NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY

Know the Earth... Show the Way... Understand the World

NGA's Position on "Web-Mercator"

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ESRI Users Conference

July 22, 2015

NGA's Authority

- National Imagery and Mapping Agency, *Department of Defense World Geodetic System 1984 — Its Definition and Relationships with Local Geodetic Systems,* NIMA Technical Report 8350.2 Third Edition, 1997.
- CJCSI 3900.01C, *"Position (Point and Area) Reference Procedures",* 30 June 2007
- Department of Defense Directive 5105.60 (DoDD 5105.60), *"Subject: National Geospatial-Intelligence Agency (NGA)",* July 29, 2009
- NGA.SIG.0011_1.0_WEBMERC, *"Web Mercator Map Projection",* February 18, 2014
- *NGA Advisory Notice on "Web Mercator",* May 22, 2014

http://earth-info.nga.mil/GandG/wgs84/web_mercator/index.html

Agenda

1. What is “web-Mercator”?
2. Why was it invented?
3. What’s wrong with it?
4. What does NGA recommend instead?

Short Answers

1. What is “web-Mercator”?
   – Ellipsoidal Lat./Lon. used with abbreviated (spherical) Mercator formula

2. Why was it invented?
   – Better than Plate Carrée; simpler than true (ellipsoidal) Mercator

3. What’s wrong with it?
   – Conflicts with Mercator; impedes interoperability; duplicates IT effort

4. What does NGA recommend instead?
   – Mercator; projections like NGA standard products; Tiled Mercator

Agenda

1. **What is “web-Mercator”?**
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Symbols Explained

$a =$ semi-major axis of the ellipsoid (radius of the Equator)

$e =$ eccentricity of the ellipsoid (shape of the ellipsoid)

$\lambda =$ longitude (in radians), "lambda"

$\phi =$ latitude (in radians), "phi"

$x =$ horizontal map-projection coordinate

$y =$ vertical map-projection coordinate

$\text{arctanh} = \tanh^{-1}$ (two notations for the inverse hyperbolic tangent)

Mercator *v.* web-Mercator

The formulas for Mercator (EPSG::3395) are:

$$x = a\,\lambda$$

$$y = a\,\text{arctanh}\,(\sin\phi) - a\,e\,\text{arctanh}\,(e\,\sin\phi)$$

The formulas for web-Mercator (EPSG::3857) are:

$$x = a\,\lambda$$

$$y = a\,\text{arctanh}\,(\sin\phi)$$

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Mercator *v.* web-Mercator *v.* Plate Carrée

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The formulas for web-Mercator (EPSG::3857) are:

$$x = a\,\lambda$$

$$y = a\,\mathrm{arctanh}\,(\sin\phi)$$

The formulas for Plate Carrée (~EPSG::4326) are:

$$x = a\,\lambda$$

$$y = a\,\phi$$

Web-Mercator's Properties

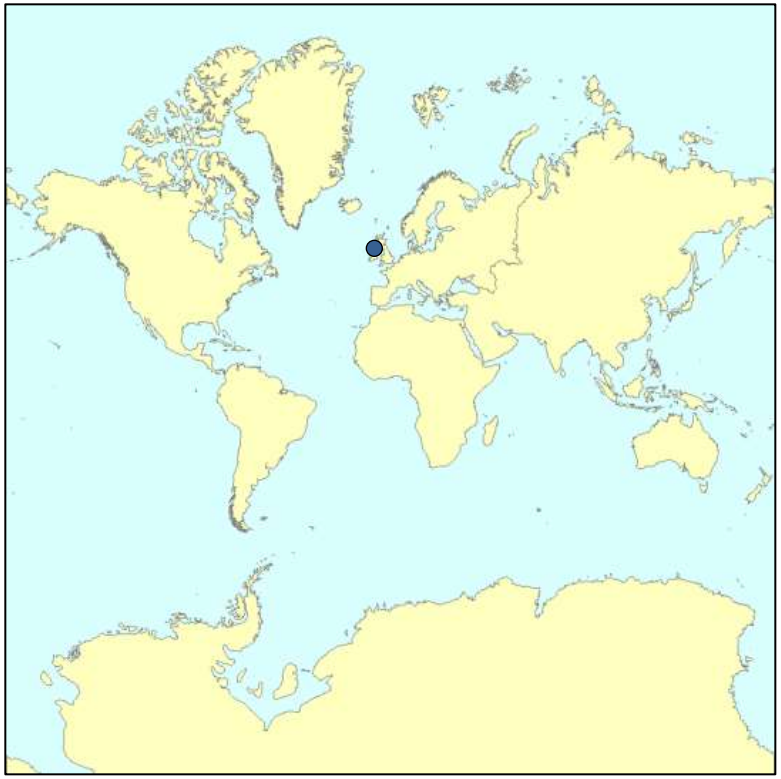
1. Almost conformal

2. Inverse, *i.e*. (x, y) to (Lon., Lat.), is accurate

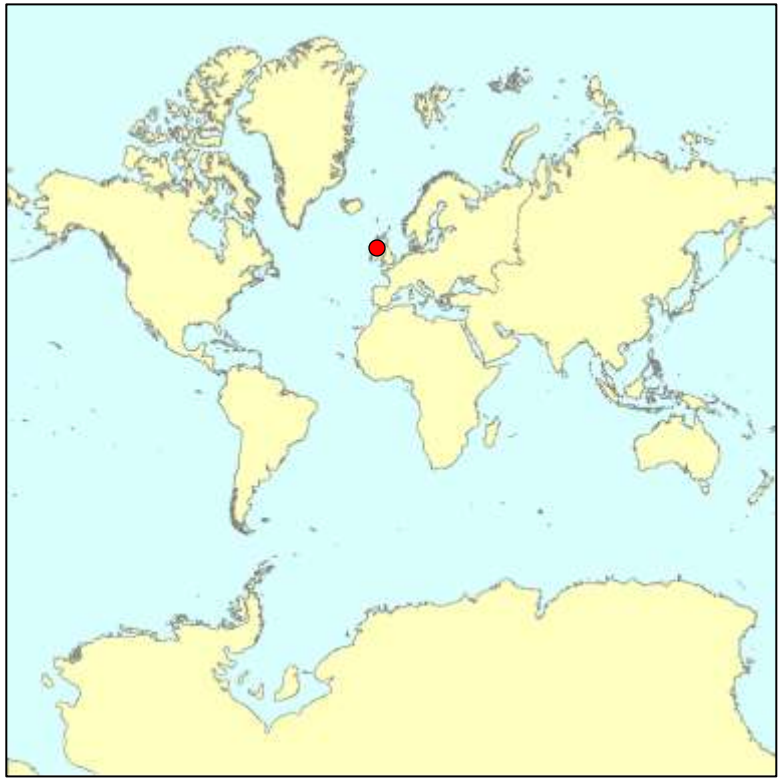
3. Inverse is faster and easier to code

Mercator *v.* web-Mercator

Mercator



web-Mercator



Agenda

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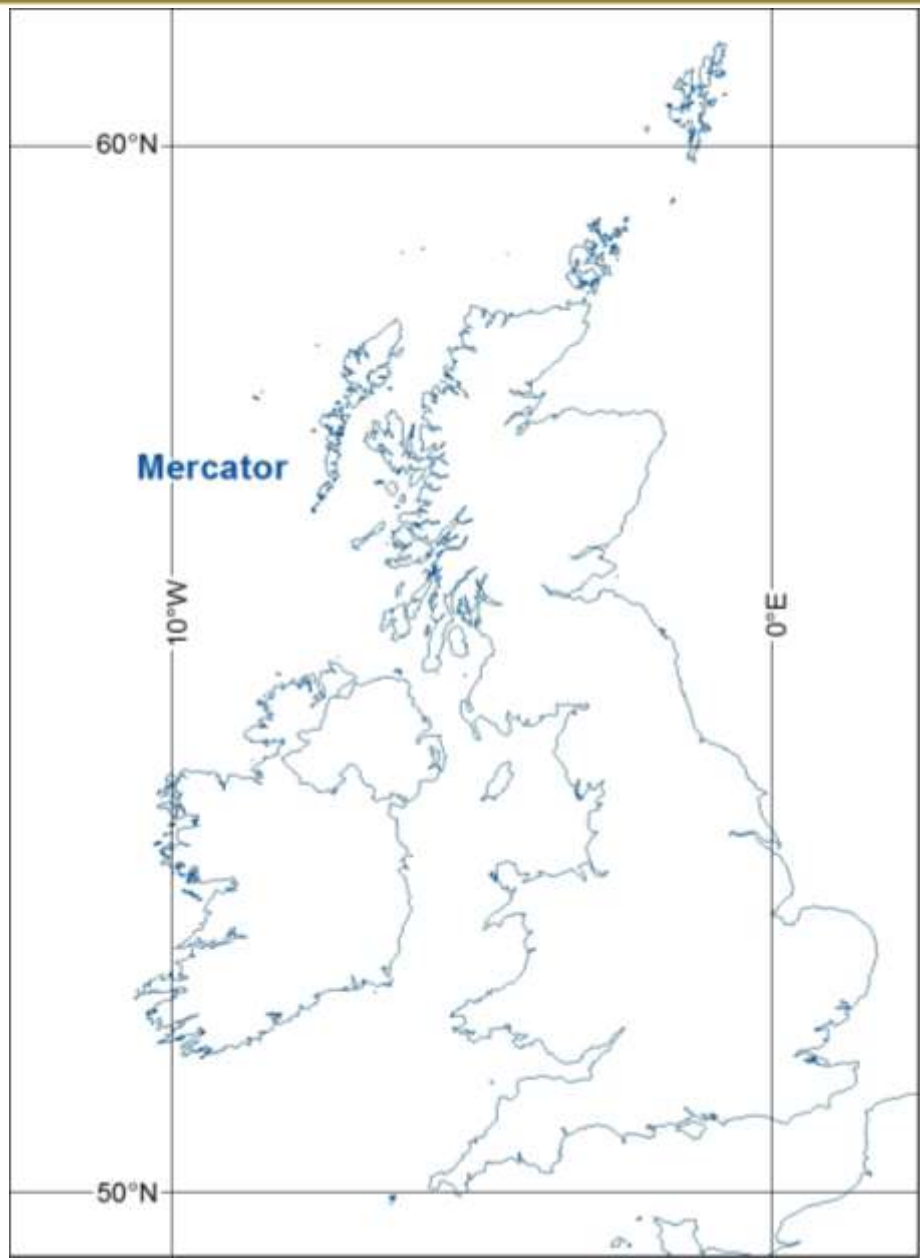
Commonality

- $x = 0$ is the Prime Meridian
- $y = 0$ is the Equator
- The Equator is represented at scale 1:1

Mercator
v.
web-Mercator

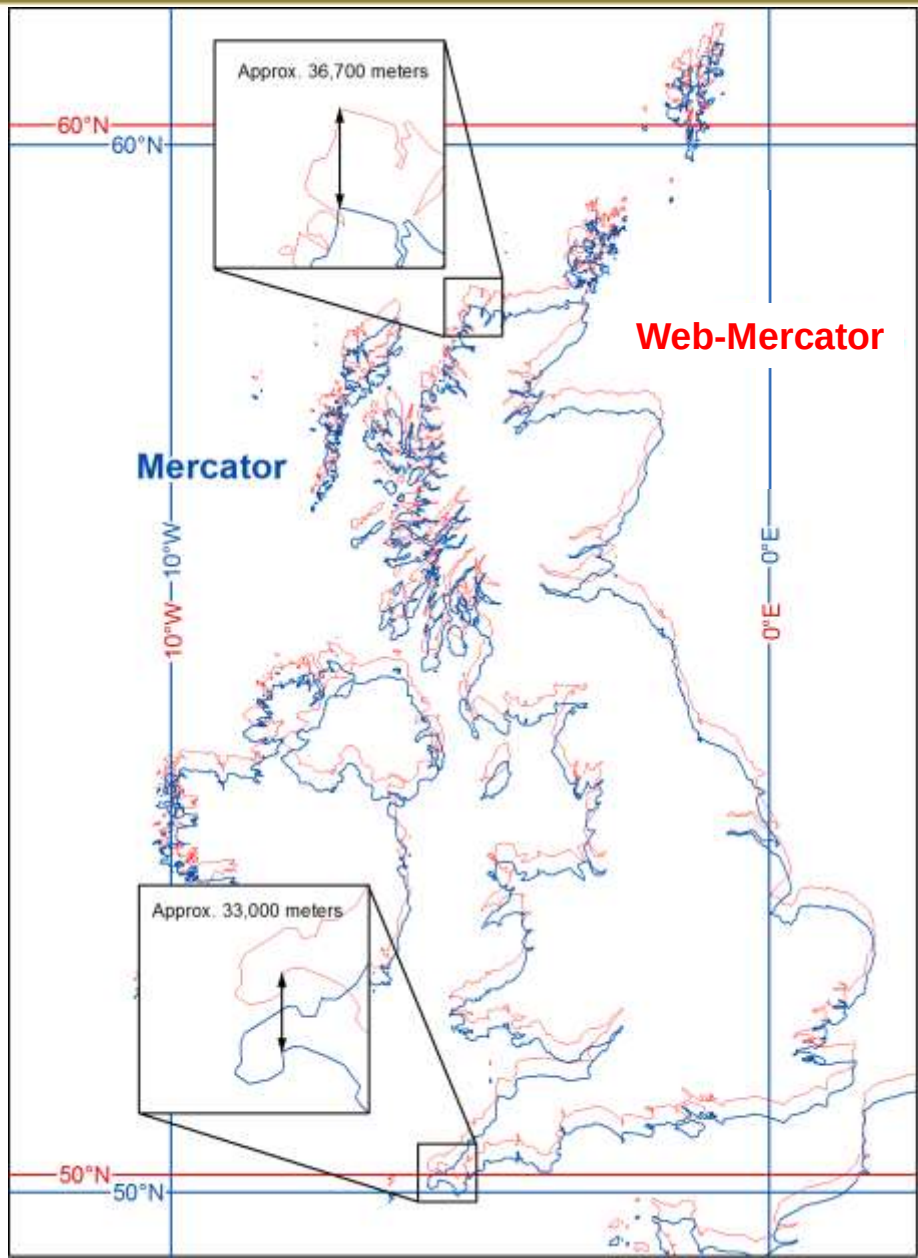


Mercator *v.* web-Mercator

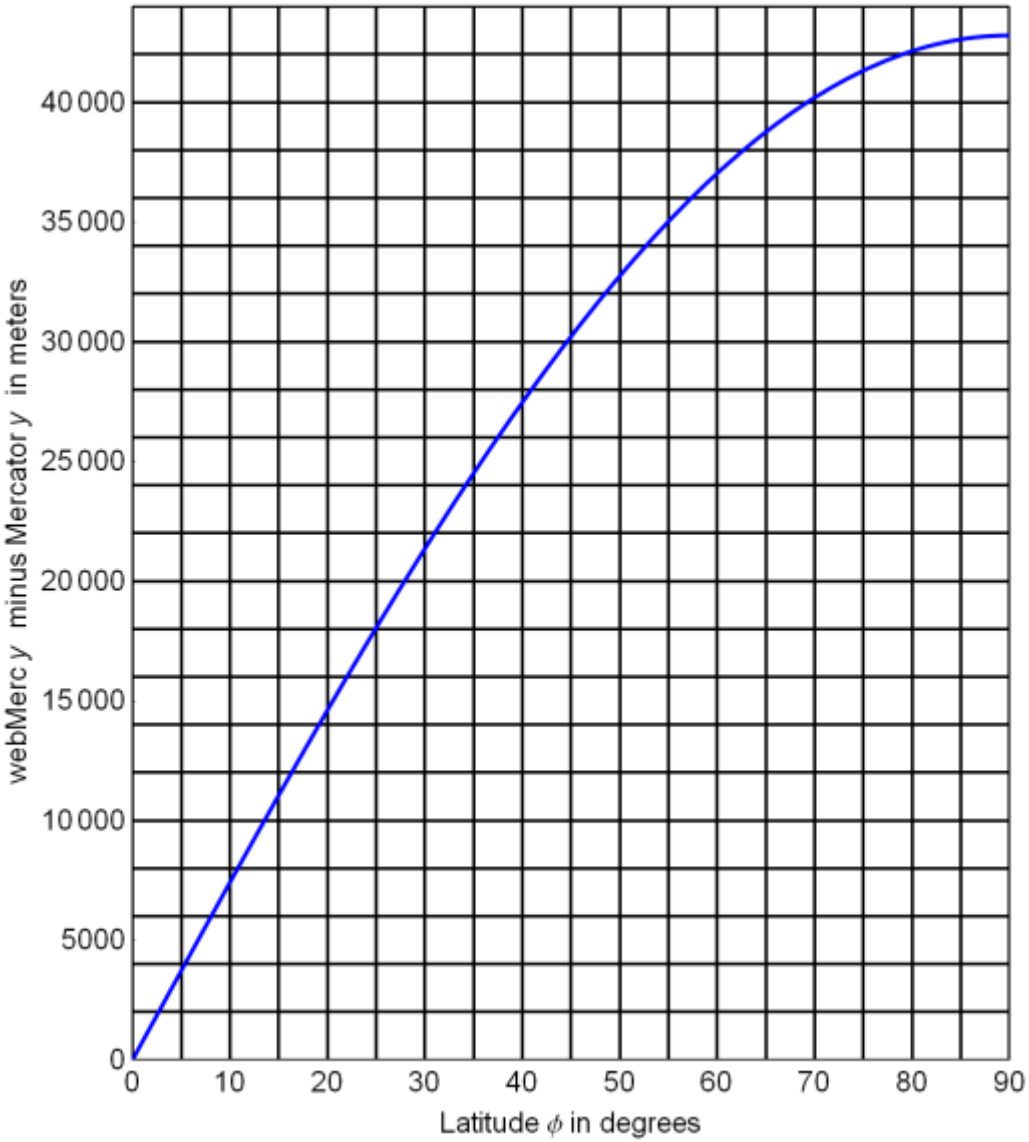
36,700 m at 59°N

Visual illustration of the difference in map-projection

33,000 m at 50°N



Mercator *v.* web-Mercator



Plot of the difference in map-projection

Mercator *v.* web-Mercator

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The formulas for web-Mercator (EPSG::3857) are:

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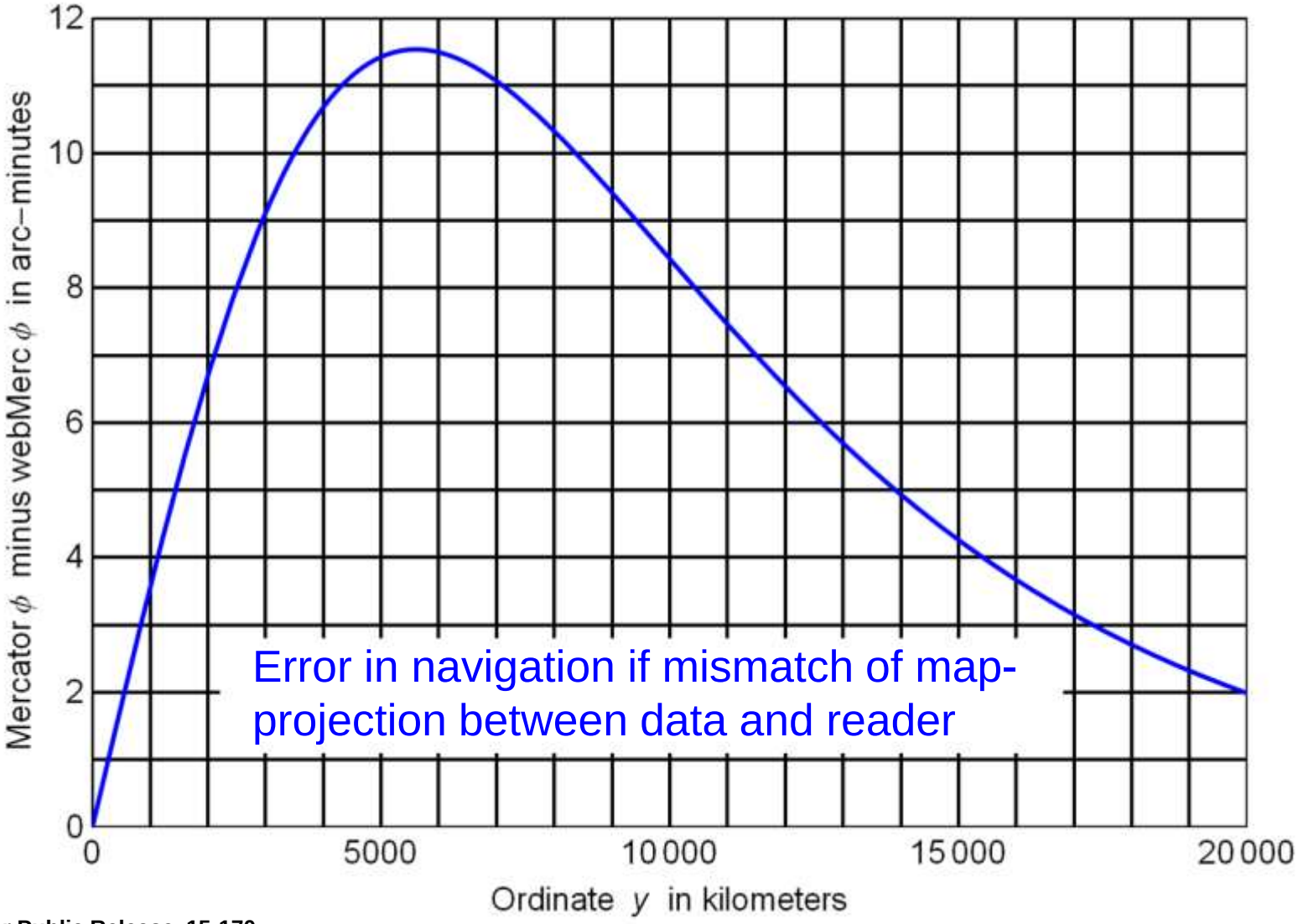
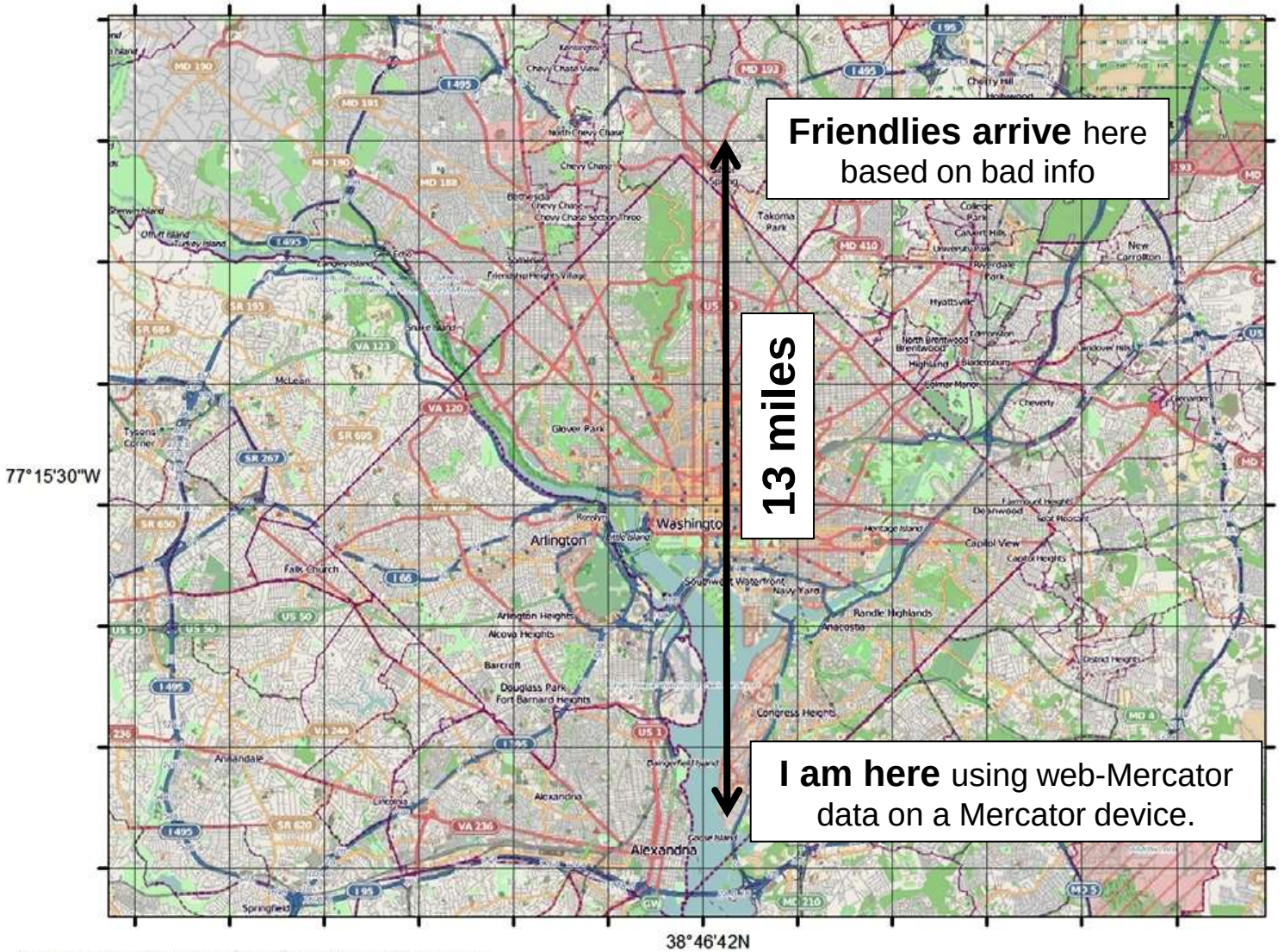
$$y = a\,\text{arctanh}\,(\sin\phi)$$

Mercator *v.* web-Mercator





Navigation Error: 11′ of Lat. (13 mi)

(if data and reader are mismatched)

2′ graticule

Mercator projection

What's wrong with web-Mercator?

1. Conflicts with Mercator, *e.g.* NGA nautical charts
2. Is non-conformal, unlike NGA standard products
3. Contributes no new desirable property
4. Cuts-corners on Mercator implementation

Its defenders say…

1. Almost conformal.
2. Inverse, *i.e*. (x, y) to (Lon., Lat.), is accurate.
3. Inverse is faster and easier to code.
4. No one cares about (x, y) anyway.
5. “Visualization only”.
6. “Industry standard”.

NGA replies …

1. Almost conformal. **Mercator actually is**
2. Inverse, *i.e*. (x, y) to (Lon., Lat.), is accurate. **(True)**
3. Inverse is faster and easier to code. **Devices: more power**
4. No one cares about (x, y) anyway. **Know the future? Pix**
5. “Visualization only”. **Likely not; analysts will use data**
6. “Industry standard”. **DoD, IC are to use WGS 84 ellipsoid**

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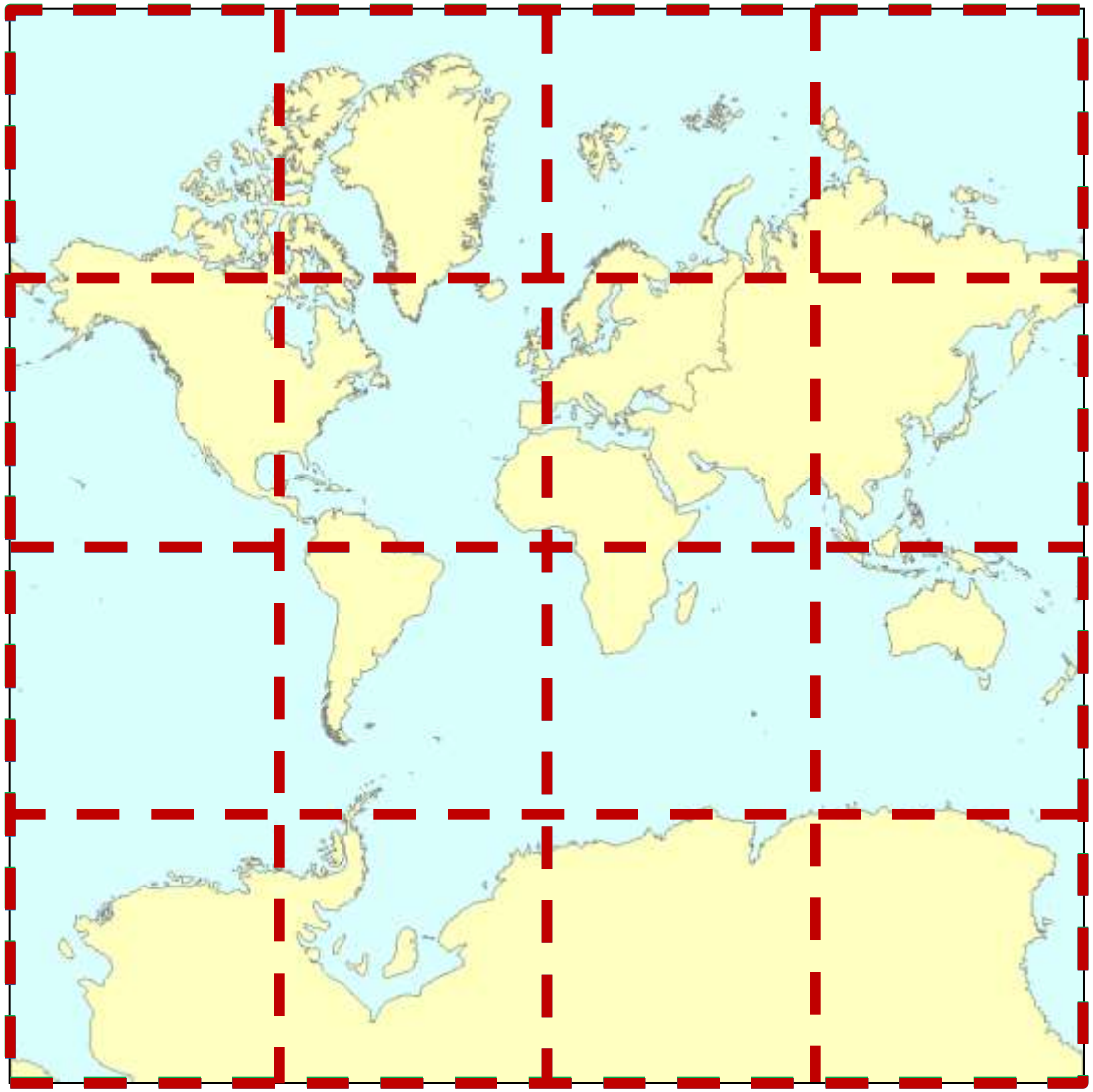
Tiled Mercator

- Zoom level n has:
  - 2^n tiles across
  - 2^n tiles down
- Each tile is 256 x 256 pixels
- Level-0 Tile extent:
  180°W to 180°E (exact), between latitudes:
  ±85.0840590501104°



Level 0
Level 1
Level 2

Summary

1. What is “web-Mercator”?
   – Ellipsoidal Lat./Lon. used with abbreviated (spherical) Mercator formula

2. Why was it invented?
   – Better than Plate Carrée; simpler than true (ellipsoidal) Mercator;

3. Why is it wrong for DoD and IC?
   – Conflicts with Mercator; impedes interoperability; duplicates IT effort

4. What does NGA recommend instead?
   – Mercator; projections like NGA standard products; Tiled Mercator

Questions?

NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY

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Other topics

5. **Sphere**
6. WGS 84 compliance
7. Nautical charting
8. Non-conformality of web-Mercator
9. Web-Mercator x, y is never used ?
10. NGA's guidance for tiled raster graphics

Mercator *v.* web-Mercator

The formulas for Mercator (EPSG::3395) are:

$$x = a\,\lambda$$

$$y = a\,\operatorname{arctanh}(\sin\phi) - a\,e\,\operatorname{arctanh}(e\,\sin\phi)$$

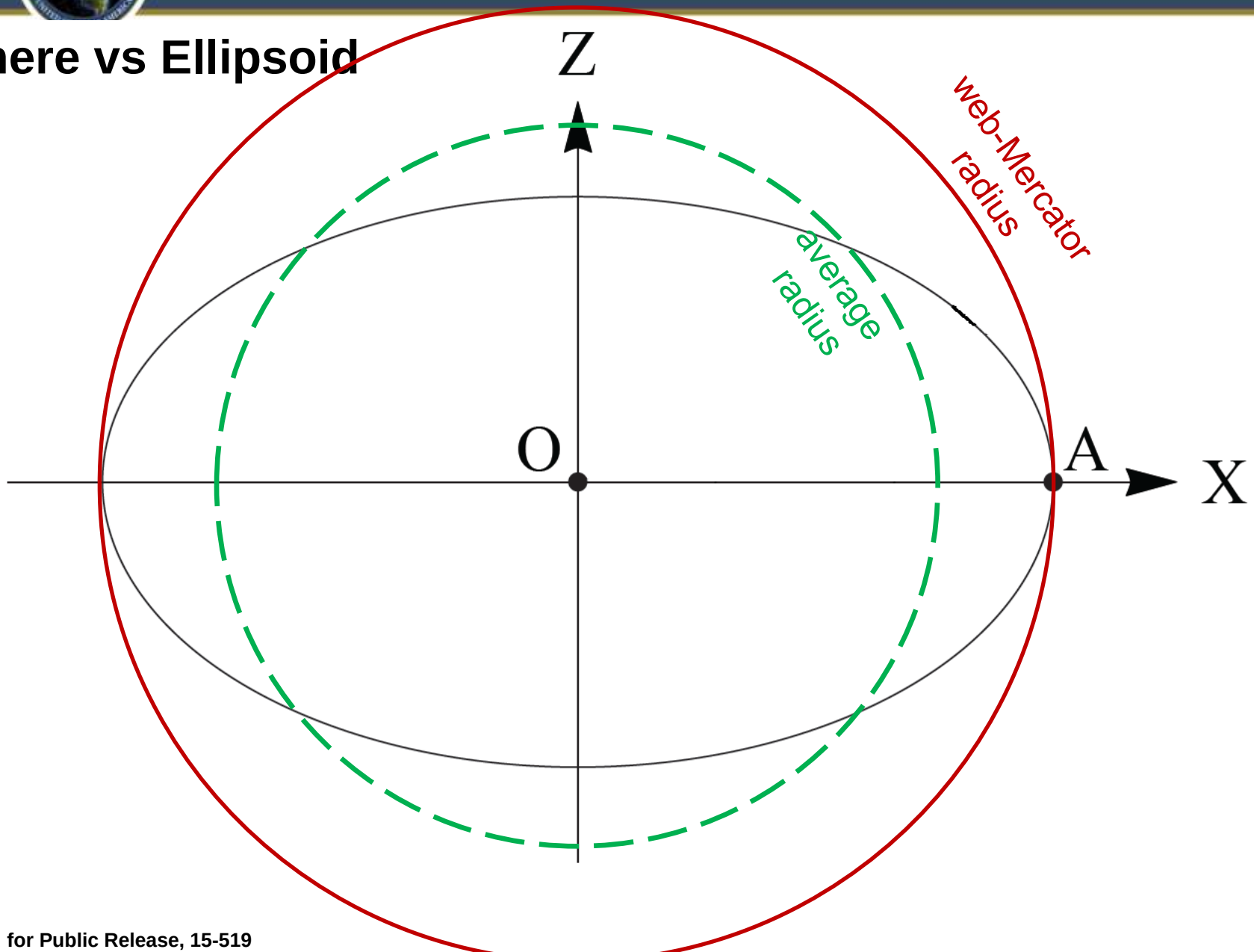
The formulas for web-Mercator (EPSG::3857) are:

$$x = a\,\lambda$$

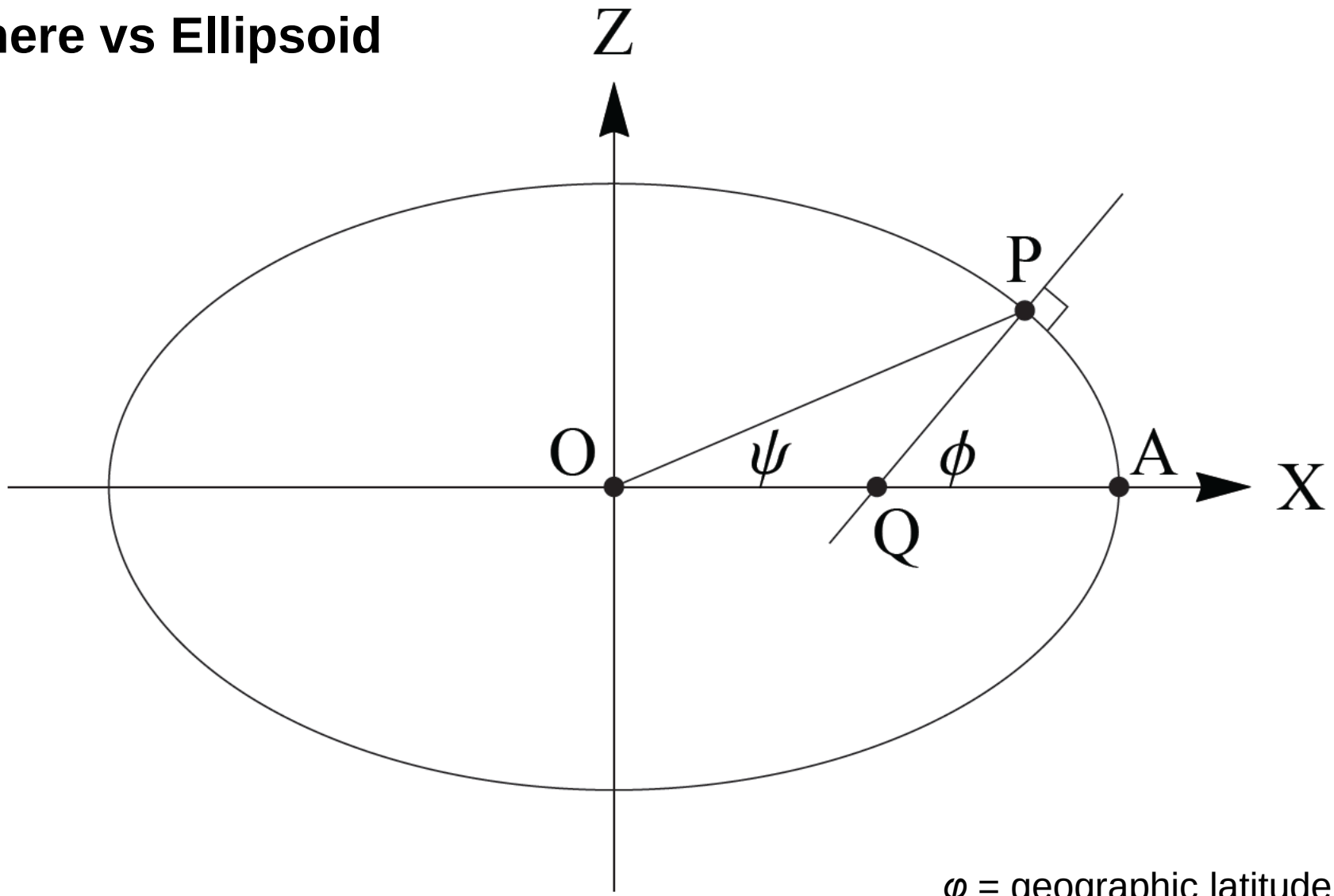
$$y = a\,\operatorname{arctanh}(\sin\phi)$$

Note that $e = 0$ gives a sphere of radius a.

Sphere vs Ellipsoid

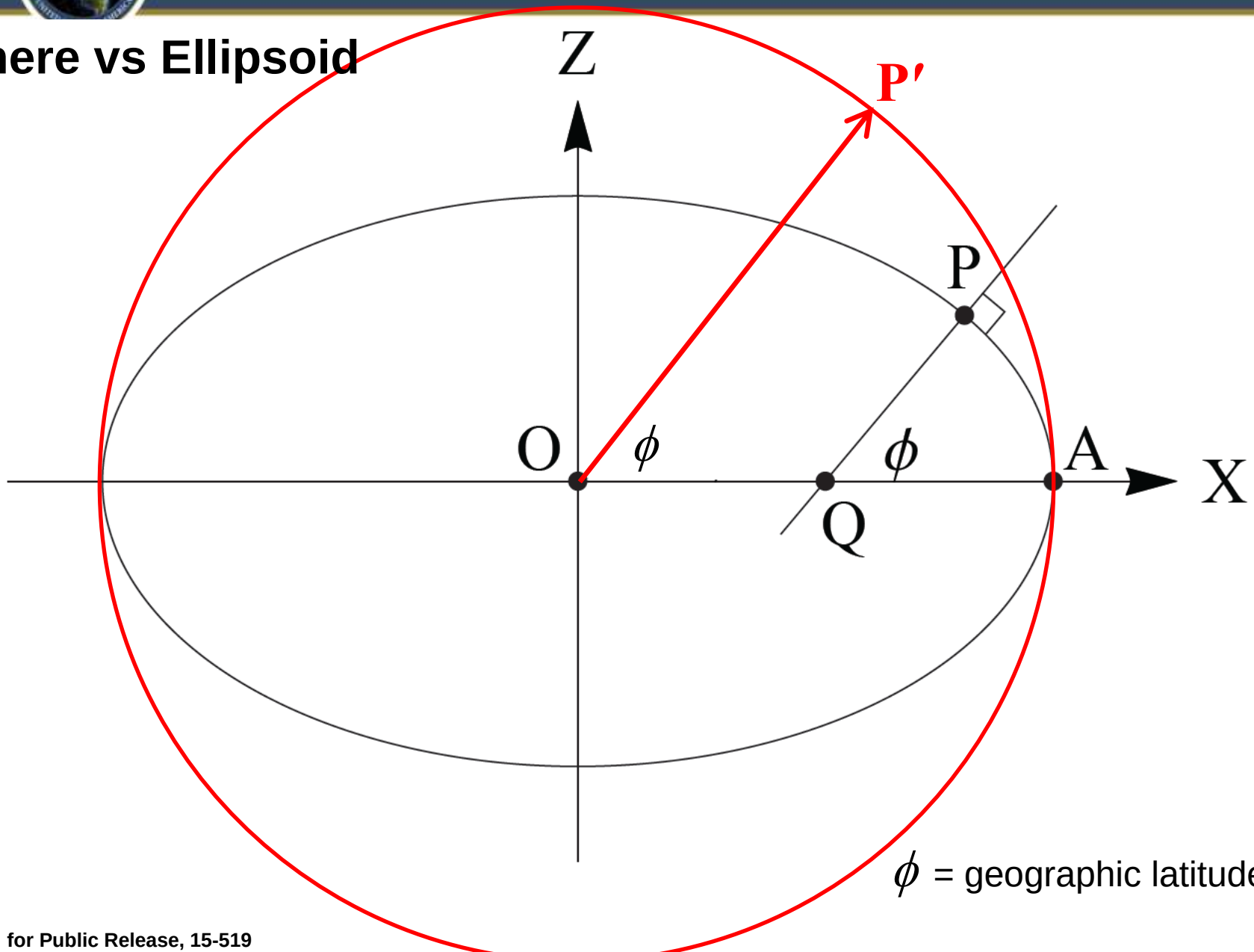


Sphere vs Ellipsoid



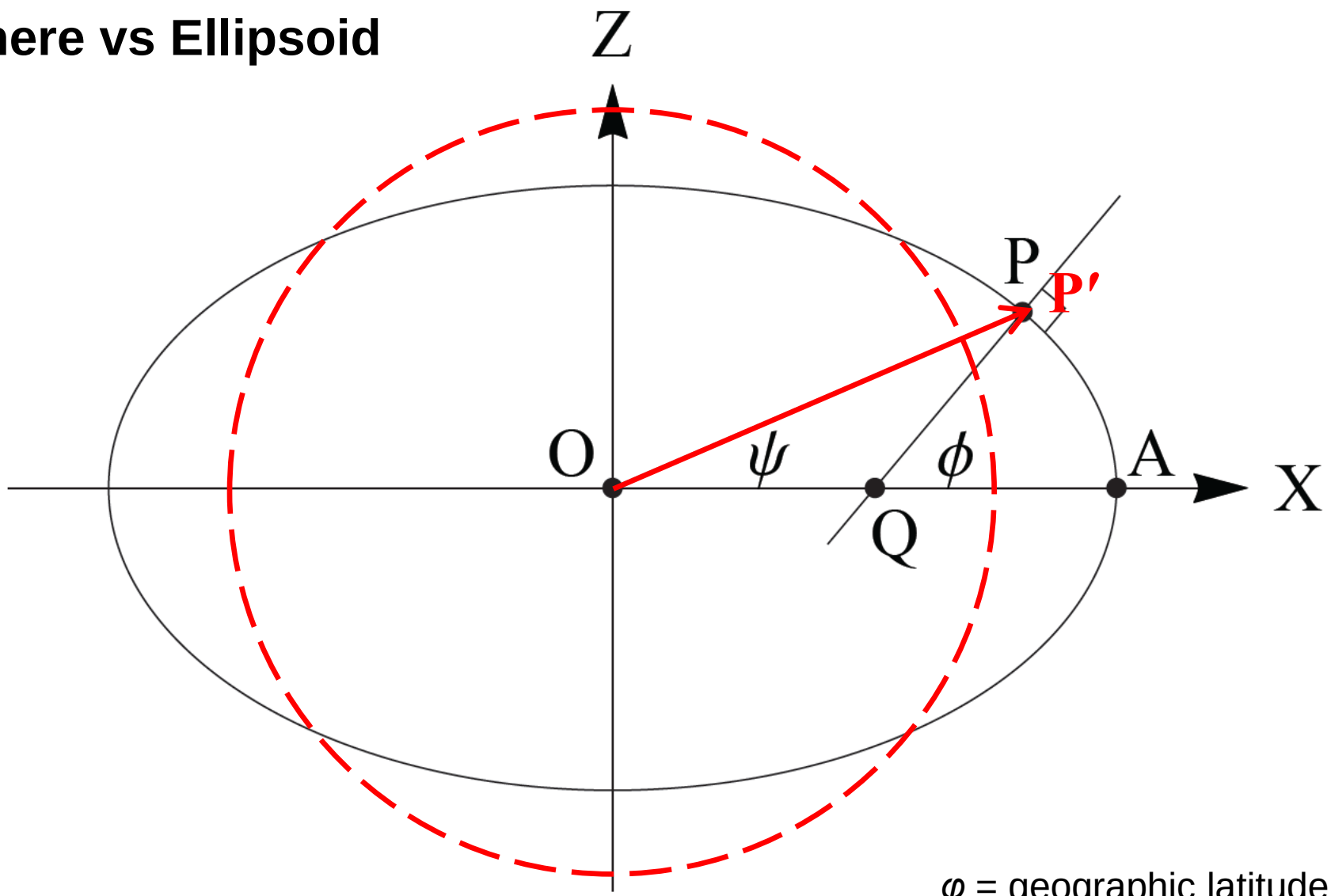
φ = geographic latitude
ψ = geocentric latitude

Sphere vs Ellipsoid



ϕ = geographic latitude

Sphere vs Ellipsoid



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Other topics

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Datum & ellipsoid

Datum	Ellipsoid
(historic):	
NAD 27	Clarke 1866
Luzon	Clarke 1866
European 1950	International 1924
Hong Kong 1963	International 1924
(modern):	
NAD 83	GRS 80
WGS 84	WGS 84

Web-Mercator confuses things:

- Datum's ellipsoid ≠ map-projection's ellipsoid

- Conundrum:
  - Spherical Mercator is conformal
  - web-Mercator is spherical Mercator (?)
  - web-Mercator is **NOT** conformal

- Map-projection ***procedure*** ≠ map-projection ***properties***

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Nautical charts

Chart type	Mercator	Other	TOTAL
Harbor	3856	825	4681
Approach	1218	108	1326
Coastal	2567	327	2894
Bottom Contour	505	22	527
Bathymetric Nav. Planning	586	30	616
TOTAL	8732	1312	10044

- Source: Production Management Alternate Architecture (PMAA, 4/23/2015)
- PMAA combines Harbor/Approach. Here, harbor charts are 1:50,000 or larger
- "Other": transverse Mercator, gnomonic, polyconic, polar stereographic, other
- **BUT there are no instances of web-Mercator ("pseudo-Mercator")**

GeoPackage Technical Meeting

Putting Digital Nautical Charts and other data in mobile customer's hands

NGA Maritime Safety Office

DNC Mobile Apps

7 April 2015

Other topics

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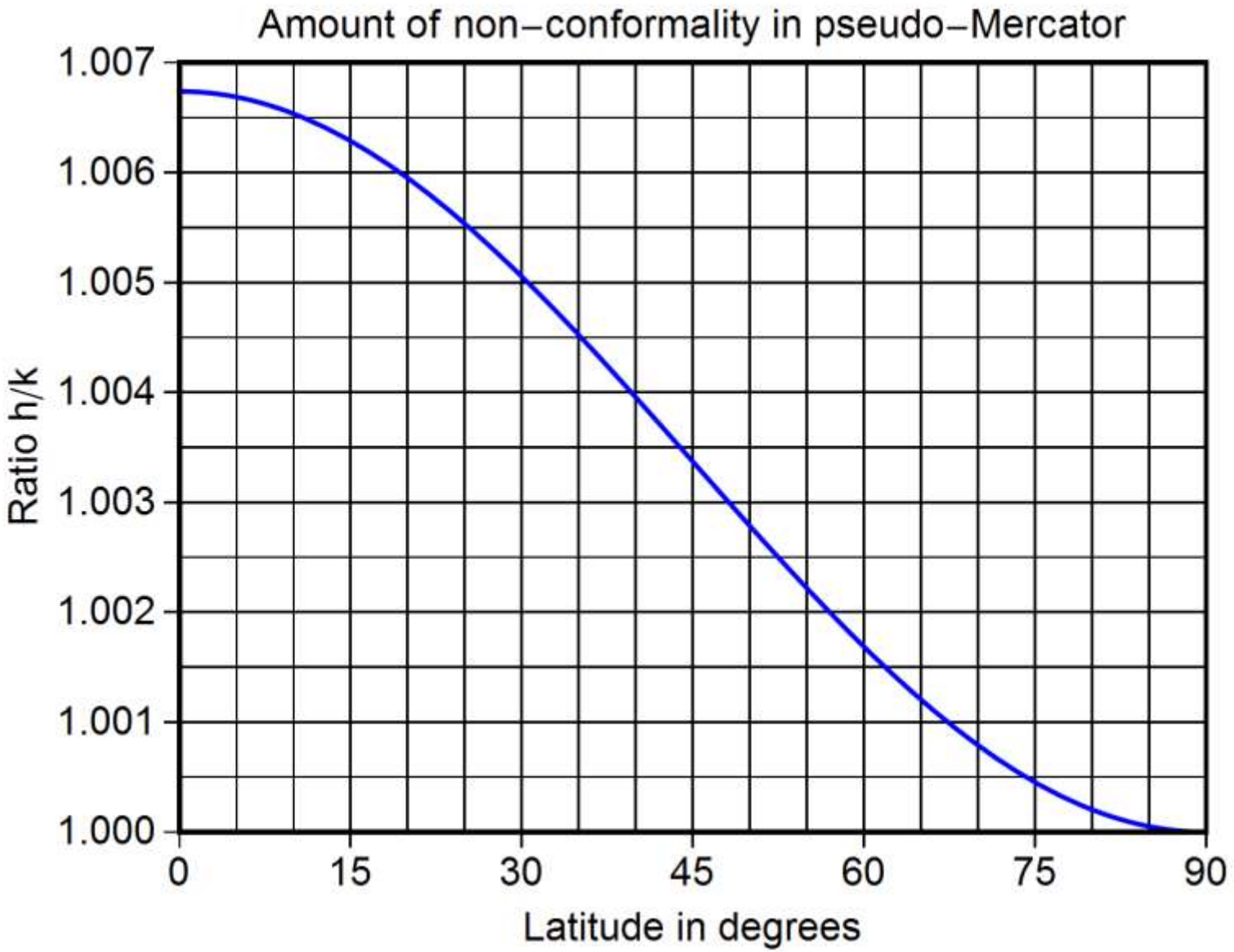

Meters/pixel at latitude 2 deg

n	Mercator E-W Mercator N-S web-Mercator E-W	web-Mercator N-S
0	156448.30995015	155402.25260025
2	39112.07748754	38850.56315006
4	9778.01937188	9712.64078752
6	2444.50484297	2428.16019688
8	611.12621074	607.04004922
10	152.78155269	151.76001230
12	38.19538817	37.94000308
14	9.54884704	9.48500077
16	2.38721176	2.37125019
18	0.59680294	0.59281255
20	0.14920074	0.14820314
22	0.03730018	0.03705078
24	0.00932505	0.00926270

1 km scale bars at latitude 2 deg for web-Mercator

zoom level	E-W bar pixels	N-S bar pixels	Scale
13	52	53	1:68000
14	105	105	1:34000
15	209	211	1:17000
16	419	422	1:8500
17	838	843	1:4200
18	1676	1687	1:2100
19	3351	3374	1:1100
20	6702	6747	1:530

(Scale is calculated using 0.28 mm as the device pixel size)

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9. **Web-Mercator x, y is never used ?**
10. NGA's guidance for tiled raster graphics

Web-Mercator x, y is never used ?

The user-specified footprint corresponding to Figure 1 is hard-coded in this example with Web Mercator coordinates specified in meters and using the Well-Known Text (WKT) format.

```
# Footprint specified in WKT with web Mercator
# coordinates
fp_webmerc = "POLYGON((-9152998.67 4312042.45,
  -8866818.44 4319380.41,-8866818.44 4099241.77,
  -9143214.73 4101687.75,-9152998.67 4312042.45))"
# Input GIS data
layer="power_plant_platts_existing"
```

A database connection is then established, and a cursor is created.

Kuiper, James A., Andrew J. Ayers, Michael E. Holm, and Michael J. Nowak. "Python Coding of Geospatial Processing in Web-based Mapping Applications." *PROC. OF THE 13th PYTHON IN SCIENCE CONF* : 40-46. *SCIPY 2014*. Web.

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10. **NGA's guidance for tiled raster graphics**

Army Program: Raster Graphics for Mobile/Hand-Held Devices

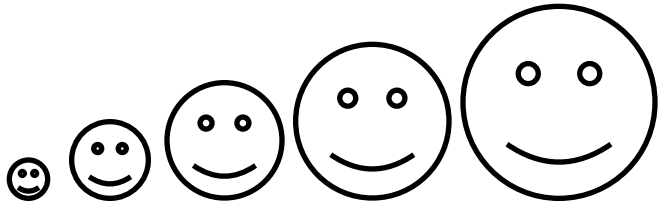
- GeoPackage
- Allowed map-projections:
  - Tiled Mercator
  - Tiled Transverse Mercator
  - Tiled Polar Stereographic
- Actual meters/pixel depends on …
  - Common tile pyramid
  - Map-projection scale parameters
  - Zoom-level
  - Location on Earth

Zoom Level	Meters/pixel
0	134217.728
1	67108.864
2	33554.432
3	16777.216
4	8388.608
5	4194.304
6	2097.152
7	1048.576
8	524.288
9	262.144
10	131.072
11	65.536
12	32.768
13	16.384
14	8.192
15	4.096
16	2.048
17	1.024
18	0.512
19	0.256
20	0.128
21	0.064
22	0.032
23	0.016
24	0.008

$$\frac{Millimeters}{Pixel} = 2^{(27-zoom\ level)}$$

What's the Difference?

- Scale!

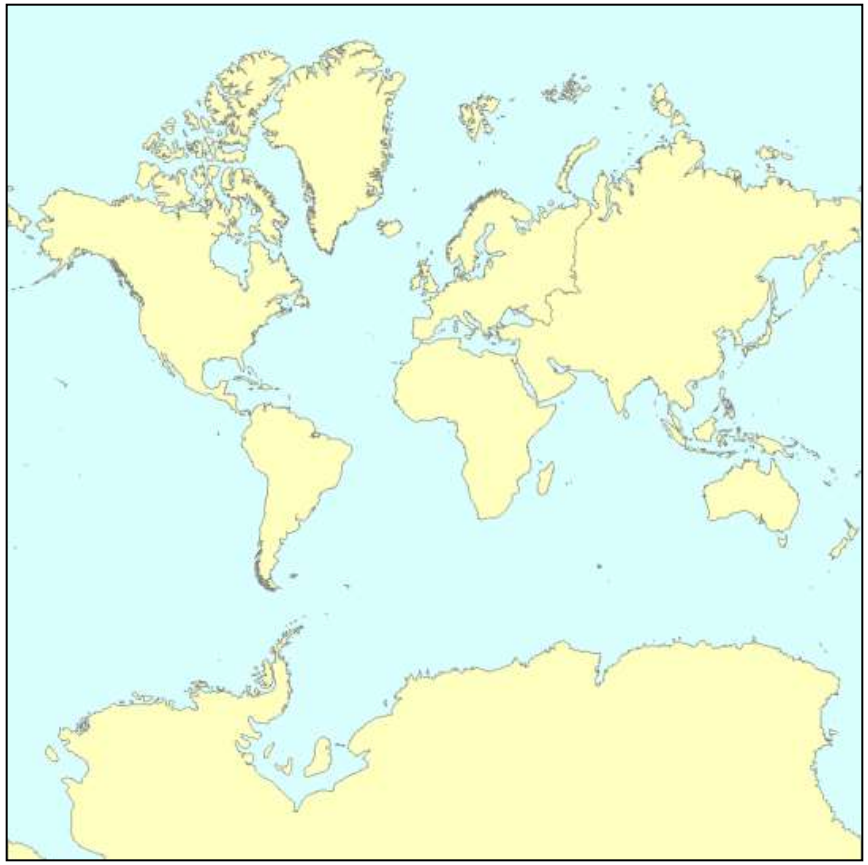


	World Mercator	Transverse Mercator	Polar Stereographic
Customary Projections	1.0	0.9996	0.994
Tiled Projections	0.857385503731176	0.85882463752355	0.9286474122935

Zoom Level	Meters/pixel
0	134217.728
1	67108.864
2	33554.432
…	…
22	0.032
23	0.016
24	0.008

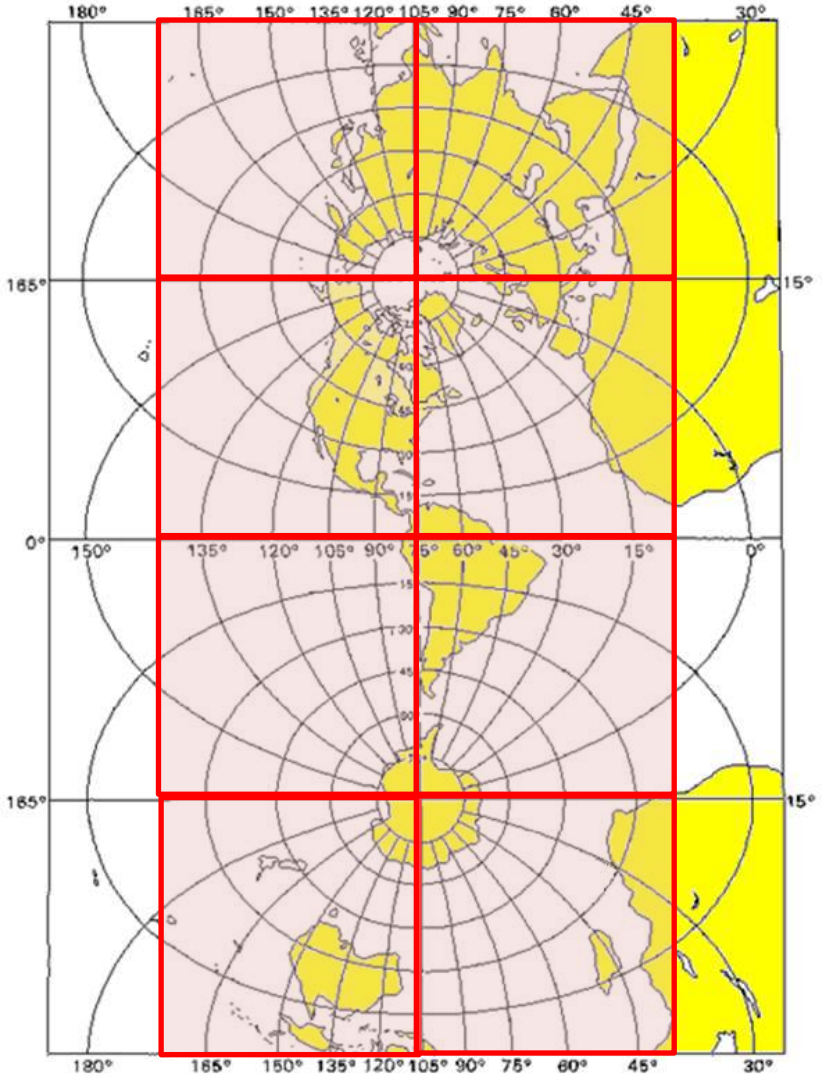
Tiled Mercator

- Used in nautical products
- Latitude of true scale is: **±31.0606963703645°**.
- Scale reduction factor at the Equator is **0.857385503731176**.
- Level-0 tile is 180°W to 180°E (exactly) and between latitudes: **±85.0840590501104°**.



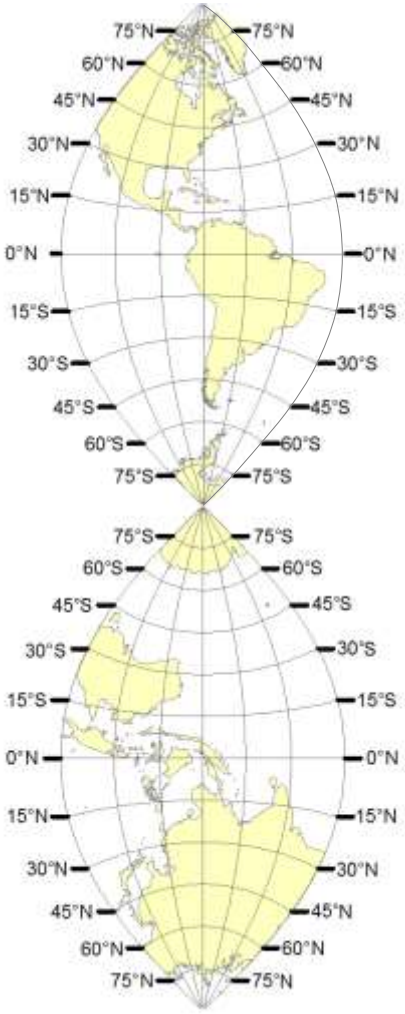
Tiled Transverse Mercator

- Used in topographic products
- Scale reduction factor at the Central Meridian (CM) is **0.85882463752355**.
- Longitude-at-the-Equator of true scale is **±30.700524332812°** from the CM.
- The vertical extent is the entire central and anti-central meridians.

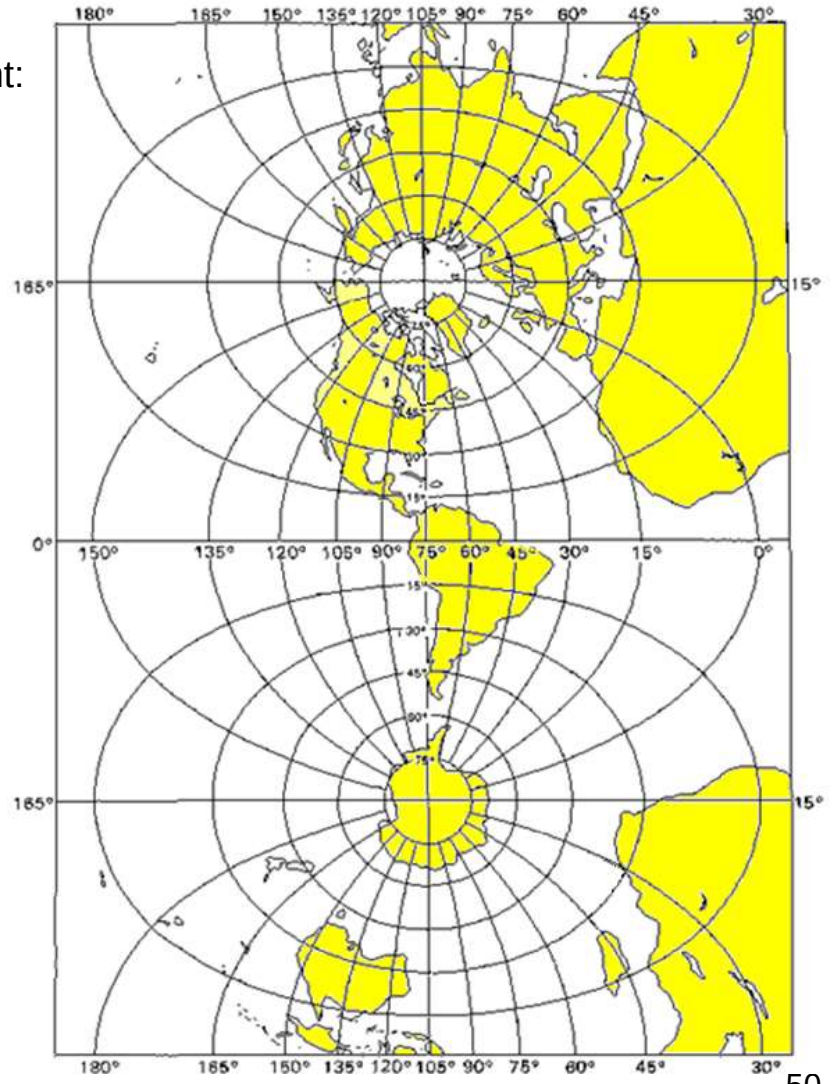


Transverse Mercator in ArcGIS

What we have:

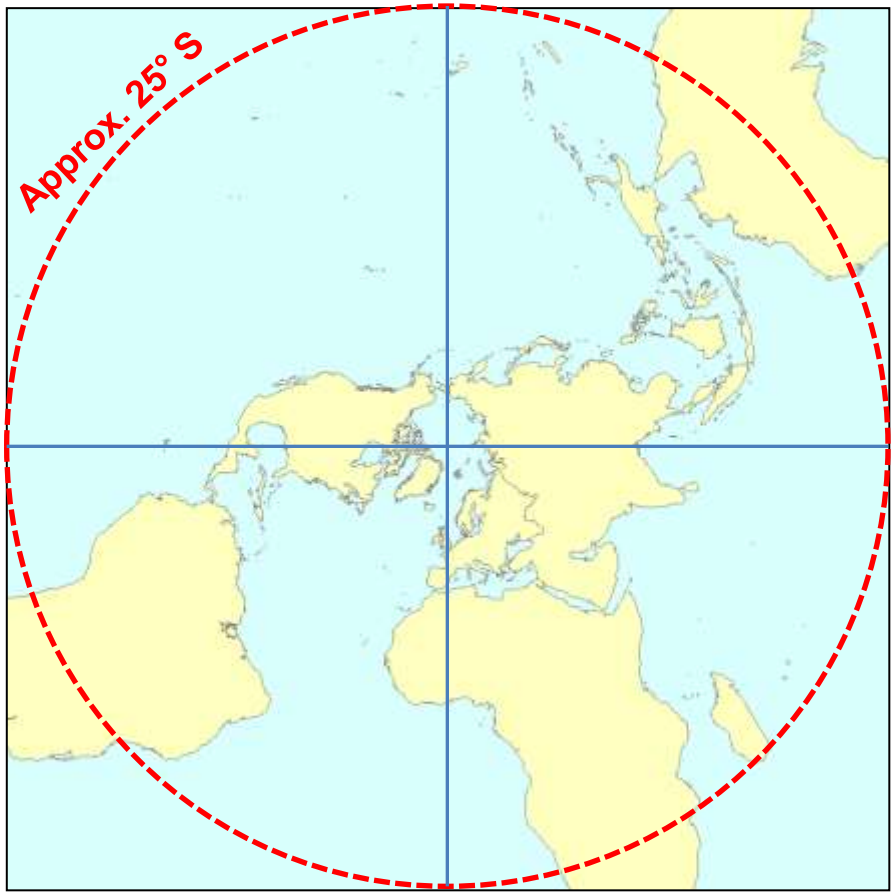


What we want:

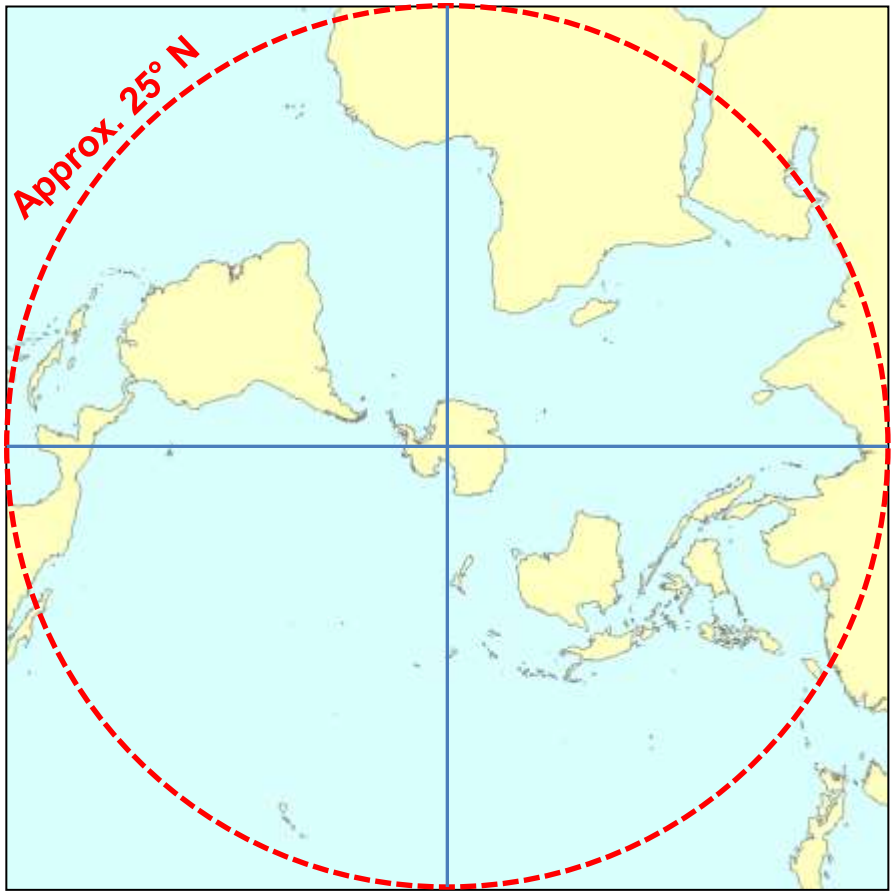


Tiled Polar Stereographic

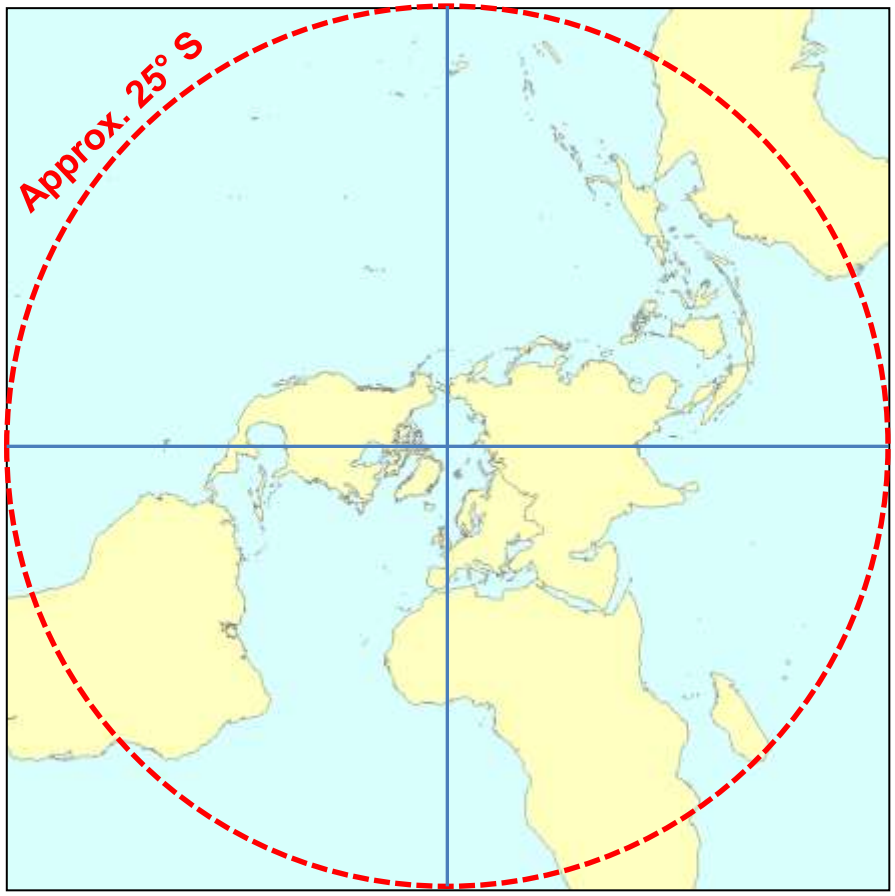
- Used in products near the pole
- Scale factor at the latitude of true scale is **0.9286474122935**.
- Latitude of true scale is exactly **59°N or 59°S**.
- North and South have separate tiles.



Tiled Polar Stereographic



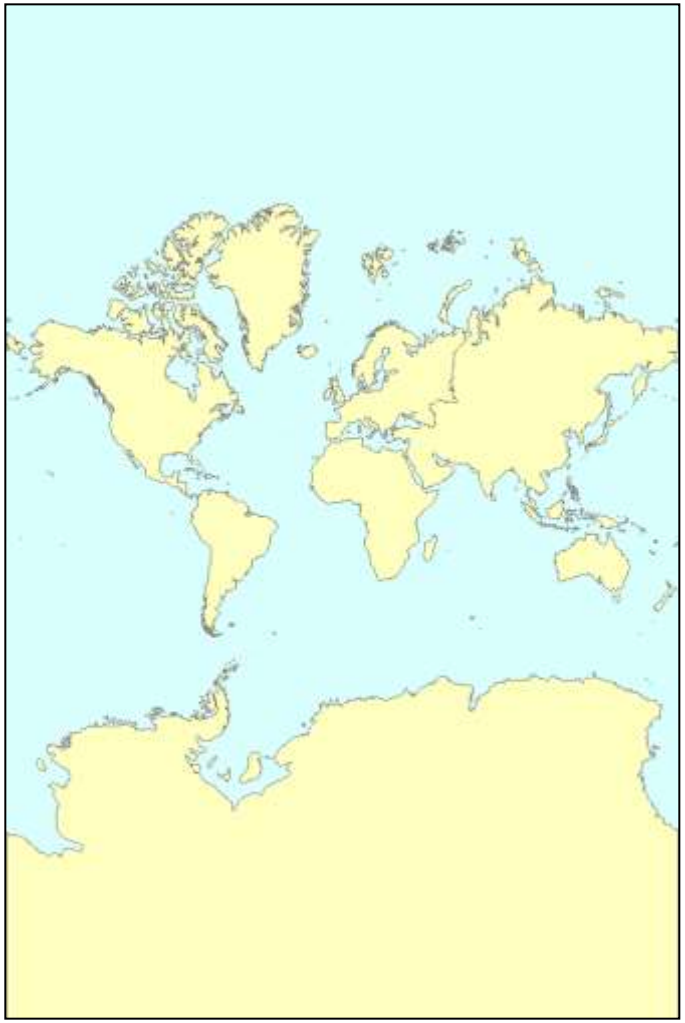
South



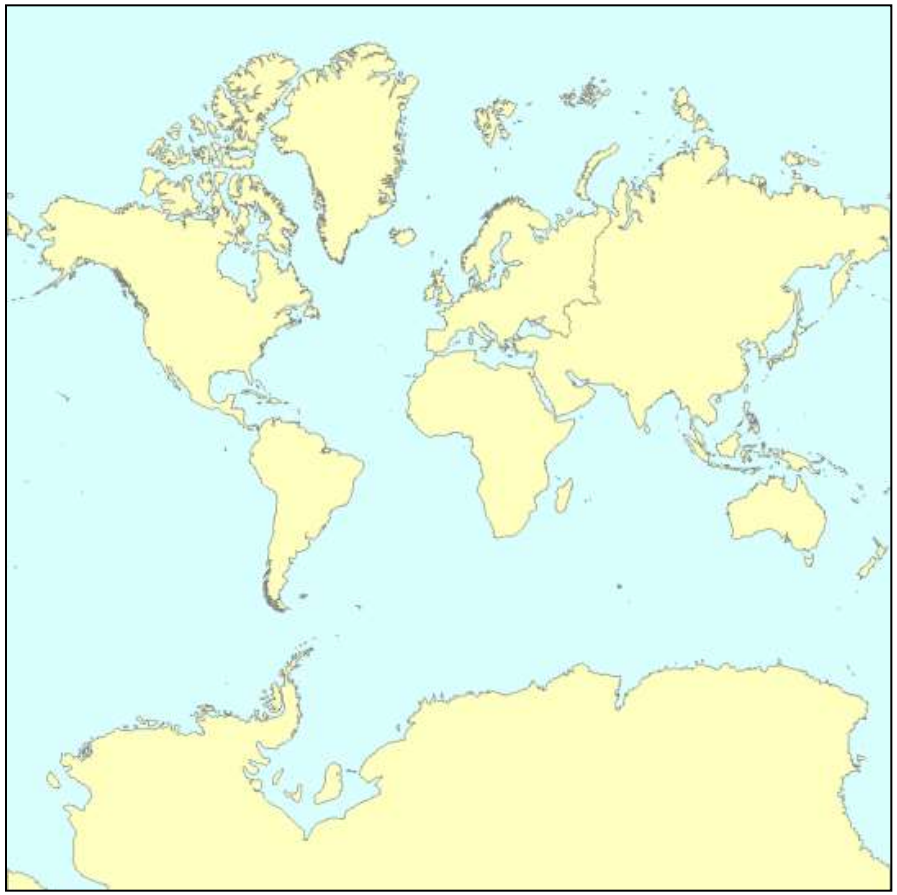
North

How to Display Tiled Mercator in ArcGIS

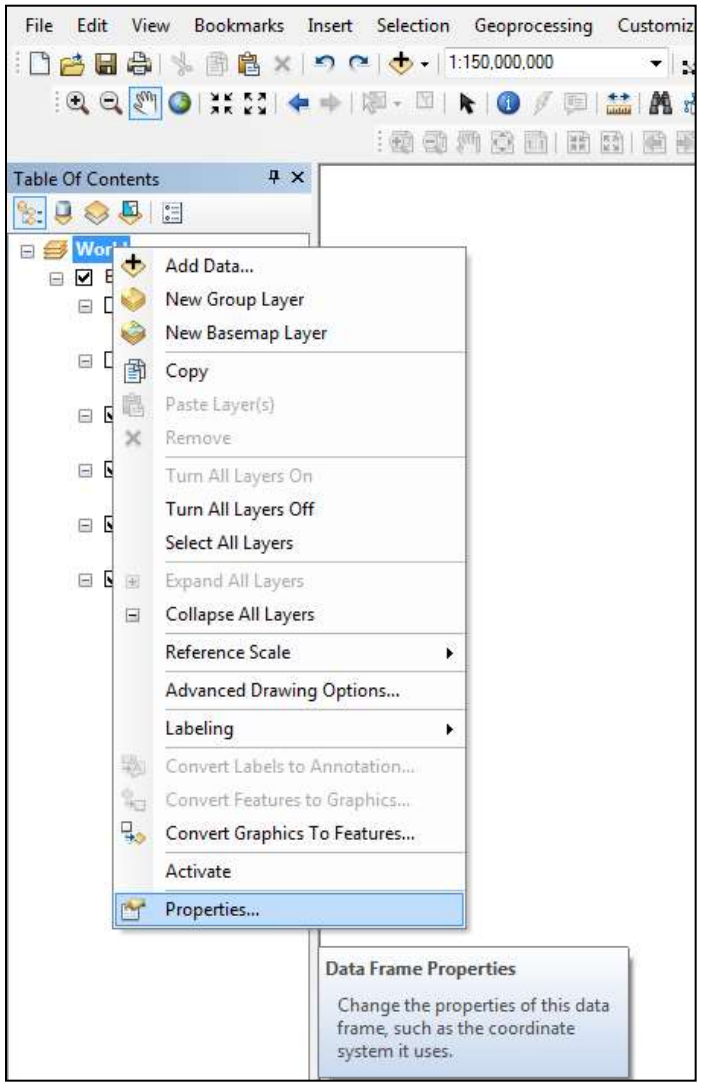
What we have:

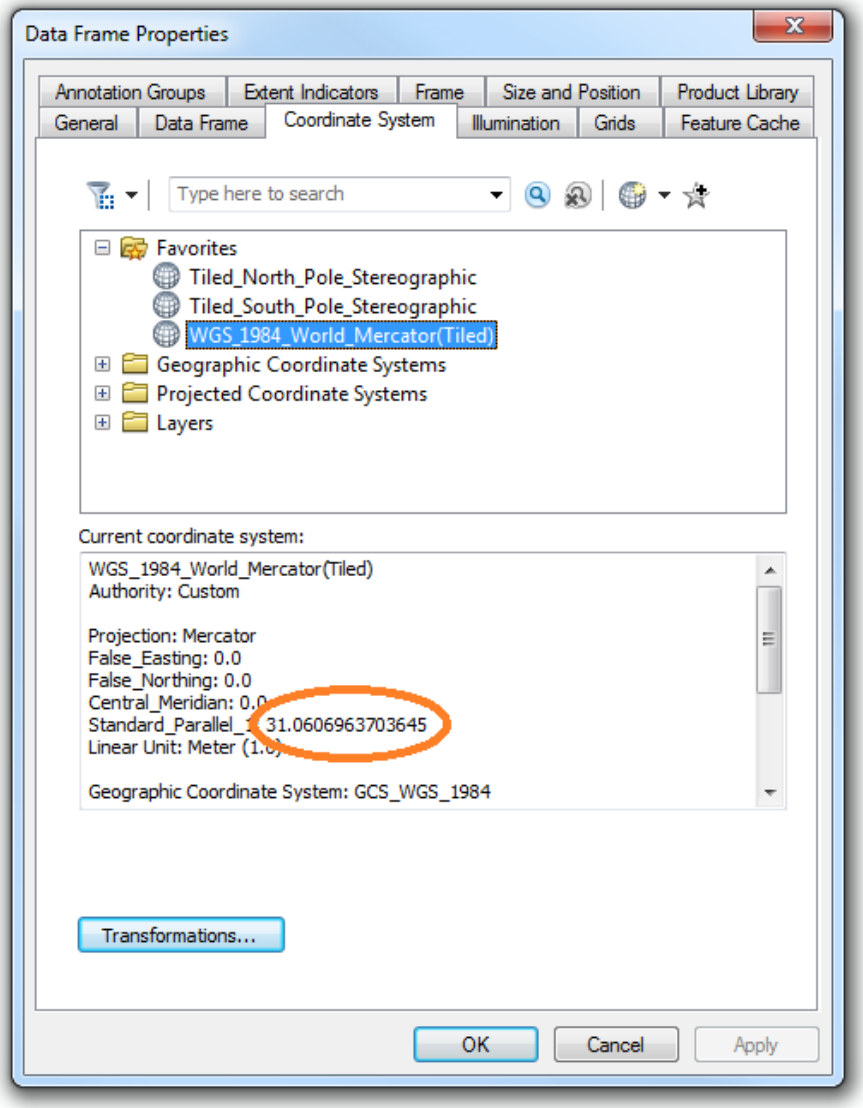


What we want:

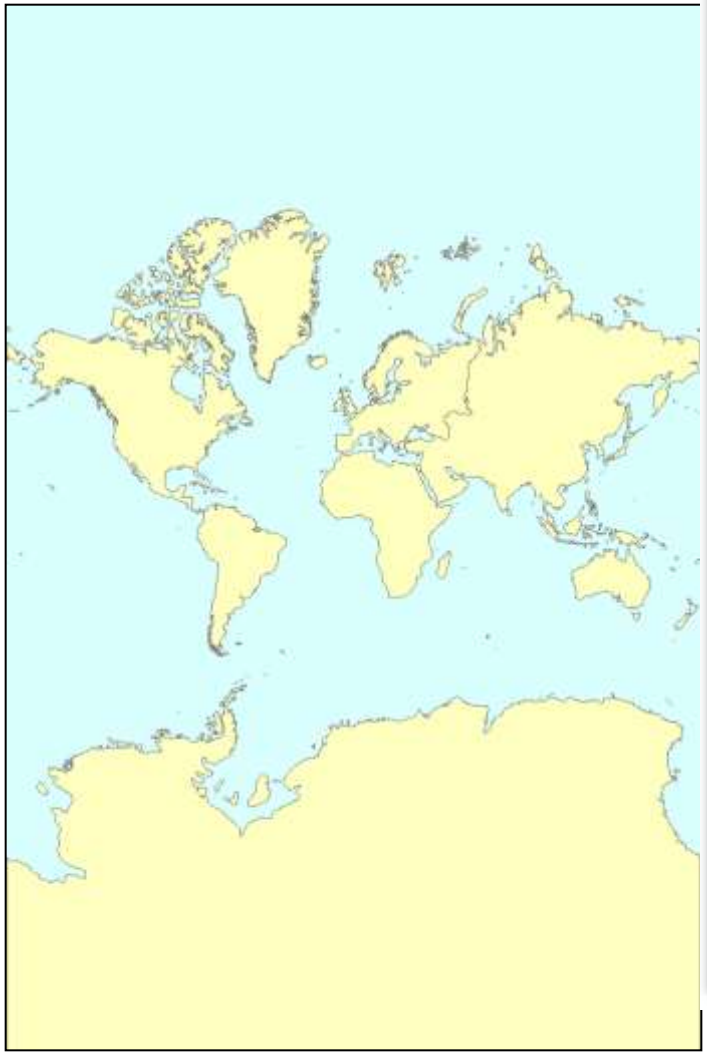


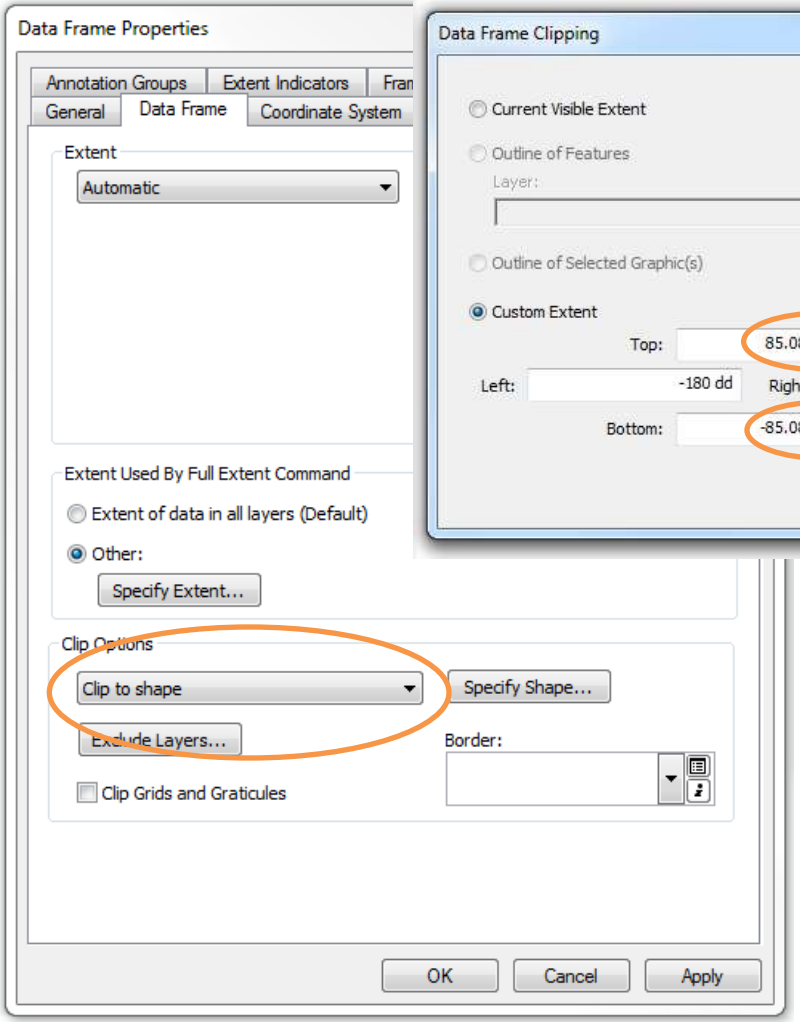
Adjust the Scale



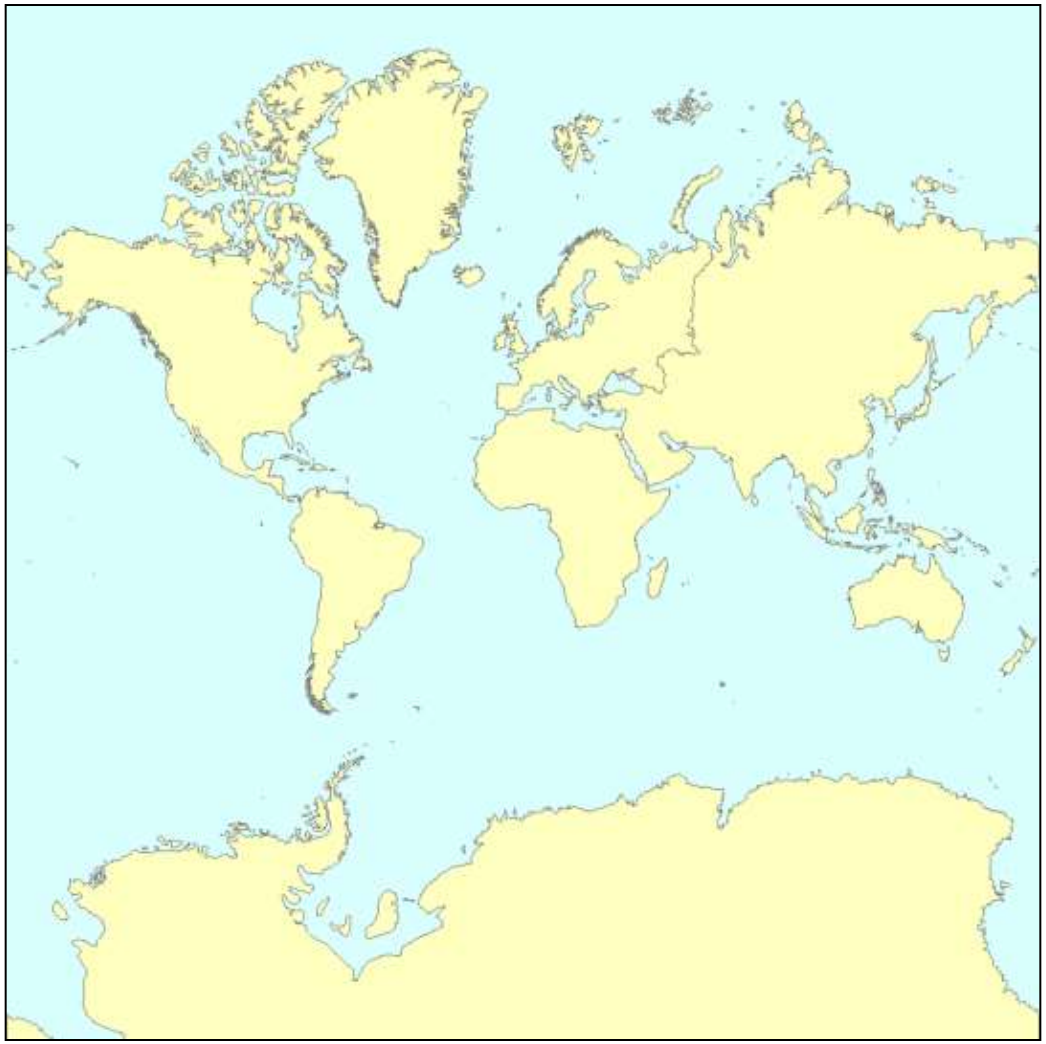


Clip into a Square





The New Projections in ArcGIS

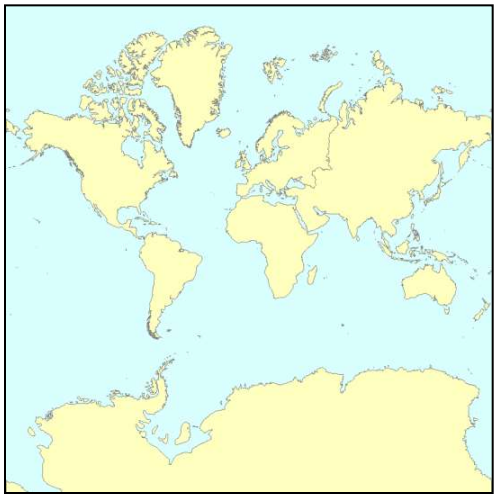


Tiled Mercator!

Summary

- No more web-Mercator!
- Replacements are conformal, and thus suitable for navigation and targeting
- The replacements are:

Tiled Mercator



Tiled Transverse Mercator

Tiled Polar Stereographic (North and South)

Additional Slides

Mercator *v.* web-Mercator

The formulas for Mercator (EPSG::3395) are:

$$x = a\,\lambda$$

$$y = a \ln\left(\tan\left(\frac{\pi}{4} + \frac{\phi}{2} \right) \left(\frac{1 - e\sin\phi}{1 + e\sin\phi} \right)^{e/2} \right)$$

The formulas for web-Mercator (EPSG::3857) are:

$$x = a\,\lambda$$

$$y = a \ln\left(\tan\left(\frac{\pi}{4} + \frac{\phi}{2} \right) \right)$$

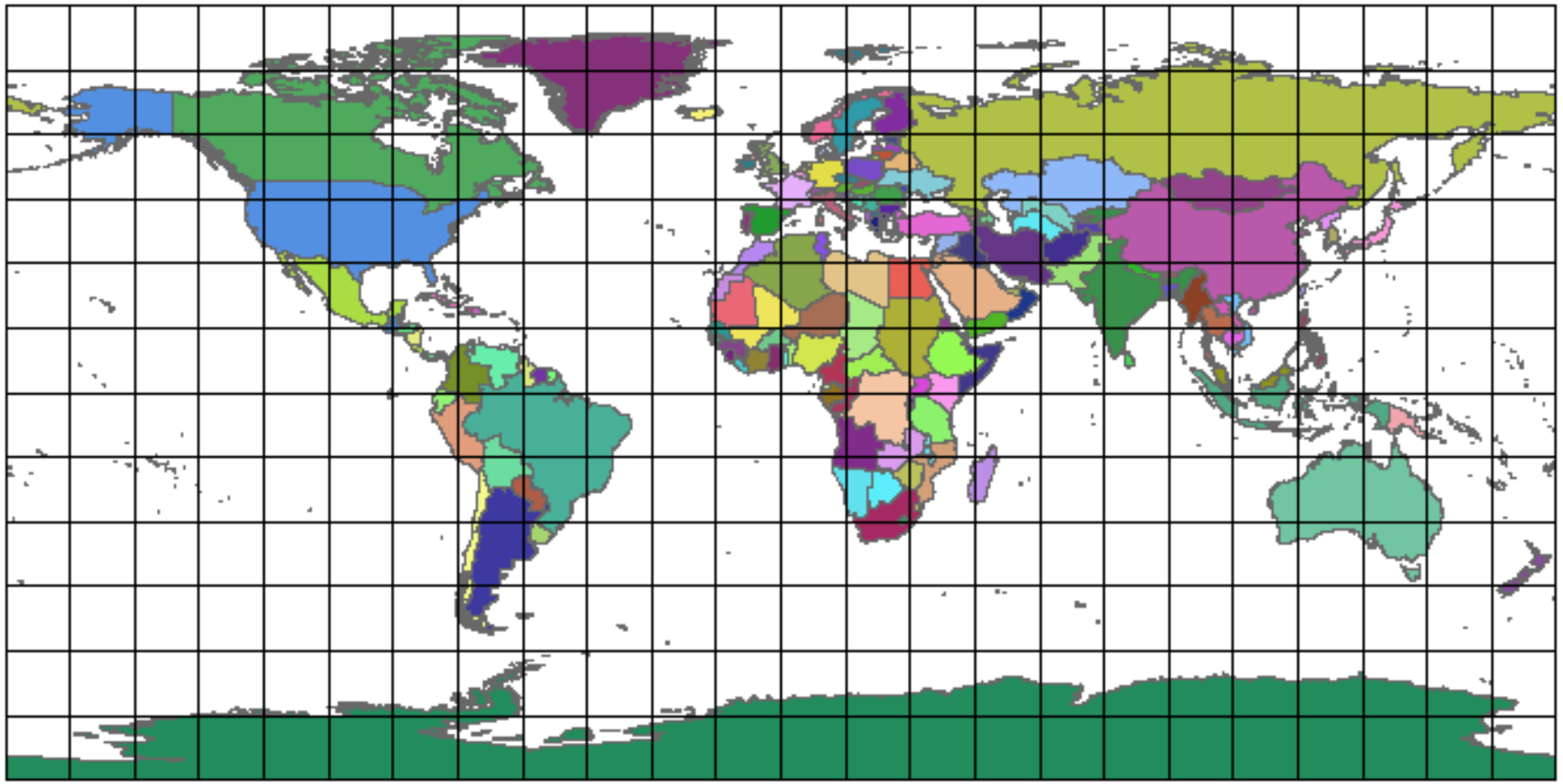


Plate Carrée

15° x 15° graticule