to 1,921,277).

3.4 Evaluate and refine design to achieve optimal performance for zone

The previous three steps provide a process for zone design, but the various design elements often conflict with one another, which can make it difficult to determine which should prevail. To help make design decisions, the following secondary characteristics were also considered in evaluating performance:

- Minimize distortion range and/or balance positive and negative distortion for cities
- Obtain negative distortion for ~60%–80% of the total design area
- Limit positive distortion to less than twice the magnitude of negative distortion
- Balance positive distortion along zone edges on both sides of projection axis

An additional and important part of evaluating zone design is creation and inspection of distortion maps. There are many situations where viewing a map can yield insights that are not apparent through analysis of statistics. Distortion maps were created for every SPCS2022 zone designed by NGS. Examples of such maps are shown in Figs. 4 and 5 of the next section, aggregated for zones by state in the three SPCS2022 CONUS layers.

PRELIMINARY SPCS2022 ZONE DESIGN RESULTS

Preliminary SPCS2022 design results for CONUS are shown in three distortion maps in Figs. 4 and 5, along with a map of SPCS 83. All four maps use the same color scheme and a distortion increment of 50 ppm to facilitate comparison. The numeric results corresponding to these maps are given in Table 2 as percentage of population, cities, and area that fall within ±20, ±50, ±100, and ±400 ppm, as well as statistics (min, max, range, and mean) for cities and total area, along with the mean weighted by population. At the time of this writing (February 2023), SPCS2022 zone definitions are not yet finalized and there may be minor changes in the zone definitions. But this should have minimal impact on the results given here.

The top map in Fig. 4 shows distortion for the 106 SPCS 83 zones in CONUS (excluding the statewide zone in Kentucky). The bottom map shows distortion for preliminary designs of the 49 SPCS2022 statewide zones. Some SPCS 83 zones are also statewide, and the two that stand out most (due to high negative distortion) are Montana and Nebraska. SPCS2022 distortion magnitude for these two states is much less, and the same is true for other SPCS 83 statewide zones. In some states with two SPCS 83 zones, the statewide SPCS2022 zone has less distortion, most notably Maine and West Virginia. There is very little red (positive) distortion for SPCS 83, but substantial negative (blue) distortion, especially in west CONUS (due to high elevations). In contrast, there is considerable positive distortion at the edges of the SPCS2022 statewide zones, particularly in large states. This is due to minimizing distortion at the topographic surface and balancing of positive and negative distortion. Particularly noticeable is the extremely high distortion of the Texas statewide zone, due to its large size. Table 2 shows that the aggregate performance of statewide SPCS2022 zones is comparable to SPCS 83, where 41% of the total area of CONUS is within ±100 ppm, versus 36% for SPCS2022. The mean distortion for SPCS 83 is -98 ppm (-75 ppm weighted by population) and for SPCS2022 is -83 ppm (-100 ppm weighted).

Fig. 5 shows distortion maps for the two multiple-zone SPCS2022 layers in CONUS, with 646 complete coverage zones in 35 states (top) and 184 partial coverage zones in 10 states (bottom). For the complete coverage layer, a large middle portion of CONUS includes states with many zones and low distortion (well within the ±50 ppm increment shown on the map); these are LDP zones designed by state stakeholders. Comparison with SPCS 83 zones is best done for SPCS2022 states that have the same number of zones as SPCS 83. The most striking differences are in west CONUS. Although Texas has substantially less distortion than SPCS 83 for its five complete coverage zones, the distortion is still significant. To reduce distortion further, Texas submitted 50 LDP zones for a partial coverage layer. A similar approach was done in other states to achieve lower distortion in specific areas than obtained with the complete coverage layer, such as in Arizona and Utah. Table 2 shows that both multiple-zone SPCS2022 layers achieve aggregate performance that meets or exceeds a ±50 ppm distortion design criterion (i.e., includes at least 90% of population, 75% of cities, and 50% of total area). Both multiple-zone layers also have mean distortion weighted by population near zero (-4 ppm for complete and -0.5 ppm for partial coverage).

Table 2. Distortion statistics for SPCS 83 and preliminary SPCS2022 designs (CONUS).

Zone layer (CONUS only)	Percent within distortion range				Distortion statistics (ppm)		
	Distortion	**Population**	**Cities**	**Area**	**Statistic**	**Cities**	**Area**
Existing SPCS 83 106 zones (48 states + 1 territory); excludes Kentucky statewide zone	**±20 ppm**	17%	11%	6%	**Min**	-913	-1038
	±50 ppm	40%	30%	17%	**Max**	+206	+223
	±100 ppm	74%	68%	41%	**Range**	1120	1261
	±400 ppm	99%	98%	91%	**Mean**	-98	-178
					Mean weighted by pop = -75		
Preliminary SPCS2022 statewide layer 49 zones (48 states + 1 territory)	**±20 ppm**	14%	12%	7%	**Min**	-1512	-1627
	±50 ppm	27%	26%	18%	**Max**	+2888	+2987
	±100 ppm	48%	48%	36%	**Range**	4400	4614
	±400 ppm	91%	93%	88%	**Mean**	-86	-120
					Mean weighted by pop = -100		
Preliminary SPCS2022 complete-coverage multi-zone layer 646 zones (35 states)	**±20 ppm**	76%	70%	54%	**Min**	-400	-684
	±50 ppm	92%	88%	73%	**Max**	+245	+295
	±100 ppm	98%	97%	89%	**Range**	644	979
	±400 ppm	100%	100%	99.9%	**Mean**	-5	-23
					Mean weighted by pop = -4		
Preliminary SPCS2022 partial-coverage multi-zone layer 184 zones (10 states)	**±20 ppm**	79%	79%	73%	**Min**	-256	-463
	±50 ppm	91%	91%	88%	**Max**	+120	+230
	±100 ppm	99.8%	99%	97%	**Range**	376	693
	±400 ppm	100%	100%	100%	**Mean**	-3	-13
					Mean weighted by pop = -0.5		

SUMMARY AND CONCLUSIONS

Design of SPCS2022 will be completed in 2023, well before the 2025 release of the modernized NSRS. Although SPCS2022 uses the same projection types and reference ellipsoid as SPCS 83, the two systems are substantially different. The main distinction is that SPCS2022 zones were designed to minimize linear distortion at the topographic surface, whereas SPCS 83 and 27 minimized distortion at the ellipsoid surface. In addition, SPCS2022 distortion optimization took into account population distribution, to improve performance in areas where people live and work.

Preliminary results show that much lower distortion was achieved than exists in SPCS 83, which is unsurprising given the design objectives and approach used for SPCS2022. The more important benefit is that SPCS2022 was designed cooperatively with our state stakeholders. Several states made requests for zones designed by NGS, and 28 states submitted their own designs (mostly consisting of LDPs). This resulted in 802 stakeholder-designed zones, much greater than the 165 zones designed by NGS. SPCS2022 design was coordinated with stakeholders to encourage their constituencies to use the SPCS (and thus the NSRS) for their engineering, surveying, mapping, and other geospatial work. As such, SPCS2022 represents a truly customer-driven approach to modernizing the NSRS, one that enables the creation and use of spatially consistent data and products for a wide variety of applications throughout the United States.

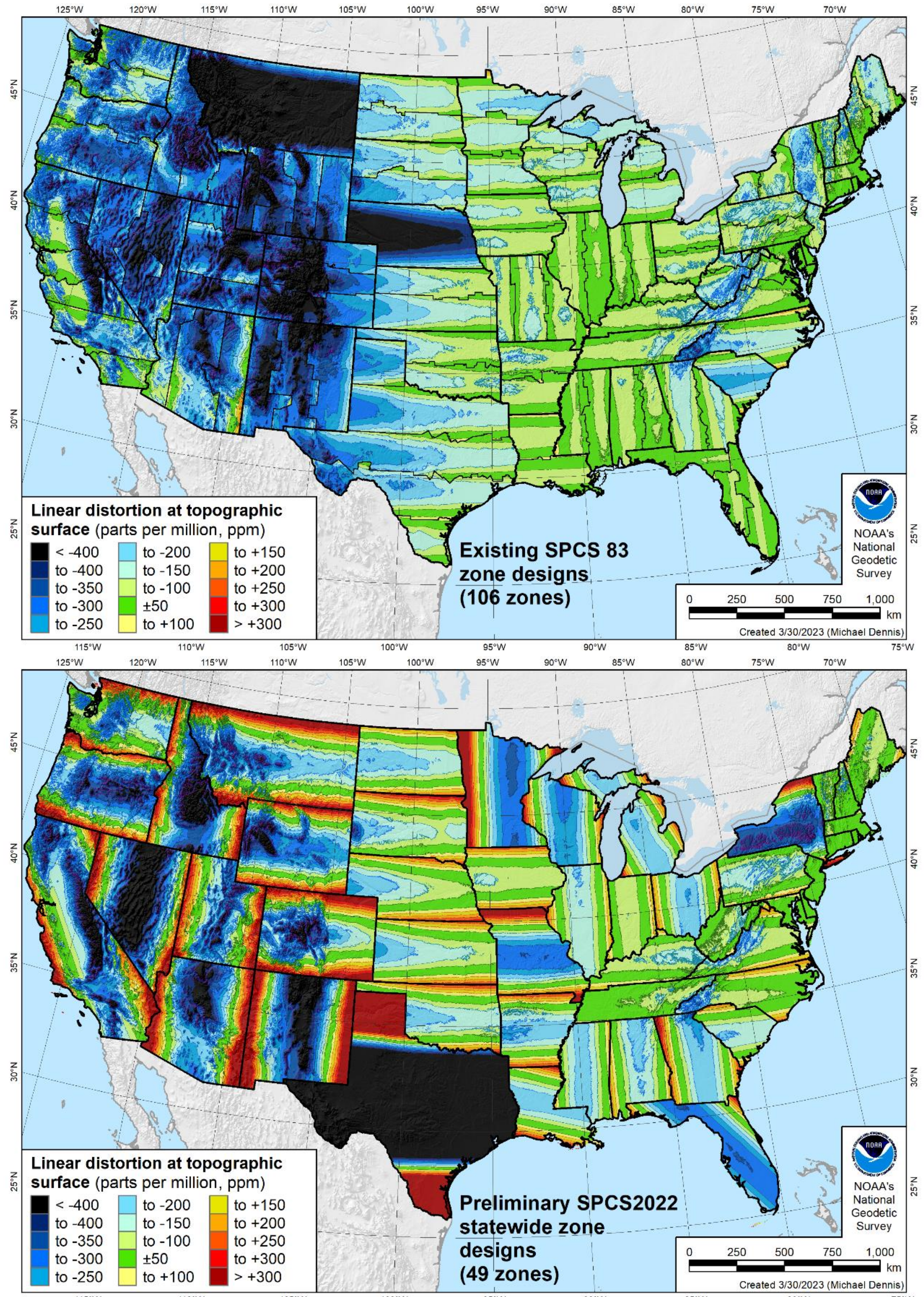

Figure 4. Existing SPCS 83 (top) and preliminary SPCS2022 statewide zones (bottom).

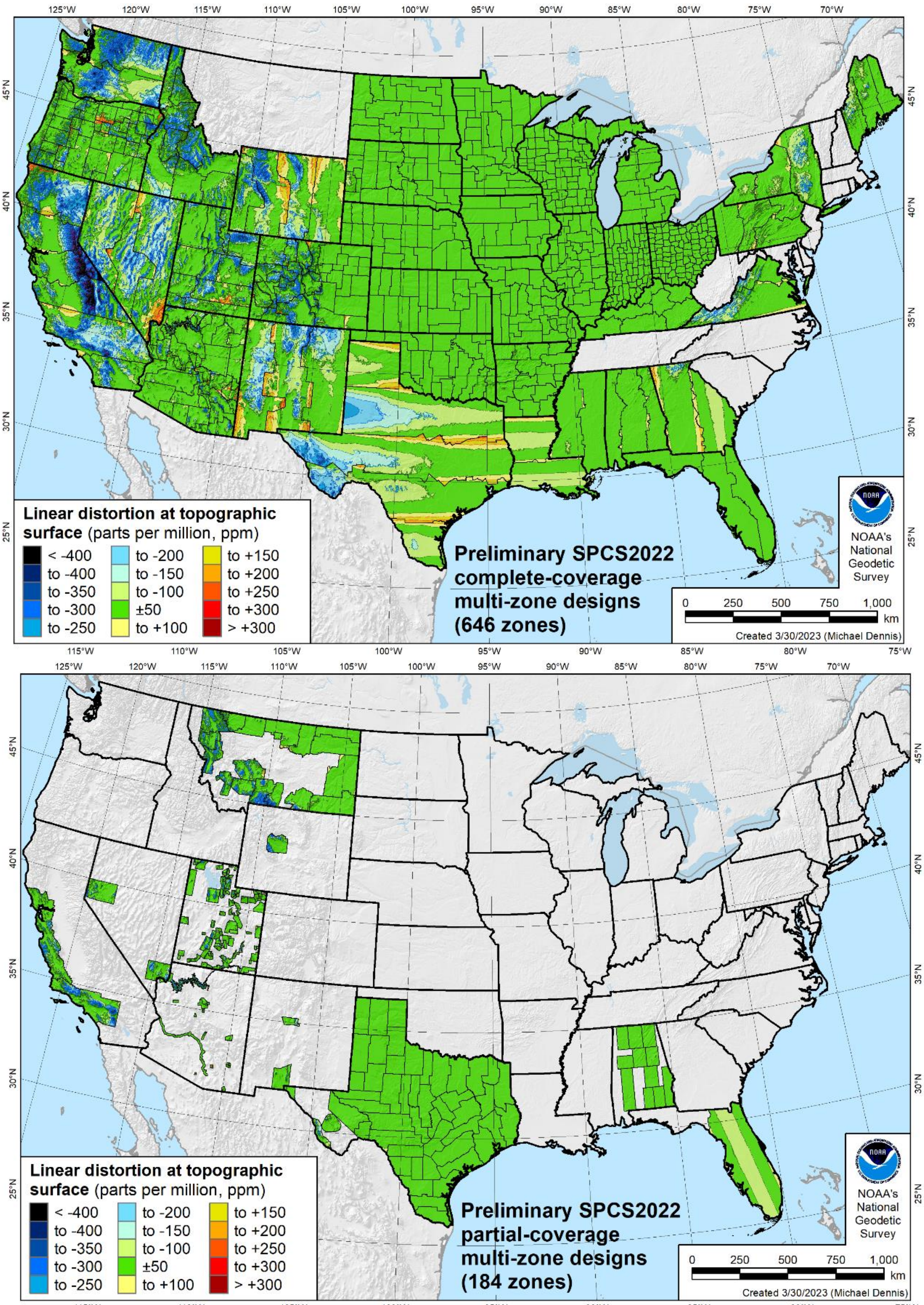

Figure 5. Complete (top) and partial (bottom) coverage multiple-zone SPCS2022 layers.

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BIOGRAPHICAL NOTES

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