

IZE OF



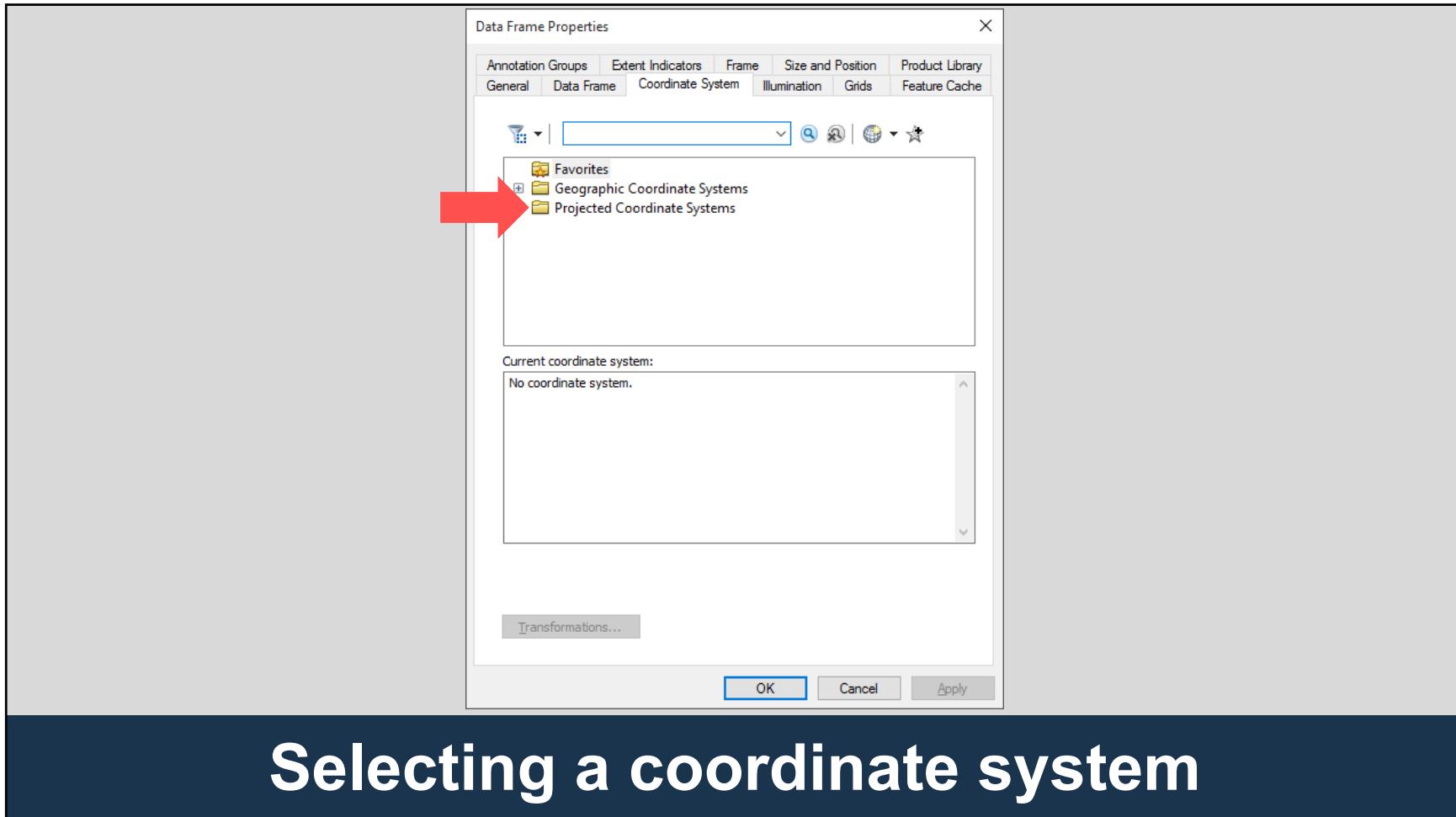
ear Map

Arctic Ocean

Arctic

Purpose of map projections





Globe vs. Map

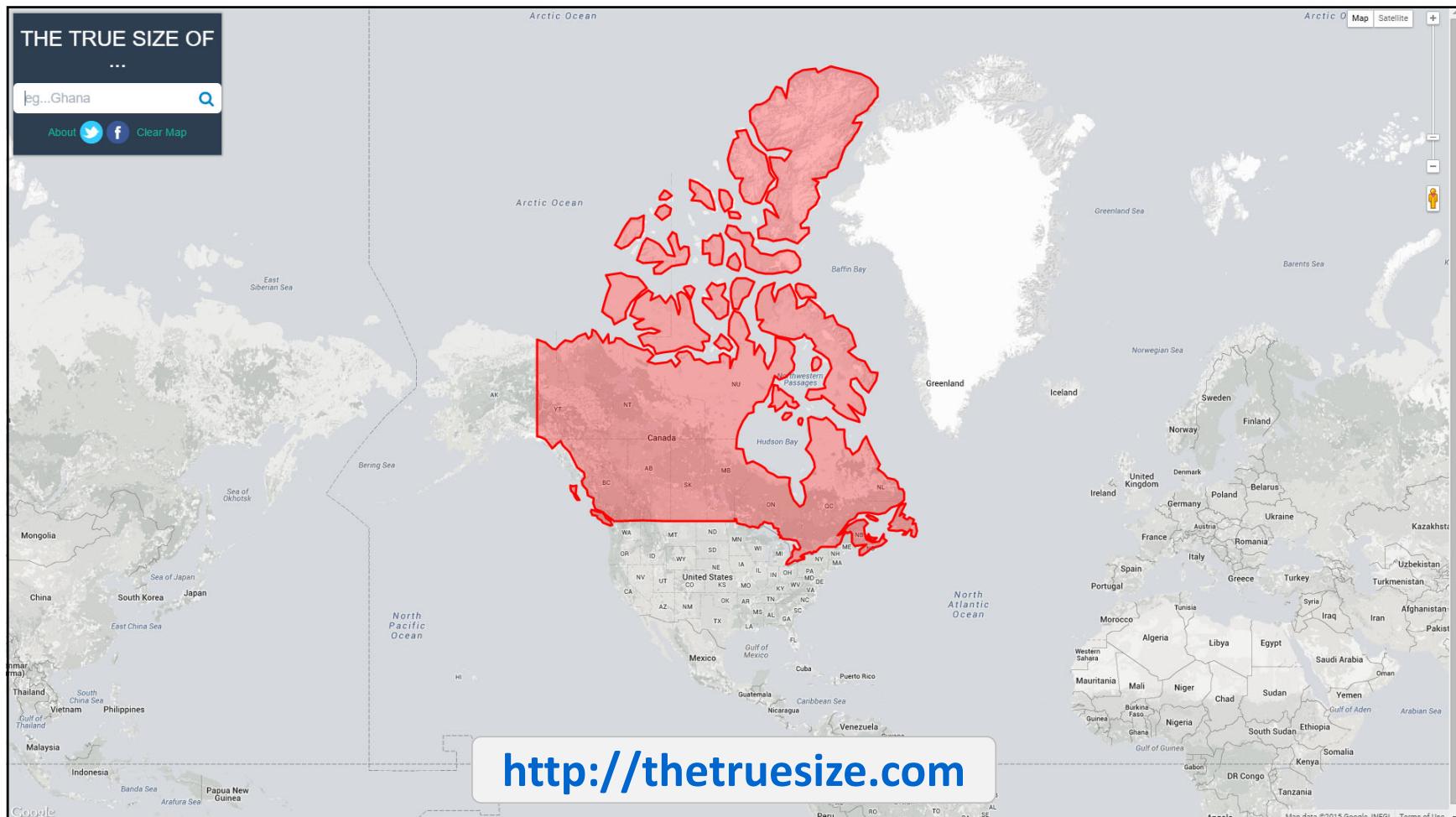


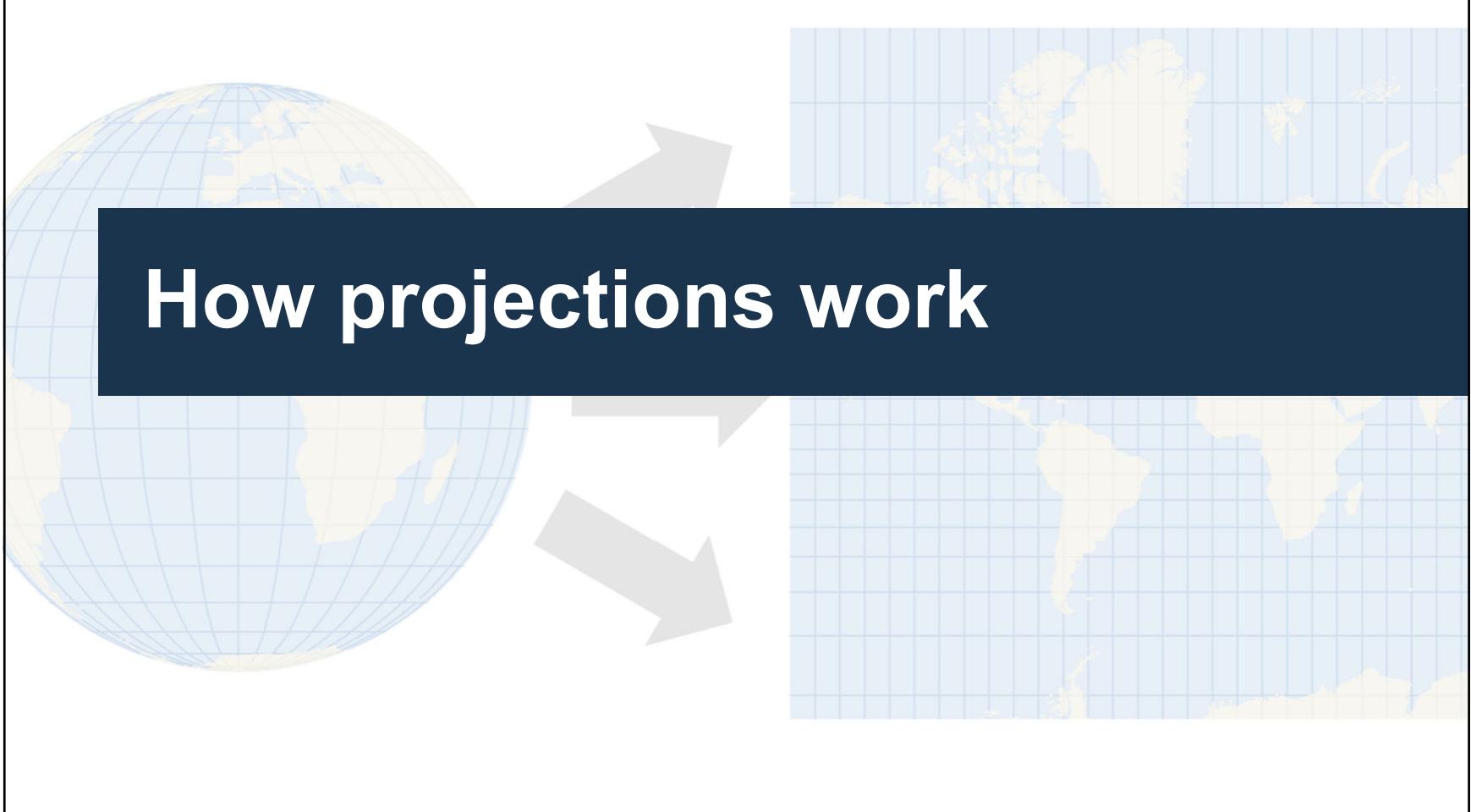
Globe:

- Three-dimensional (3D)
- Expensive, cumbersome, no detail, but no distortion

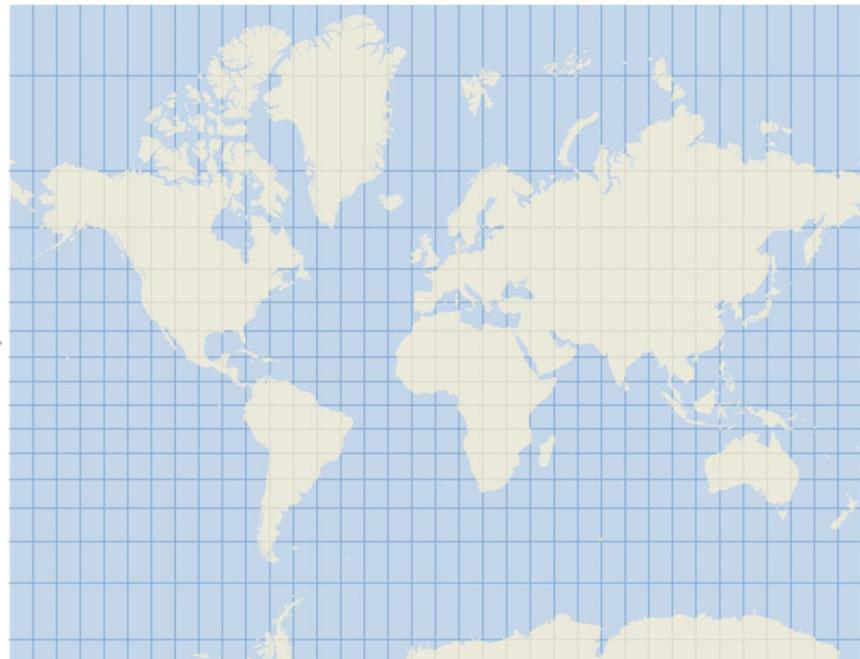
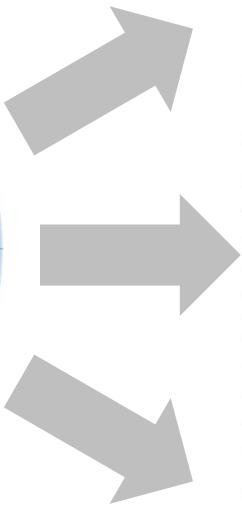
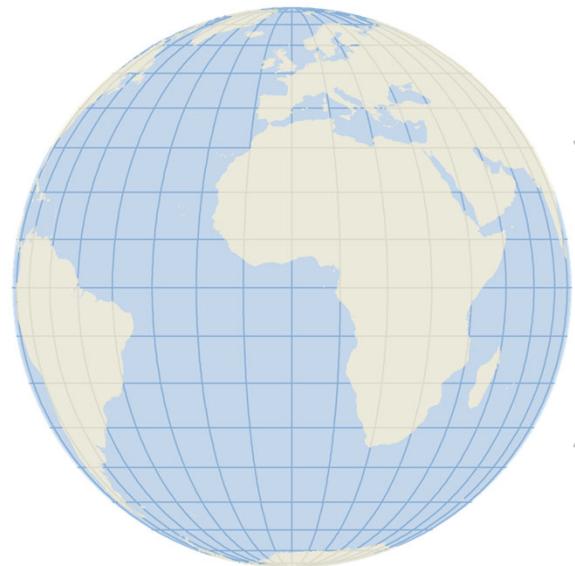
Map:

- Two-dimensional (2D)
- Easier to measure distance, area, direction
- Can show more detail
- Easy to work with, portable, cheaper
- Distortion.





How projections work

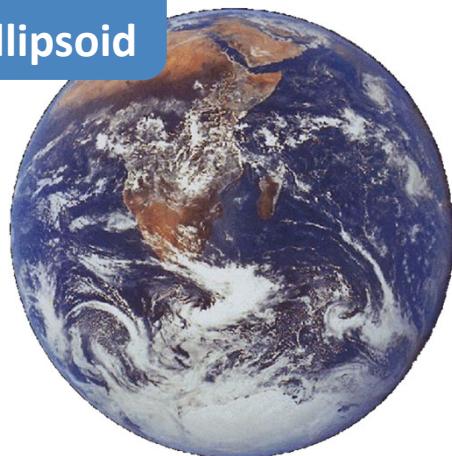


Transformation of 3D Earth to a 2D map

What is a map projection?

First, imagine that the Earth
has been shrunk to the desired scale

Can use either
sphere or ellipsoid



Full-sized Earth



Reference
Globe

1:100,000,000
Principal scale

Goal: Flat map with scale of 1:100,000,000



1:100,000,000

Hypothetical
Still 3D
Principal scale =

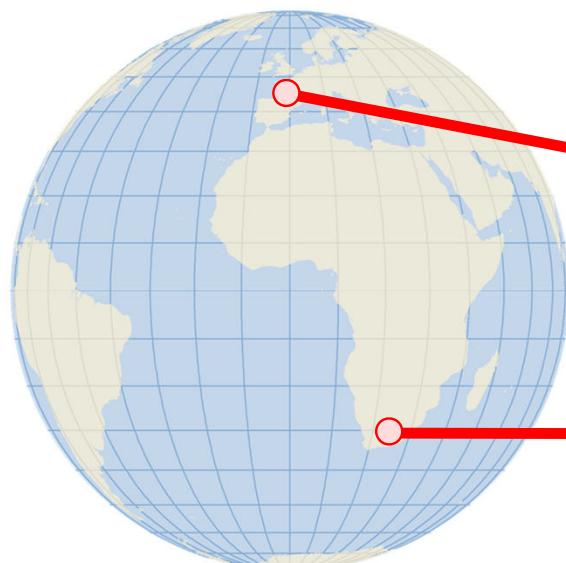
Reference globe radius
Earth's radius

$$\frac{6.378 \text{ cm}}{637813700 \text{ cm}} = 0.00000001$$

or **1:100,000,000**

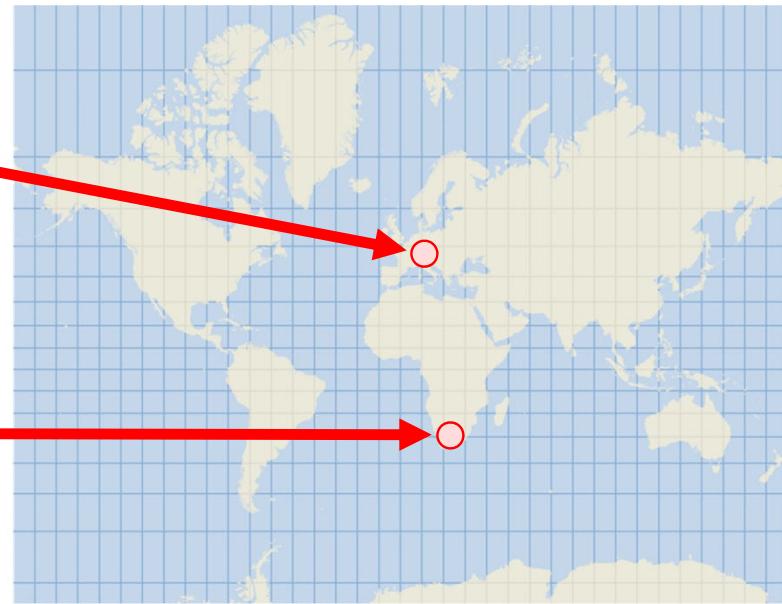
Reference globe

Reference Globe (3D)



1:100,000,000

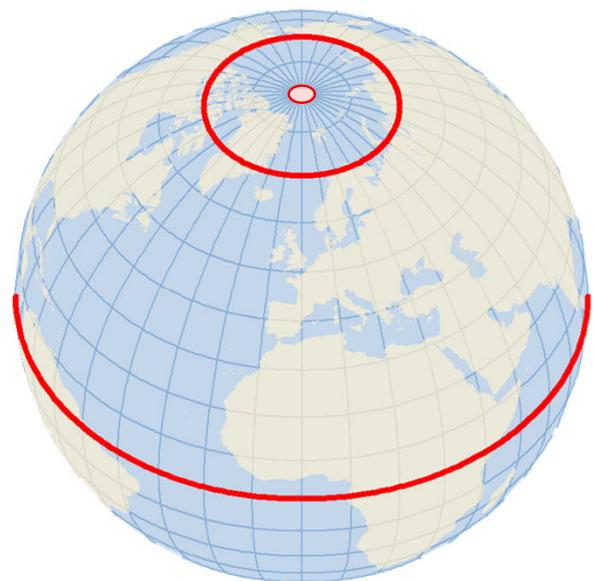
Flat Map (2D)



1:100,000,000

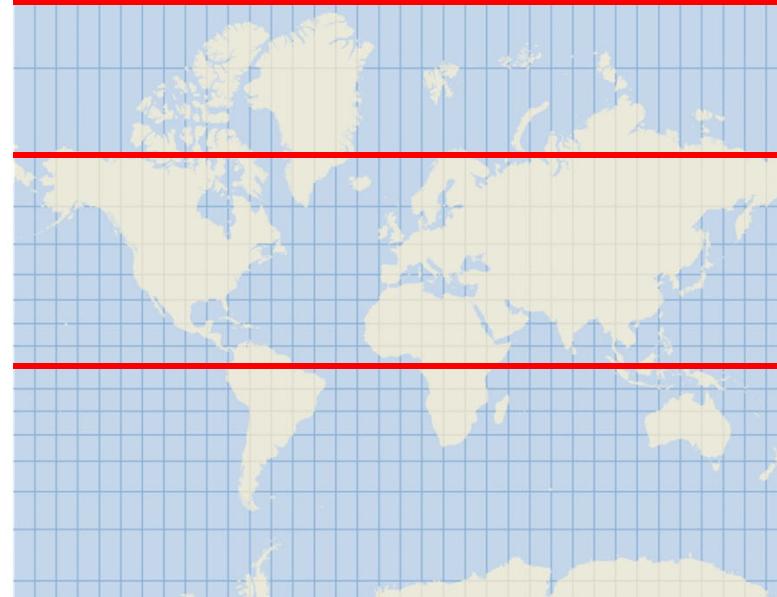
Transfer all points from 3D globe to 2D map...

Reference Globe (3D)



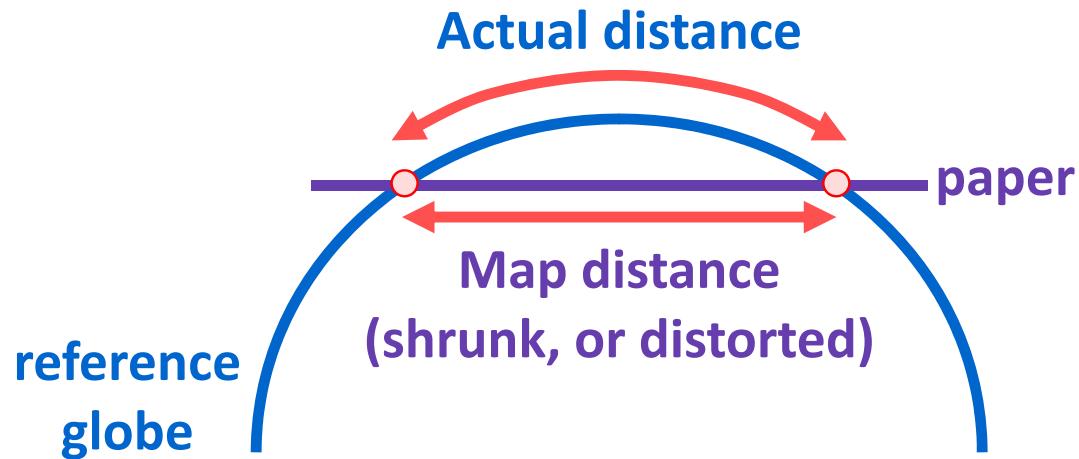
1:100,000,000

Flat Map (2D)



1:100,000,000

Distances are distorted



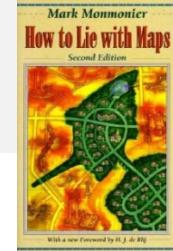
To flatten globe, must stretch, tear, or distort...

(based on Melita and Kopp, 2004)

From curved surface to flat

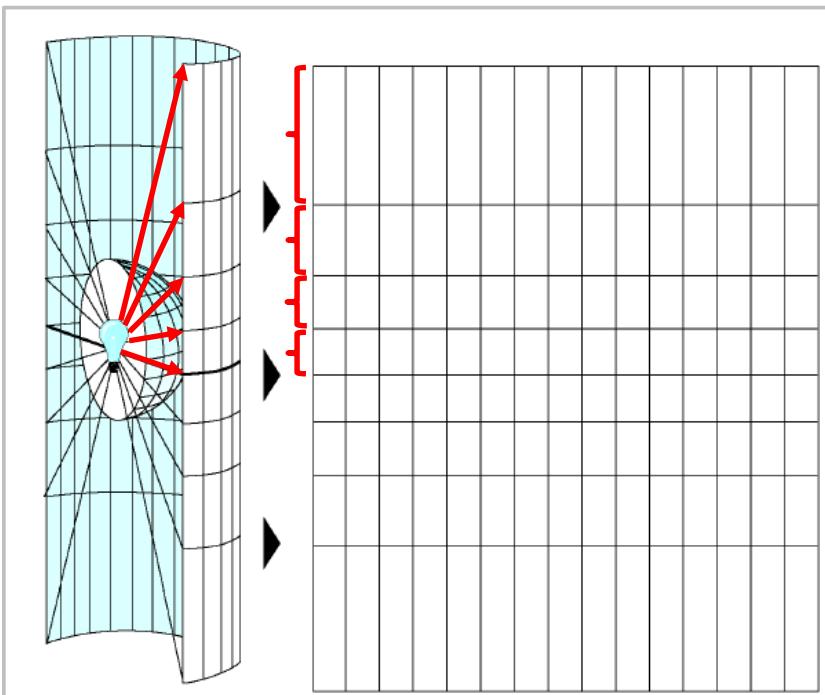
How to lie with maps...

"Not only is it easy to lie with maps, it's essential. To portray meaningful relationships for a complex, three-dimensional world on a flat sheet of paper or video screen, a map must distort reality"

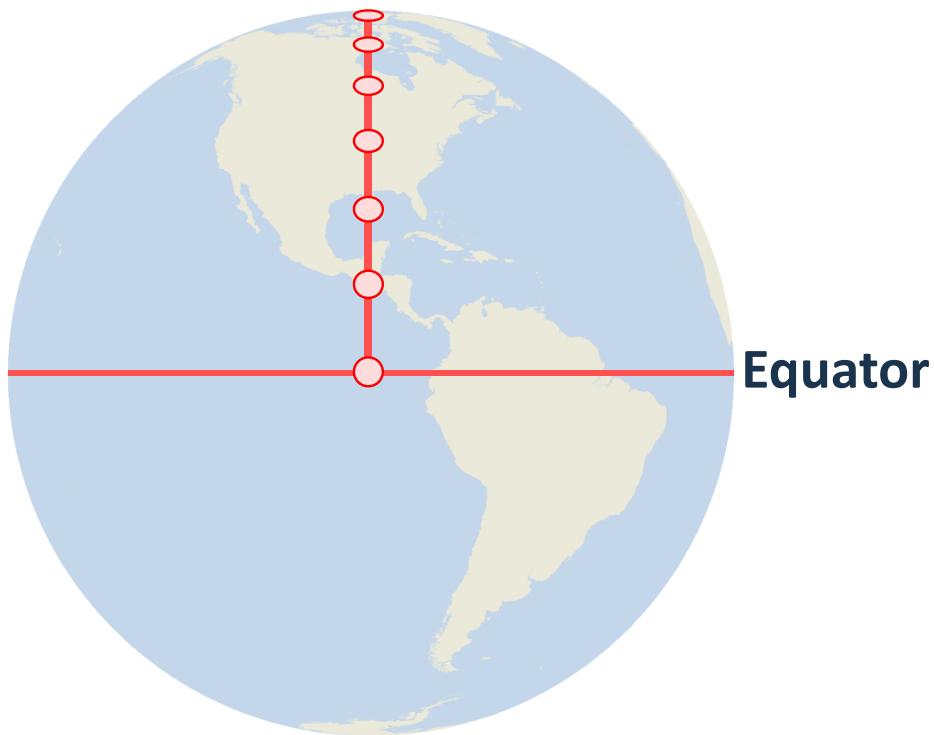


Mark Monmonier, How to Lie with Maps, 1996

Associating points from 3D to 2D



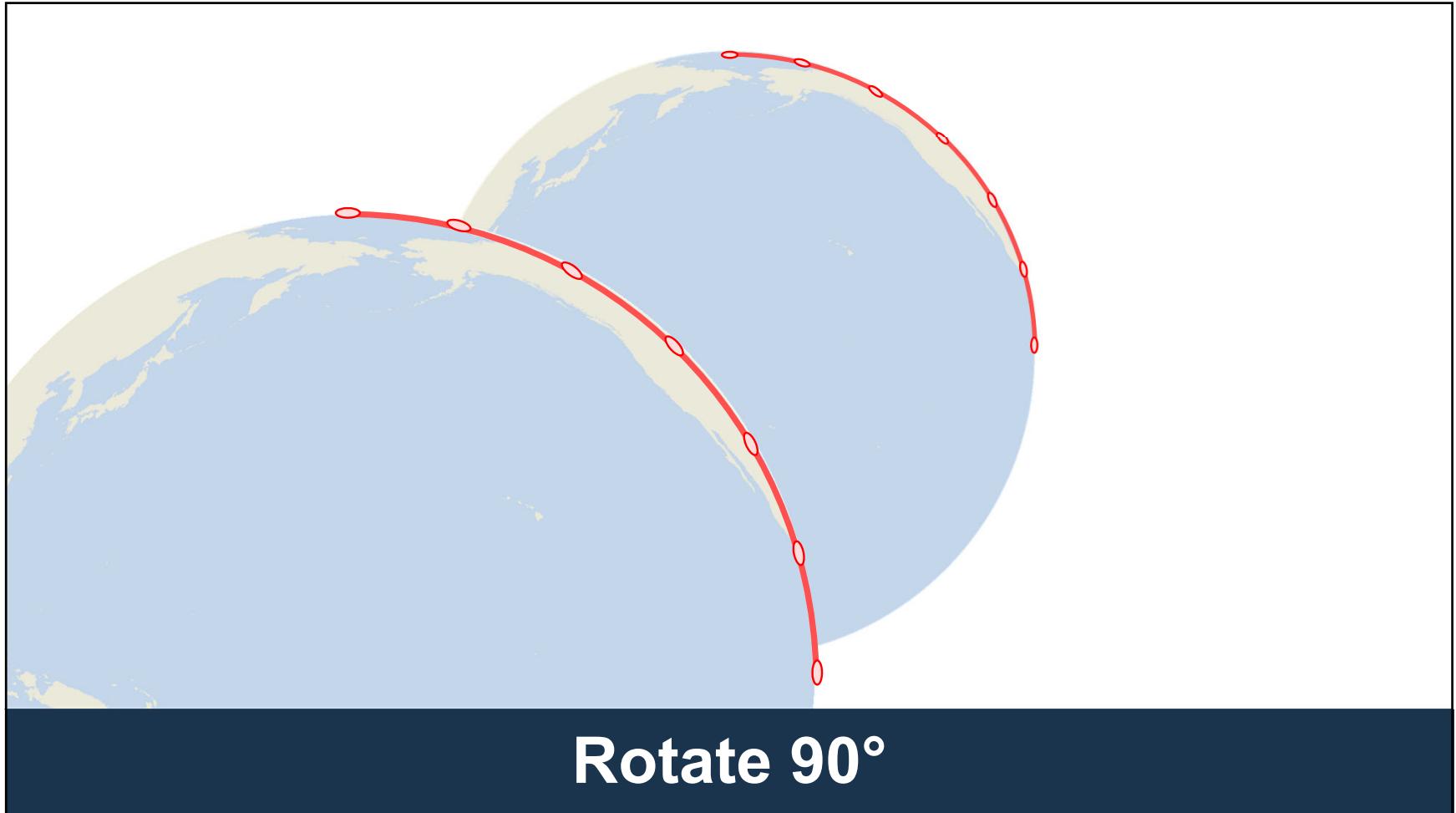
Associating points

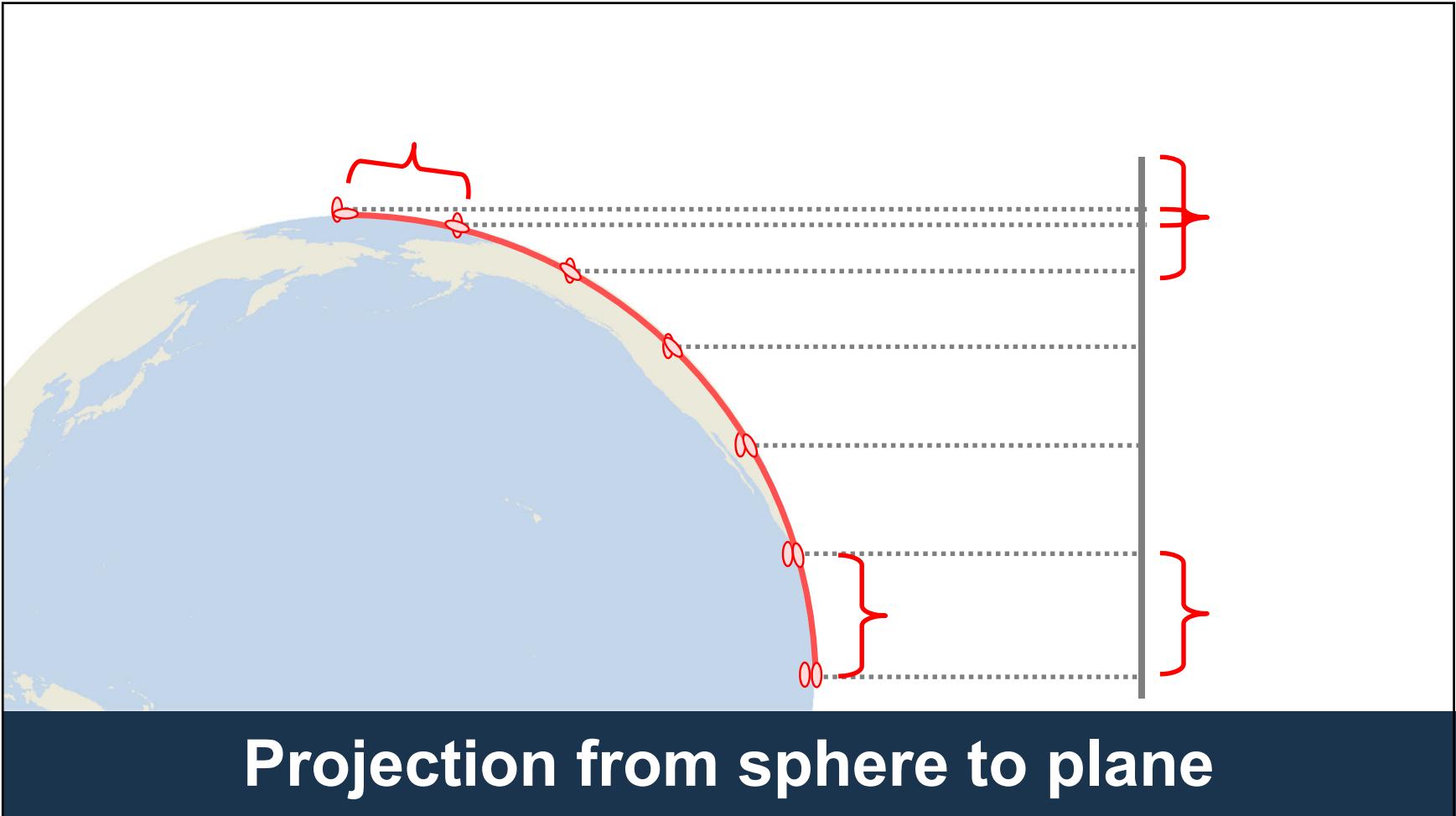


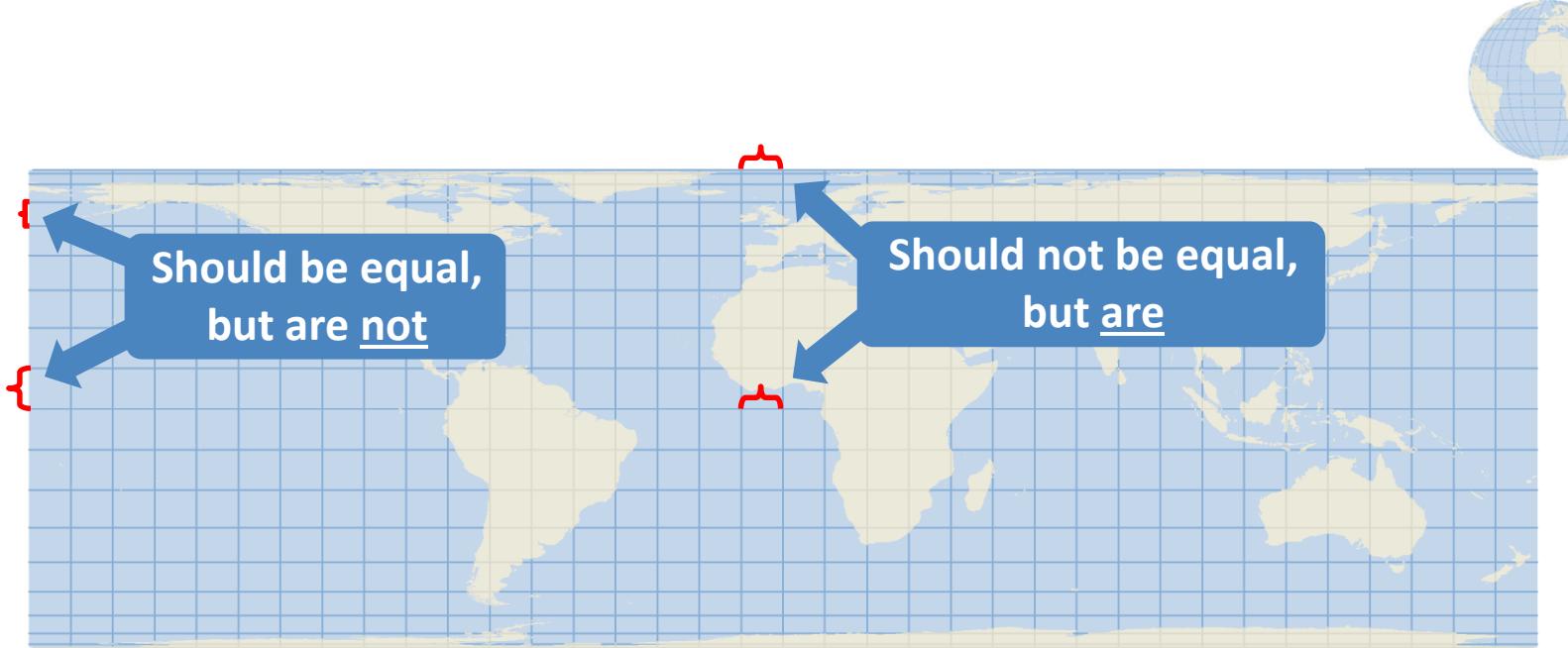
Draw a line from the equator to the pole...



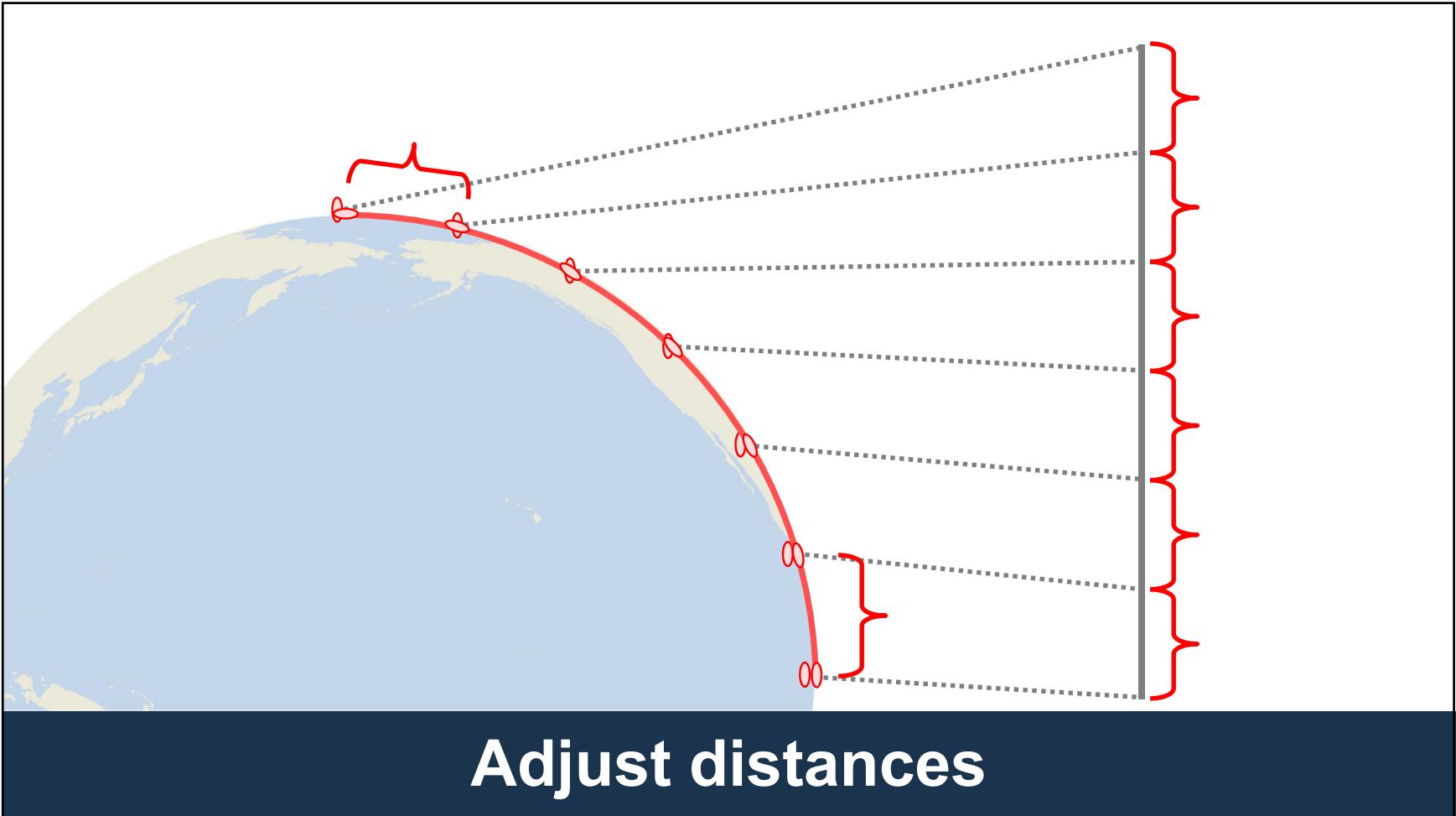
Rotate 90°

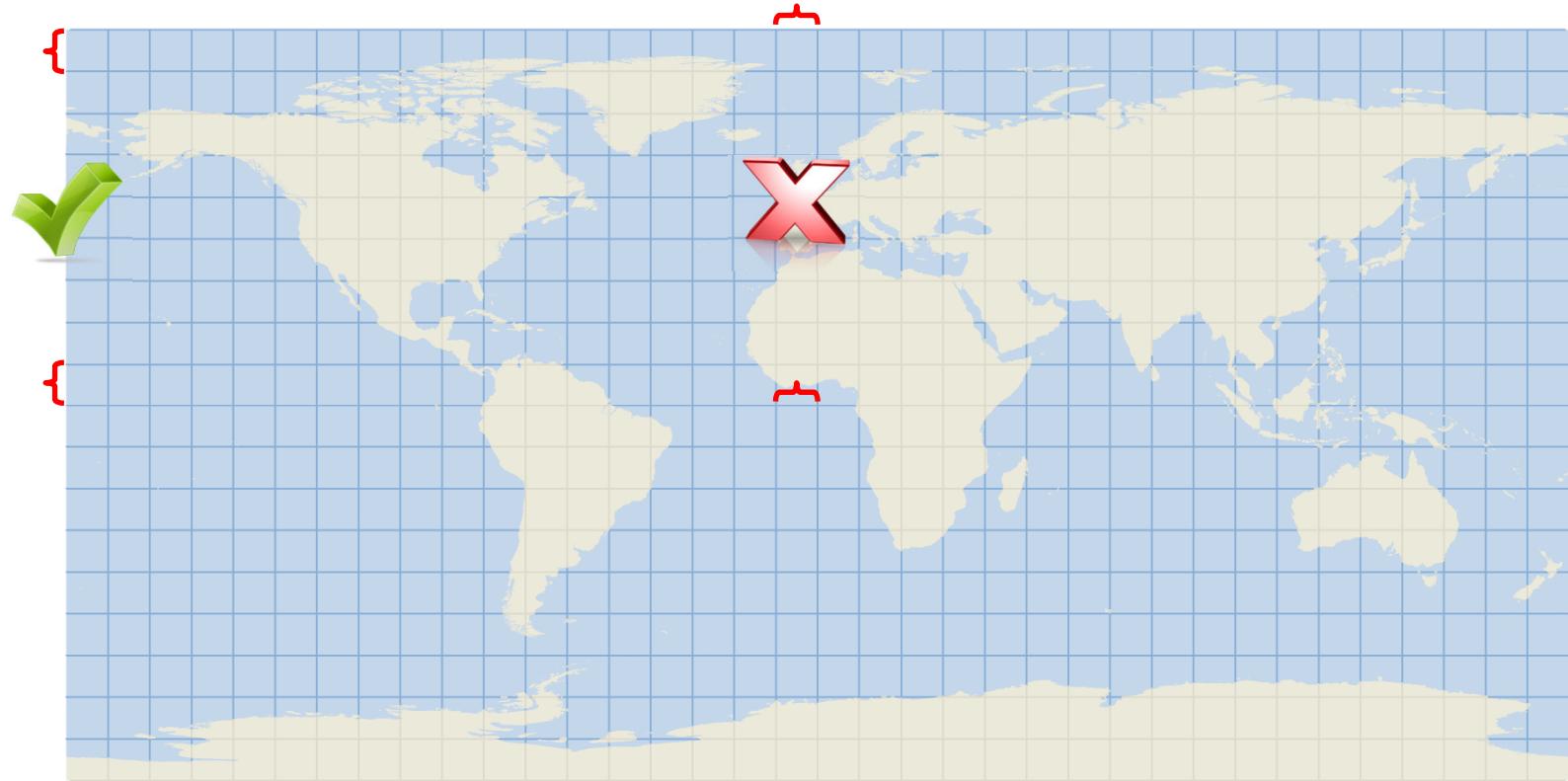






Cylindrical Equal Area

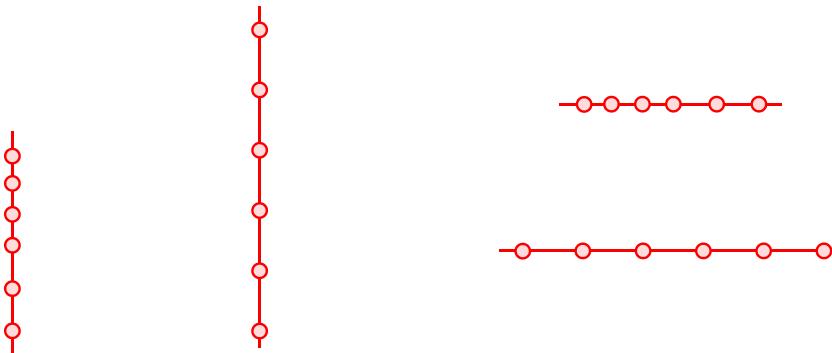


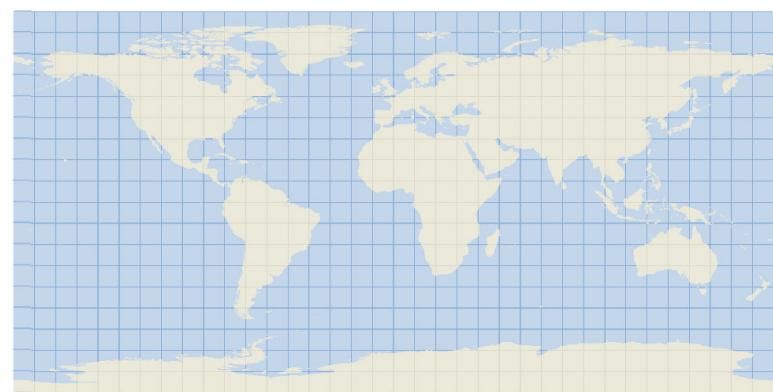
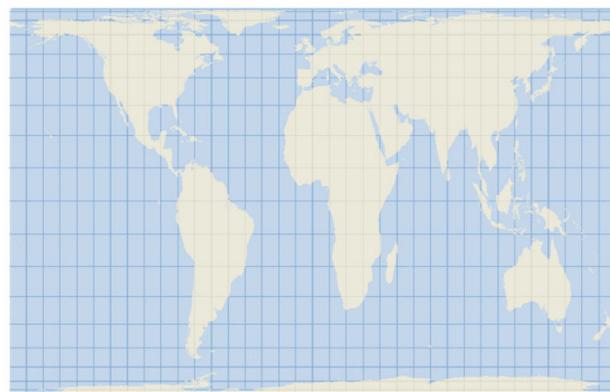
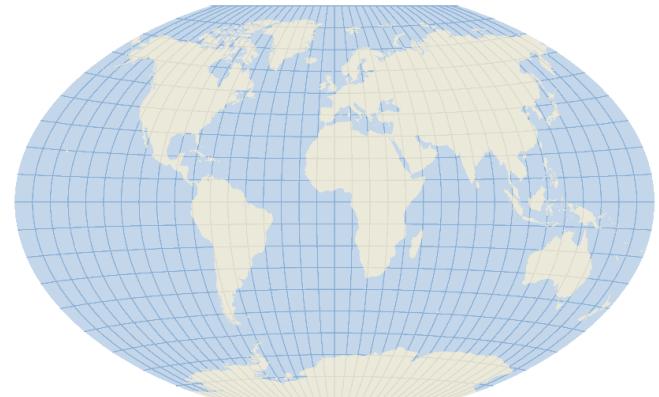
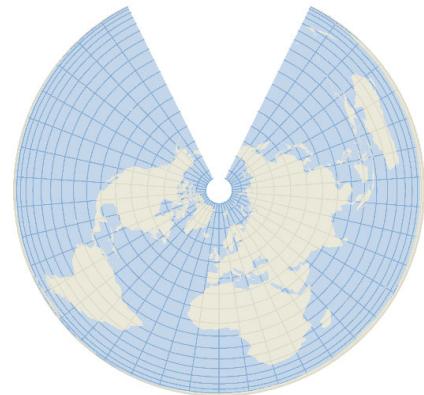


Equirectangular projection

Two perpendicular directions

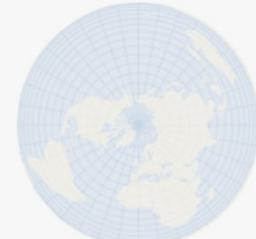
- We adjusted points along a meridian
- Same can be done along a parallel
- Can adjust both, and in different ways.





Graticule: indicates how projections work

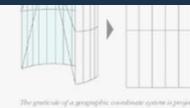
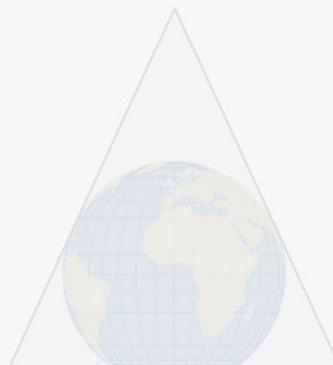
Planar



Projection class (developable surfaces)

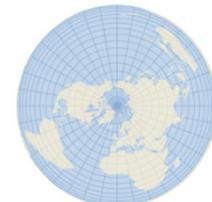
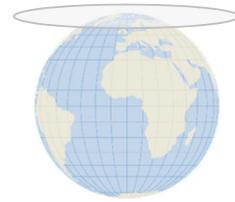
Cyl

Conic

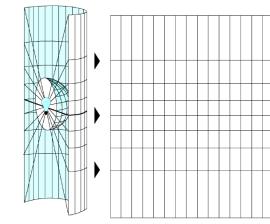
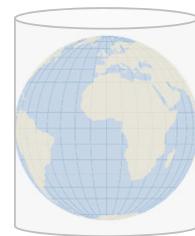


The generic side of a geographic coordinate system is projected onto a cylinder.

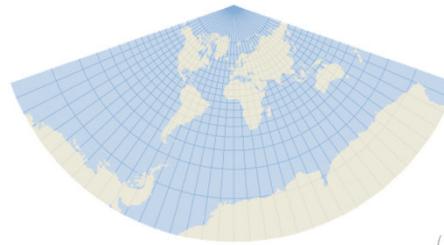
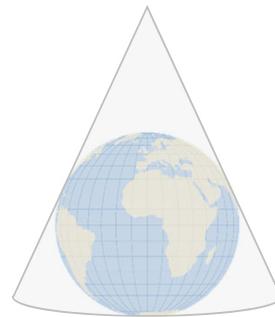
Planar



Cylindrical



Conic



(adapted from Lo and Yeung, 2006)

Projection classes



$$SF = \frac{\text{Local scale}}{\text{Principal scale}}$$

Scale on
map

Scale on

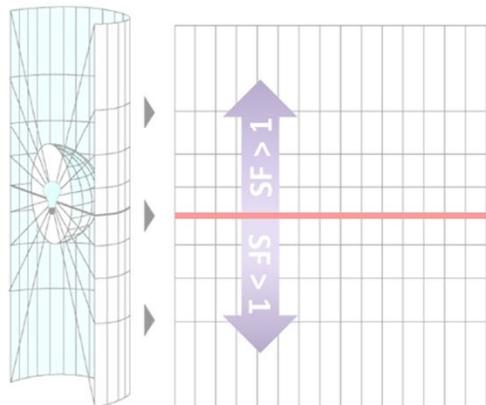
Standard line and scale factor

i.e., where is there no distortion?

$$SF = \frac{1/100,000,000}{1/100,000,000}$$

SF = 1 at the standard line

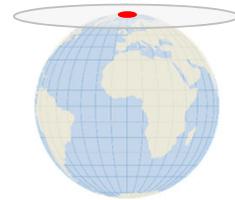
What happens to the SF as you move away from the standard line?



The graticule of a geographic coordinate system is projected onto a cylindrical projection surface.

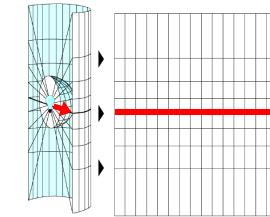
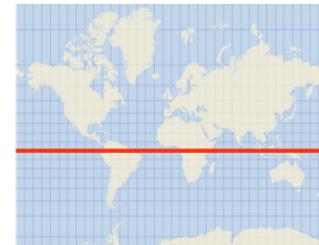
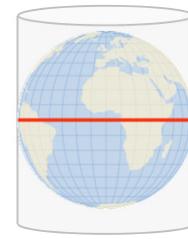
(Kennedy et al., 2004)

Planar

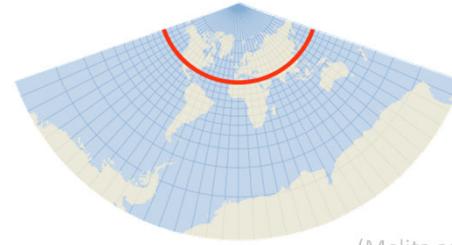
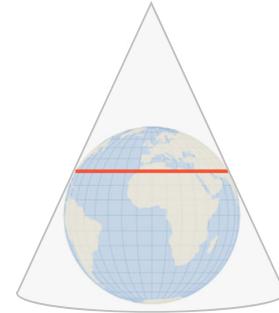


**Where globe
touches
developable surface**

Cylindrical



Conic



(Melita and Kopp, 2004; Lo and Yeung, 2006)

Standard point or line



1:100,000,000

Hypothetical
Still 3D

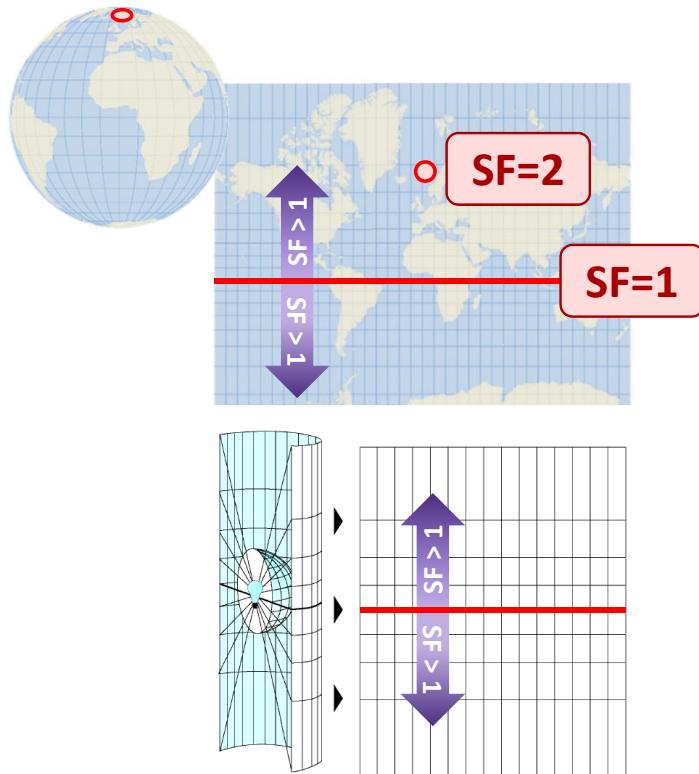
Principal scale = Reference globe radius

Earth's radius

$$\frac{6.378 \text{ cm}}{637813700 \text{ cm}} \\ = 0.00000001$$

or **1:100,000,000**

Reference globe



$$SF = \frac{\text{Local scale}}{\text{Principal scale}}$$

Scale on
map

Scale on
ref. globe

*Where will the local scale
be the same as the principal scale?
i.e., where is there no distortion?*

$$SF = \frac{1/100,000,000}{1/100,000,000}$$

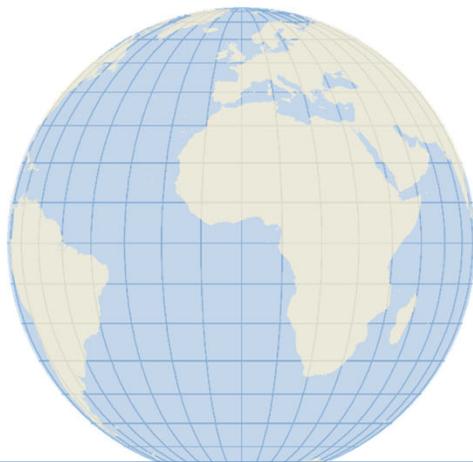
SF = 1 at the standard line

*What happens to the SF as you
move away from the standard line?*

(Kennedy et al., 2004)

Scale factor

No distortion (3D)



3D Reference Globe

**1:100,000,000
(at all locations)**

Scale factor varies

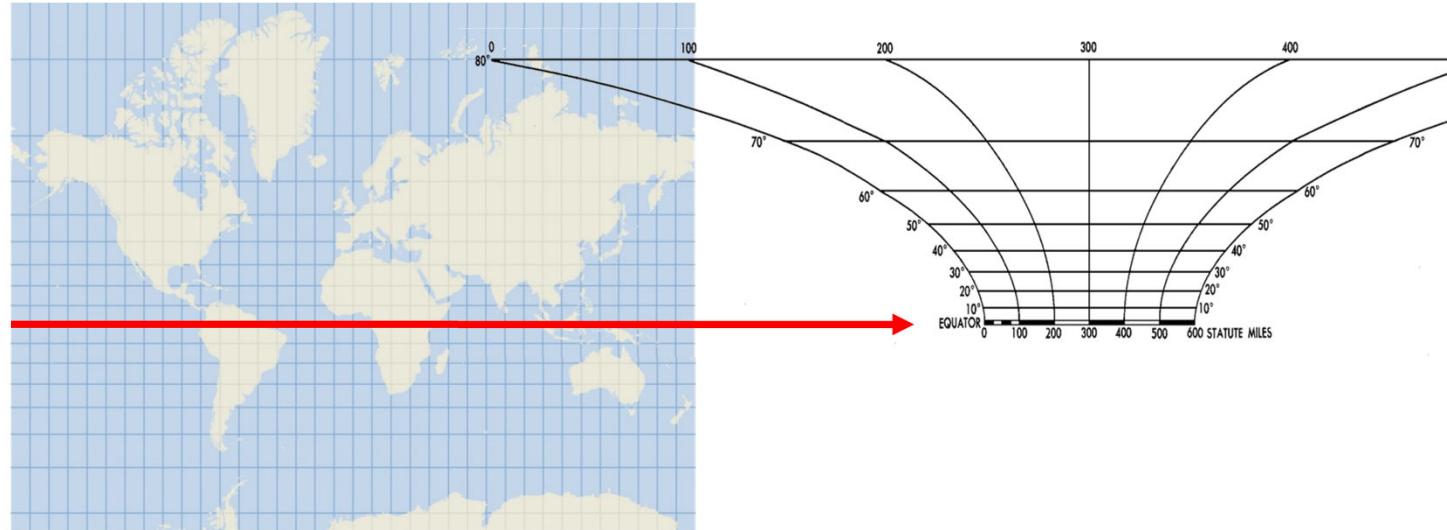


2D Projected Map

**1:100,000,000
(only along standard line)**

(Kimerling et al., 2009)

Scale factor



http://en.wikipedia.org/wiki/Mercator_projection

Variable scale bar

1:500,000
Representative fraction
(absolute scale)

“one inch to one mile”
Verbal scale

> 1:250,000



Bar scale

Projection case

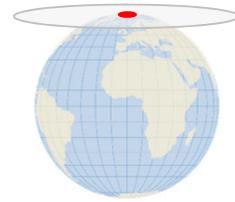


Scale factor > 1



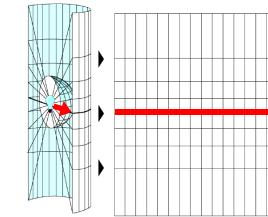
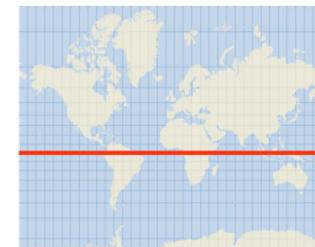
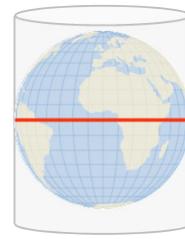
Scale factor < 1

Planar



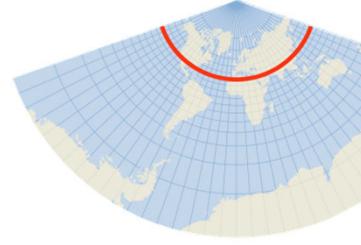
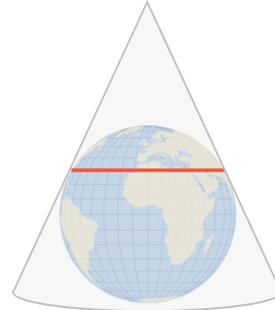
**Scale factor = 1
at standard lines**

Cylindrical



The graticule of a geographic coordinate system is projected onto a cylindrical projection surface.

Conic

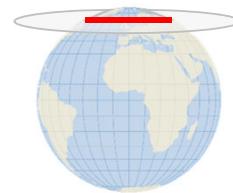


***How can we
reduce distortion?***

(adapted from Lo and Yeung, 2006)

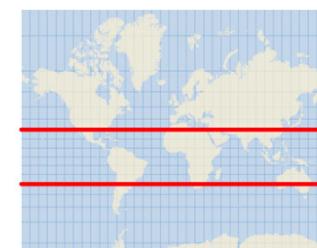
Tangent case

Planar

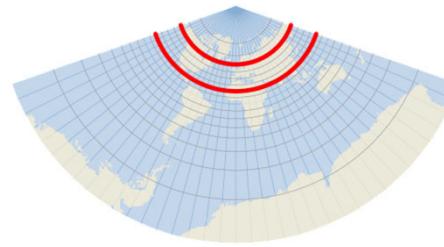
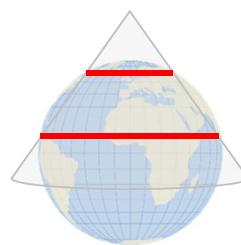


**Scale factor = 1
at standard lines**

Cylindrical

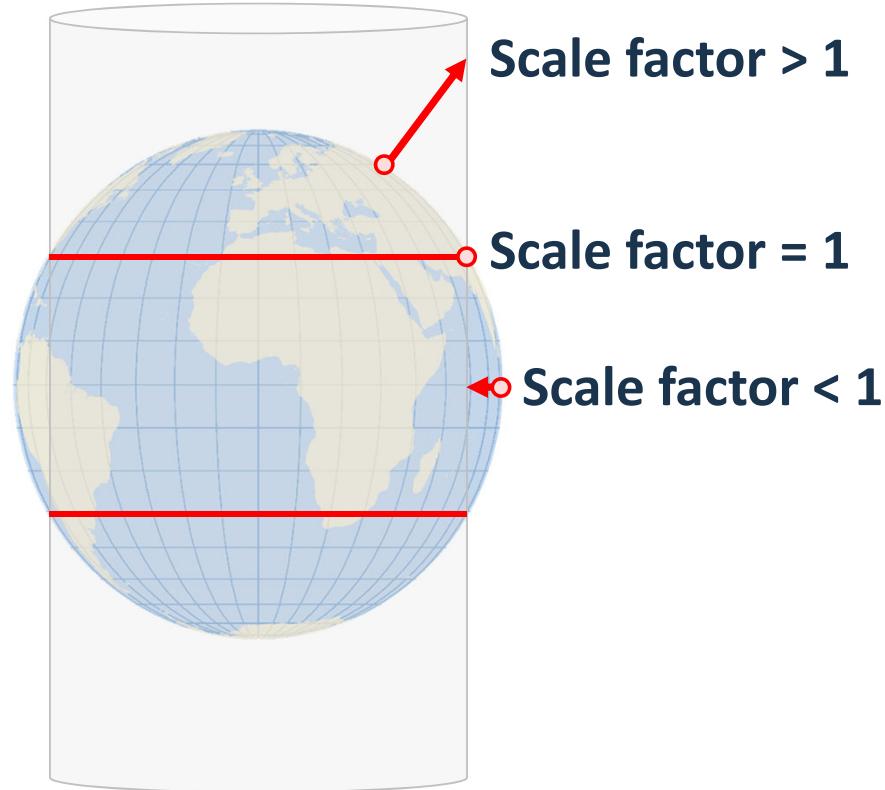


Conic

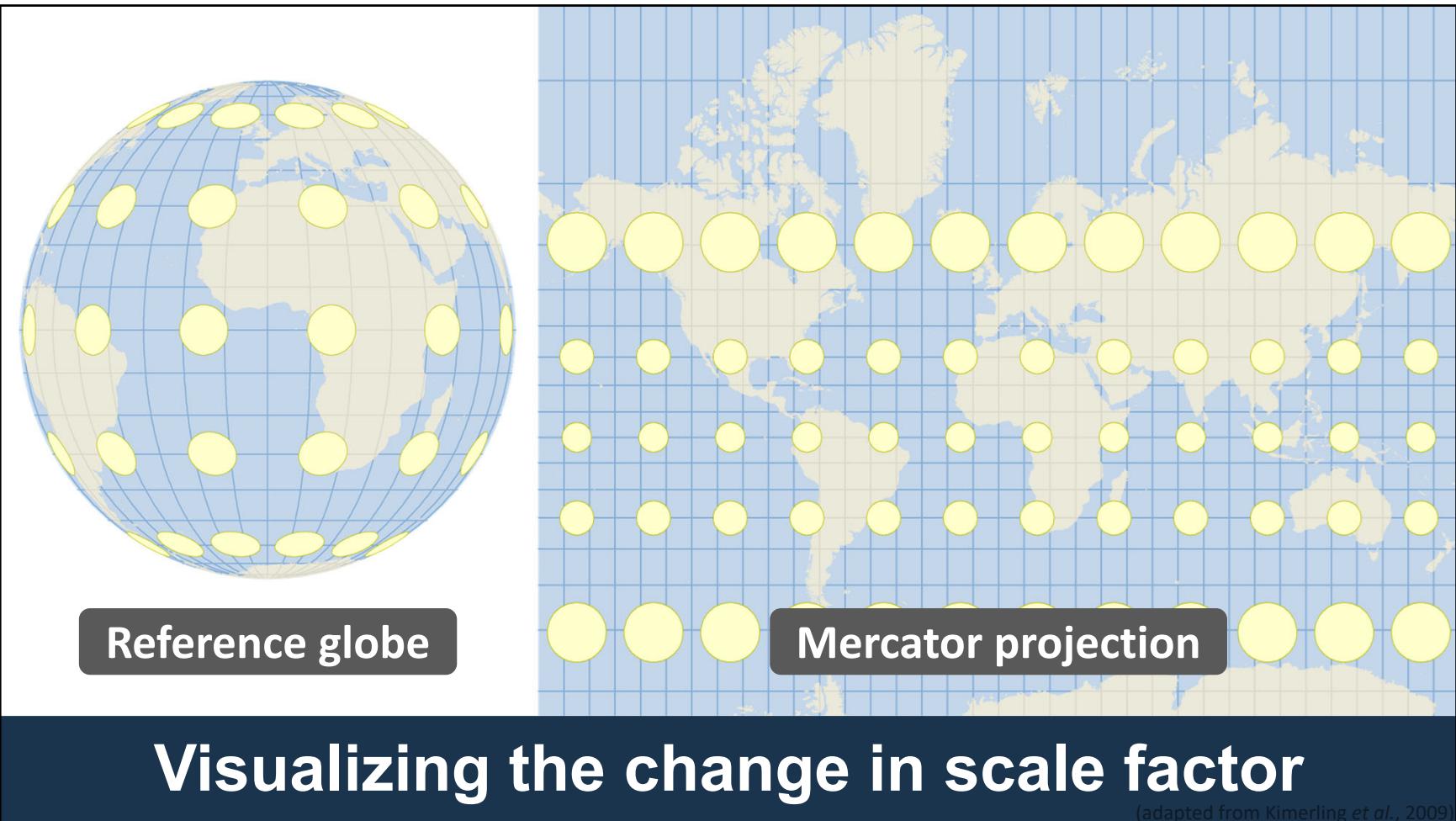


(adapted from Lo and Yeung, 2006)

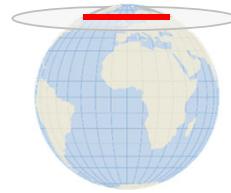
Secant case



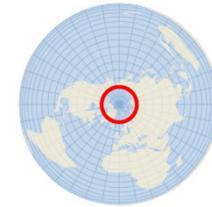
Scale factor with two standard lines



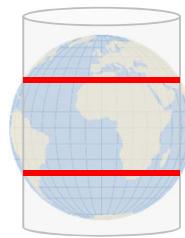
Planar



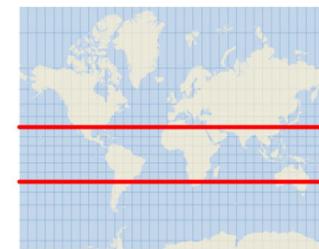
Polar



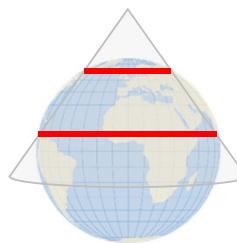
Cylindrical



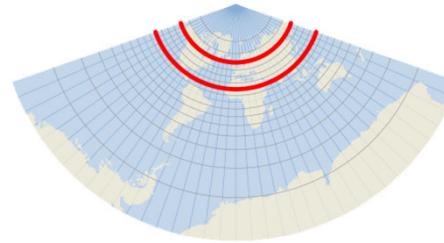
Tropical



Conic



Temperate



(adapted from Lo and Yeung, 2006)

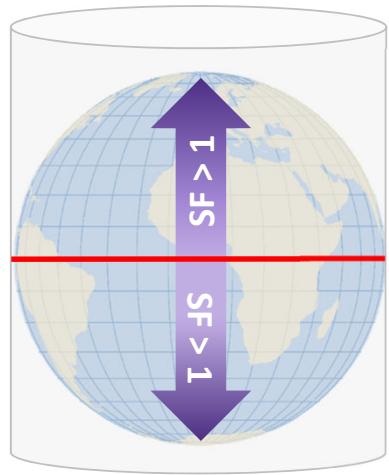
**Rule of thumb: match region to projection
where distortion is minimized**

Projection aspect

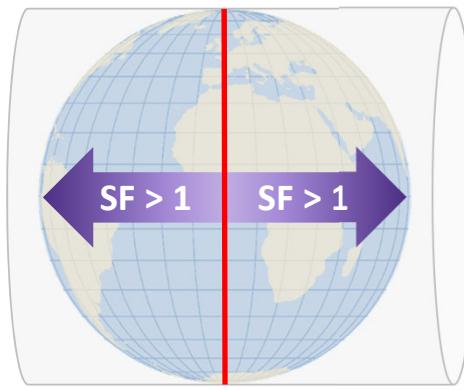
ar

Equatorial

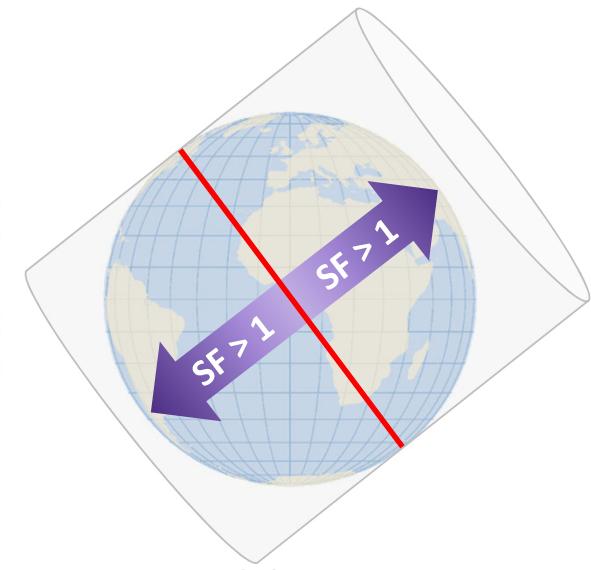
Ob



Normal



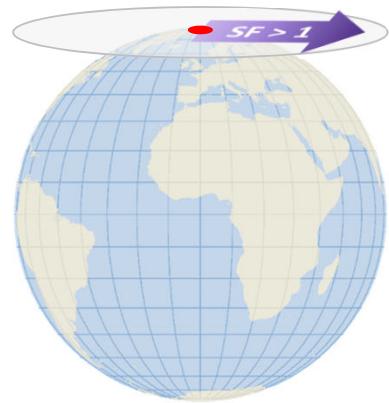
Transverse



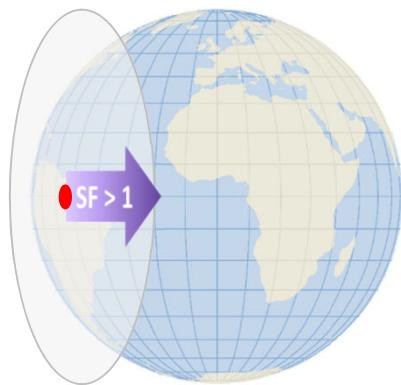
Oblique

(adapted from Lo and Yeung, 2006)

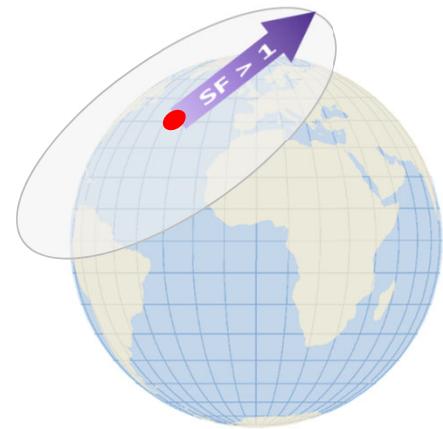
Aspect



Polar



Equatorial



Oblique

(adapted from Kimerling *et al.*, 2006)

Aspect



<http://www.nrcan.gc.ca/earth-sciences/geography/atlas-canada/wall-maps/16870>

The Atlas of Canada Reference Map Series

Série de cartes de référence de l'Atlas du Canada

Scale 1:9 000 000 / Échelle 1/9 000 000

1 centimetre represents 90 kilometres / 1 centimètre représente 90 kilomètres



Azimuthal Equidistant Projection / Projection azimutale équidistante

Radius of sphere: 6 370 997 metres. Latitude of origin: 90° 00' 00" N. Datum: ArcInfo Sphere (custom)
Rayon de la sphère : 6 370 997 mètres. Latitude d'origine : 90° 00' 00" N. Datum : ArcInfo Sphere (personnalisé)



Visit atlas.gc.ca for information on purchasing the paper map **MCR0001** or
downloading the digital version free of charge.

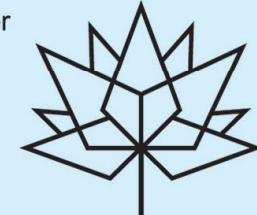
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Natural Resources Canada. Printed in 2017.

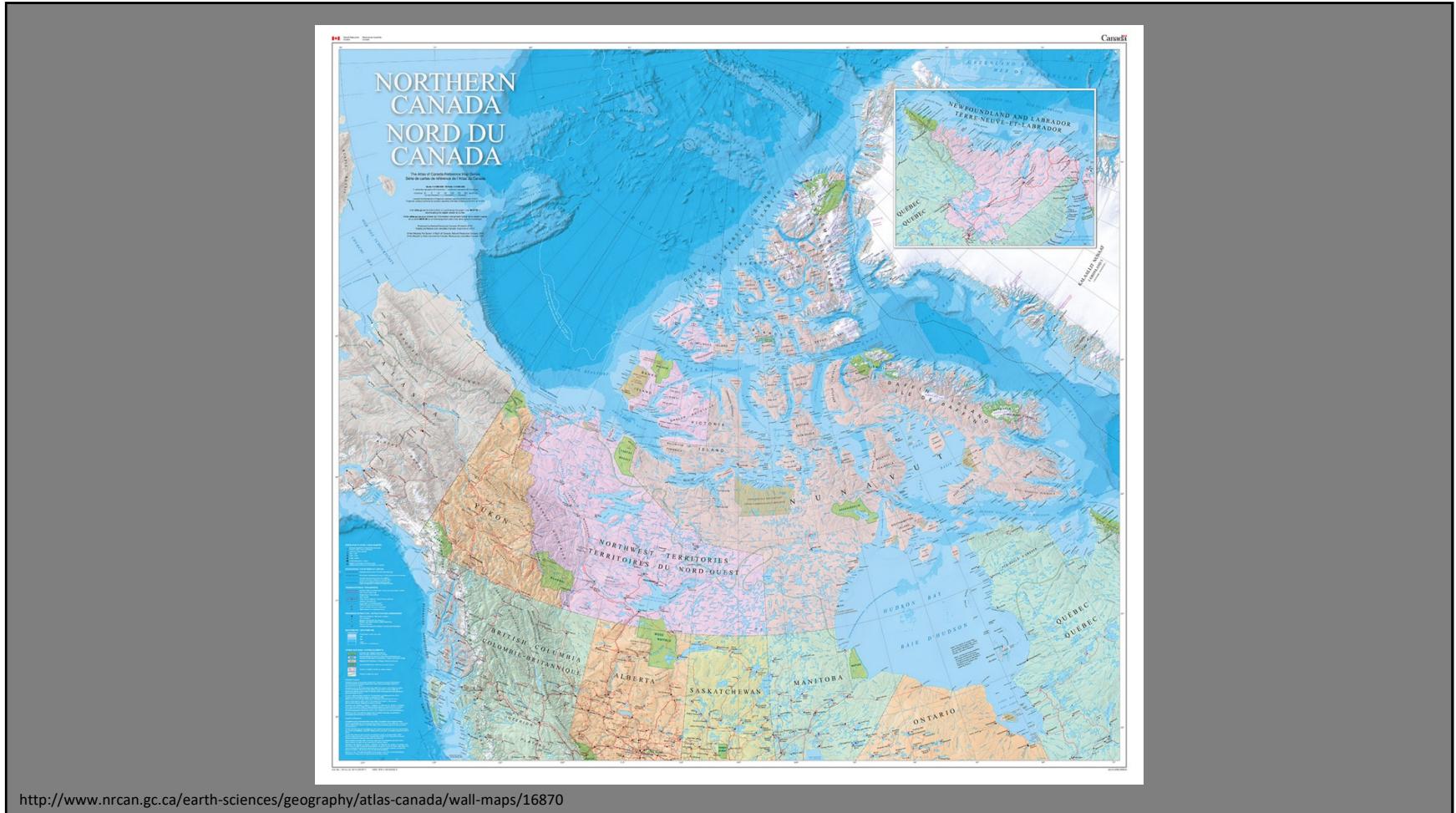
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Ressources naturelles Canada. Imprimée en 2017.

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<http://www.nrcan.gc.ca/earth-sciences/geography/atlas-canada/wall-maps/16870k>



CANADA 150

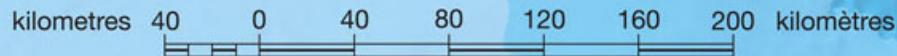


The Atlas of Canada Reference Map Series

Série de cartes de référence de l'Atlas du Canada

Scale 1:4 000 000 / Échelle 1/4 000 000

1 centimetre represents 40 kilometres / 1 centimètre représente 40 kilomètres



Lambert Conformal Conic Projection; standard parallels 60°00'N and 75°00'N
Projection conique conforme de Lambert; parallèles d'échelle conservée à 60°00'N et 75°00'N

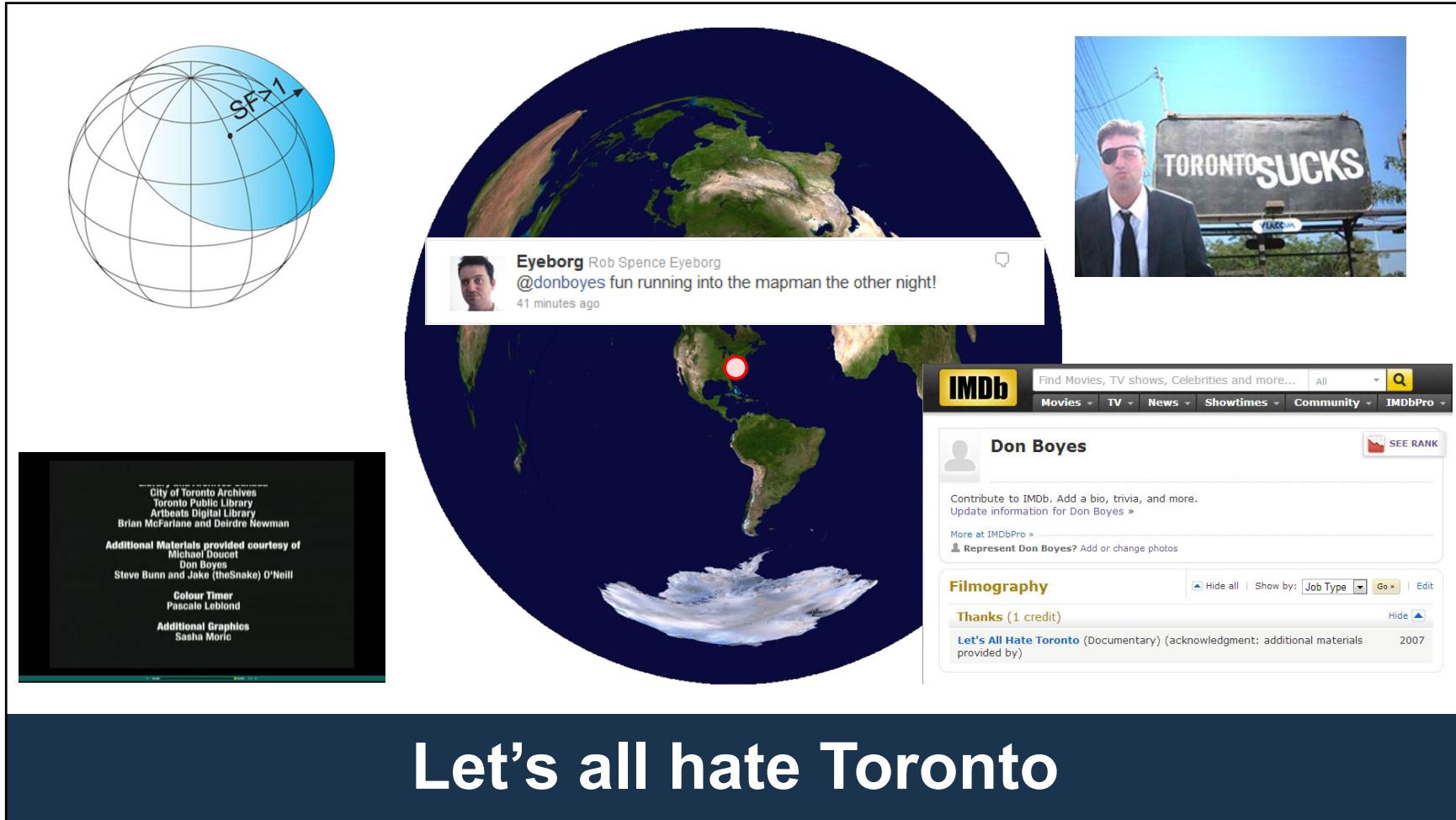
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<http://www.nrcan.gc.ca/earth-sciences/geography/atlas-canada/wall-maps/16870k>

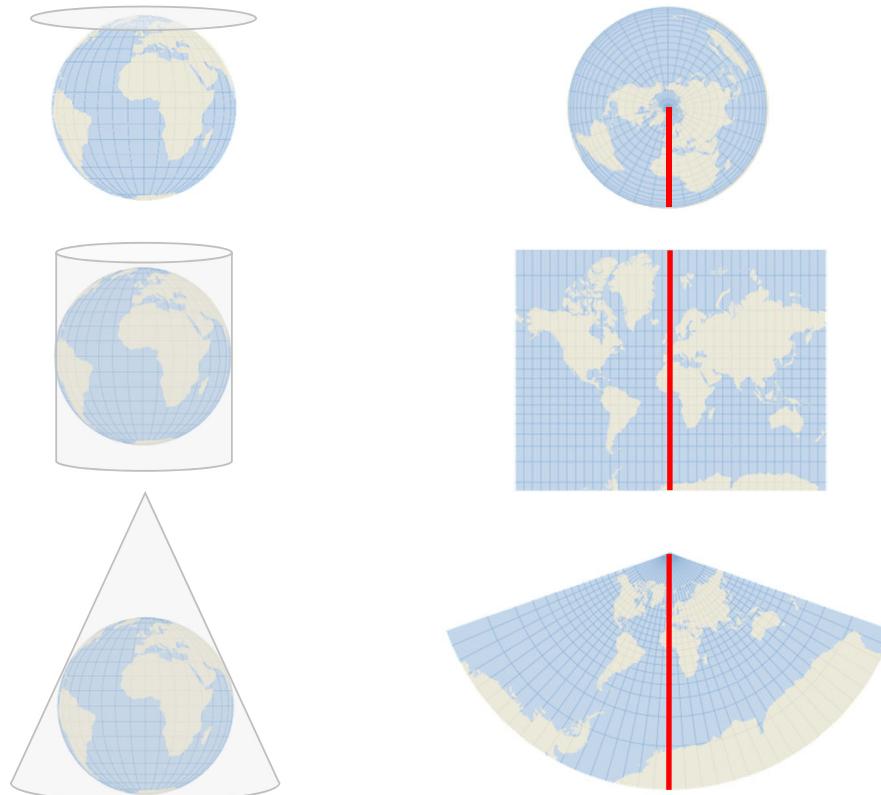


Projection central meridian

ar

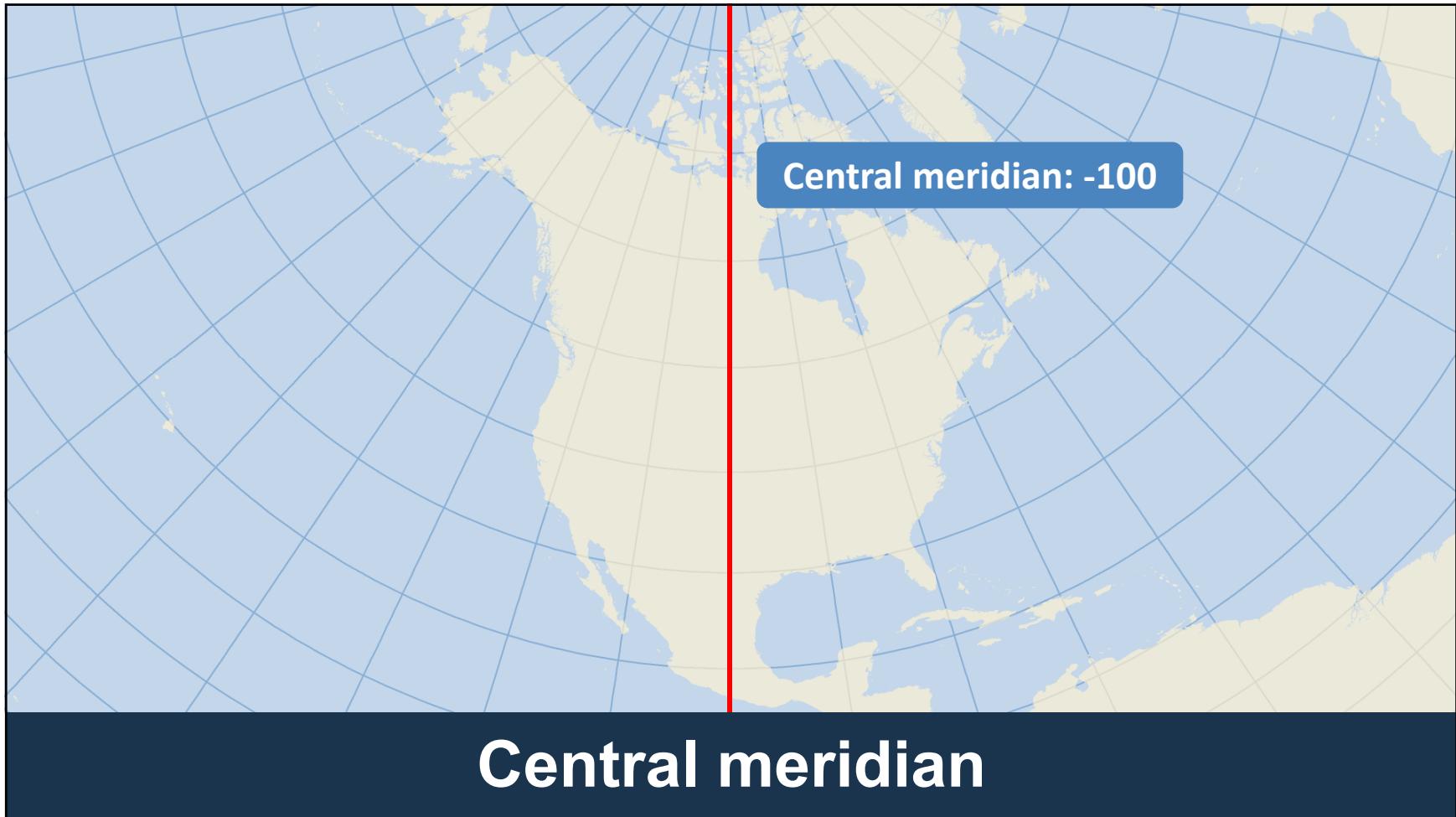
Equatorial

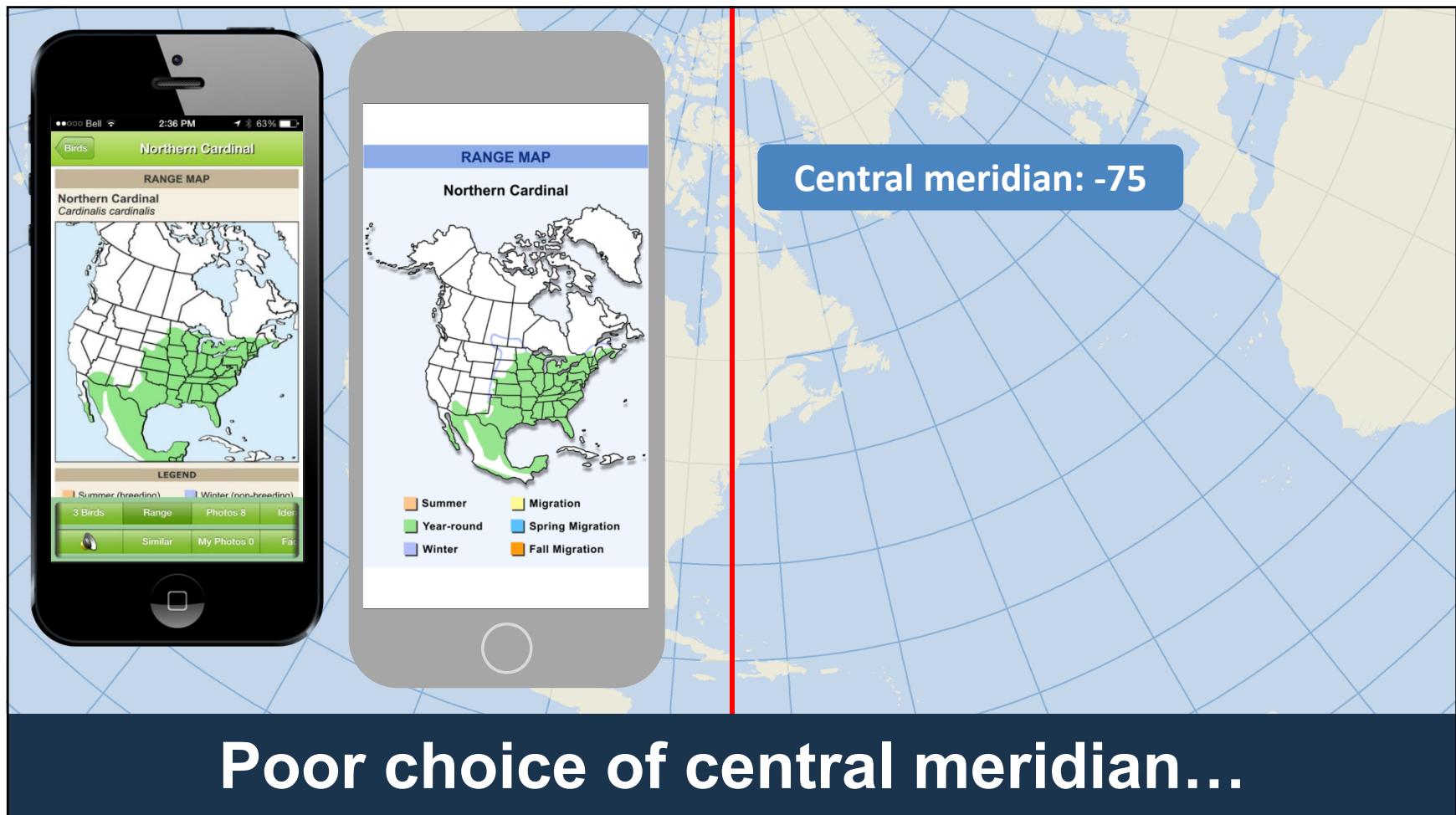
Ob



(adapted from Lo and Yeung, 2006)

Central meridian





Greenland Overseas

Home > Greenland Overseas

[GREENLAND IN NORTH AMERICA](#) [GREENLAND IN AUSTRALIA](#) [GREENLAND IN EUROPE](#) [GREENLAND IN ASIA](#)

Based on the global horizon innovative development strategy since 2012, Greenland Group has taken a new path of overseas expansion and capitalized development, and successfully entered four continents, 9 countries including USA, Australia, Canada and UK and 13 cities, with steady growth in market expansion and increasing maturation of business model.

Greenland Group has stimulated dynamic vitality of deepening enterprise transformation through participation in global market competition. Aiming at cultivating a world-class enterprise in the future, Greenland Group will strive for an ever growing enterprise with brilliant prospects against the background of economic globalization.

http://www.greenlands.com/en/World_America.aspx

Poor choice of central meridian...

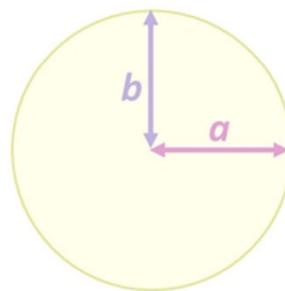


Area

Tissot's indicatrix



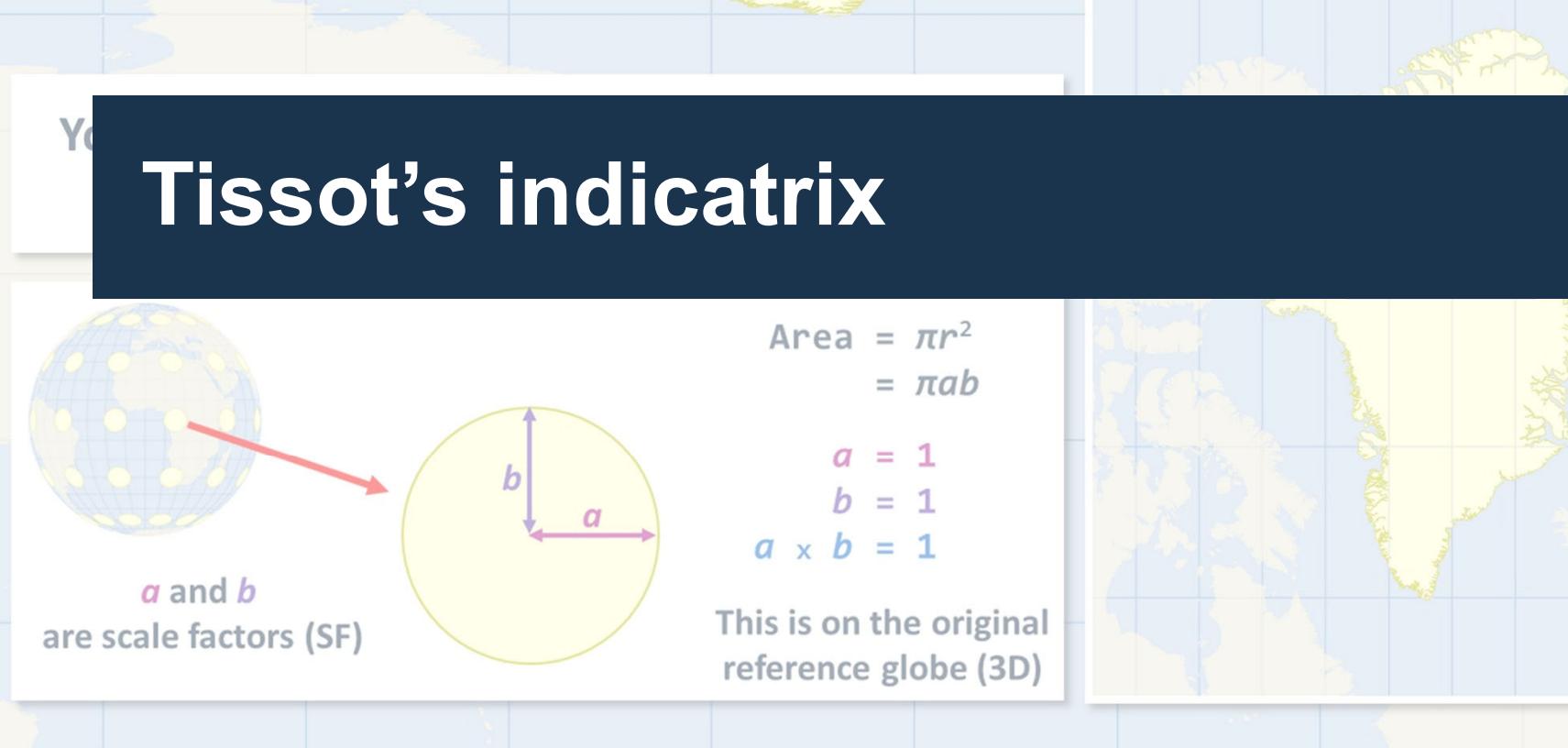
a and b
are scale factors (SF)



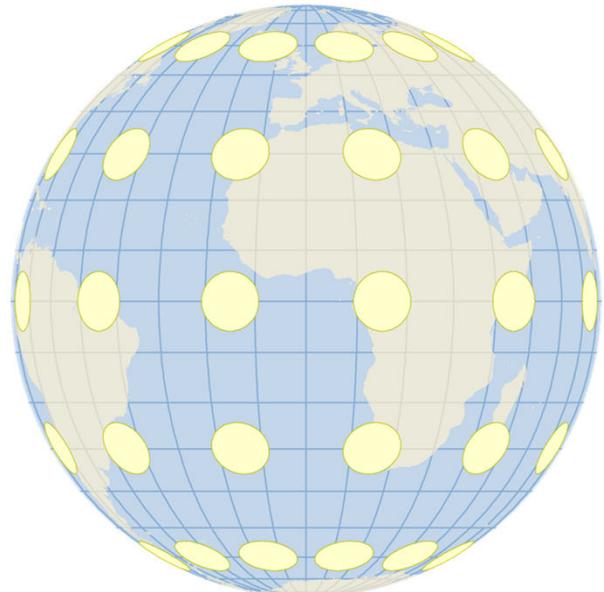
$$\text{Area} = \pi r^2
= \pi ab$$

$$a = 1
b = 1
a \times b = 1$$

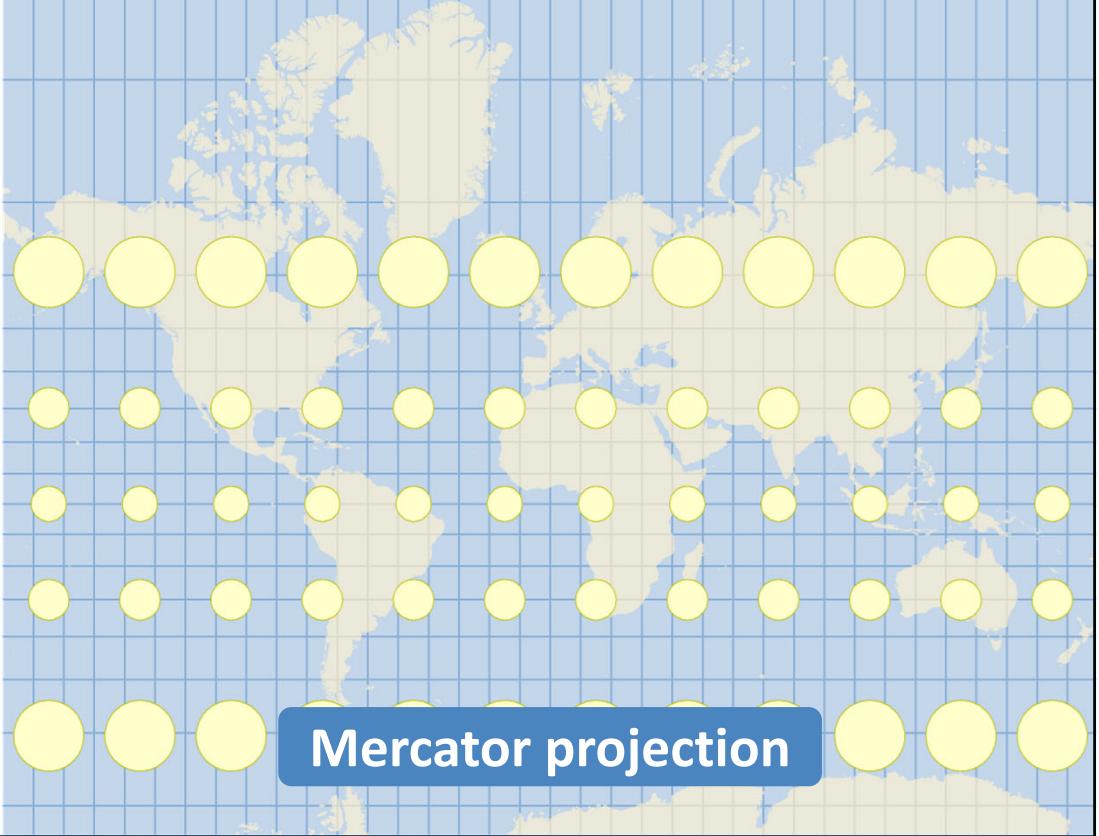
This is on the original
reference globe (3D)







Reference globe

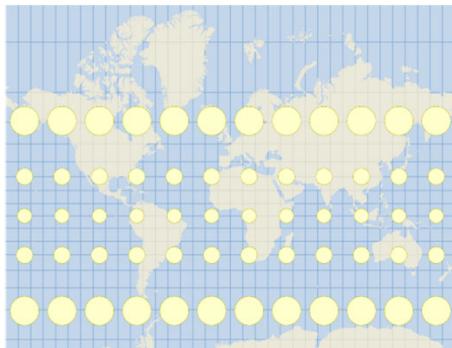
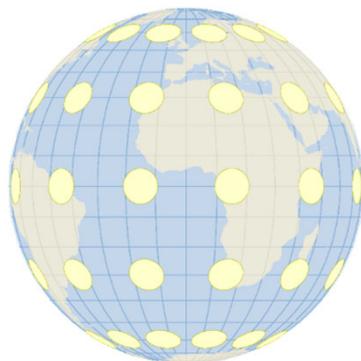


Mercator projection

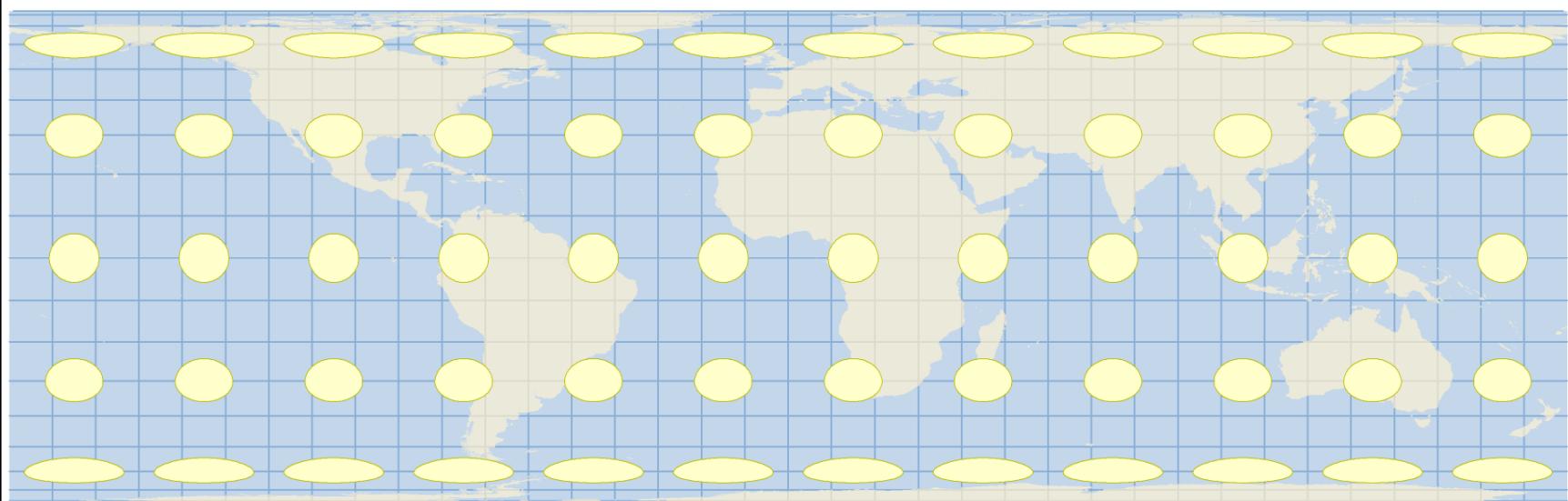
Visualizing the change in scale factor

(adapted from Kimerling *et al.*, 2009)

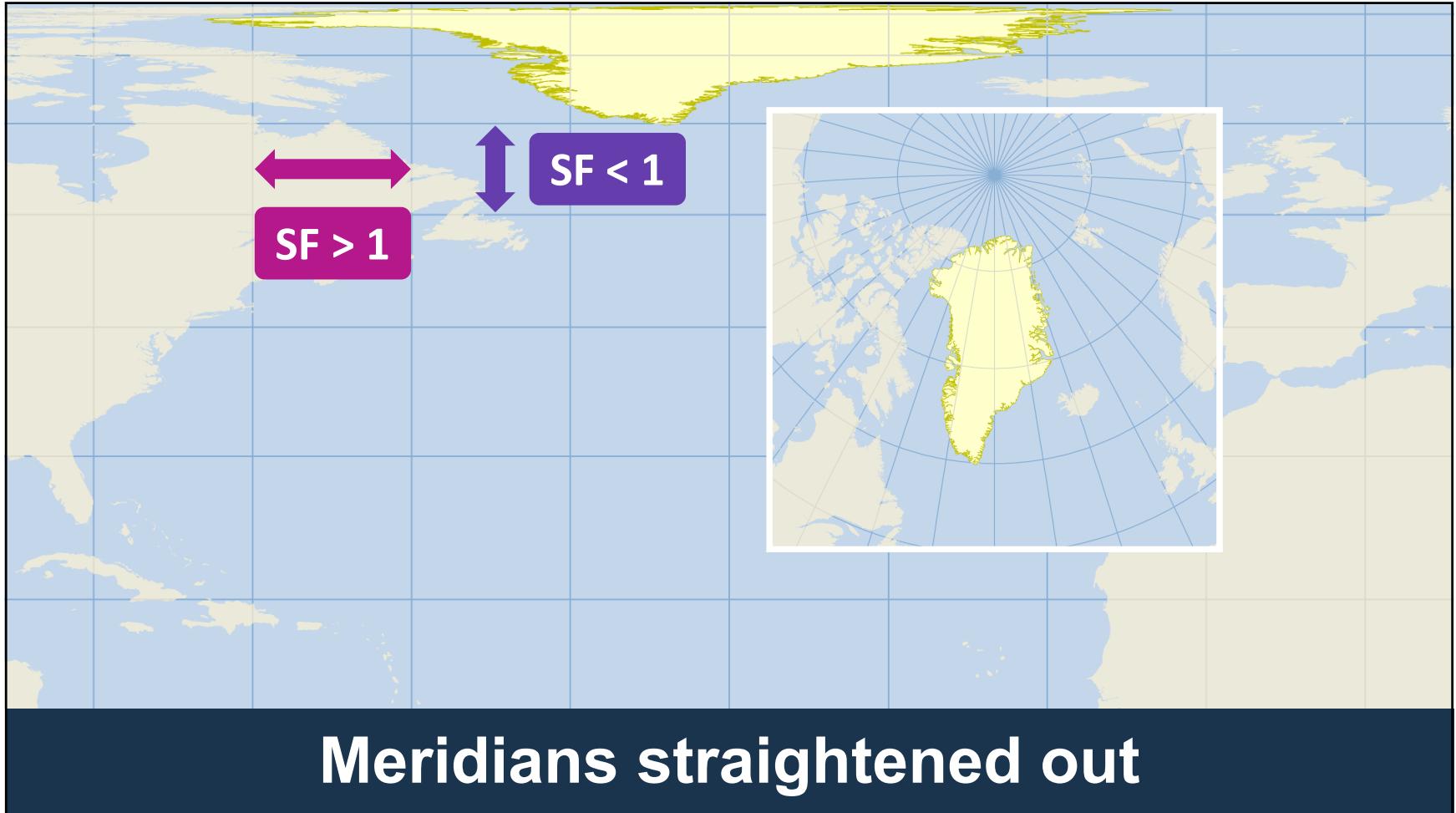
Tissot's Indicatrix

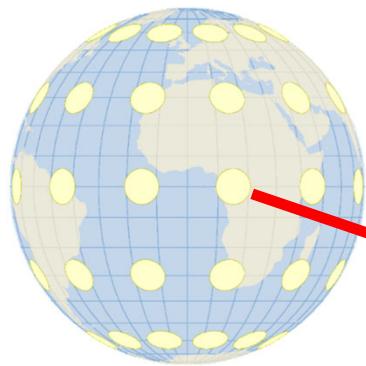


- Draw infinitely small circles on reference globe
- On globe, they are circles
- When projected, they are distorted in shape and/or size

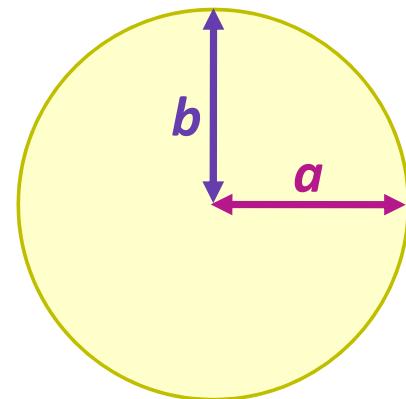


Tissot's Indicatrix: Cylindrical Equal Area





a and *b*
are scale factors (SF)

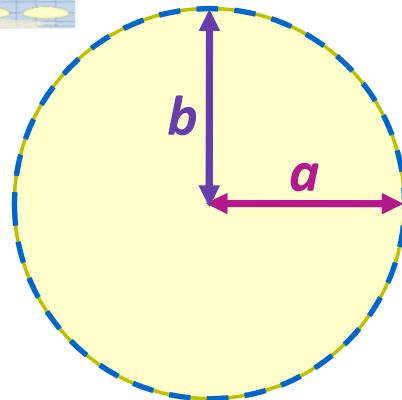
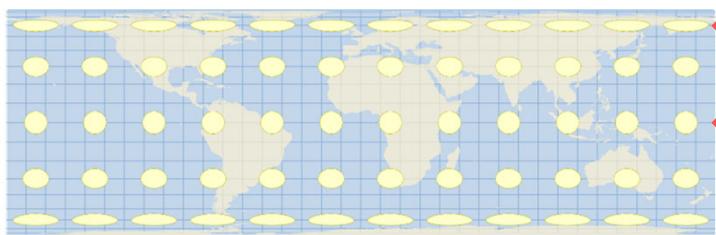


$$\begin{aligned}\text{Area} &= \pi r^2 \\ &= \pi ab\end{aligned}$$

$$\begin{aligned}a &= 1 \\ b &= 1 \\ a \times b &= 1\end{aligned}$$

This is on the original
reference globe (3D)

Tissot's Indicatrix

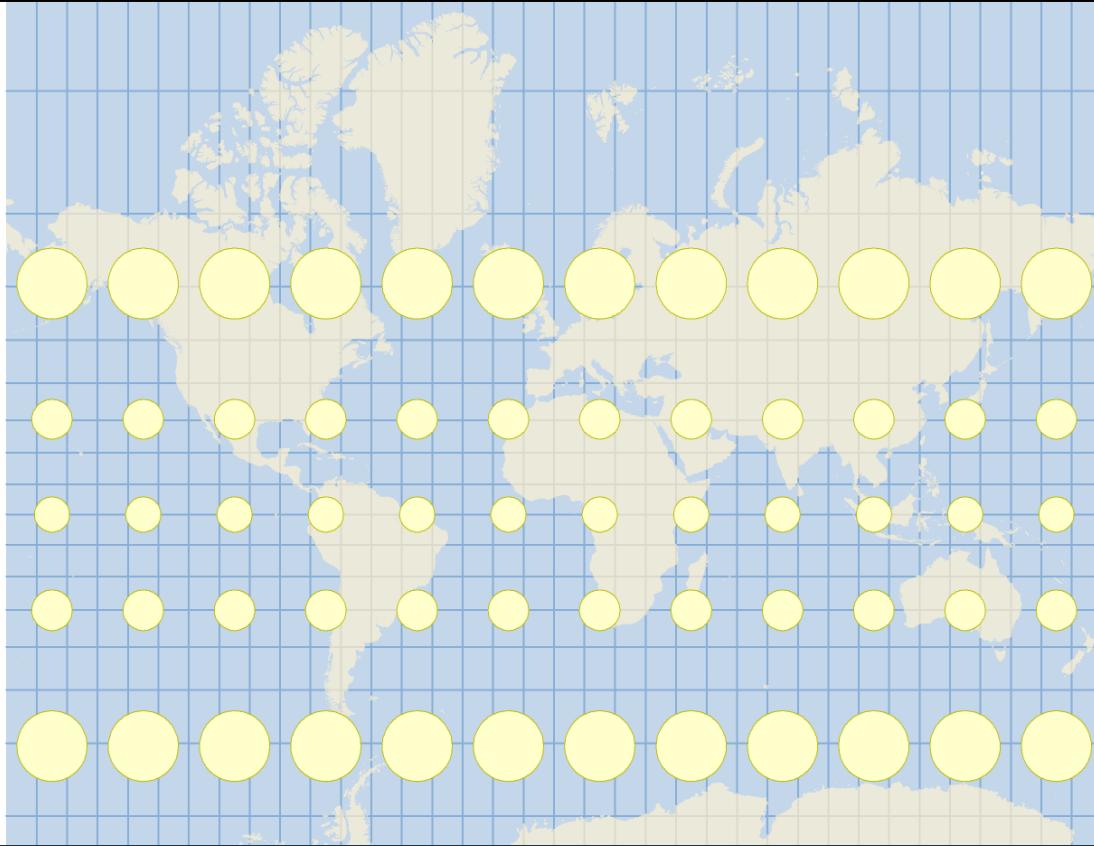


$$\begin{aligned} \text{Area} &= \pi r^2 \\ &= \pi ab \end{aligned}$$

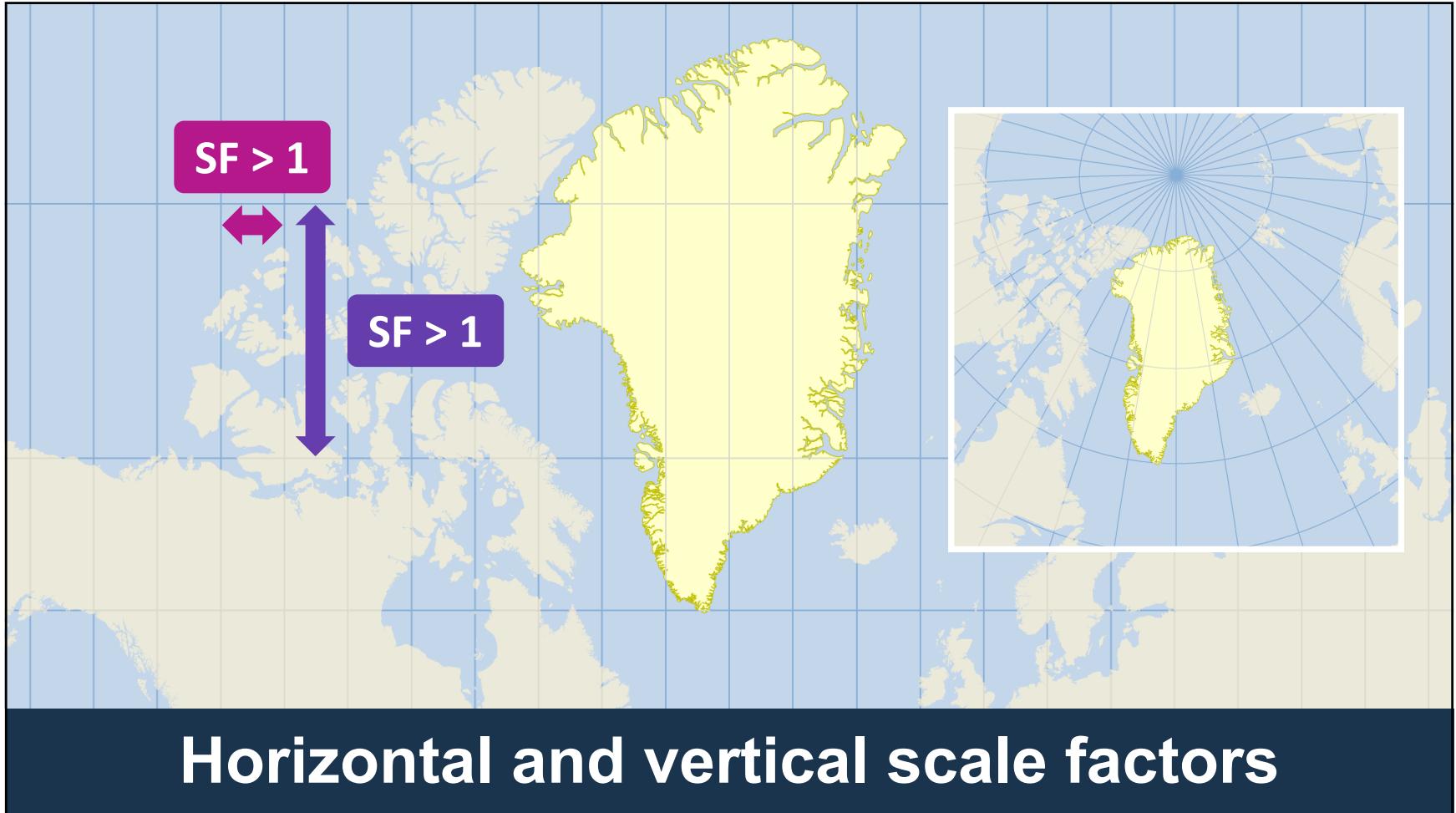
$$\begin{aligned} a &= 1.25 \\ b &= 0.8 \\ a \times b &= 1 \end{aligned}$$

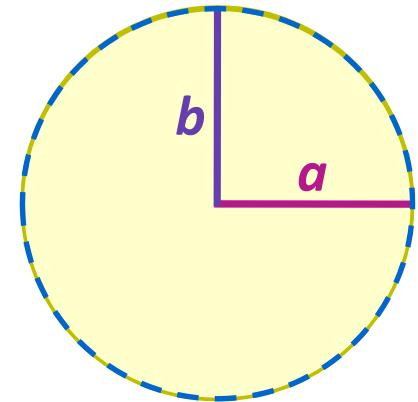
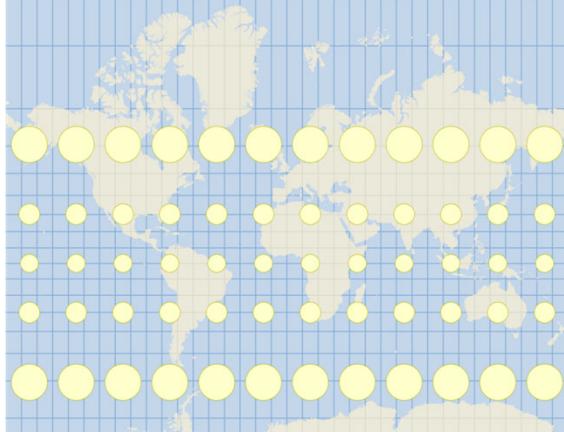
Since $a \times b = 1$,
2D map is equal-area
but $a \neq b$
so map is not conformal

Shapes distorted



Tissot's Indicatrix: Mercator





$$\begin{aligned}\text{Area} &= \pi r^2 \\ &= \pi ab\end{aligned}$$

$$\begin{aligned}a &= 1.25 \\ b &= 1.25 \\ a \times b &= 1.5625\end{aligned}$$

Since $a \times b \neq 1$,
2D map is not equal-area
but $a = b$
so map is conformal

Sizes distorted

Area

You can preserve area or shape, but not both
 $a = b$ or $a \times b = 1$

Shape

a and b
are scale factors (SF)

a b

$\text{Area} = \pi r^2$
 $= \pi ab$

$a = 1$
 $b = 1$
 $a \times b = 1$

This is on the original reference globe (3D)

Area vs. Shape

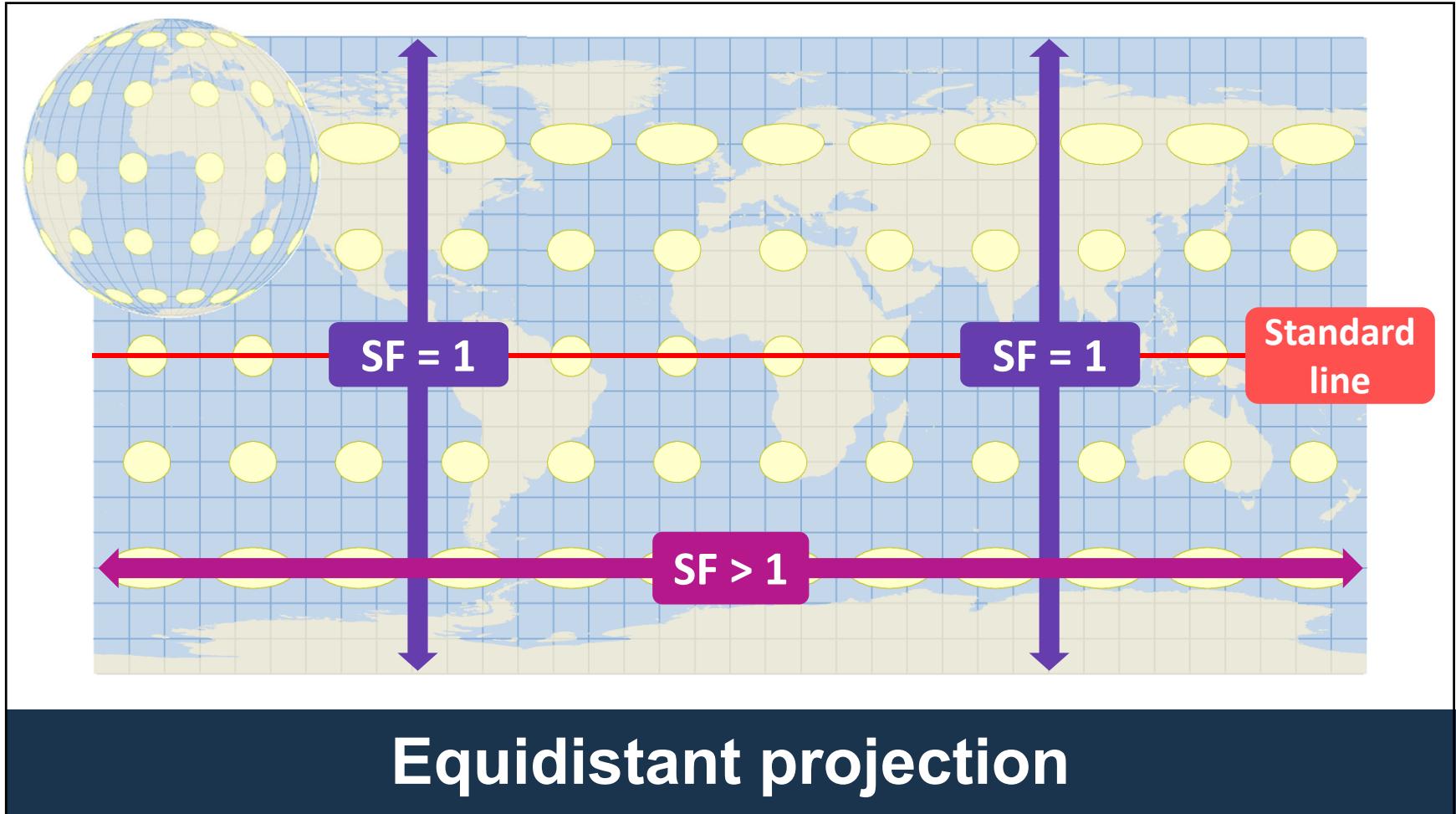
Equidistant projection

SF = 1

SF = 1

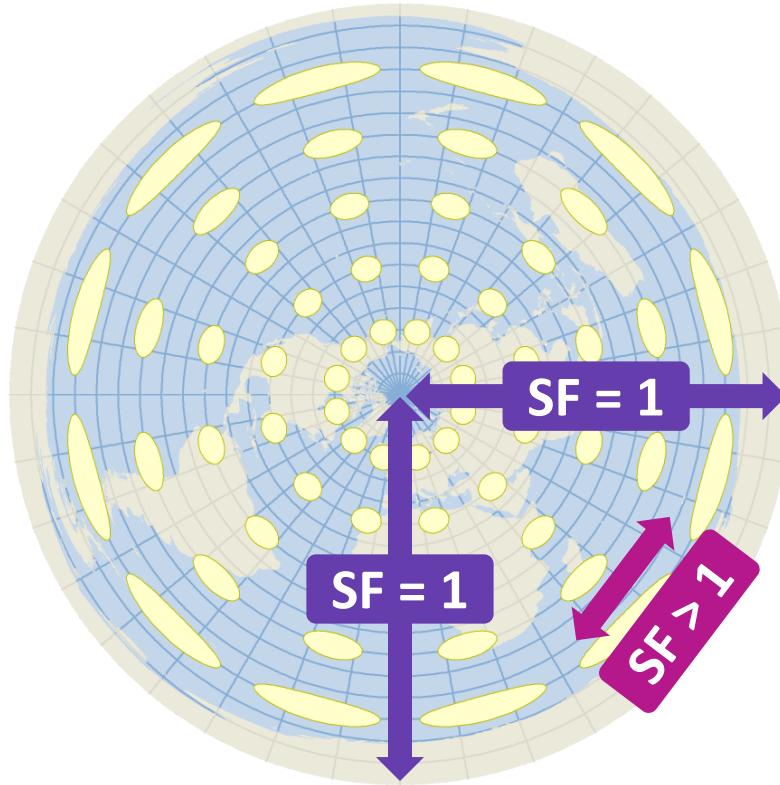
line

SF > 1

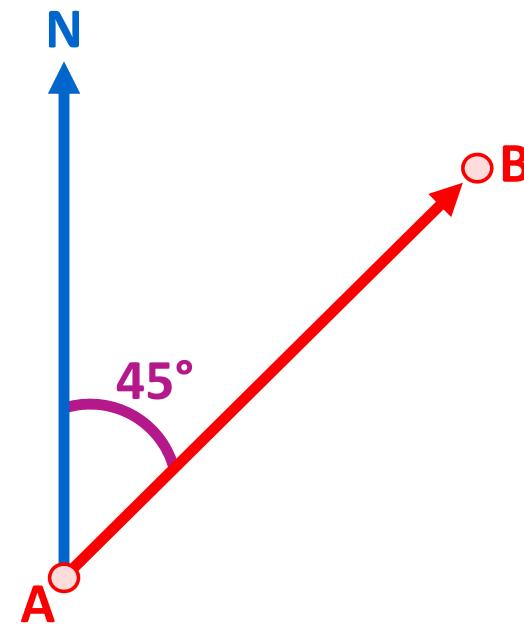


Great circles and rhumb lines

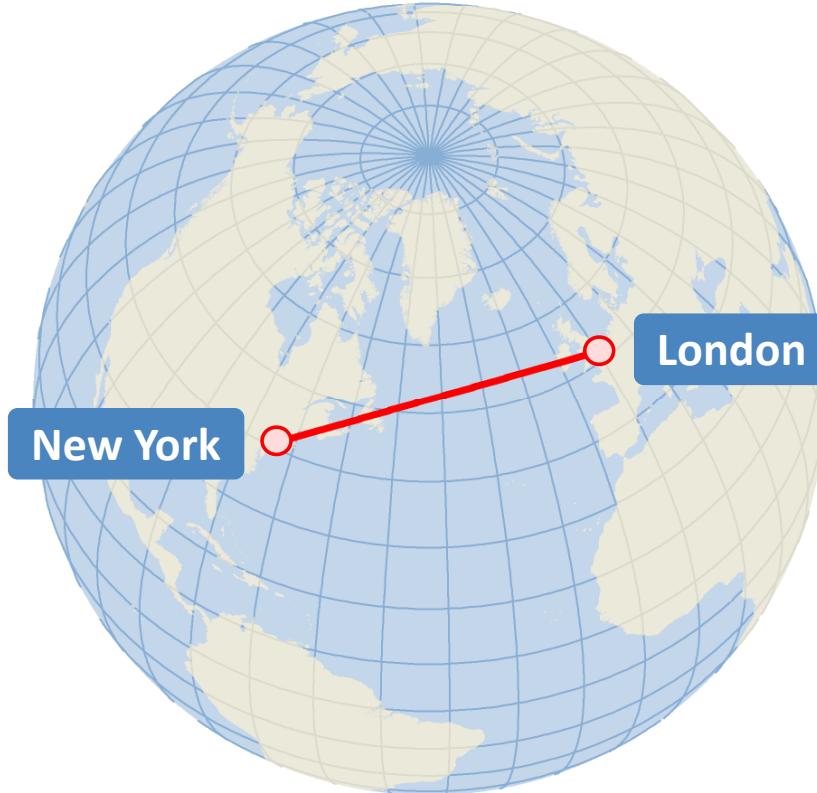




Equidistant projection

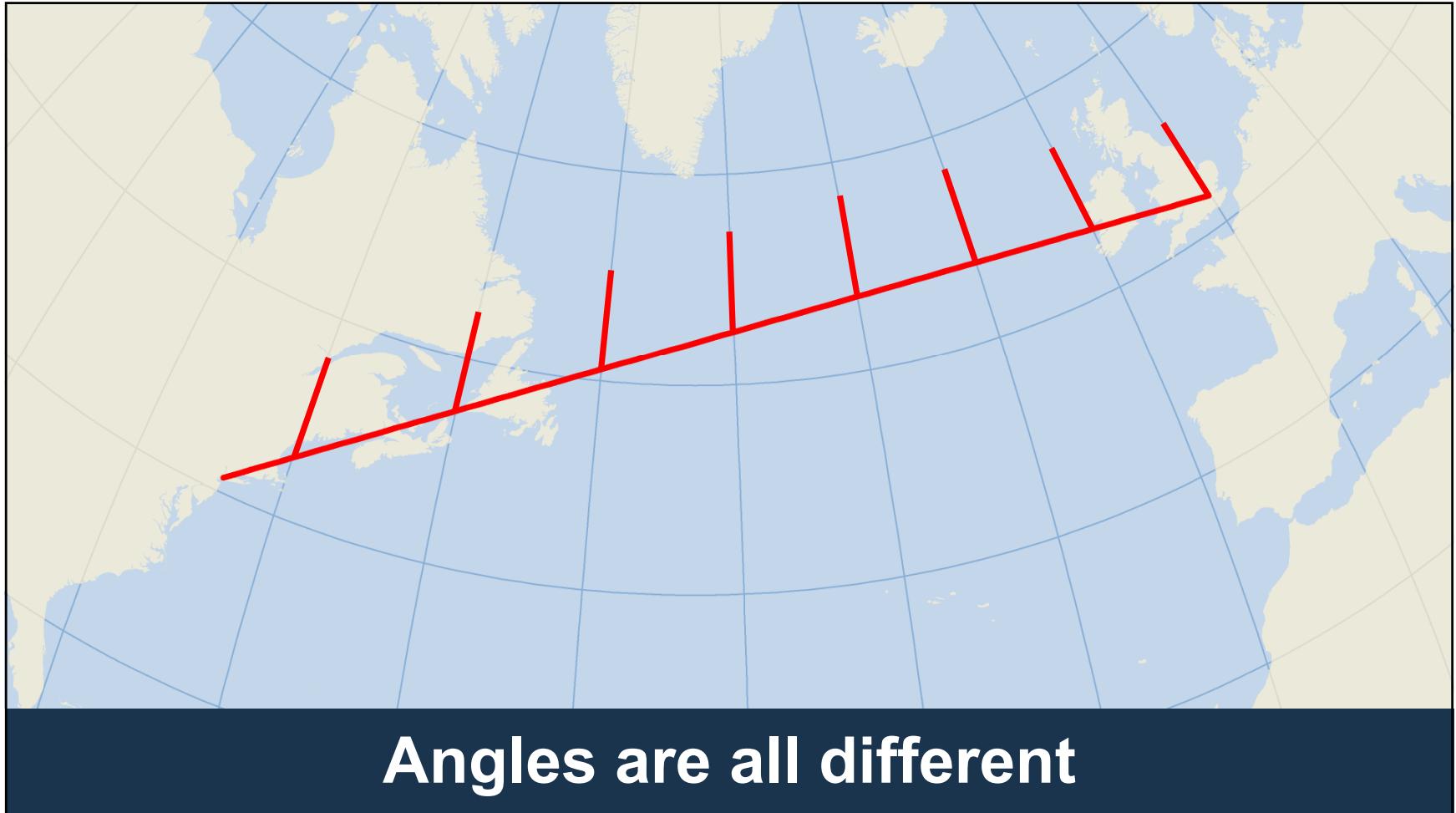


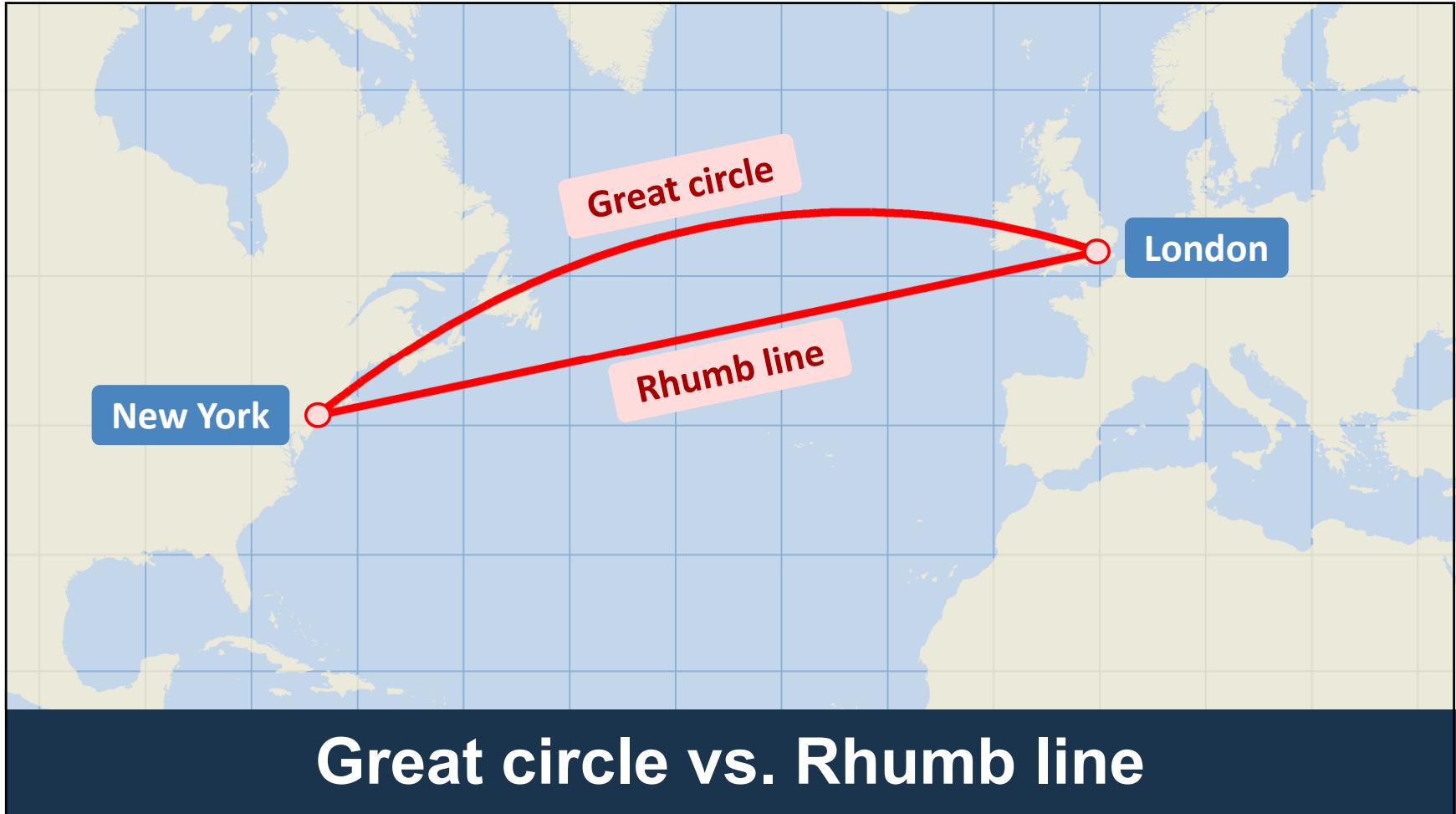
Azimuth

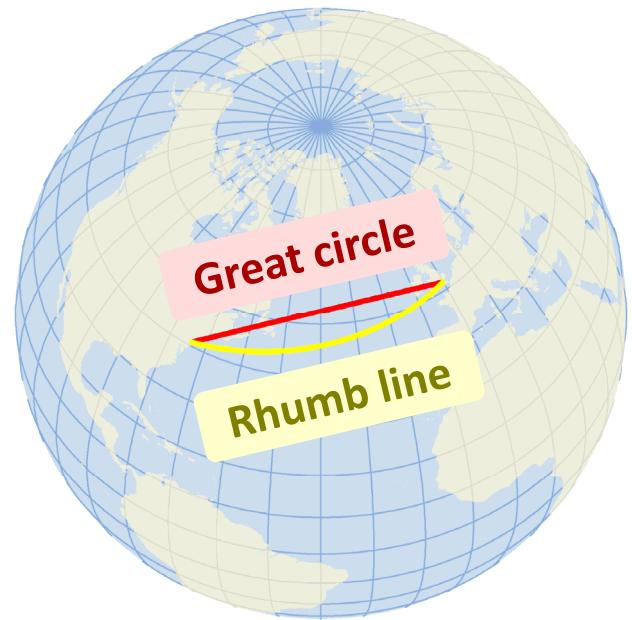


Great circle route

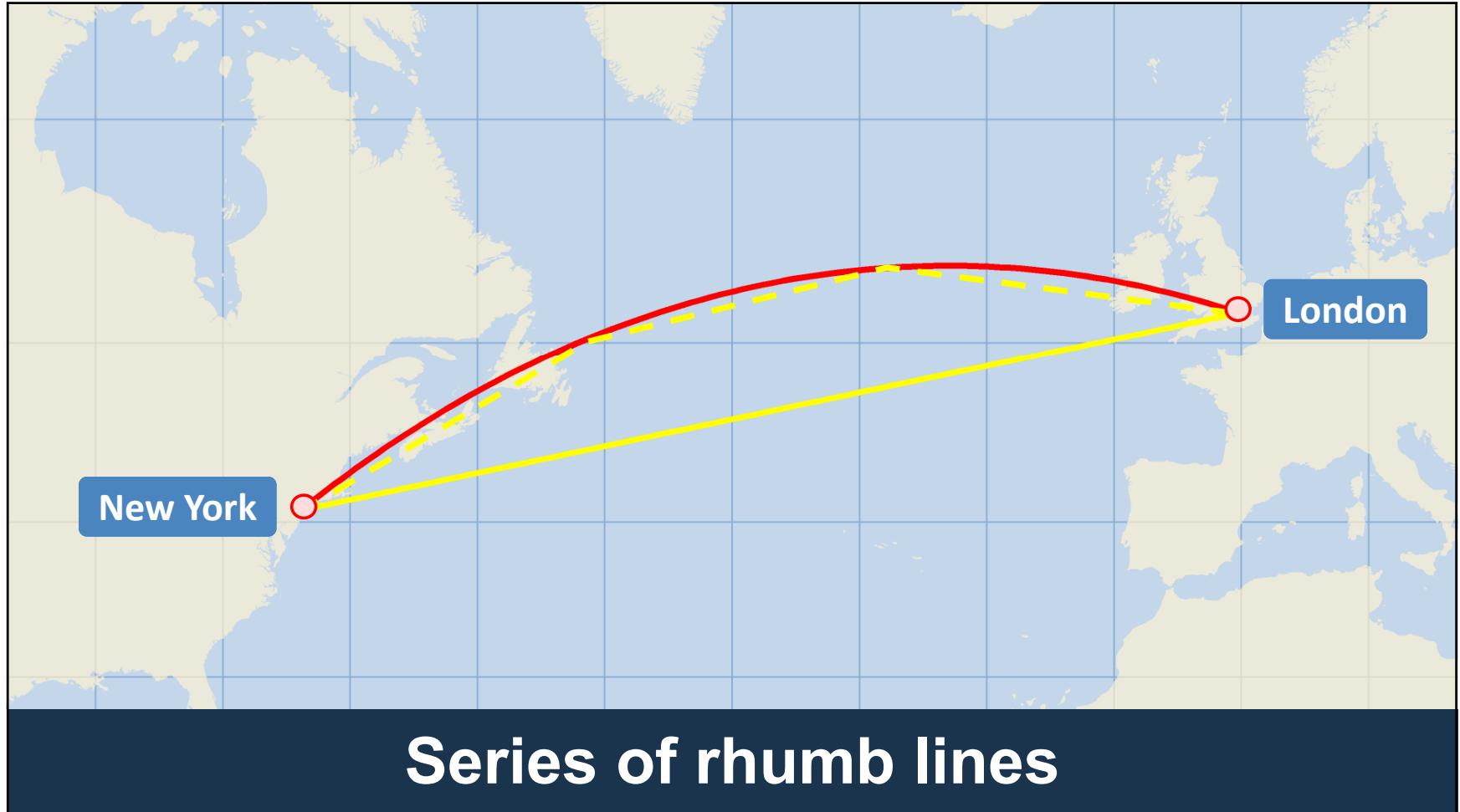








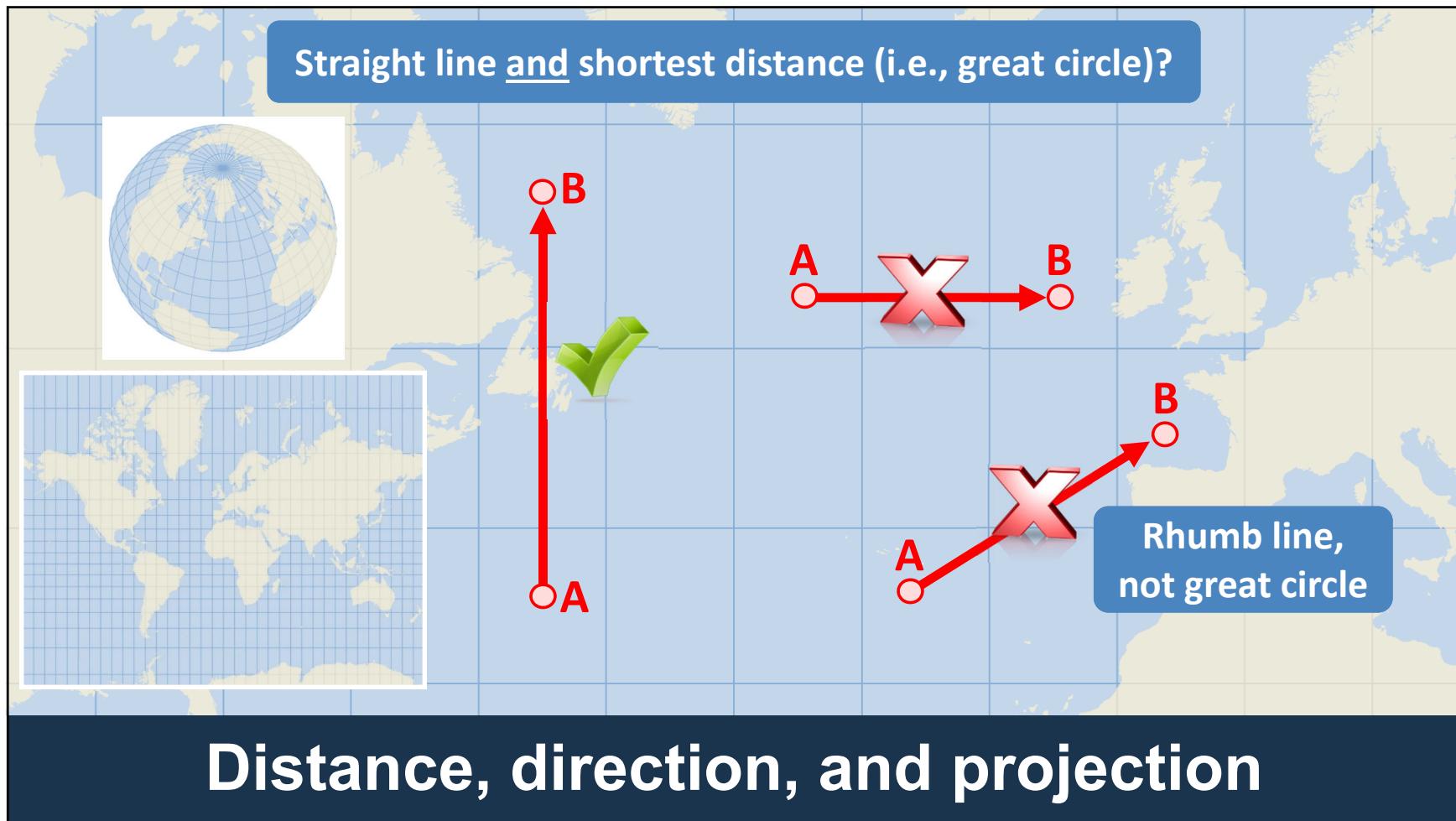
Rhumb lines are longer (really!)

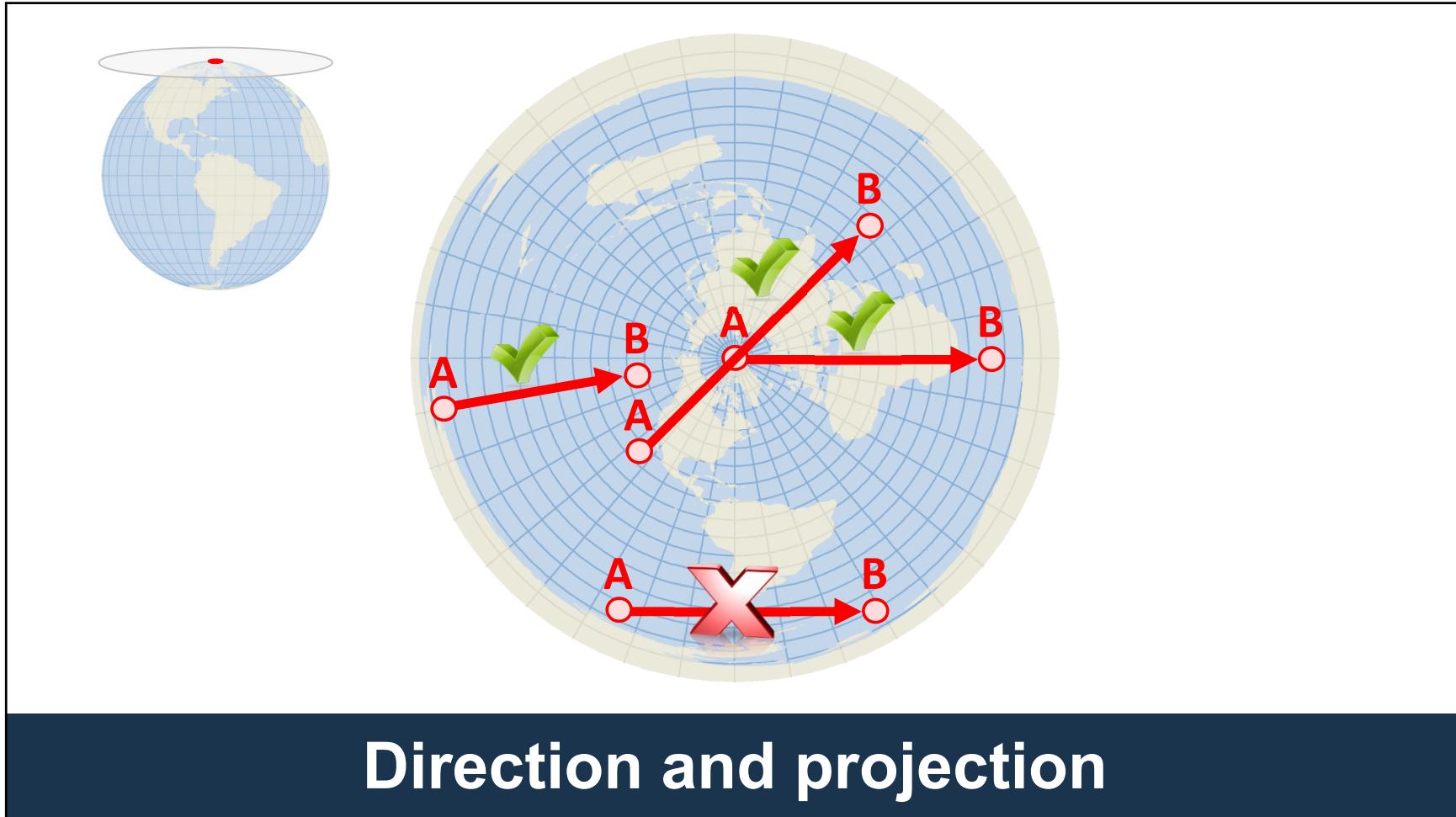


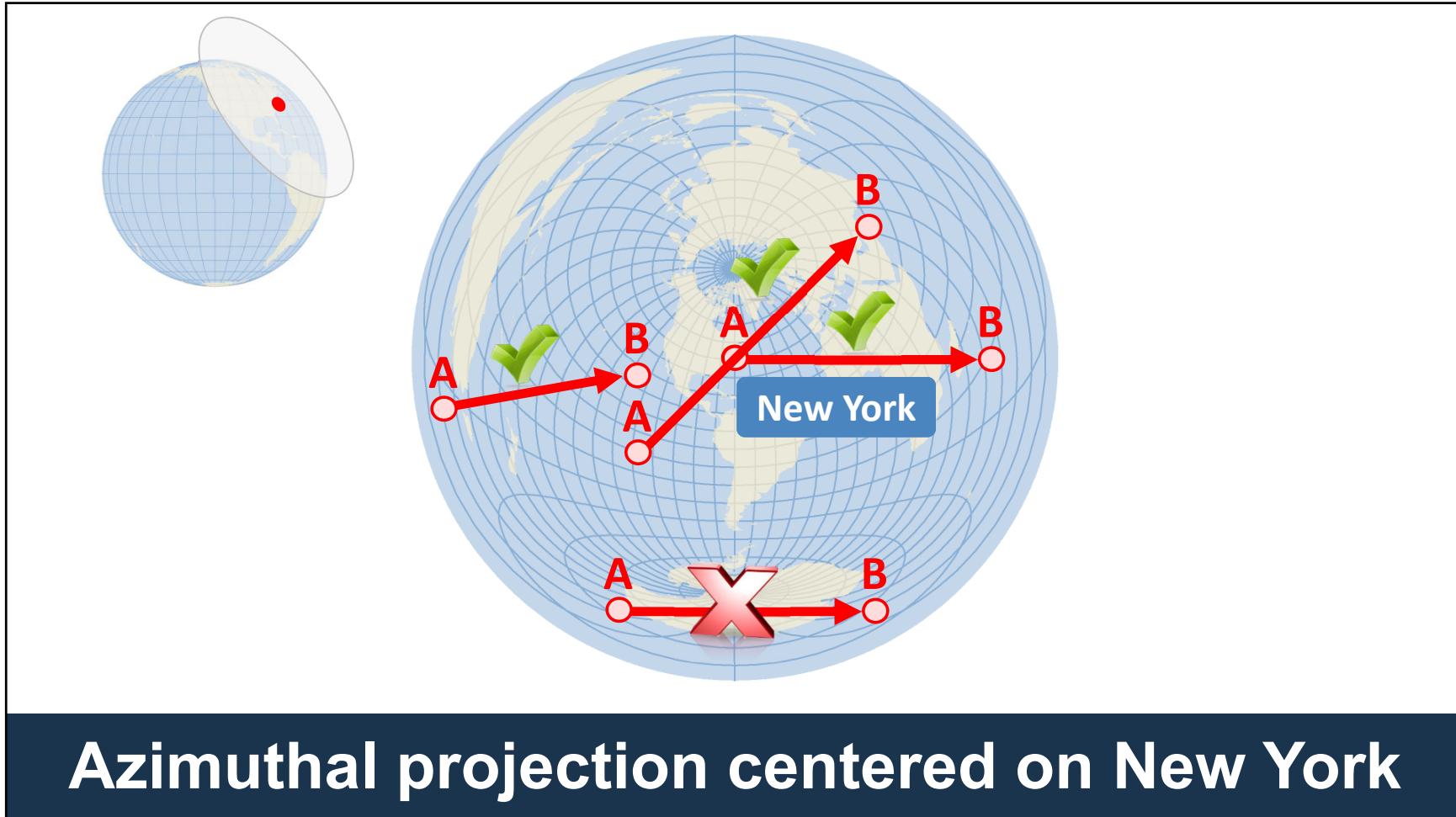
Straight line and shortest distance (i.e., great circle)?

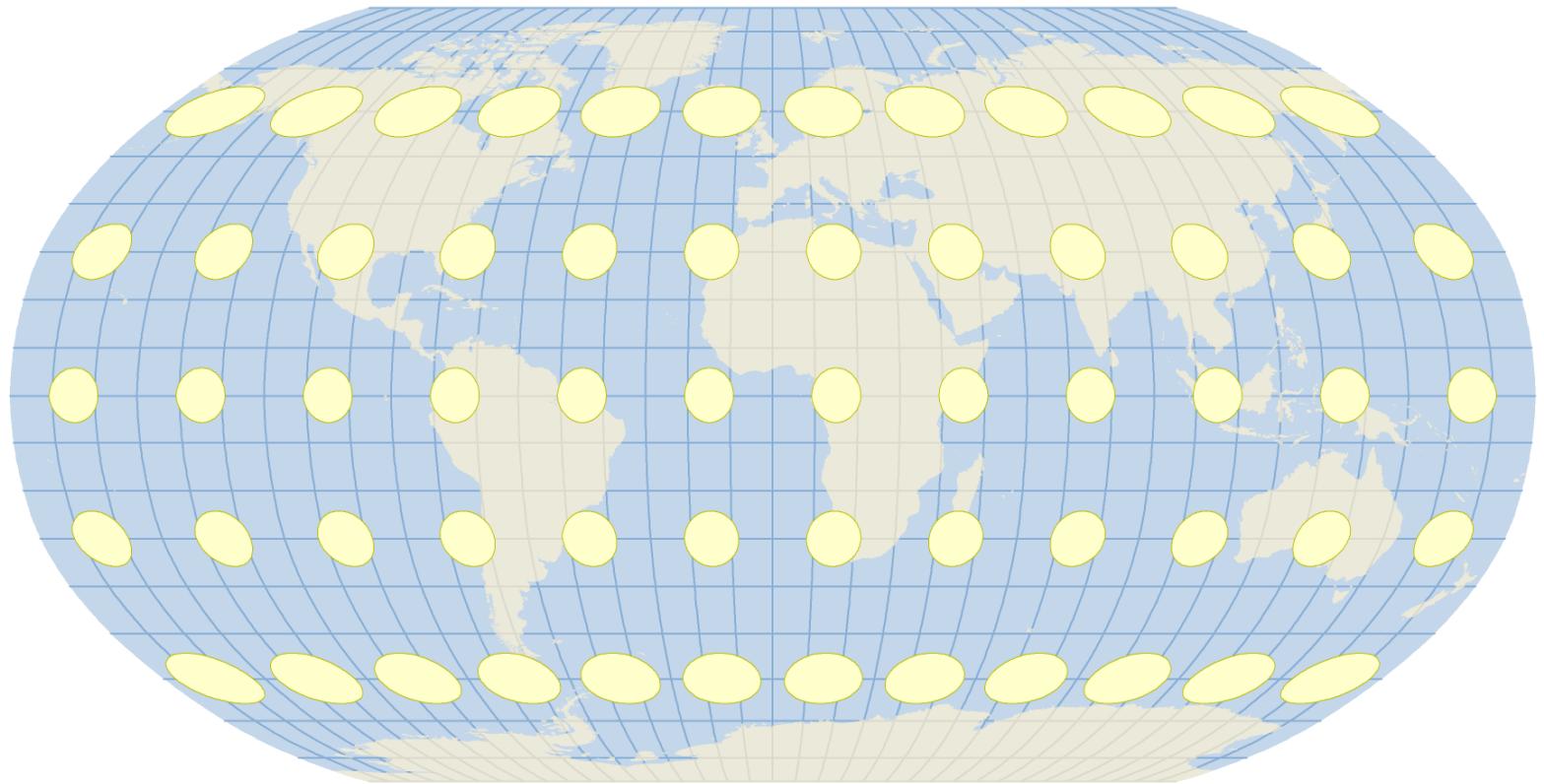
Projection distance and direction





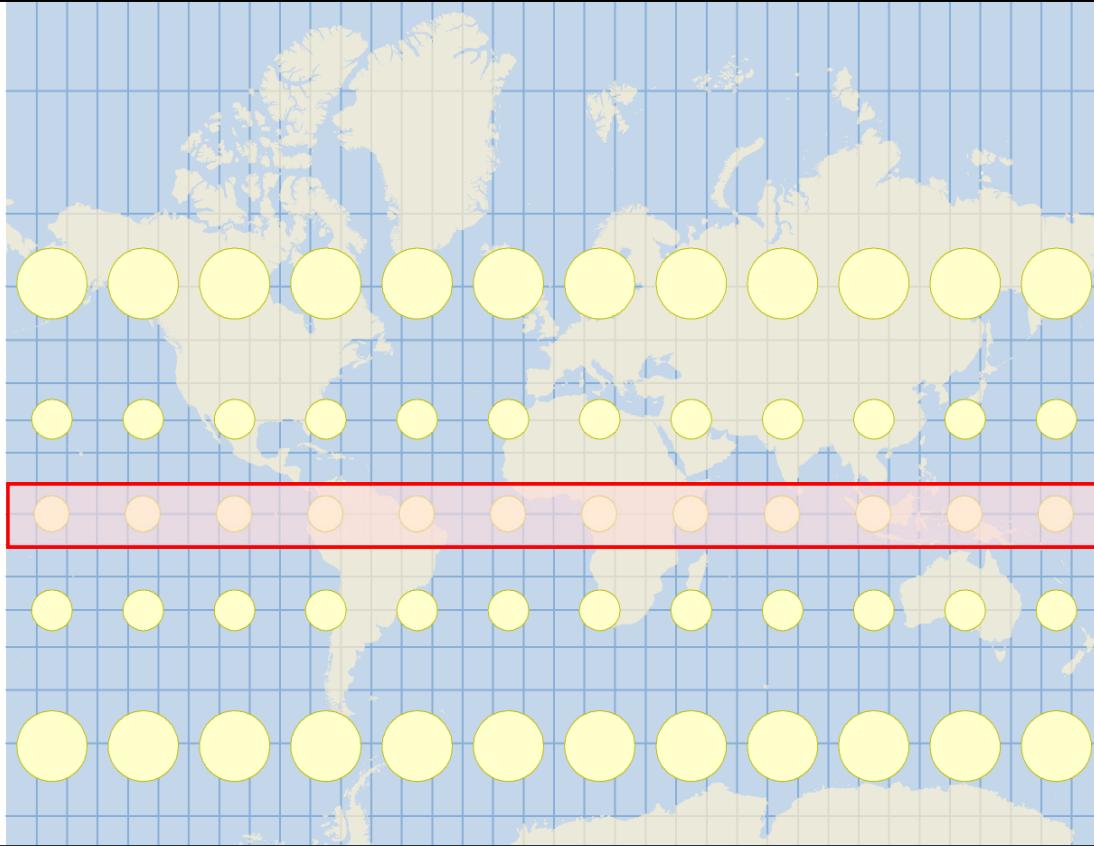




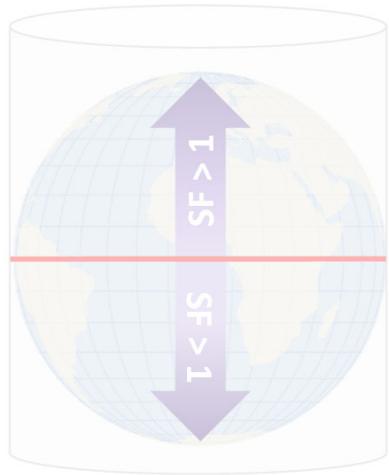


None of the above: Compromise

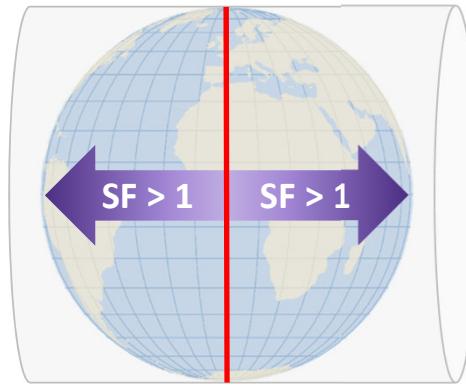
Grid coordinate systems and UTM



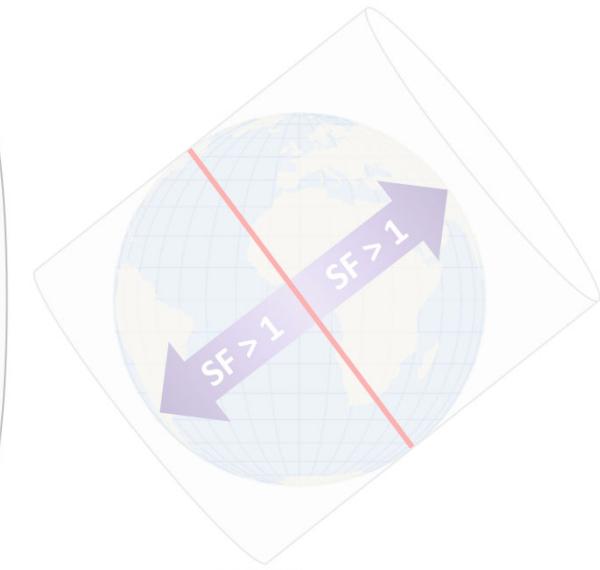
Mercator projection



Normal



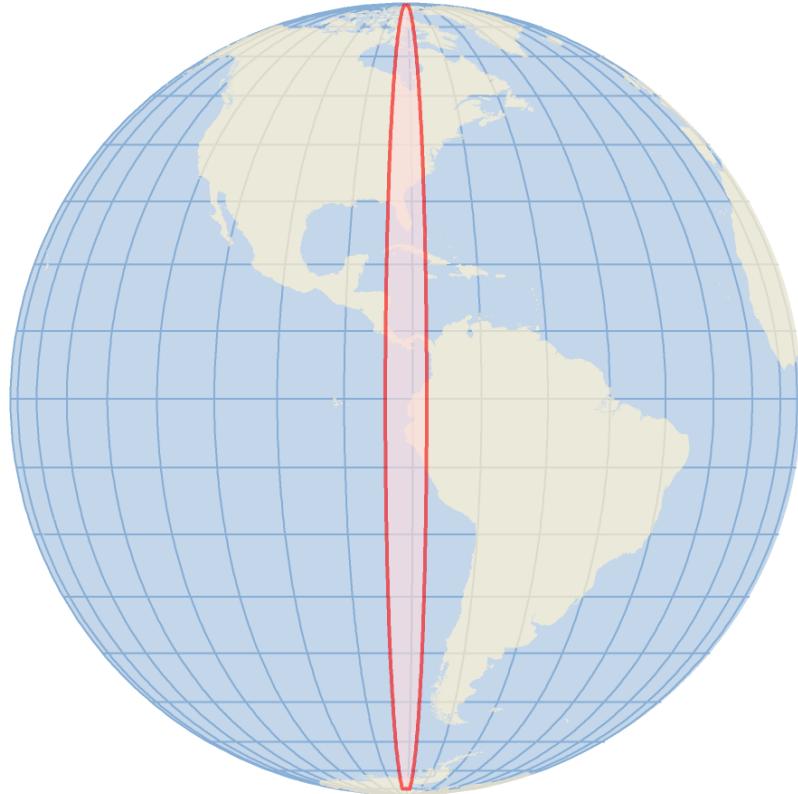
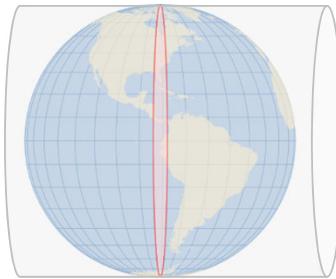
Transverse



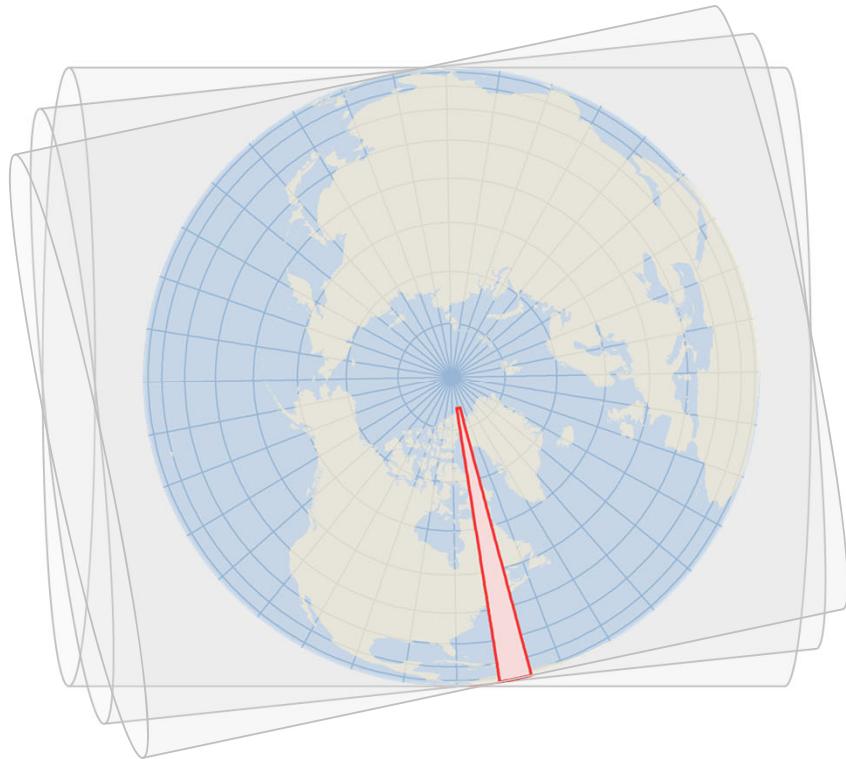
Oblique

(adapted from Lo and Yeung, 2006)

Transverse Mercator

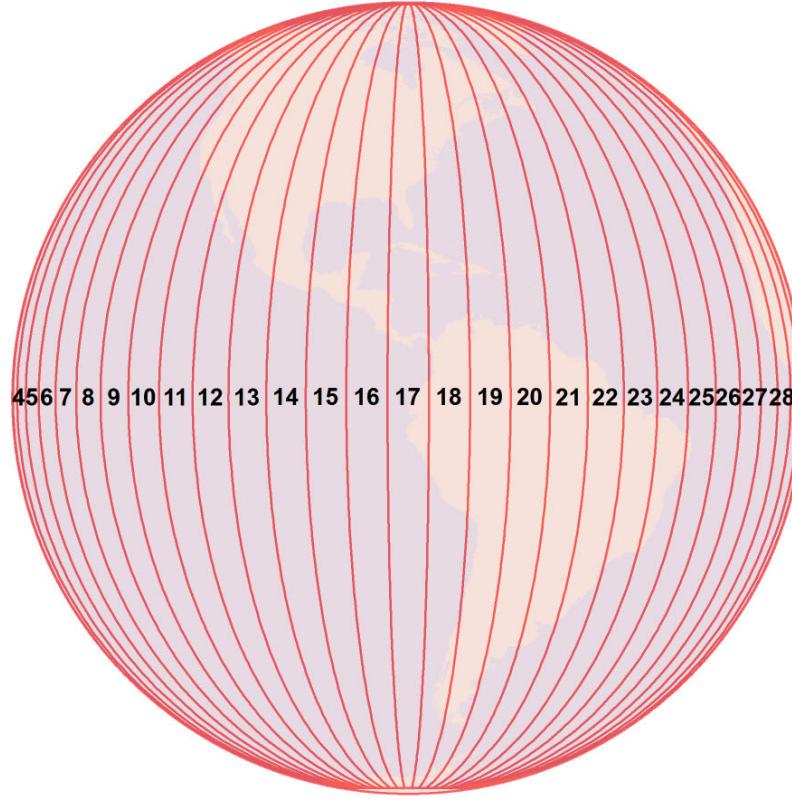


One UTM zone (6° wide)

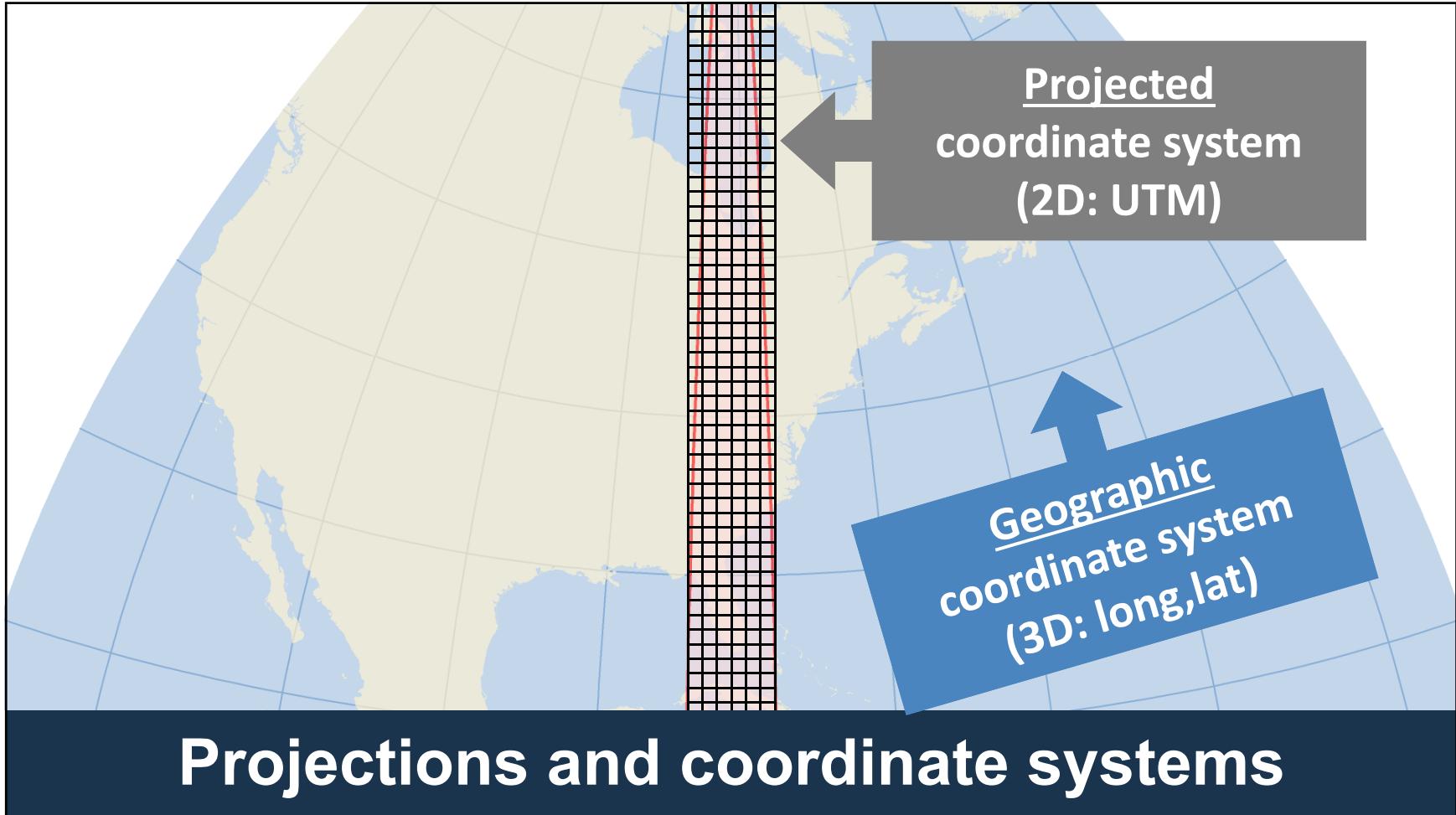


(adapted from Lo and Yeung, 2006)

Rotate cylinder, create new zone



UTM zones



Second
Quadrant

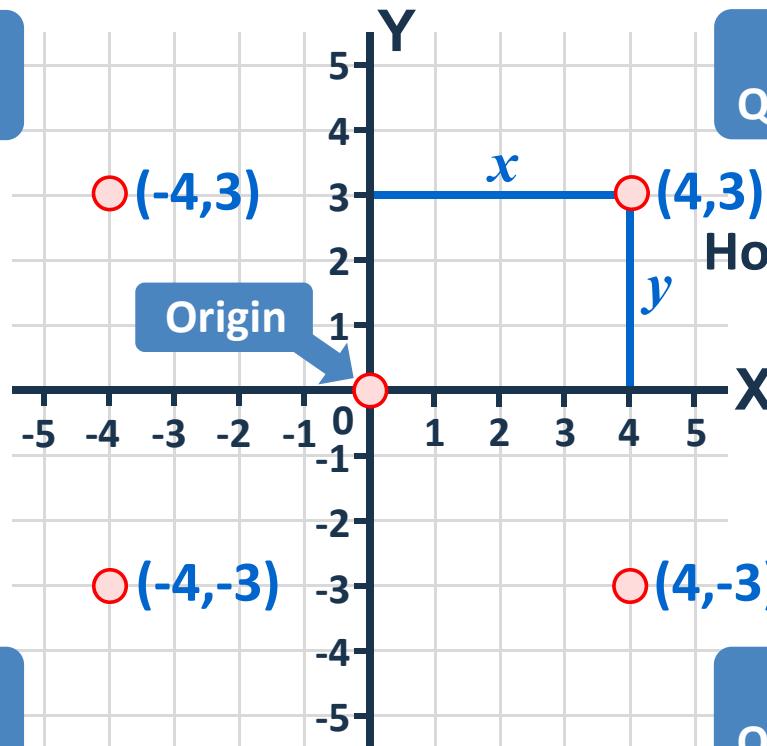
First
Quadrant

Origin

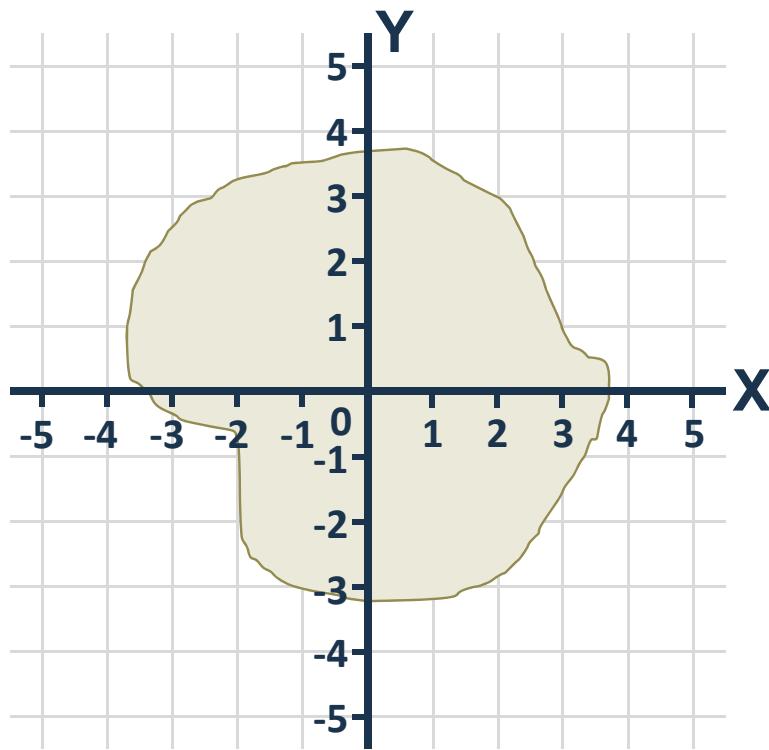
How do we describe
where this is?

Third
Quadrant

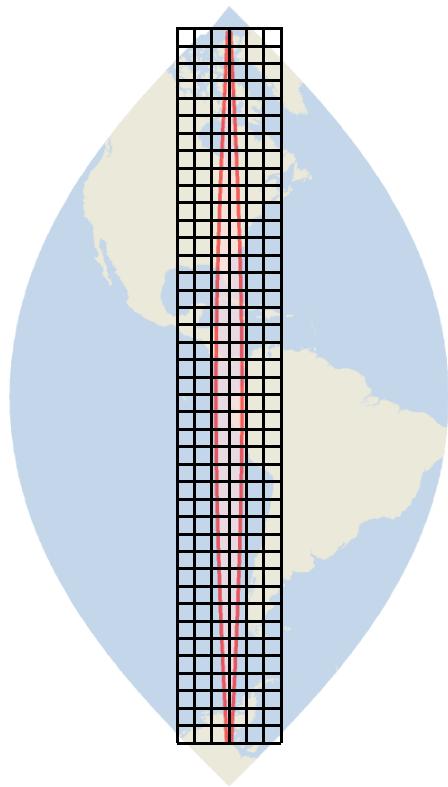
Fourth
Quadrant



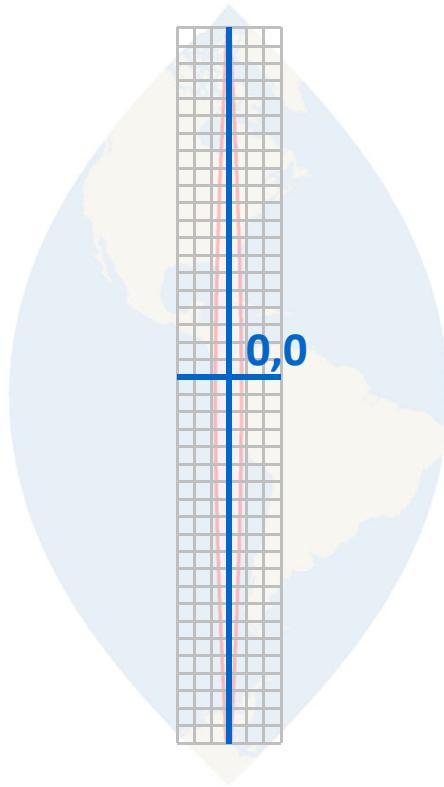
Plane rectangular coordinate system



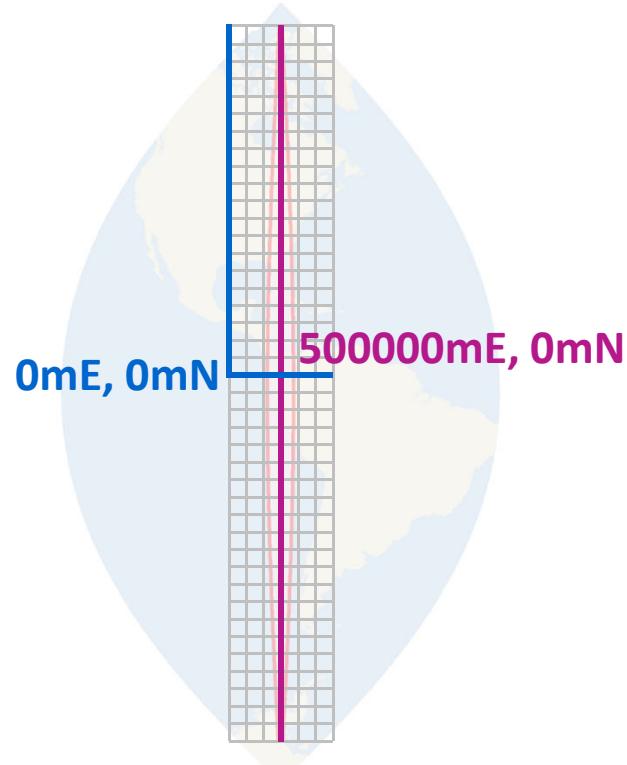
Staying positive!



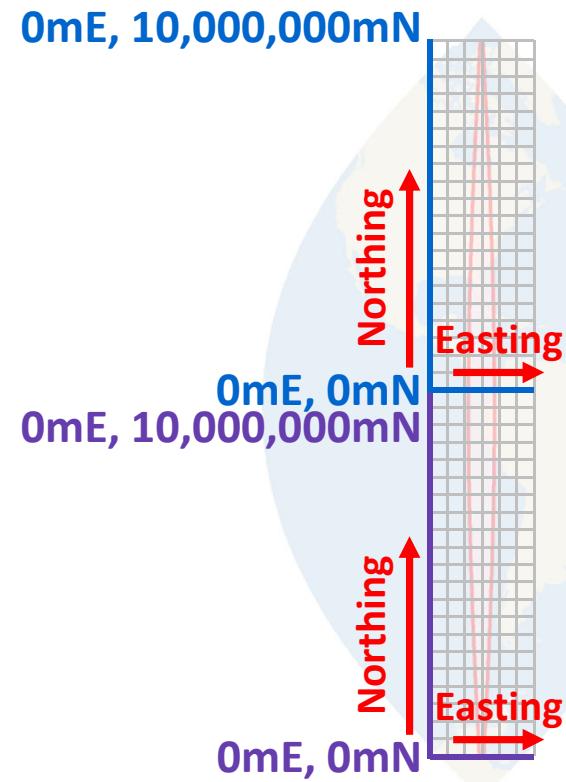
UTM coordinate grid



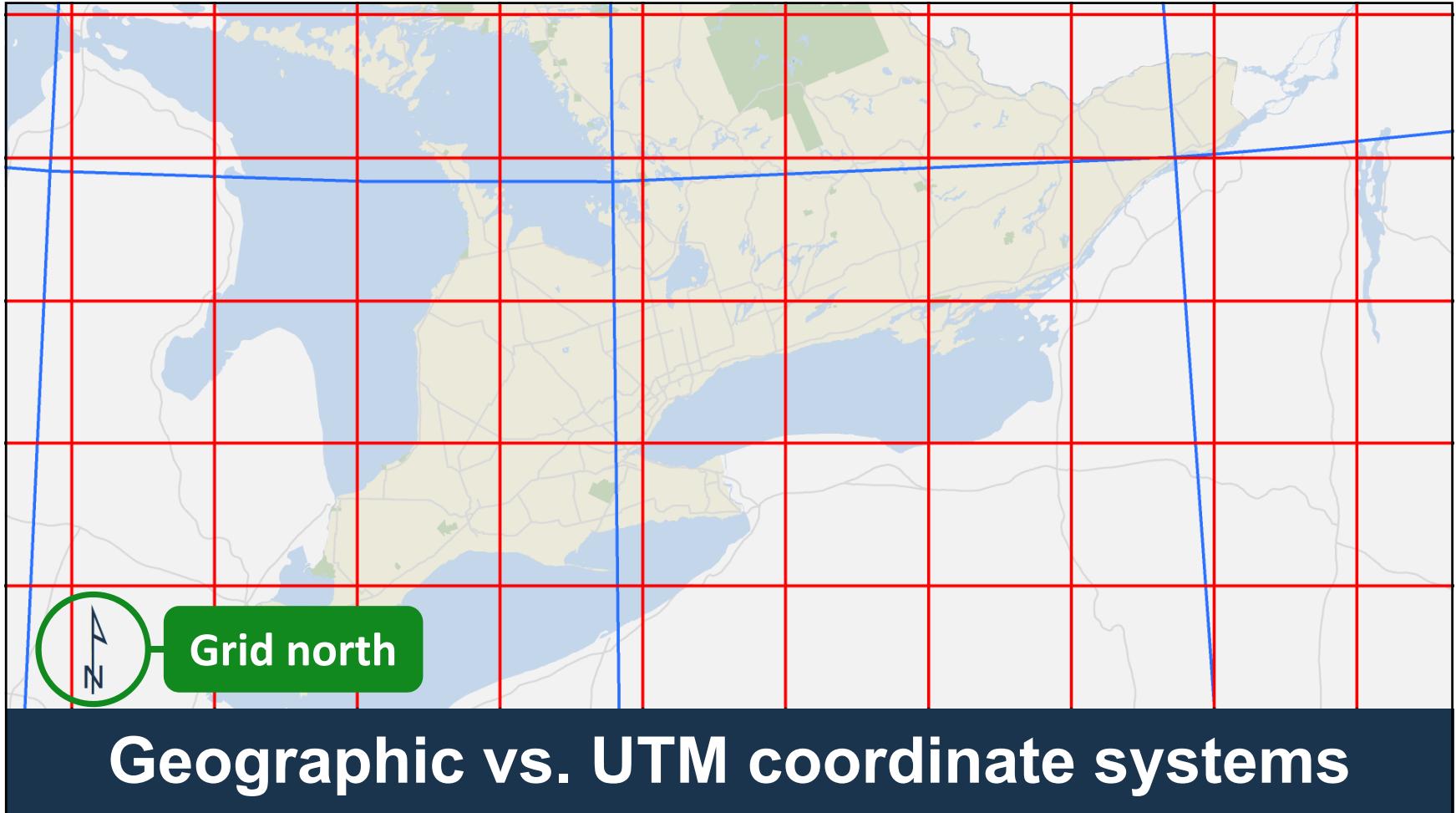
Where origin would normally be...

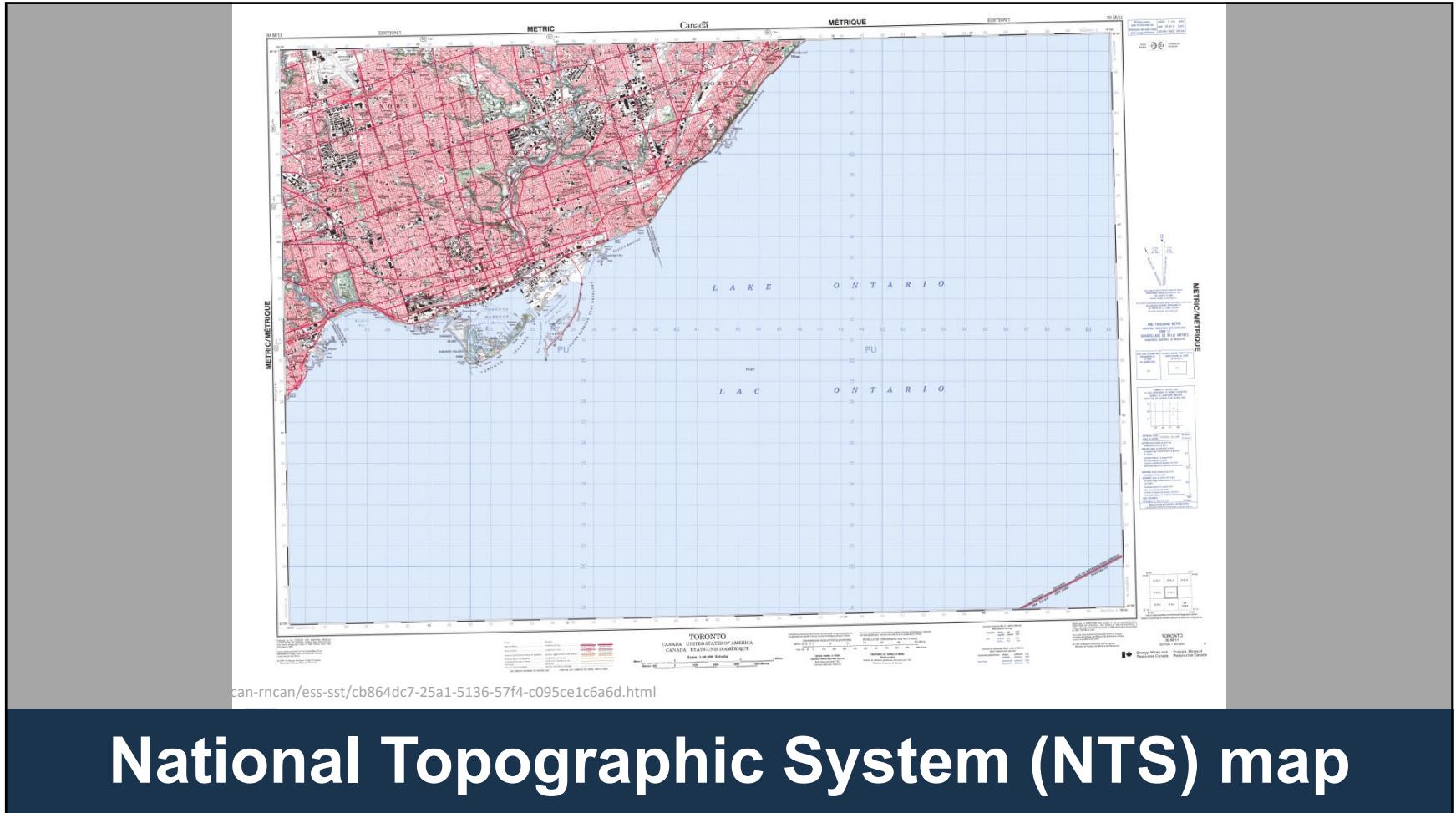


False easting

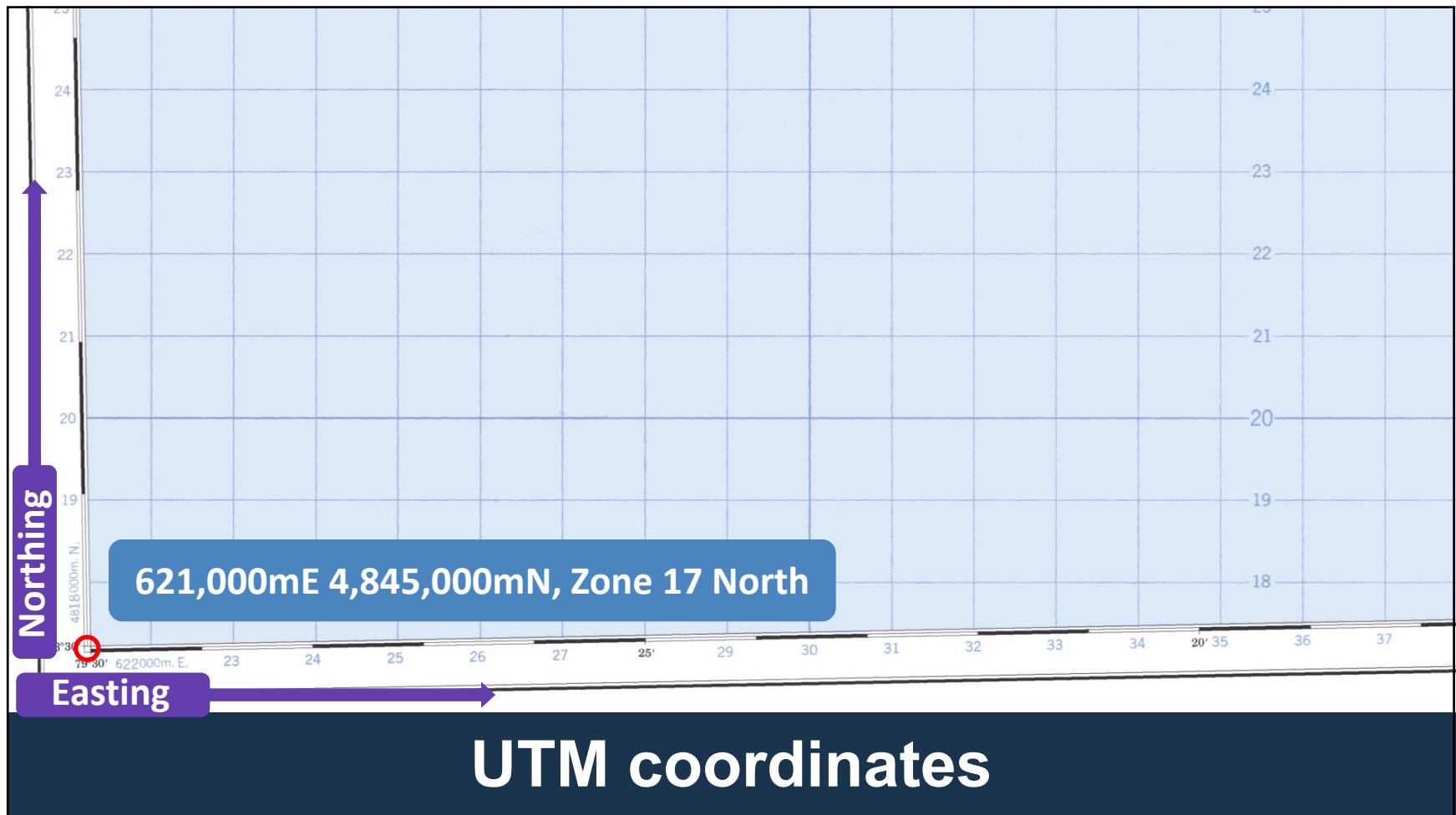


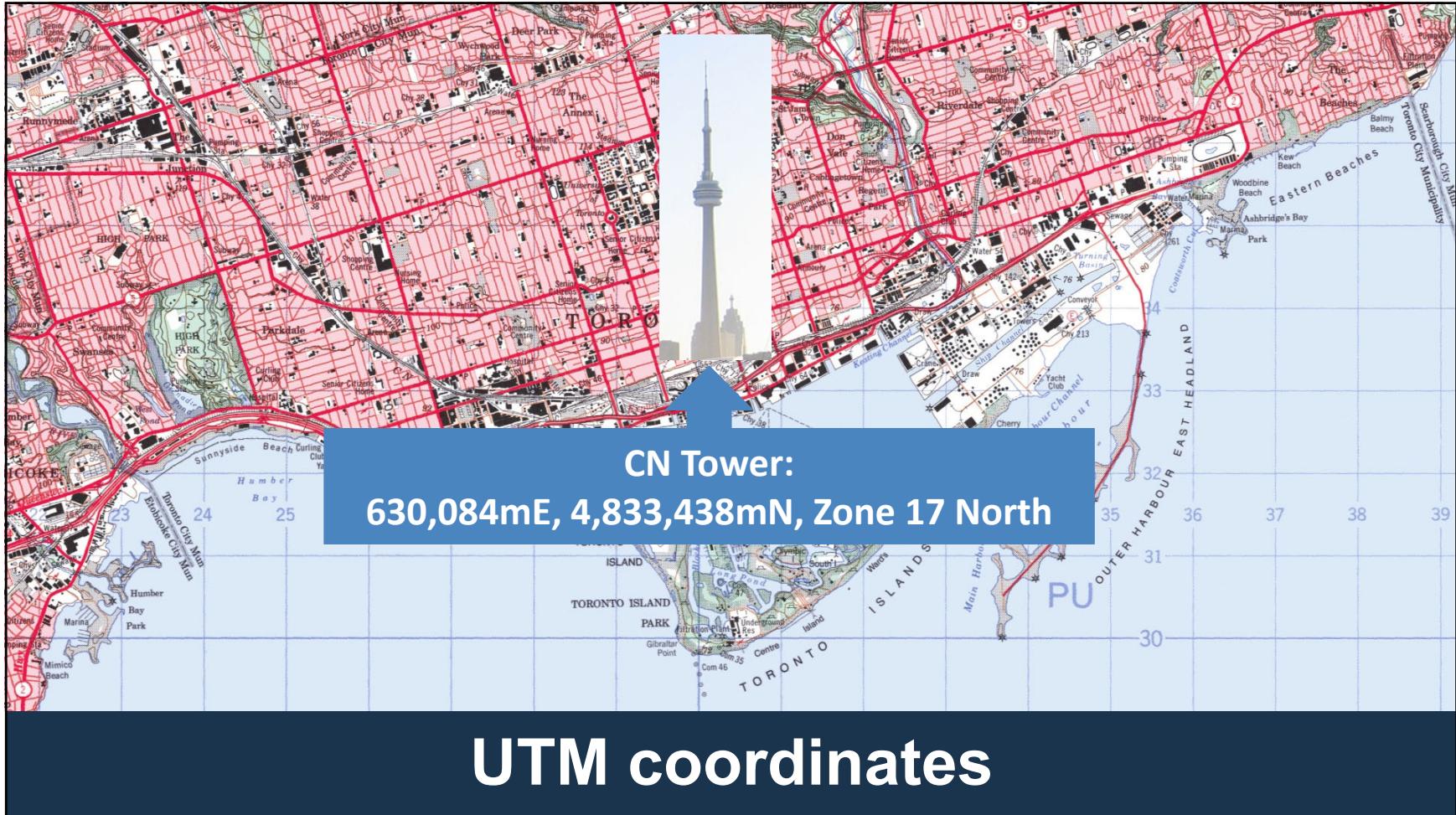
North vs. South hemispheres

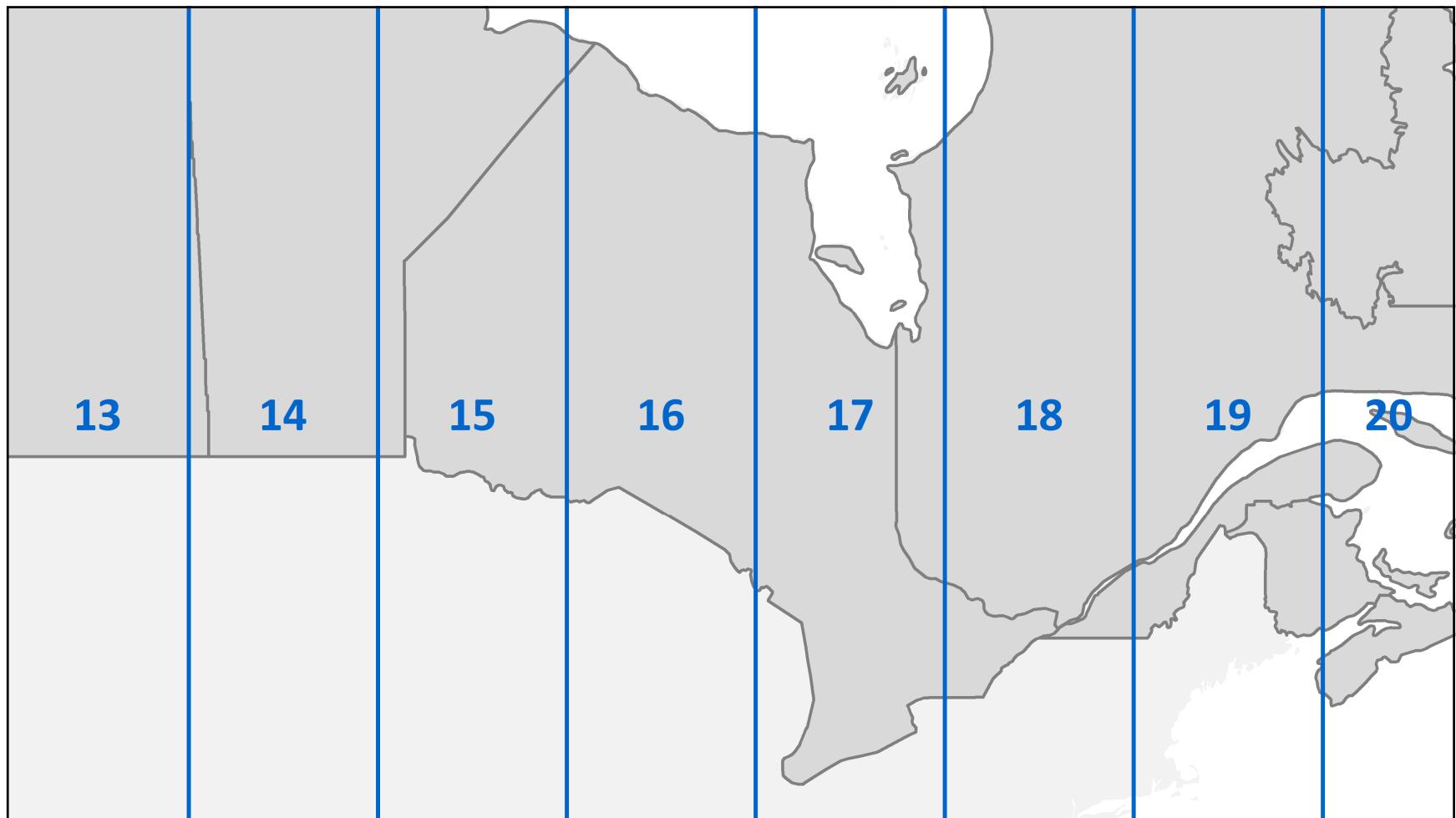




National Topographic System (NTS) map







Menu and toolbars

Table of
Contents

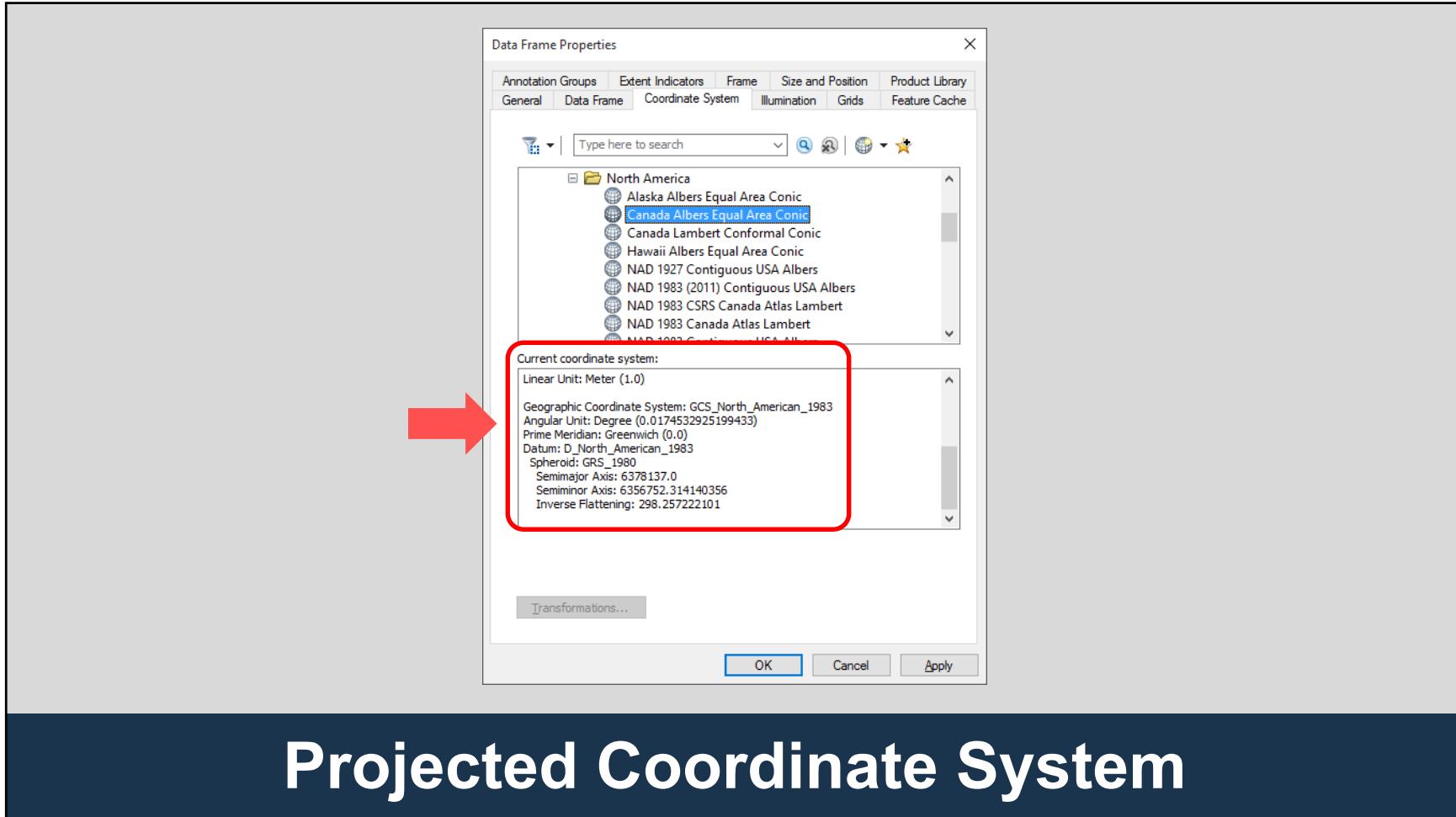
ArcCatalog

Projections and ArcGIS

Robinson

"on the fly"

Geographic
and
Projected



Menu and toolbars

Table of contents



Mercator



Robinson

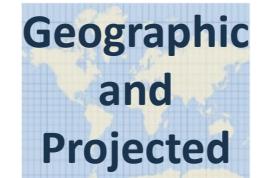
"on the fly"



ArcCatalog



Geographic



Geographic
and
Projected

ArcMap and coordinate systems

Projection changes to data files

- Data can be saved to new file in new projection
- Coordinates in the data file are recalculated and adjusted to match the new projection
- You can't always transform it "back" to exactly the same coordinates due to rounding errors.

To avoid errors...

- Exchange GIS data in a 3D geographic coordinate system, not a 2D projected coordinate system