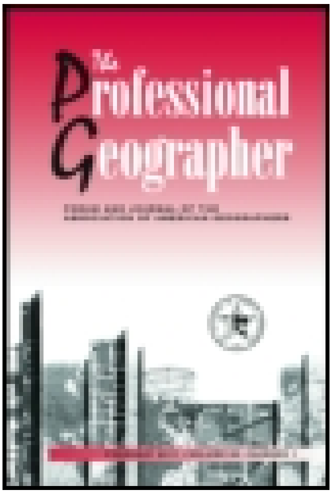

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A New Method for Finding Geographic Centers, with Application to U.S. States

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A New Method for Finding Geographic Centers, with Application to U.S. States

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The geographic center of a region is a fundamental geographic concept, and yet there is no commonly accepted method for its determination. This article discusses some of its history as well as its definition and calculation, and a new method for its calculation is suggested. The new method minimizes the sum of squared great circle distances from all points in the region to the center. This entails (1) projecting regional boundary points using an azimuthal equidistant projection, (2) finding the geographic center of the projected two-dimensional region, and (3) then transforming this location back to a latitude and longitude. This new approach is used to find the geographic center of the contiguous United States and to provide a new list of the geographic centers for U.S. states. This list improves on the widely used but inaccurate list published by the United States Geological Survey in 1923. **Key Words: azimuthal equidistant projection, centroid, geographic center.**

一区域的地理中心，根本上是地理的概念，但如何决定此一中心，却尚未有共同接受的办法。本文探讨地理中心的历史、定义与计算，并提出一个计算的新方法。此一新方法，最小化区域的中心到所有地点的平方大圆距离之和。此方法需要（1）运用正方位等距投影来投影区域边界点，（2）找出投影的二维区域的地理中心，以及（3）将此地点转换回经纬度。此一新方法，用来发掘美国大陆的地理中心，并为美国各州提供新的地理中心之名单。此一名单，改进了1923 年美国地质调查所发佈的受到广泛使用、却不够精确的名单。 **关键词: 正方位等距投影，重心，地理中心**。

El centro geográfico de una región es un concepto geográfico fundamental, pero con todo no existe un método comúnmente aceptado para su determinación. Este artículo discute algo de su historia lo mismo que su definición y cálculo, al tiempo que se sugiere un nuevo método para calcularlo. El nuevo método minimiza la suma de las distancias den el gran círculo al cuadrado, desde todos los puntos de la región hasta el centro. Esto implica, (1) proyectar los puntos del límite regional usando una proyección equidistante azimutal, (2) hallar el centro geográfico de la región bidimensional proyectada, y (3) luego transformar esta localización otra vez a expresiones de latitud y longitud. Este nuevo enfoque es usado para hallar el centro geográfico de los Estados Unidos contiguos y para proveer una nueva lista de centros geográficos de cada uno de los estados de los EE.UU. La nueva lista mejora la tan ampliamente usada como inexacta lista publicada por el Servicio Geológico de los Estados Unidos en 1923. **Palabras clave: proyección equidistante azimutal, centroide, centro geográfico.**

The fundamental concept of a region's geographic center has a long history in geography. In the early and mid-nineteenth century, county seats in the United States were routinely chosen to be accessible to the population via a central location within the county. Among the earliest attempts to determine a center on a larger geographic scale were the U.S. Bureau of the Census's calculations of centers of population in the 1870s (United States Census Office 1874). There the center of population was defined as the "center of gravity of the population of the country," and it was described as the balance point if everyone in the country was of equal weight and stood at their enumerated location.[1] A generally agreed-on characteristic of a regional centroid or geographic center is a similar one—that it represents a balance point for the two-dimensional case of a plane with uniform thickness in the shape of the region. An early work by Hayford (1902) suggested that a similar definition of the geographic center was the average location.

Neft (1966) noted that Mendeleev (1906) determined the center of gravity of Russia, and that interest in the subject of centers became so intense that a "center" for such studies, the Mendeleev Centrographical Laboratory, came into being in 1925. During this period of time, Neft stated that there was an international race between the Americans, Russians, and Italians to see who could compute the largest number of centers.

An important defining characteristic of a center of population or a regional centroid is that it is a point of maximum accessibility to people or places, respectively. More formally, Neft (1966) was consistent with others in defining the arithmetic mean center (in two dimensions) as the location of the minimum value of the second moment of the areal distribution. It is equivalent to the center of gravity as used in physics. A consequence is that the geographic center is the location that minimizes the sum of squared distances from all points within the region to the center.

The geographic center is identical to the location of the center of population in the special conceptual case of a perfectly uniform population spread out across the region. It can be found in principle by averaging

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the x coordinates (and y coordinates) of all points lying within the region. Mendeleev recognized that for a country as large as Russia, geographic and population centers could not be found this easily because the region was more adequately represented as the surface of a three-dimensional object such as a sphere.

Although relatively straightforward in two dimensions, different approaches and definitions are possible when the concept is extended to three dimensions. For example, should one allow a three-dimensional solution for the center to be at a location under the earth's surface? Other questions naturally "surface" when considering the question: Are islands outside of the mainland included? Are coastal waters included? Inland lakes?

The following section of this article provides a look into the occasionally colorful history of geographic centers. Next, alternative definitions and methods of calculation are discussed, followed by the presentation of a new method for finding the geographic center. The method is applied to find the location of geographic centers for the fifty United States, plus the District of Columbia. The final section provides a summary.

The Relevance and Sometimes Contentious Nature of Geographic Centers

Interest in the geographic center falls into two broad categories. It is a location of interest in many geographic studies but particularly so in transportation and location analyses. This occurs, for example, when models use interregional distances as a measure of spatial interaction, and in these cases the variable of interest (e.g., population, travel demand, etc.) is allocated entirely to the center of the region (Cascetta 2009).

A second kind of interest is one that has to do with the rather strong level of attachment that individuals and communities can sometimes have with these locations. On the one hand, it might be argued that the locations are somewhat gimmicky—for individuals and families they represent quirky places to stumble upon or stop along the way in the midst of vacation trips, and for communities they create opportunities to erect monuments, to locate plaques, and, hopefully, to attract tourists. The associated attachments often run surprisingly deep—deep enough for communities to do (usually good-natured) battle with each other and for journalists to run feel-good, public interest stories on what lies at the core of their region.

As evidence, the literature is replete with stories of political squabbles over the selection of county seats, and the location of the geographic center figures prominently in many of them. Indeed, one of the primary criteria in the selection of a county seat is often the location of the county's geographic center, and this led to one of the earliest applications of the concept. In some places, laws are still in place to ensure the key role of the geographic center. For example, Chapter 73 of current local government code in Texas still calls for county seats to be located within five miles of the geographic center, unless a two-thirds vote is obtained.

The geographic center was the official location of the county seat of Kaufman County, Texas, from April 1848 to August 1850 (Kaufman County, Texas 2014). The first meeting of the District Court was held under an oak tree, about five miles north of present-day Kaufman, where the center was thought to be. A surveyor was commissioned to determine a more precise location, but just six months after he submitted his finding, the state legislature changed the boundaries of the county, in February 1850. A new election was called, and on 18 June 1850, the results were tabulated for the three choices: Kingsborough had fifty-one votes, Willow Pond had thirty-nine votes, and the center itself had thirty-seven votes. Because none had a majority, there was a runoff election and because it was also found that law called for the seat to be within five miles of the center, Willow Pond was left off of the runoff ballot. On 18 August 1850, the center received 113 votes, and Kingsborough 106. Kingsborough contested the election, but the county commissioners upheld the result. Undeterred, Kingsborough officials then went to the state legislature, which called for another election. On 31 March 1851, Kingsborough prevailed over the center, ninety-three to ninety, and the name of the town was changed to Kaufman.

In the United States, an early mention of geographic centers at a larger geographic scale is by Deetz (1918), who, writing in a publication of the U.S. Coast and Geodetic Survey, gave the latitude and longitude of the geographical center of the contiguous forty-eight states (and the District of Columbia) at 39.8333N, 98.5333W. This location has withstood the test of time, at least in the sense that it continues to be used in publications and because it is the approximate location of a monument erected in 1941 in Lebanon, Kansas. Although Deetz did not give details on its computation, he noted that it is the center of gravity, equally weighted by area, of a spherical surface in the shape of the outline of the United States. Adams (1932) related that it was found by using the method employed at the time by the U.S. Coast and Geodetic Survey for finding the balance point on a cardboard cutout of an equal area map of the United States. This balance point was found by suspending the map from a string and drawing a vertical line on the map from the suspension point. The map was then rotated, and it was again suspended using a string; a new vertical line was drawn from the new suspension point. The amount of rotation was such that the new vertical line was "approximately at right angles to the first." The intersection of the two lines marked the center. Adams noted that the solution thus found will depend on the type of projection used (and he did not argue that the equal area projection is the correct one to use). In a U.S. Geological Survey (USGS) report, Douglas (1930, p.253) noted that "the geographic center of an area may be defined as that point on which the surface of the area would balance if it were a plane of uniform thickness, or in other words the center of gravity of the surface. The exact position of the center of each State cannot be determined from the data available, but the following approximate positions are sufficiently exact for ordinary purposes. . . . [I]slands adjacent to coast lines and large water bodies on boundaries are excluded."

In an appendix to a report (White et al. 1922), the USGS gave the locations of geographic centers for states. Subsequent reports (Douglas 1923, 1930; U.S. Department of the Interior 1964; Van Zandt 1966, 1976) repeat this list, with updated locations for a handful of states. Locations are given in miles from nearby towns or cities; latitude and longitude coordinates are not provided. In turn, the list has been propelled into and maintained in the public consciousness through almanacs, statistical abstracts, and Web sites such as 50states.com, Netstate.com, and the Wikipedia article on "Geographic centers of the United States" (see http://en.wikipedia.org/wiki/Geographic_centers_of_the_United_States).

As this historic list of geographic centers for states becomes more entrenched, however, so, too, does long-standing caution about actually declaring any specific place "the center." Adams (1932), at the time a senior mathematician with the U.S. Coast and Geodetic Survey, began his discussion by preparing his readers to give up any hope of finding the center, arguing that we "should allow our intelligence to curb our curiosity in cases where it is needed and should not insist upon a definite statement where no exactitude exists" (586). He went on to make a rather curious distinction between "center of gravity" and "center of area," incorrectly stating that the latter can be found only when the area is symmetric with respect to the center. He did note that we might consider a three-dimensional center of gravity, with the difficulty of finding it underground. He came to the conclusion, though, that "there is no such thing as the geographical center of any state, country, or continent" (586).

The USGS also began to exercise restraint in making the locations official, beginning a publication with the statement, "There is no generally accepted definition of geographic center, and no completely satisfactory method for determining it. Because of this, there may be as many geographic centers of a State or country as there are definitions of the term." It then goes on to give them anyway, and like their previous publications, there is no summary of methodology provided (U.S. Department of the Interior 1964).[2]

The USGS locations and, in some cases, the alternative locations determined by the subsequent attempts of others, have also given rise to a host of stories documenting the contentiousness the locations have engendered.

Gray (1989) reported that local legend has it that a Texas land commissioner held up a cardboard cutout on the tip of a pencil to determine the state's geographic center (this might derive from some of the methods that may have been used by federal agencies prior to the 1930s). Official recognition came in 1929 when the General Land Office affirmed that the center was about twenty miles northeast of Brady, on what in 1989 was John Jones's ranch. The spot is "a source of civic pride"—in May of each year it is host to the Heart of Texas Golf Tournament, and in June, the Miss Heart of Texas Pageant is held there. Lampasas surveyor Jerry Goodson, at the request of the Texas Society of Professional Surveyors, came up with a location for the center that is between the towns of Vick and Eden, on Billy Dan and Gloria Sorrell's sheep, goat, and cattle ranch. Goodson, though, found the new center by inscribing a rectangle around the state, and then found the center of the rectangle. He noted that one could also find the center of the smallest circle inscribing the state, the center of the land mass, or the point where east–west and north–south lines divide the state into four equal areas. The town of Brady was apparently not shaken by the kerfuffle—the Heart of Texas motel kept its name, and the mayor was quoted as saying, "I have been to the spot on the Jones ranch and have seen the marker. And, by golly, that's where it is. That's the center of Texas."

In 2008, the *Boston Globe* carried a story ("Lots of heart" 2008) on the competing claims of Wakefield, New Hampshire, and Sanford, Maine, as the center of New England (comprising Maine, New Hampshire, Vermont, Connecticut, Rhode Island, and Massachusetts). Both places came up with the notion that they were the center, unabashedly doing so for marketing reasons. Wakefield once had a sign on its outskirts stating its claim to be "The Center of New England," and one of Sanford's goals was to get away from the slogan, "The town that refused to die." The article quoted Suchi Gopal, professor of geography at Boston University, as finding the center in Dumbarton, New Hampshire at 43.117199N, 71.593498W.

In 2010, Mississippi Senate Resolution 53 acknowledged and designated the center of the state as being located in Leake County, the location having been determined by surveyors to be nine miles northwest of Carthage. It was noted that the "resolution shall be forwarded to the Governor, the Secretary of State for appropriate inclusion in the Mississippi Official and Statistical Register, the Board of Supervisors of Leake County and the Mayor and Board of Aldermen of Carthage, Mississippi, and be made available to the Capitol Press Corps." After being referred to Rules, the resolution died in Committee.

Although competition can be heated, it is often done with tongue in cheek. An April Fool's issue of *The Herald of Randolph* ("Randolph no longer center of Vermont" 2010) reported that the governor had rescinded Randolph's designation as the geographic center, citing the supporting data to be insufficient, thereby giving it unfair advantage. Additionally, he mandated that the various plaques throughout the area be removed.

The Fife Folklore Archives at Utah State University contain a story by Sanders (1974) relating the story that it is not coincidence that Levan, Utah, is *navel* spelled backward—it was thought to be near the center of the state and such an appellation would then be entirely appropriate.

A review of the literature finds that there have been at least two attempts to give careful attention to the problem of finding a state's geographic center. Boscoe (2001) divided the state of Pennsylvania up into cells, 96 percent of which had regular grids based on latitude and longitude. He used planimetry to estimate the areas of the remaining, irregular cells. He implicitly employed the sinusoidal projection when calculating the centroid for each of the regular cells and this resulted in a location that is close to, but not at, the location of the minimum sum of squared great circle distances from the center to all points in the state. His analysis is an extremely careful one in many respects; he, for example, used an ellipsoidal model for the earth, which is an improvement (albeit a slight one) over the more usual assumption of a sphere. He also provided a detailed error analysis, evaluating the potential effects of each assumption.

Barmore (1993a) found methods based on treating the earth in three-dimensional space to be "distasteful," presumably because the solution lies beneath the earth's surface and needs to be projected back to the surface. Barmore was interested in finding the geographic center of Wisconsin; like Boscoe, he began by dividing the state into regular quadrangles on the interior, and he dealt separately with irregular regions along the boundary. The irregular areas were "traced onto a uniform sheet whose areal density had been previously determined with the aid of an electronic 'balance,' cut out, reweighed to determine their area and suspended from several points to determine their centers." These regions constituted approximately 13 percent of the state's area. Centers for the regular quadrangles were determined using elliptical geometry (Bomford 1977).

One measure of the level of public interest in the geographic center of states is the fact that they continue to be listed in almanacs and statistical abstracts—this suggests that they must be at least as important and relevant as the state bird and the state flower. Whatever the source of interest in centroids, one underlying point cannot be ignored: The locations of geographic centers have been widely disseminated and it is therefore incumbent on geographers to ensure that we at least know what they are, we know how to find them, and we are able to develop an accurate list of them for public consumption.

Finding the Geographic Center

A defining characteristic of the geographic center is that it is the point where the sum of squared distances from the center to all points in the region is a minimum. For a two-dimensional representation of a geographic area, this can be found by averaging all of the x and y coordinates within the region, but to do so in practice requires integrating over all of the infinite number of locations within the region. For a two-dimensional polygon, a direct solution for the centroid (C_x, C_y) of a polygon with vertices (x_0, y_0), (x_1, y_1), ..., $(x_n - 1, y_{n-1})$ may be found as follows (Bashein and Detmer 1994):

$$x_c = \frac{1}{6A}\left\{\sum_{i=0}^{n-1}(x_i + x_{i+1})(x_i y_{i+1} - x_{i+1} y_i)\right\}$$
$$y_c = \frac{1}{6A}\left\{\sum_{i=0}^{n-1}(y_i + y_{i+1})(x_i y_{i+1} - x_{i+1} y_i)\right\}. \quad (1)$$

The area, A, of the polygon is found as

$$A = 0.5\left\{\sum_{i=0}^{n-1} x_i y_{i+1} - x_{i+1} y_i\right\} \quad (2)$$

and it should be noted that the n coordinate pairs are numbered sequentially and counterclockwise as they occur along the perimeter, beginning with 0 and ending with $n - 1$, and where

$$(x_n, y_n) = (x_0, y_0).$$

If the pairs are numbered in clockwise order, the area will be negative, but the coordinates of the centroid will still be correct.

The geographic center or center of gravity, defined this way, does not necessarily have to reside within the region itself. In addition, the location is sensitive to outlying locations (and this is intuitive in light of the fact that the sum of squared distances is minimized; the center gets pulled toward distant locations).

The adequacy of this approach for finding regional centroids declines as the size of the region increases, due to the curvature of the earth, and several alternatives have been suggested. Buss and Fillmore (2001) provided an approach to preserve the minimum sum of squared distance characteristic for the center of a set of points on the surface of a sphere, but unfortunately the method is limited to situations where there is a finite number of source points.

The TIGERweb system (U.S. Bureau of the Census 2014) lists centroids for states. These are found by transforming latitude–longitude coordinates to a local tangent plane Cartesian coordinate system, finding the centroid, and then projecting back to latitude and longitude. They include both land and water polygons in the calculation, and the three-mile coastal water limit is included. For states with multiple polygons, the centroid is found as a weighted average of the centroids of each polygon, where the weights represent the area of the polygon. Because Cartesian coordinates are used, this procedure results in a location that is close to, but not at, the true geographic center.

Jenness (2011) provided an alternative method, suggesting that the polygon be broken into a set of triangles, using a fixed external point, and two consecutive vertices for each triangle. The area and centroid are found for each triangle, and the centroid of the polygon is the weighted average of the triangle centroids, where the weights are the areas.[3] Jenness suggested finding the centroid of the spherical triangle by converting latitude and longitude to three-dimensional Cartesian coordinates, finding the centroid (which will be beneath the surface of the earth) and then projecting it back to the surface of the earth. Like the approach used by the census, this method finds a location close to the geographic center, but it, too, does not minimize the sum of squared great circle distances from the center to all points in the region.

A slight improvement over these last two ideas is to use spherical geometry to find the centroid of the spherical polygon and then project back onto the sphere. Brock (1975) gave the formula for area of a spherical triangle, which is needed in the case of multiple polygons.

Yet another tactic would be to overlay a fine grid of points over the region and then find the geographic center via brute force—many alternatives for the center could be evaluated and compared by computing the sum of squared great circle distances from each potential center to all grid points.

The "geosphere" package in R (Hijmans 2014) projects latitude and longitude coordinates using a Mercator projection, finds the centroid of the resulting two-dimensional polygon, and then projects back to latitude and longitude. Because distance is not preserved in a Mercator projection, the resulting location will not be a balance point characterized by a minimum sum of squared great circle distances. The next section suggests a projection that does preserve distance and is therefore appropriate in finding the geographic center.

A New Suggestion for Finding Geographic Centers

In this section, I describe a procedure to find the geographic center of a region that could be represented as a polygon on the surface of a sphere. The center has the property of minimizing the sum of squared great circle distances from the center to all points in the region. Provision is also made for the common case where a "region" consists of multiple polygons (as is the case, e.g., with states that have offshore islands).

Determination of the geographical center begins by projecting the latitude and longitude rcoordinates of the vertices associated with the boundary into two-dimensional space, using an azimuthal equidistant projection centered on an initial guess for the centroid.[4] This creates a two-dimensional polygon, and one can find its centroid using Equation 1. A new iteration repeats this, centering the projection on the new centroid and creating a new polygon with a new centroid. The iterations converge quickly, with a projection centered on the centroid of the polygon projected into its space. The x and y coordinates of this polygon can then be projected back to latitude–longitude coordinates (see Appendix for the equations associated with the azimuthal equidistant projection).

Because the azimuthal equidistant projection preserves distances from the location the projection is centered on, the location of the centroid will retain the desirable property of minimizing the sum of squared great circle distances from all locations to the center.[5]

When a region is defined by more than one polygon, the centroid may be found as a weighted average of the centroids of the individual polygons, where the weights are the relative areas of the polygons. With the centroids for each polygon in hand using the preceding approach, the initial step in combining the polygons is to find the relative areas of the polygons using an area-preserving projection. The Sanson–Flamsteed sinusoidal projection is particularly simple to employ; the y coordinate is simply equal to the latitude, and the x coordinate is equal to the longitude, multiplied by the cosine of the latitude. Equation 2 can then be used to find the area of the polygon.

The final step is to project the coordinates of all polygon centroids using the azimuthal equidistant projection (with the projection initially centered on a guess for the final centroid location). The projected coordinates are weighted by area to find an improved estimate of the final centroid. A new iteration uses this location as the center of the projection, and the process quickly converges to one where the center of the projection is the same as the location of the geographic center.

Data

The boundary files used here were produced in conjunction with the National Atlas of the United States and they are at the scale of 1:1,000,000. The files are available from the USGS (2014) and consist of vertices for both land and water polygons; the total number of vertices in the files is 727,977. The number of points in each state file ranges from 1,540 for Wyoming to more than 129,000 for Alaska. Some states are represented by just one polygon. States with islands outside of their mainland boundary have multiple polygons. Polygons representing water outside of the mainland boundary are available for states bordering the Great Lakes. In the analysis here, only polygons representing land are included. It should also be noted that these polygons, unlike those used by the Census, do not include the three-mile coastal water boundary for coastal states. The centroids found here thus represent for states the center of land and interior waters, and this is comparable to what was used in the original determination of geographic centers for states by the USGS.

So that the geographic center could be found for the entire country, the boundary file for the United States was also used. The file for the forty-eight contiguous states plus the District of Columbia contained 300,279 points; 214,576 of these were on the polygon associated with the principal boundary. To make the file size more manageable for computing, every fourth point of the principal polygon was used, resulting in a final file with (214,576/4) + (300,279 − 214,576) = 139,347 points.

Results

Table 1 gives the locations of the geographic centers for all fifty states, plus the District of Columbia, along with a comparison with the centers as defined by the

Table 1 *Geographic centers for U.S. states*

State	Latitude, Longitude	Distance to census' geographic center (in miles)	Location of geographic center	Location of the USGS geographic center	Alternative description of location of new center
(1)	(2)	(3)	(4)	(5)	(6)
Alabama	32.7784, 86.8290	2.61	12.1 mi SW of Clanton	12 mi SW of Clanton	2.6 mi E of Maplesville
Alaska	64.0610, 152.2307	48.31	77.1 mi NW of Mt. McKinley	63.8333N 152.0000W; 60 mi NW of Mt. McKinley	
Arizona	34.2740, 111.6582	0.15	49.7 mi ESE of Prescott	55 mi ESE of Prescott	13.8 mi SW of Pine
Arkansas	34.8938, 92.4429	0.02	14.2 mi NW of Little Rock	12 mi NW of Little Rock	1.3 mi NW of Maumelle
California	37.1992, 119.4505	5.24	37.4 mi NE of Madera	38 mi E of Madera	4.3 mi SE of North Fork
Colorado	38.9979, 105.5495	0.09	29.1 mi NW of Pikes Peak	30 mi NW of Pikes Peak	13.5 mi E of Hartsel
Connecticut	41.6220, 72.7272	3.3	1.1 mi E of Berlin	at East Berlin	—
Delaware	38.9895, 75.5051	2.89	11.7 mi S of Dover	11 mi S of Dover	2.5 mi SW of Frederica
DC	38.9101, 77.0147	0.38	Near 3rd St. and P St., NW	Near 4th St. and L St., NW	—
Florida	28.6282, 82.4426	11.63	5.8 mi NW of Brooksville	12 mi NNW of Brookille	—
Georgia	32.6405, 83.4418	1.71	17.7 mi SE of Macon	18 mi SW of Macon	6.2 mi SW of Jeffersonville
Hawaii	20.2951, 156.3720	116.95	27.7 mi S of Wailea-Makena	20.25, 156.3333 off Maui	(4.0 mi apart)
Idaho	44.3538, 114.6086	0.26	21.4 mi WSW of Challis;	At Custer, 24 mi SW of Challis	
Illinois	40.0411, 89.1965	4.78	28.8 mi NE of Springfield	28 mi NE of Springfield	5.3 mi NE of Mt. Pulaski
Indiana	39.8938, 86.2818	0.89	10.8 mi NW of Indianapolis	14 mi NNW of Indianapolis	4.0 mi S of Zionsville
Iowa	42.0753, 93.4959	0.01	7.0 mi NE of Ames	5 mi NE of Ames	—
Kansas	38.4949, 98.3801	0.11	22.6 mi NE of Great Bend	15 mi NE of Great Bend	0.8 mi SE of Bushton
Kentucky	37.5360, 85.3021	0.06	3.4 mi SW of Lebanon	3 mi NNW of Lebanon	—
Louisiana	31.0689, 91.9952	16.35	5.8 mi SE of Marksville	3 mi SE of Marksville	3.3 mi E of Mansura
Maine	45.3702, 69.2438	7.67	12.6 mi N of Dover	18 mi N of Dover	10.9 mi NW of Brownville
Maryland	39.0550, 76.7909	9.6	12.6 mi NW of Davidsonville	4.5 mi NW of Davidsonville	3.6 mi ESE of South Laurel
Massachusetts	42.2596, 71.8083	17.26	Irving St. and Wellington St., Worcester (in northern part of Worcester)	North part of city of Worcester	
Michigan	44.3461, 85.4114	36.17	6.6 mi N of Cadillac	5 mi NNW of Cadillac	4.5 mi S of Manton
Minnesota	46.2810, 94.3046	5.63	7.3 mi SW of Brainerd	10 mi SW of Brainerd	5.0 mi S of Baxter
Mississippi	32.7351, 89.6680	2.7	7.7 mi W of Carthage	9 mi NNW of Carthage	—
Missouri	38.3568, 92.4571	0.06	21 mi SW of Jefferson City	20 mi SW of Jefferson City	6.9 mi E of Eldon
Montana	47.0527, 109.645	0.57	10.1 mi W of Lewiston	12 mi W of Lewiston	5.9 mi NE of Moore
Nebraska	41.5392, 99.7968	0.12	12.4 NW of Broken Bow	10 mi NW of Broken Bow	4.2 mi NNW of Merna
Nevada	39.3306, 116.6268	0.26	26.0 mi SE of Austin	26 mi SE of Austin	—
New Hampshire	43.6805, 71.5818	0.6	2.6 mi E of Ashland	3 mi E of Ashland	—
New Jersey	40.1907, 74.6733	5.97	4.3 mi SE of Trenton	5 mi SE of Trenton	—
New Mexico	34.4066, 106.1128	0.07	13.8 mi SSW of Willard	12 mi SSW of Willard	—
New York	42.9543, 75.5262	4.18	11.5 mi SSE of Oneida	6 mi SSE of Oneida	—
North Carolina	35.5579, 79.3856	14.4	12.7 mi NW of Sanford	10 mi NW of Sanford	4.0 mi SW of Goldston
North Dakota	47.4499, 100.4674	0.07	2.7 mi SW of McClusky	5 mi SW of McClusky	—
Ohio	40.2863, 82.7938	9.43	24.9 mi NNE of Columbus	25 mi NNE of Columbus	—
Oklahoma	35.5910, 97.4943	0.17	4.4 mi S of Edmond	8 mi N of Oklahoma City	—
Oregon	43.9336, 120.5617	2.48	29.1 mi SE of Prineville	25 mi SSE of Prineville	—
Pennsylvania	40.8786, 77.7985	2.53	2.6 mi SW of Bellefonte	2.5 mi SW of Bellefonte	—
Rhode Island	41.6762, 71.5562	5.9	2.4 mi W of Crompton	1 mi SSW of Crompton	—
South Carolina	33.9169, 80.8957	3.55	9.7 mi SE of Columbia	13 mi SE of Columbia	1.3 mi NW of Hopkins
South Dakota	44.4446, 100.2282	0.06	7.9 mi NE of Pierre	8 mi NE of Pierre	—
Tennessee	35.8605, 86.3504	0.17	2.5 mi NE of Murfreesboro	5 mi NE of Murfreesboro	—
Texas	31.4789, 99.3287	4.23	23.7 mi N of Brady	15 mi NE of Brady	—
Utah	39.3057, 111.6685	0.1	3.1 mi NW of Manti	3 mi N of Manti	—
Vermont	44.0688, 72.6663	0.05	3.7 mi SE of Roxbury	3 mi E of Roxbury	—
Virginia	37.5229, 78.8531	9.7	16.6 mi W of Buckingham 11.7 mi E of Amherst	5 mi SW of Buckingham 11 mi SE of Amherst; based on 1930 USGS report	1.6 mi S of Gladstone
Washington	47.3822, 120.4505	7.13	7 mi SW of Wenatchee	10 mi WSW of Wenatchee	—
West Virginia	38.6409, 80.6230	0.03	4.9 mi ESE of Sutton	4 mi E of Sutton	—
Wisconsin	44.6243, 89.9941	13.96	9.3 mi ESE of Marshfield	9 mi SE of Marshfield	1 mi E of Auburndale
Wyoming	42.9959, 107.5527	0.06	60.6 mi ENE of Lander	58 mi ENE of Lander	42.3 mi E of Riverton

Note: Distances are great circle distances. USGS = U.S. Geological Survey.

Census and the USGS. Column 4 shows the distance of the center from the town used as a reference location by the USGS, and this can be compared with the USGS description of its center, which is provided in column 5. The last column gives the distance from the center to the nearest town, for those cases where the nearest town is not the same as that given in the USGS description.

Table 1 shows that the locations for states represented with just one polygon are very close to those published by the U.S. Bureau of the Census. For coastal states, the geographic centers are at locations farther inland, in comparison with the census-based centers. The difference is as large as seventeen miles (in the case of Massachussetts, where the coastal limit extends beyond relatively distant offshore islands). The difference is even greater for Michigan, with Great Lakes' water polygons that would pull the center north and west.

For about half of the states, the new centers are within two miles of the USGS centers. There are more than twenty instances, though, where the USGS centers are more than two miles away from the geographic center and ten cases where the error is greater than five miles. There are two rows in the table for Virginia and these show that the newly derived geographic center is actually closer to the original USGS center published in 1930 than it is to the center for Virginia given in more recent USGS publications.

The geographic center of Pennsylvania is 1.01 miles away from the center found by Boscoe. The geographic center of Wisconsin is 0.75 miles away from the center determined by Barmore for territory including land and inland waters. It should be recognized that some of these differences are due to differences in method, and some are due to the possibility and indeed likelihood that different boundary files were used.

The center of New England, found by weighting each of the six states' centroids by the their areas, is at 44.2423, −70.7300, about 11 road miles west of Norway, Maine (from Norway, take Route 118 west for 10.2 miles and then go north for 0.8 miles on Higgins Road). This is about 88.8 great-circle miles from the Gopal-determined center in Dumbarton, New Hampshire, and about 55.5 and 49.8 respective great circle miles north from the competing claims of Sanford, Maine, and Wakefield, New Hampshire.

The geographic center of the contiguous forty-eight states (plus the District of Columbia) is at 39.8355 N, 99.0909 W. This location in Kansas is 5.3 miles from Agra and 5.5 miles from Kensington, at the intersection of East 1300 Road and East Mohawk Road. It lies 29.5 great circle miles west of the long-standing designated center of Lebanon, Kansas.

Discussion

The geographic center of a region is a fundamental concept of geography. It has conceptual appeal as a location with maximum accessibility, and its utility in spatial analyses has been recognized through its longstanding use. For regions such as states, geographic centers can serve not only as tourist attractions but also as points of community pride.

Despite its role in geography, there is a lack of widespread appreciation for its definition and characteristics, and consequently, little agreement on a proper method for its calculation. By projecting boundary points in the form of latitude and longitude using an azimuthal equidistant projection, true distances are maintained, and this enables one to find the location that minimizes the sum of squared distances from the center to all points in the region. For regions with multiple polygons, relative areas can be determined using the area-preserving sinusoidal projection, and then the geographic center can be found by weighting the centers of all polygons by area.

One limitation in the approach is due to the fact that the azimuthal equidistant and sinusoidal projections assume that the earth is a sphere. A more accurate projection would take into account the fact that the earth's shape is not a perfect spheroid (see, e.g., Snyder 1987). Boscoe (2001) evaluated the sensitivity of the results to this assumption; for a state the size of Pennsylvania, the location of the geographic center would only change by about eight meters. ■

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Notes

[1] An even earlier discussion along these lines is found in the work of Hilgard (1872).

[2] Netstate.com posts the following disclaimer on its site, which provides the USGS coordinates and descriptions of their locations: "We have received numerous questions regarding this information including complaints that the coordinates don't align with the location descriptions. In response to the questions we have received, we contacted the U.S.G.S. Essentially, we have tried to get information about the methodology used to calculate the coordinates and the location descriptions. We have been unsuccessful. The U.S.G.S. has taken the position that the source for this information is unknown and that there is no official definition for a geographic center and, therefore, no official methodology for determining a geographic center. The U.S.G.S. has removed virtually all of the coordinate information that they provided online, but they still maintain a list of location descriptions."

[3] For regions with multiple polygons, it is necessary to weight each centroid by (spherical) area. The area of a spherical

triangle is equal to R^2E, where E is the spherical excess:

$$tan\frac{E}{4} = \sqrt{\tan\left(\frac{S}{2}\right)\tan\left(\frac{S-AB}{2}\right)\tan\left(\frac{S-BC}{2}\right)\tan\left(\frac{S-CA}{2}\right)}$$

and where AB, BC, and CA are the lengths of the edges, and S is equal to one-half of the perimeter of the triangle. Chamberlain and Duquette (2007) gave an approximation for the area of a spherical polygon as

$$A = -\frac{R^2}{2}\sum_{i=1}^{n-1}(\lambda_i - \lambda_i)\sin\phi_i.$$

[4] Use of the azimuthal equidistant projection to find centers of population using a set of population centroids was originally suggested by Barmore (1993b) and has recently been used by Plane and Rogerson (forthcoming) along with other definitions for centers of population in their analysis of population redistribution in the United States.

[5] A small amount of error will be introduced because the straight lines connecting the vertices of the polygon do not, in general, represent great circles. To assess the potential for error, the geographic centers for all of the states consisting of one polygon were recomputed after deleting every other vertex. In seven of the seventeen states, there was no change in the centroid—the same center would have been found with half of the points. In eight of the other ten cases, there was a change of only one digit, in the last decimal place—a change in location of less than fifty feet. In two cases—Idaho and Oklahoma, the change in latitude or longitude was as large as 0.0008, which is still less than 350 feet. If additional accuracy is desired, there are at least two ways forward—one would be to use the (larger) USGS data files available at the finer scale of one to 5 million, and the other would be to create additional vertices for each state. This could be done by finding the midpoint along the great circle connecting each pair of vertices (see, e.g., Williams [2011] for the relevant equations). Of course the actual boundary itself might or might not always be one that is represented by the great circle connecting two consecutive vertices.

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Appendix
Equations for the Azimuthal Equidistant Projection (Snyder, 1987)

(1) To convert a latitude-longitude pair (ϕ, γ) to x–y coordinates when projection is centered on $(\phi_1,\ \gamma_1)$:

$$x = Rk^{'} \cos\phi \sin(\gamma - \gamma_1)$$
$$y = Rk^{'} [\cos\phi \sin\phi - \sin\phi \cos\phi c\, \phi \cos\gamma {-} \gamma_1]$$

where $k' = c/\sin c$, and

$$\cos c = \sin\phi_1 \sin\phi + \cos\phi_1 \cos\phi \cos(\gamma - \gamma_1)$$

(2) To convert an x–y coordinate pair to latitude–longitude:

$$\phi = \arcsin[\cos c \sin\phi_1 + y \mathrm{sinc} \cos\phi_1/\pi]$$
$$\gamma = \gamma_1 + \arctan[x \sin c/(\pi \cos\phi_1 \cos c - y \sin\phi_1 \,\mathrm{sinc})]$$