Choosing a projection

Even with all you've learned about map projections, you may feel that you still don't know how to pick a good one—that is, a projection that meets your needs. So what makes a projection good? Two main things.

First, if your map requires that a particular spatial property be held true, then a good projection must preserve that property. In the first concept of this topic, you'll look at this issue in more detail.

Second, a good projection minimizes distortion in your area of interest. This issue is complicated (for instance, are all types of distortion equally important?) and also too mathematical to be explored in great detail. But the second and third concepts in this topic will present some fairly simple and useful rules.

Most of the time, it's not that hard to pick a good projection. Apart from what you'll learn in the rest of the topic, here are a few points to keep in mind:

- **ArcMap can help.** ArcMap has a large number of predefined projections organized by world, continent, and country. You can navigate quickly to appropriate projections for any part of the world.
- **Distortion is often insignificant.** When you're working at large scales—for example, provinces or districts within countries—distortion doesn't play a significant role, and almost any projection that is centered on your area of interest is okay. To put it more picturesquely, you can't flatten a beachball without a lot of distortion, but you can flatten a postage stamp on a beachball.
- **You're not stuck with a bad choice.** It's easy to change projections and to modify projection parameters in ArcMap. So it's almost never too late to correct a flawed choice.
- **You don't always have to choose.** You may be working on a project or for an organization where the question of which map projection to use has already been decided. For example, the State Plane and UTM coordinate systems are established standards for many large and medium-scale maps of U.S. states. (You'll learn about these coordinate systems and the projections they are based on in the next module.)

Concepts

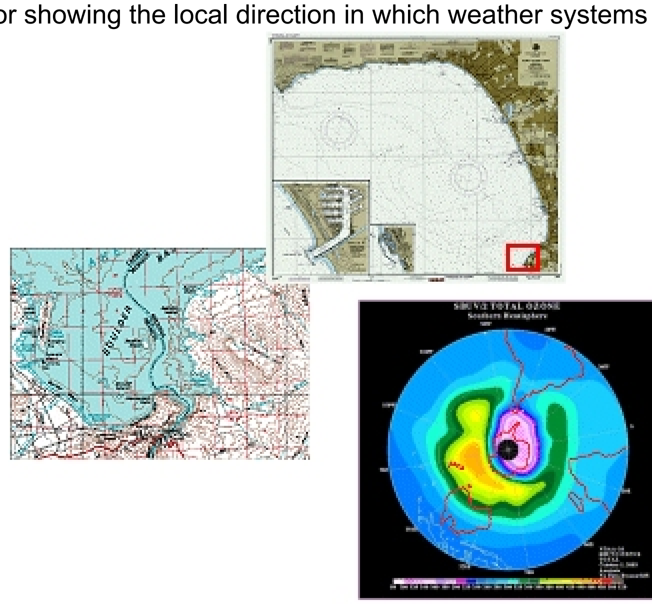
What is the map's purpose?

When you choose a projection, the first thing to consider is the purpose of your map. For general reference and atlas maps, you usually want to balance shape and area distortion. If your map has a specific purpose, you may need to preserve a certain spatial property—most commonly shape or area—to achieve that purpose.

Maps that preserve shape

On a conformal projection, all local angles measured from a point are correct and all local shapes are true. You should use a conformal projection when the map's main purpose involves measuring angles, showing accurate local directions, or representing the shapes of features or contour lines. This category includes:

- Topographic maps and cadastral (land parcel) maps
- Navigation charts (for plotting course bearings and wind direction)
- Civil engineering maps
- Military maps
- Weather maps (for showing the local direction in which weather systems are moving)



Click each of the maps above to learn more about them and the projections they are in.

Most of the maps in the list above would be large or medium-scale. In fact, most large-scale maps nowadays are conformal, regardless of their purpose.

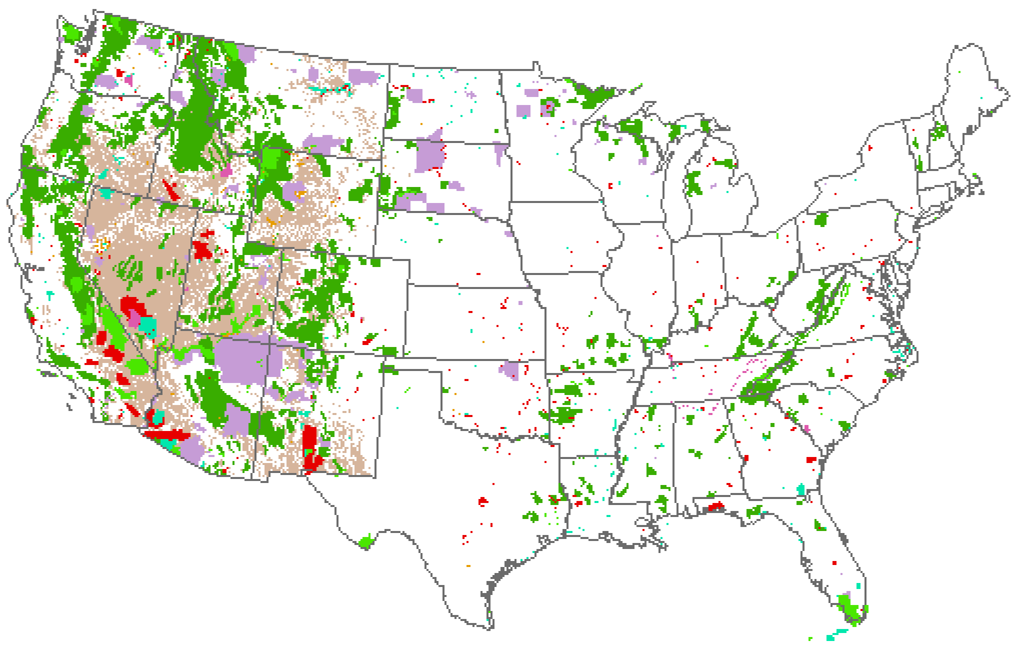
Why are most large-scale maps conformal?

At large scales, a conformal projection centered on the area of interest produces insignificant errors in distance and area. These errors are often smaller than what D.H. Maling, author of *Coordinate Systems and Map Projections*, calls the "zero dimension"—the point at which projection distortion is less than the error caused by physical properties of the map (paper shrinkage, pen width, and so on).
"Large-scale" is not an exact term, but in this context it should hold for scales of 1:100,000 or larger. It may also apply to smaller scales if the area of interest has a compact shape. For example, Maling says that the area distortion in a 1:500,000 Transverse Mercator projection of England is trivial.

Maps that preserve area
On an equal-area projection, the size of any area on the map is in true proportion to its size on the earth. You should use equal-area projections to show:

- The density of an attribute with dots (for example, population density)
- The spatial extent of a categorical attribute (for example, land use maps)
- Quantitative attributes by area (for example, Gross Domestic Product by country)

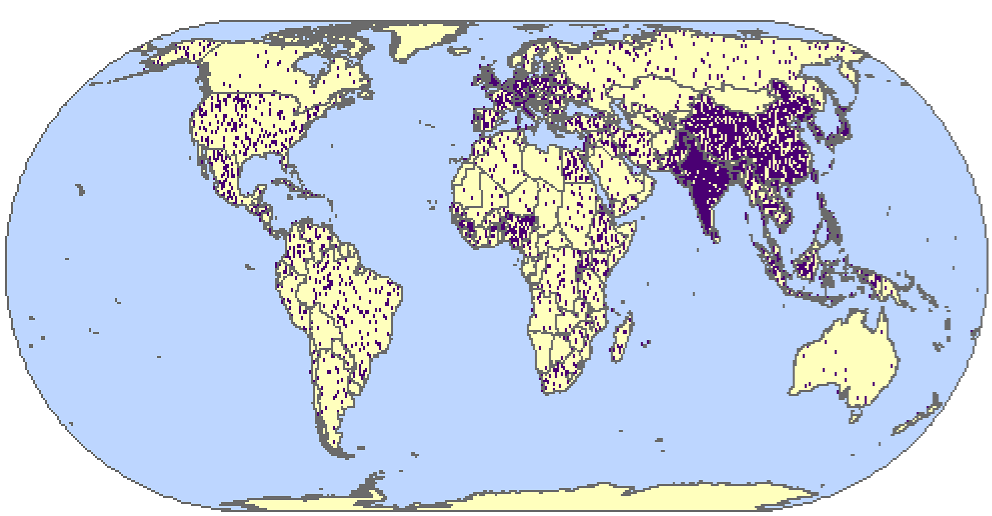
Equal-area maps have also been used as world political maps to correct popular misconceptions about the relative sizes of countries.



Dot density map of federally-owned and Indian land in the U.S. by departmental jurisdiction. Albers Equal-Area Conic projection.

Why equal-area projections are essential for dot-density maps?

Dot-density maps show the concentration of an attribute in an area. The map of world population density you looked at before (shown again below) uses one dot to represent every one million people. If areas are not in true proportion, the map will give false impressions. Countries that draw larger than their true area scale will look less dense than they should. Countries that draw smaller than their true area scale will look too dense.

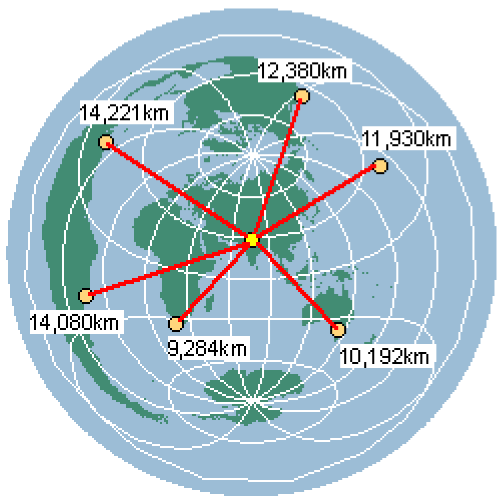


The Eckert IV projection applied here is used by the *National Geographic Atlas, 7th edition*, for several of its world thematic maps.

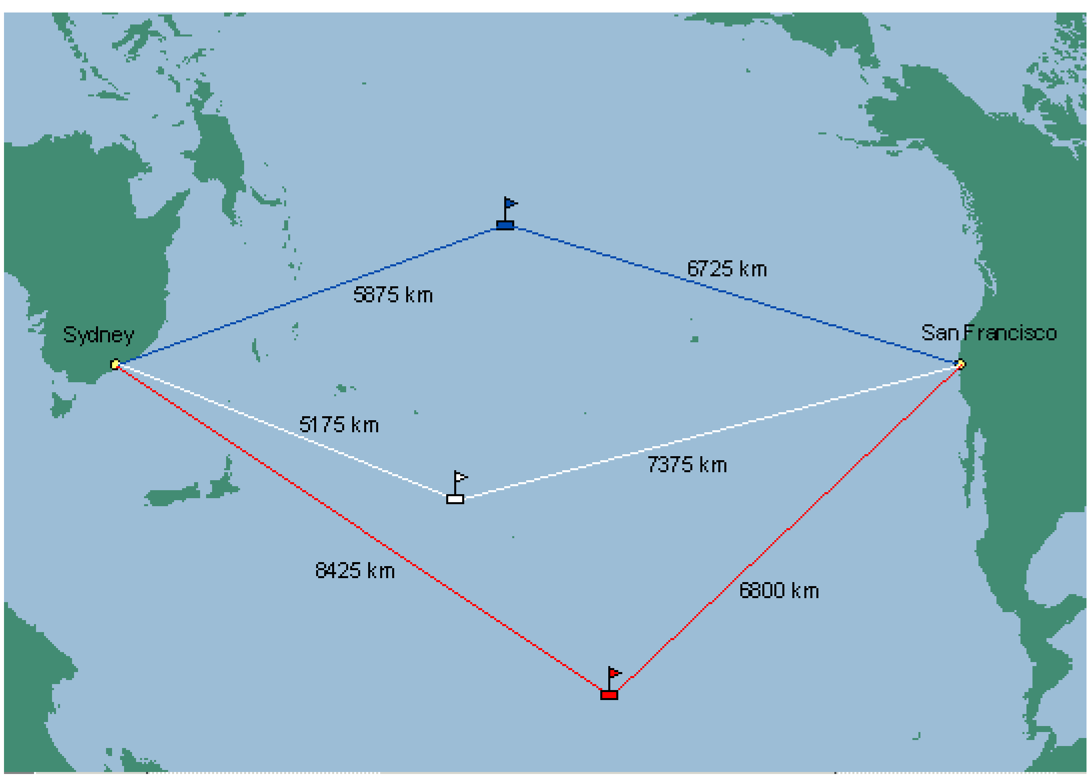
Maps that preserve scale
No map provides true-to-scale distances for any measurement you might make. The Azimuthal Equidistant projection preserves true scale *from a single specified point* on the projection to all other points on the map. Possible uses for this property include:

- Maps of airline distances from a single city to several other cities
- Seismic maps showing distances from the epicenter of an earthquake
- Maps used to calculate costs or charges based on straight-line distance from a source
- Maps used to calculate ranges; for example, the cruising ranges of airplanes or the habitats of animal species

The Two-Point Equidistant projection preserves true scale *from two specified points* on the projection to all other points on the map. This projection could be used to determine the distance of a ship at sea from the start and end of a voyage.



An Azimuthal Equidistant projection centered on New Delhi. Scale from New Delhi to all points (and likewise from all points to New Delhi) is correct.

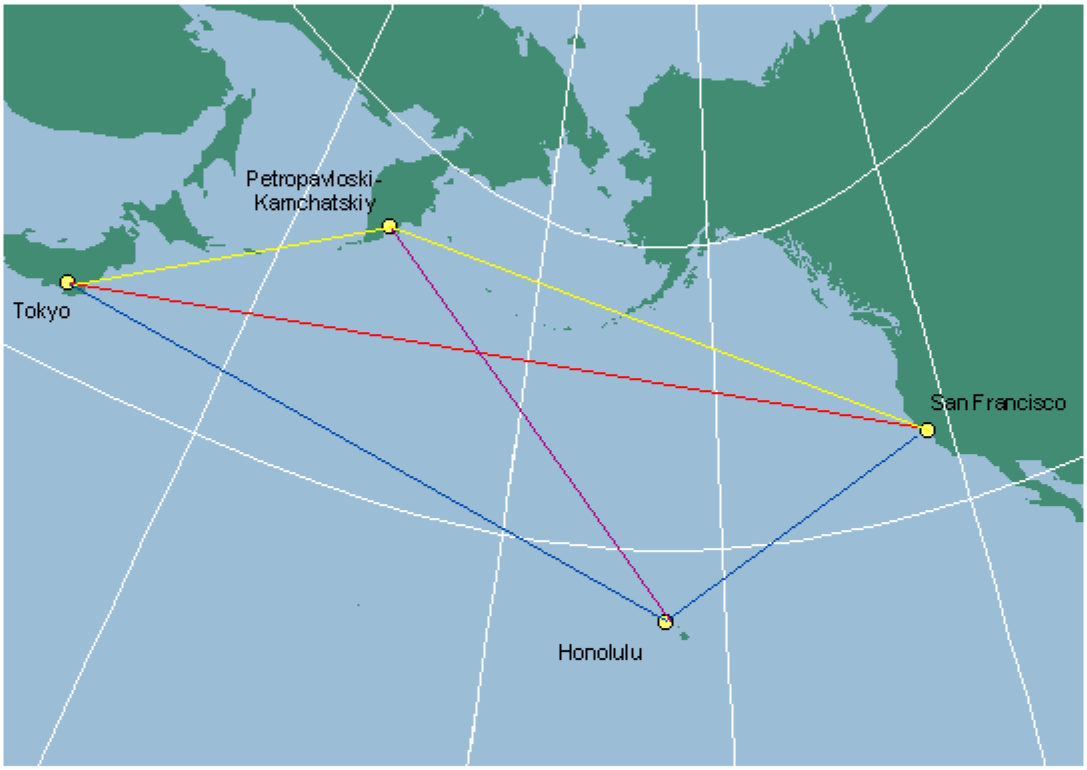


A Two-Point Equidistant projection. Scale is correct from both Sydney and San Francisco to all other points.

Maps that preserve direction

On any azimuthal projection, all azimuths, or directions, are true from a single specified point to all other points on the map. (On a conformal projection, directions are locally true, but are distorted with distance.) Direction is not typically preserved for its own sake, but in conjunction with another property.

In navigation and route planning, however, direction matters for its own sake. The Gnomonic projection is unique among azimuthals in that every straight line drawn on it represents the arc of a great circle. Since a great circle is the shortest distance between two points, Gnomonic projections are useful for planning air and sea routes and for mapping phenomena, like radio waves, that follow shortest-distance paths.



A Gnomonic projection. Every straight line on the map is the shortest distance between two points. The lines do not have true scale, however.

True direction and constant direction revisited

On the Gnomonic projection, any straight line between two points is the arc of a great circle. While good for route planning, this property is not good for practical navigation, because to follow a great circle, you have to keep changing your bearings.

On the Mercator projection—which is not azimuthal—any straight line between two points is a line of constant bearing: you follow a single compass heading to get from one point to another, but the route is longer than a great circle.

For short routes, navigators rely on the Mercator. For long routes, they may plan their course on the Gnomonic, then convert the great circle path to a series of shorter rhumb lines on the Mercator.

General purpose maps

Many compromise projections have been developed to show the world with a balanced distortion of shape and area. Among the most successful are:

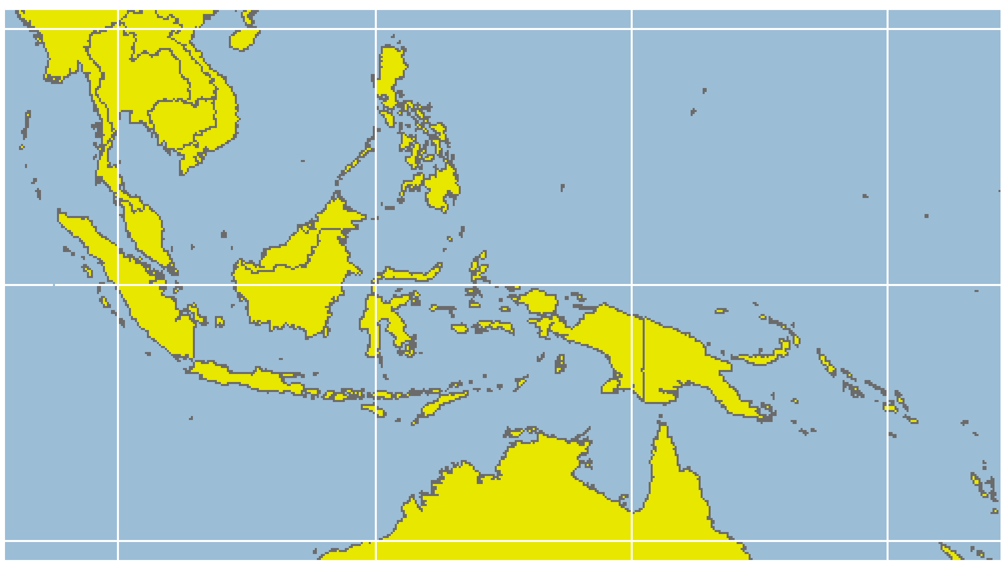
- Winkel Tripel (currently used by the National Geographic Society for world atlas maps)
- Robinson
- Miller Cylindrical

For larger-scale maps, from continents to large countries, equidistant projections (equidistant in the sense of true scale along the meridians) are good at balancing shape and area distortion. Depending on your area of interest, you might use:

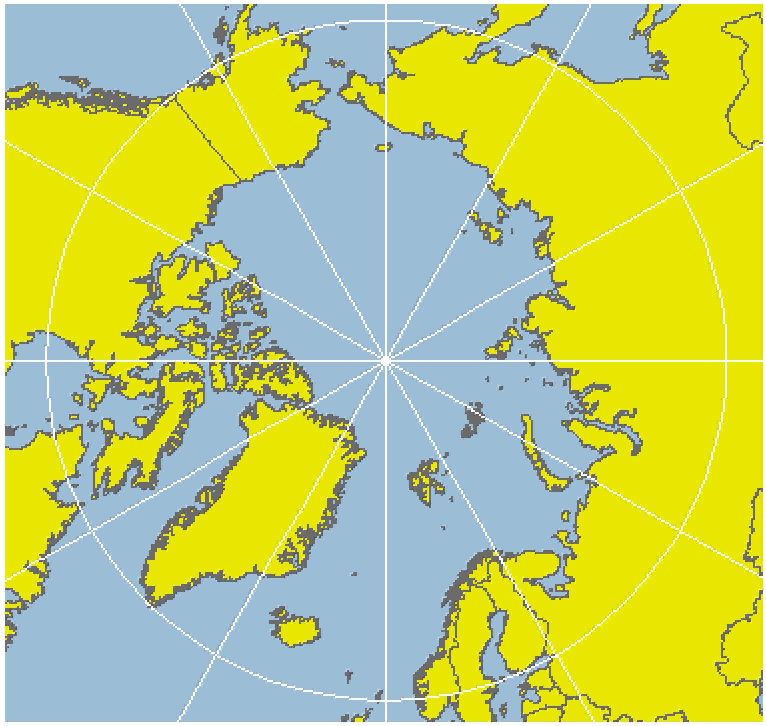
- Azimuthal Equidistant
- Equidistant Conic
- Plate Carrée

The National Geographic Society uses the Two-Point Equidistant projection to balance shape and area distortion for some maps of Asia.

An Equidistant Conic projection of South America.



A Plate Carree projection of Indonesia.



An Azimuthal Equidistant projection of the north pole.

Which part of the world does your map show?

The map's purpose narrows your choices, but doesn't determine a projection. After all, there are many conformal projections, many equal-area projections, and many compromise projections.

The next step in choosing a projection is to decide on the class of projection: cylindrical, conic, or azimuthal. A time-honored rule–dating to the 16th century–is to choose according to the latitude of your area of interest. The rule says:

- To map tropical regions, use a cylindrical projection
- To map middle latitudes, use a conic projection
- To map a polar region, use an azimuthal projection

The rule makes sense if you think about the line (or point) of zero distortion for each class of projection. In cylindrical projections, the line of zero distortion is the equator; in conic projections, it's a parallel of latitude; in azimuthal projections, it's one of the poles. Using a projection from the right class minimizes distortion for your area of interest.

But the rule applies only to the normal aspect of projections. For example, a cylindrical projection, free of distortion along the equator, obviously makes a better map of the tropics than an azimuthal projection centered on the north pole. But does it make a better map than an oblique azimuthal projection centered on the equator? Not necessarily.

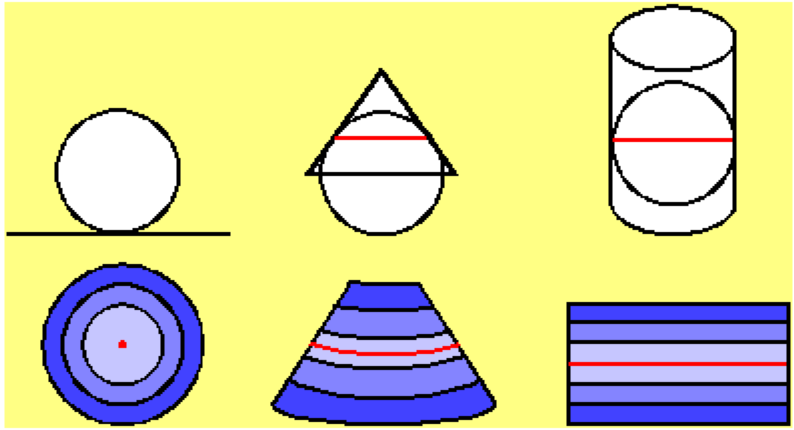
The latitude rule meant a lot before the computer age, when cartographers worked from base maps drawn in a limited number of standard projections. Changing aspect or standard lines could take weeks or months of work and might be hard to justify for the sake of experimental or limited use. Nowadays, computer software makes it easy to change aspect and to modify projection parameters so that different classes of projection can be optimized for an area of interest.

Does the latitude rule still matter?

It's still a good rule of thumb, especially if you want to choose a projection quickly and not worry about customizing the parameters. Just don't think of the rule as a limitation on your options.

What shape is your area of interest?

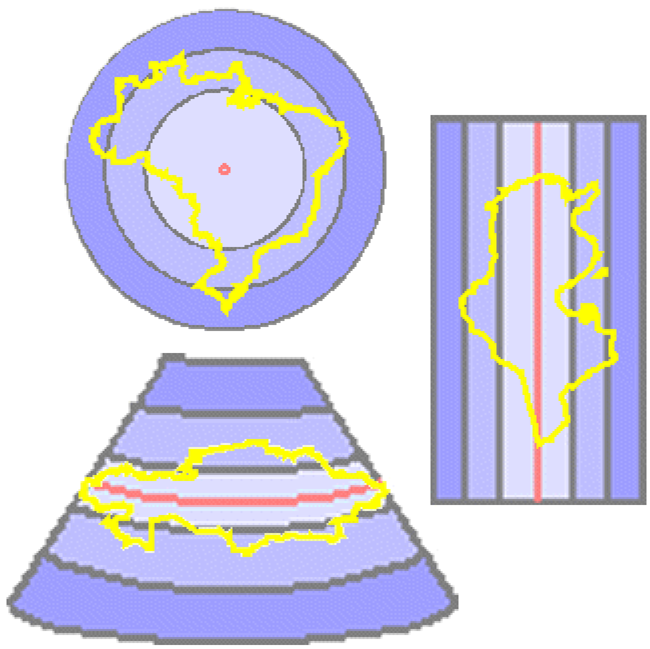
Although the latitude rule you just read about is less important than it used to be, the idea behind it—that of minimizing distortion for your area of interest—is still relevant. Azimuthal, conic, and cylindrical projections each have a distinct pattern of distortion.



Top row: Conceptual drawings of tangent azimuthal, conic, and cylindrical projections. Bottom row: The corresponding distortion patterns. Darker blue shading represents increasing distortion. Black lines represent lines of equal distortion. Red points and lines represent zero distortion. Distortion contours for secant projections are much the same.

So a useful selection principle is to match the shape of your area of interest to a distortion pattern. The old latitude rule has been given a new formulation by Frank Canters, author of *Small-scale Map Projection Design*, (in slightly different words than these):

- To map areas that extend along a great circle, use a cylindrical projection
- To map areas that extend along a small circle, use a conic projection
- To map areas that are approximately circular (or have equal extent in all directions), use an azimuthal projection

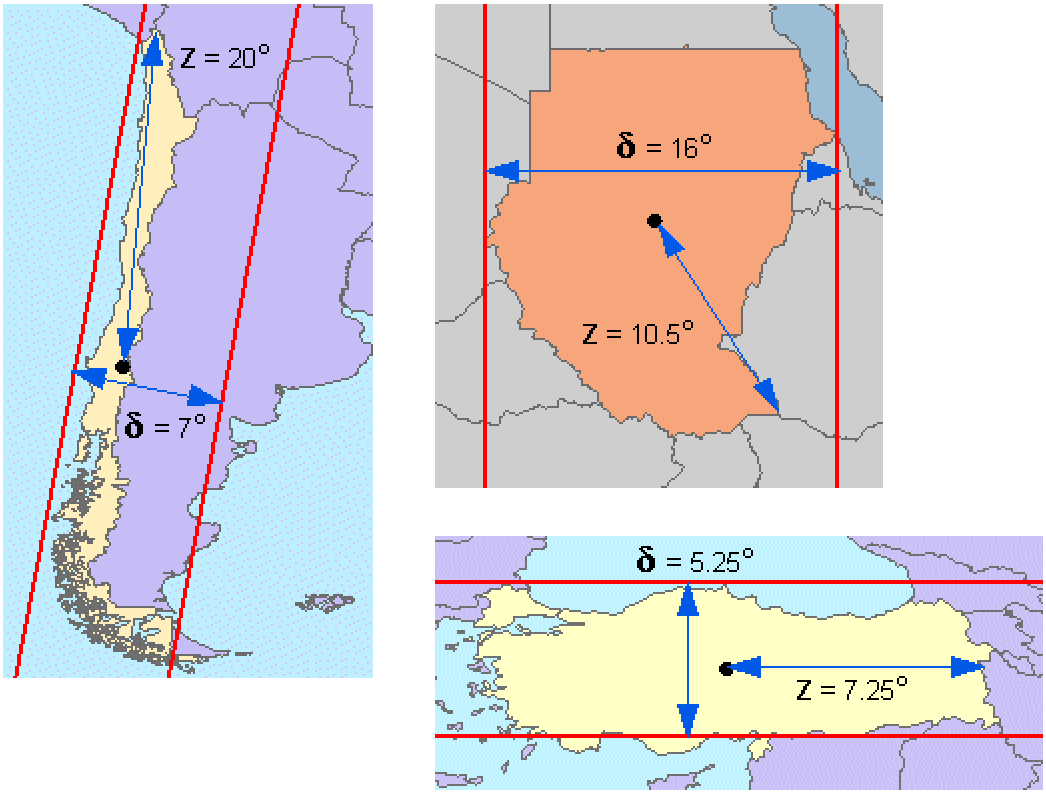


Brazil's outline superimposed on an azimuthal distortion pattern (upper left); Kazakhstan's on a conic distortion pattern (lower left), and Tunisia's on a transverse cylindrical pattern (right).

It's not always easy to tell which distortion pattern is best-suited to a shape. Looking at China, for instance, it's not obvious whether an azimuthal or a conic projection would be better. (In fact, both are reasonable.) Experts can analyze distortion values in detail across a map, but that's too much work—and too much math—for most of us. Luckily, visual judgment usually gives decent results. Make sure you look at a globe, though—don't rely on the way shapes look on a map or a computer screen.

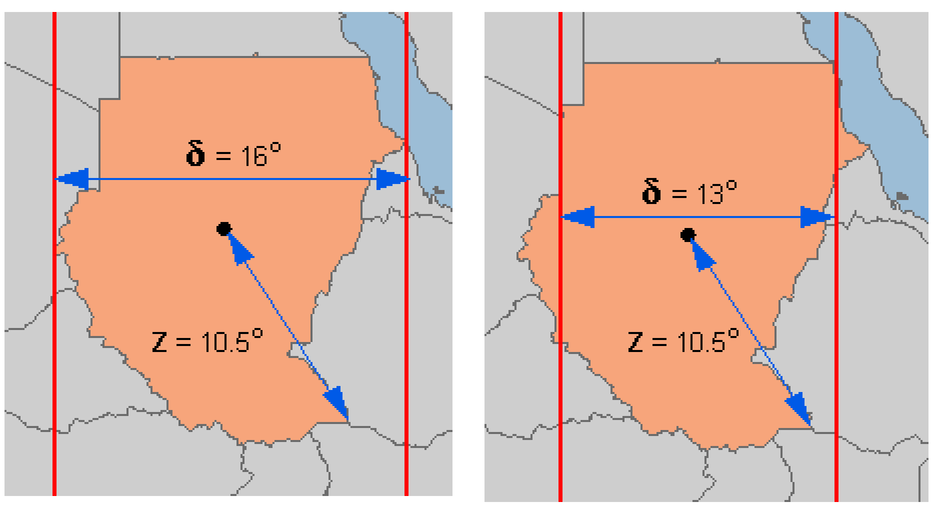
Young's Rule for selecting class of projection

In 1920, A.E. Young developed a formula for deciding when to use an azimuthal projection. It works like this: suppose you draw two parallel lines—actually, two parallel small circles on the earth's surface—that bound your area of interest in the direction of its narrowest extent. These may be parallels of latitude, but they may just as well be transverse or oblique lines. Call the angular distance (the distance in degrees) between these lines **δ**. Now measure the angular distance from the center of your area of interest to the point farthest from the center. Call this value **z**. Young's rule says that if z/δ is less than 1.41, an azimuthal projection is the most suitable. If z/δ is greater than 1.41, you should use a conic or cylindrical projection instead.



Chile's value is 2.85, double Young's threshold, so an azimuthal projection is clearly unsuitable. For Sudan, which has a value of 0.66, an azimuthal projection is the right choice. Turkey's value is 1.38, a borderline case.

Country and region outlines may have all sorts of protrusions, hollows, and weird dangling appendages. Such irregularities may be small in area but have a large effect on the spacing of your bounding parallel lines. You can adjust the value of δ by deciding how far to respect these irregularities. Likewise, the value of z is variable according to how you determine the center of the area of interest. In ArcMap, for example, polygon centroids don't always fall within the polygon boundary (Vietnam's centroid is in Laos), but you may want to stipulate that the center of an area must lie within the area's boundary.



Left: The bounding lines fully respect Sudan's outline. The value for this calculation is 0.66. Right: Moving the bounding lines closer together may give a truer, if less strictly accurate, picture of Sudan's shape. The value for this calculation is 0.81; an appreciable change, though an azimuthal projection is still recommended. Similarly, the value for Turkey can be plausibly adjusted to be either greater or less than 1.41. As a final example of measurement variability, Maling calculates the value for Chile as 2.3 (16 divided by 7), a good bit lower than the 2.85 value arrived at above.

Young's rule tells you when to use an azimuthal projection versus a conic or cylindrical projection, but it doesn't tell you how to choose between a conic and a cylindrical when an azimuthal has been ruled out. To help make this choice (repeating what was said above), look at the area of interest on a globe and see if its longer axis more closely conforms to the arc of a great circle or a small circle. Again, it's not always easy to tell, but a good look should be enough to rule out a plainly bad choice.

Using Young's Rule with ArcMap

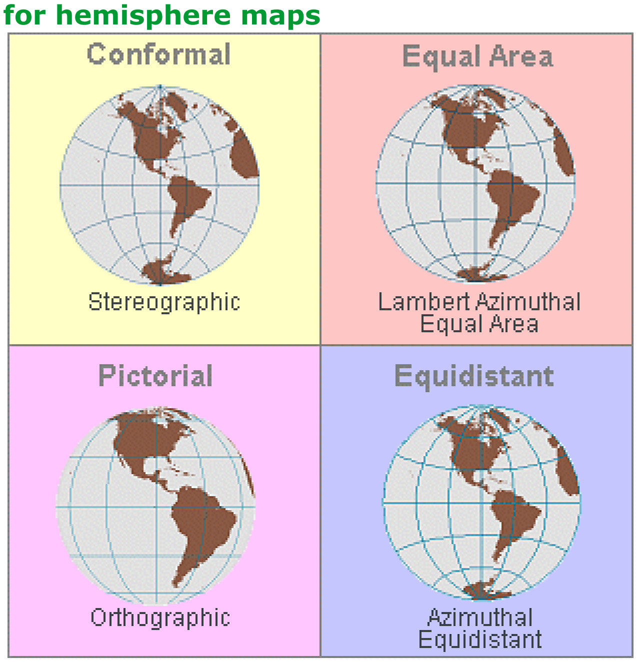
You can calculate z/δ in ArcMap with a little work:

1. Set the data frame to no projection or to a geographic projection, such as WGS84. **Note:** Your display units will default to decimal degrees. If no projection is set, ArcMap will perform your subsequent measurements on a sphere. If a geographic projection is set, the measurements will be done on a spheroid. (Either method should give good results.)
2. Draw a pair of parallel graphic lines that bound the area of interest as narrowly as possible.
3. Use the Measure tool to measure the angular distance between the lines. This is **δ**. (**Note:** Your graphic lines are lines—not parallel small circles—and may not have constant angular distance between them. Therefore, make your δ measurement across the center of the area of interest.)
4. Calculate the centroid of your area of interest. (For help, see the ArcGIS online help topic *Making field calculations*.) **Note:** If your area of interest includes two or more polygons, you'll have to dissolve them.
5. Add a graphic point at the centroid's coordinates. (**Hint:** Use the Size and Position tab of the graphic's Properties dialog.)
6. Measure the angular distance from the graphic point to the farthest boundary of the area of interest. This is **z**.
7. Calculate **z /δ**.

Recommended projections

After taking into account the purpose of your map and the shape of your area of interest, you should be able to narrow down the possibilities… if not to a single projection, then at least to a short list of all good choices.
These projections are among the best of their kind, but they are not a complete list of suitable projections. With a few exceptions, these recommendations have been taken from John Snyder, *Map Projections: A Working Manual*, pp. 34-35.

Recommended projections for hemisphere maps



Recommended hemisphere projections. The Orthographic projection does not preserve shape, area, or distance, but it has a natural appearance and is often used for illustrations.

Recommended projections for maps of continents and smaller areas

Property	Area of interest extends mainly … north to south	east to west … *along equator*	east to west … *away from equator*	equally in all directions … *centered on pole*	equally in all directions … *on or along equator*	equally in all directions … *between pole and equator*	obliquely
Conformal	Transverse Mercator	Mercator	Lambert Conformal Conic	Stereographic (polar)	Stereographic (equatorial)	Stereographic (oblique)	Hotine Oblique Mercator
Equal-area	Sinusoidal	Cylindrical Equal Area	Albers Equal Area Conic	Lambert Azimuthal Equal Area (polar)	Lambert Azimuthal Equal Area (equatorial)	Lambert Azimuthal Equal Area (oblique)	

Property	Center of projection is … at pole	at equator	between pole and equator
Equidistant (true scale on meridians)	Azimuthal Equidistant (polar aspect)	Plate Carree	Equidistant Conic

For equal area maps of north-south and oblique extents, Snyder recommends transverse and oblique aspects of the Cylindrical Equal Area. These aspects of the Cylindrical Equal Area are not supported by ArcMap.

Projection properties summarized

The two graphics below summarize properties for several popular projections. They are adapted from the fold-out chart in *Understanding Map Projections* (Kennedy, 1994-2000). This chart itself is adapted from a U.S. Geological Survey poster called *Map Projections*.

Projection names are listed across the top and projection properties along the side. The properties include the spatial property preserved by the map; the projection's appropriate extent (what size area it can cover); its appropriate spatial orientation (for instance, areas lying east–west); and its appropriate zone (for instance, mid-latitudes).

A black square means that the projection preserves a spatial property. A green square means the projection is highly suitable for a spatial extent or orientation. A blue square means lower, but still acceptable, suitability.

Orientations are a restriction on suitable extents. For example, if "continent" is a suitable extent and "east–west" is a suitable orientation, it means the projection is good for continents with an east–west orientation—not for all continents plus all areas that lie east–west.

* equidistant can be either true scale along any line from the focal point or true scale along meridians

minimal distortion

moderate distortion

	Aitoff	Albers Equal Area Conic	Azimuthal Equidistant	Behrmann Equal Area Cylindrical	Bonne	Craster Parabolic	Cylindrical Equal Area	Eckert VI	Equidistant Conic	Equidistant Cylindrical	Flat Polar Quartic	Gnomonic	Hammer-Aitoff	Hotine Oblique Mercator	Lambert Azimuthal Equal Area	Lambert Conformal Conic	Loximuthal
Properties																	
conformal														●		●	
equal area		●		●	●	●	●	●			●		●		●		
equidistant *			●						●	●							
true direction			●									●			●		
compromise	●																
straight rhumbs																	●
perspective							●					●					
Suitable Extent																	
world	minimal		moderate	minimal		minimal		minimal			minimal		minimal				
hemisphere			minimal												minimal		
continent or ocean		minimal	minimal		minimal				moderate					minimal	minimal	minimal	
region or sea		minimal	minimal						minimal			moderate		minimal	minimal	minimal	
small to medium country		minimal							minimal					minimal		minimal	
locality			moderate							minimal				minimal		minimal	
Suitable Orientation or Latitude																	
north-south					moderate												
east-west		minimal					minimal		minimal							minimal	
oblique														minimal			
equatorial			minimal				minimal					minimal			minimal		
middle latitudes		minimal	minimal						minimal			minimal			minimal	minimal	
polar / circular			minimal									minimal			minimal		

* equidistant can be either true scale along any line from the focal point or true scale along meridians

minimal distortion (green) · moderate distortion (blue)

	Mercator	Miller Cylindrical	Mollweide	Orthographic	Plate-Carree	Polyconic	Robinson	Sinusoidal	Stereographic	Transverse Mercator	Two-Point Equidistant	Van Der Grinten I	Vertical Near-Side Perspective	Winkel Tripel
Properties														
conformal	■								■	■				
equal area			■					■						
equidistant *					■						■			
true direction				■					■				■	
compromise		■				■	■					■		■
straight rhumbs	■													
perspective				■					■				■	
Suitable Extent														
world	moderate	minimal	minimal				minimal	minimal			moderate	moderate		minimal
hemisphere				minimal					minimal					
continent or ocean				minimal				minimal	minimal	minimal	minimal		minimal	
region or sea	minimal								minimal	minimal	minimal		minimal	
small to medium country	minimal					moderate				minimal				
locality	minimal				minimal	moderate				minimal				
Suitable Orientation or Latitude														
north-south						minimal		minimal		minimal				
east-west	minimal													
oblique											minimal			
equatorial	minimal			minimal				minimal	minimal	minimal			minimal	
middle latitudes				minimal					minimal	minimal			minimal	
polar / circular				minimal					minimal				minimal	