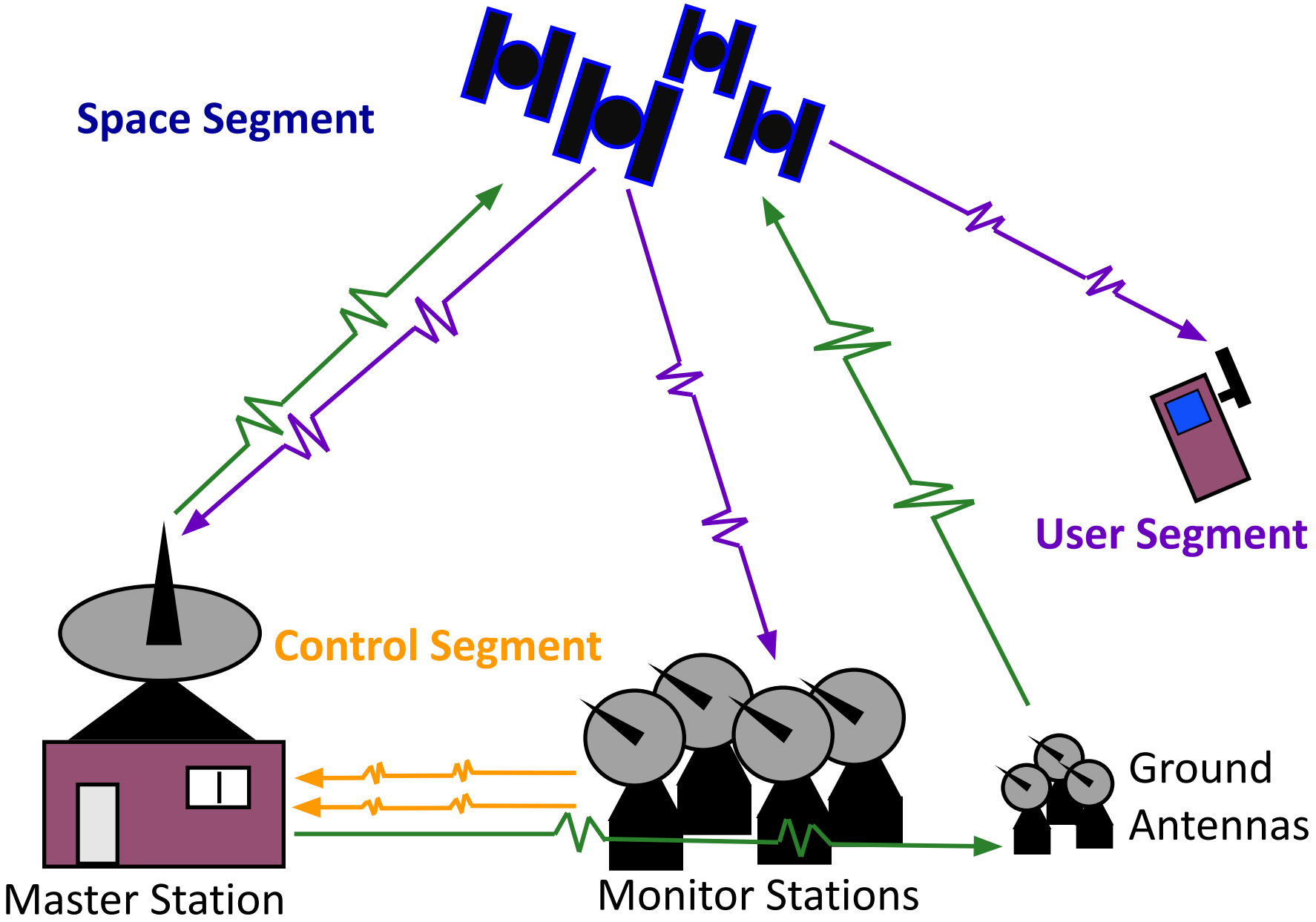
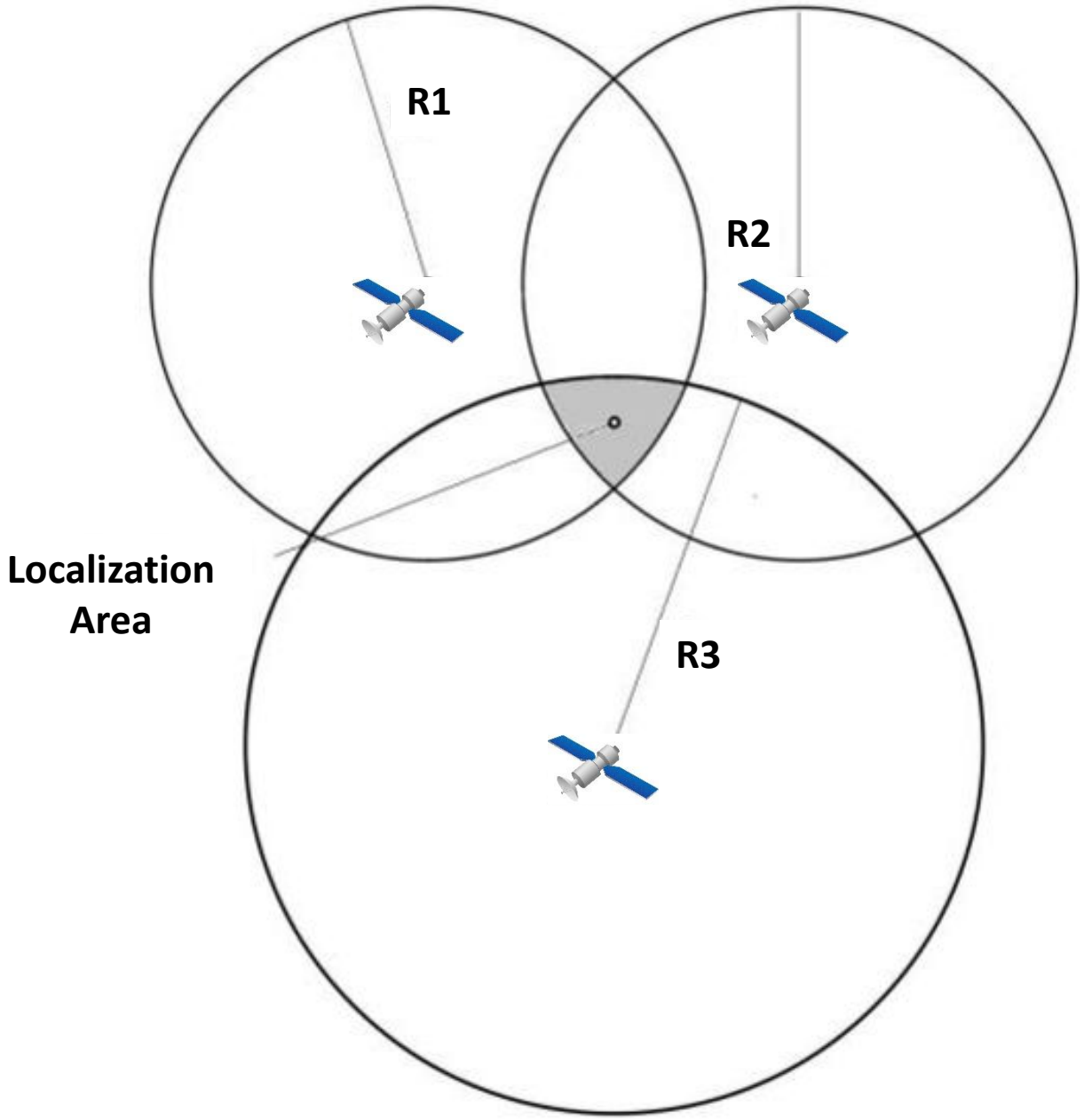
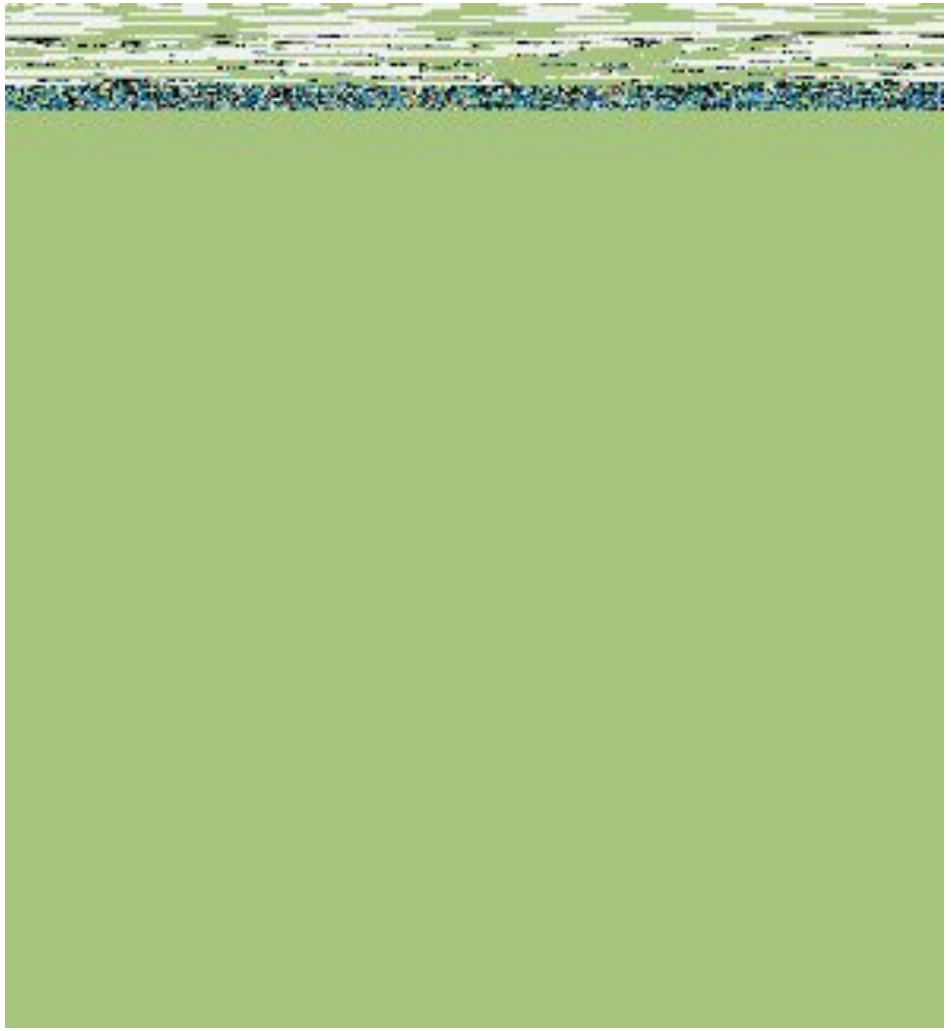
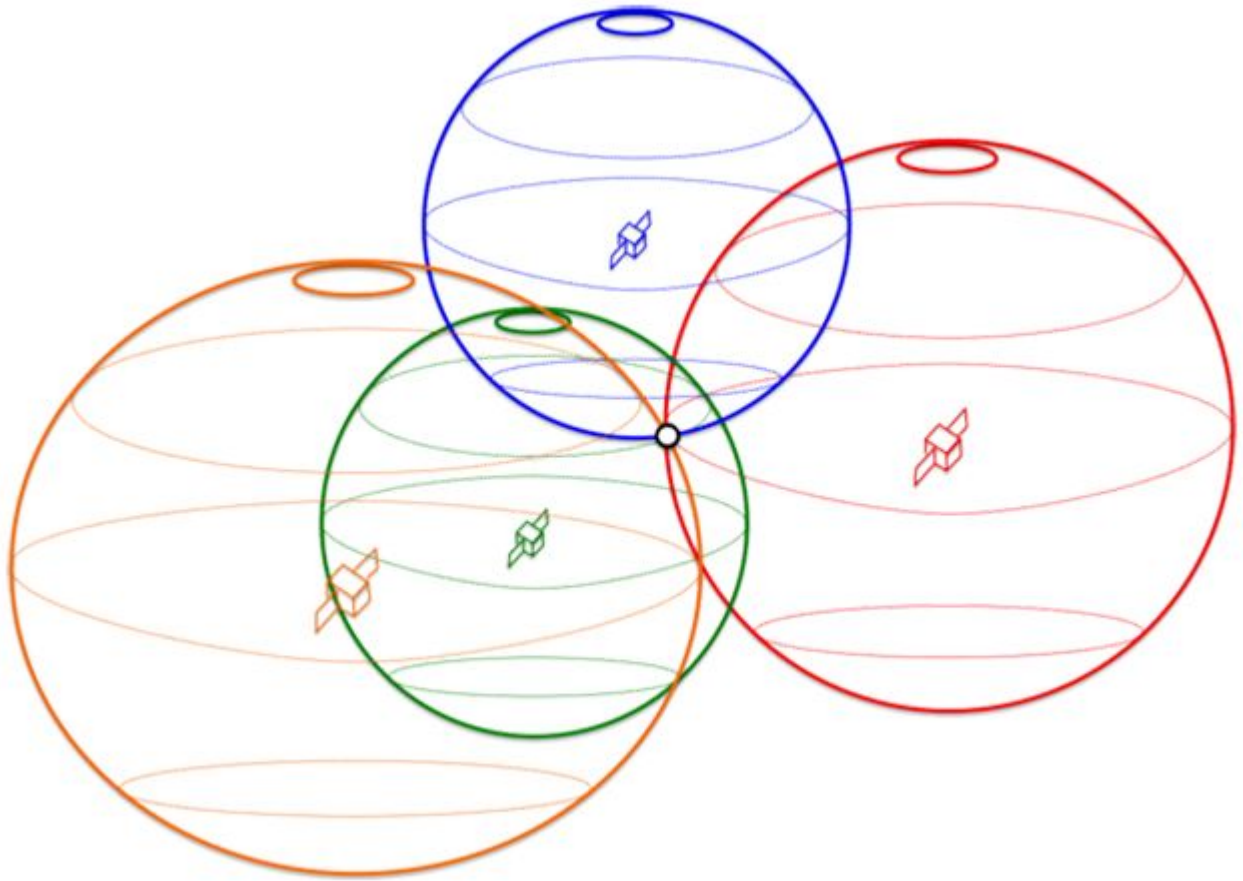
GNSS
&
Coordinate Systems

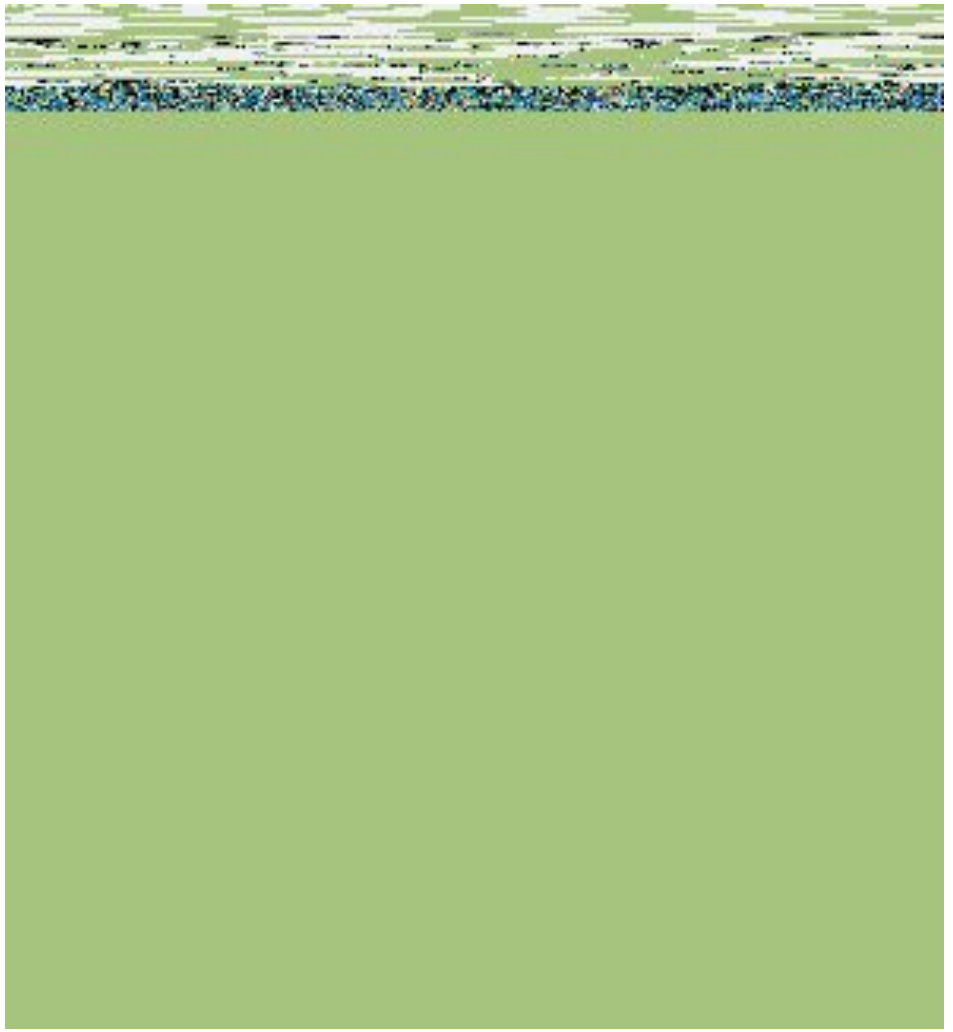
Three Segments of the GPS

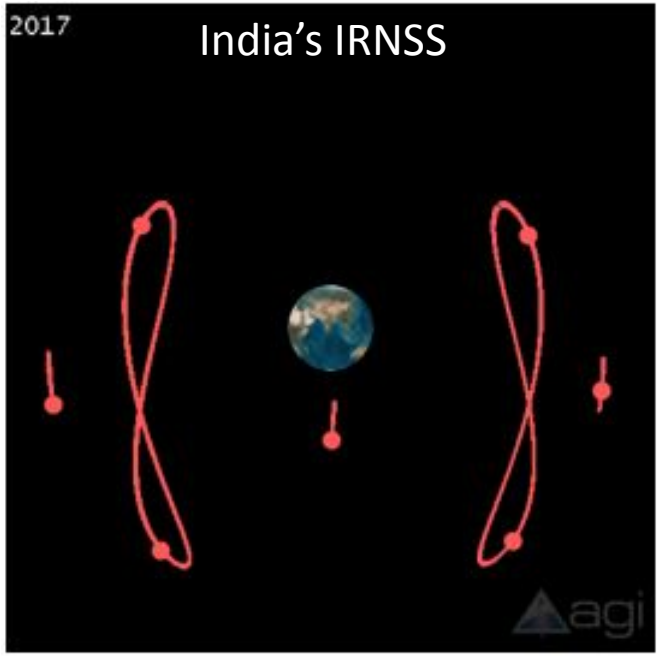


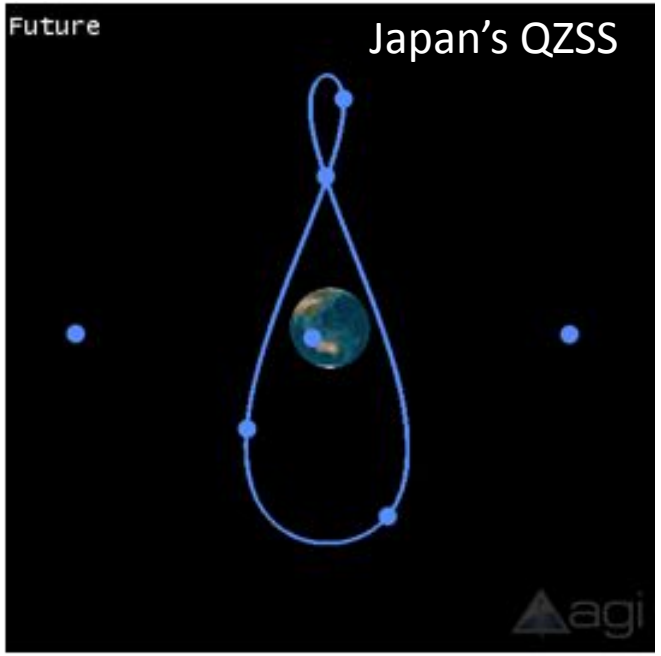

R1
R2
R3
Localization
Area

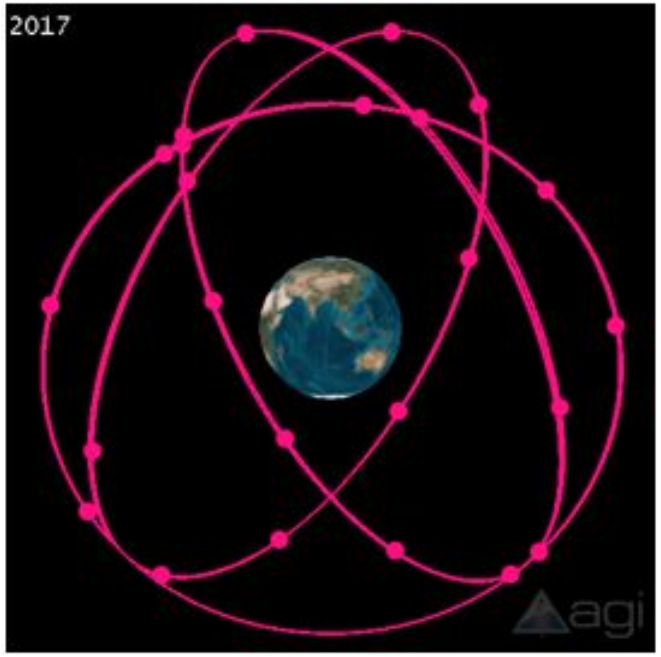


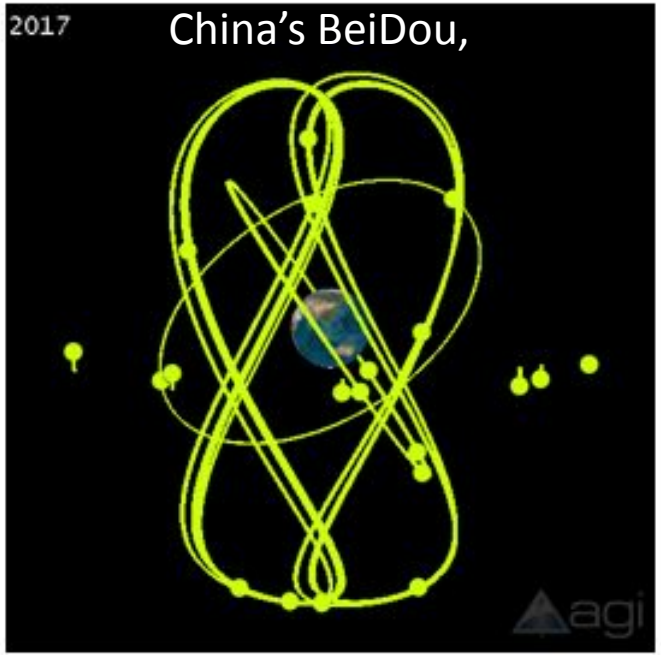




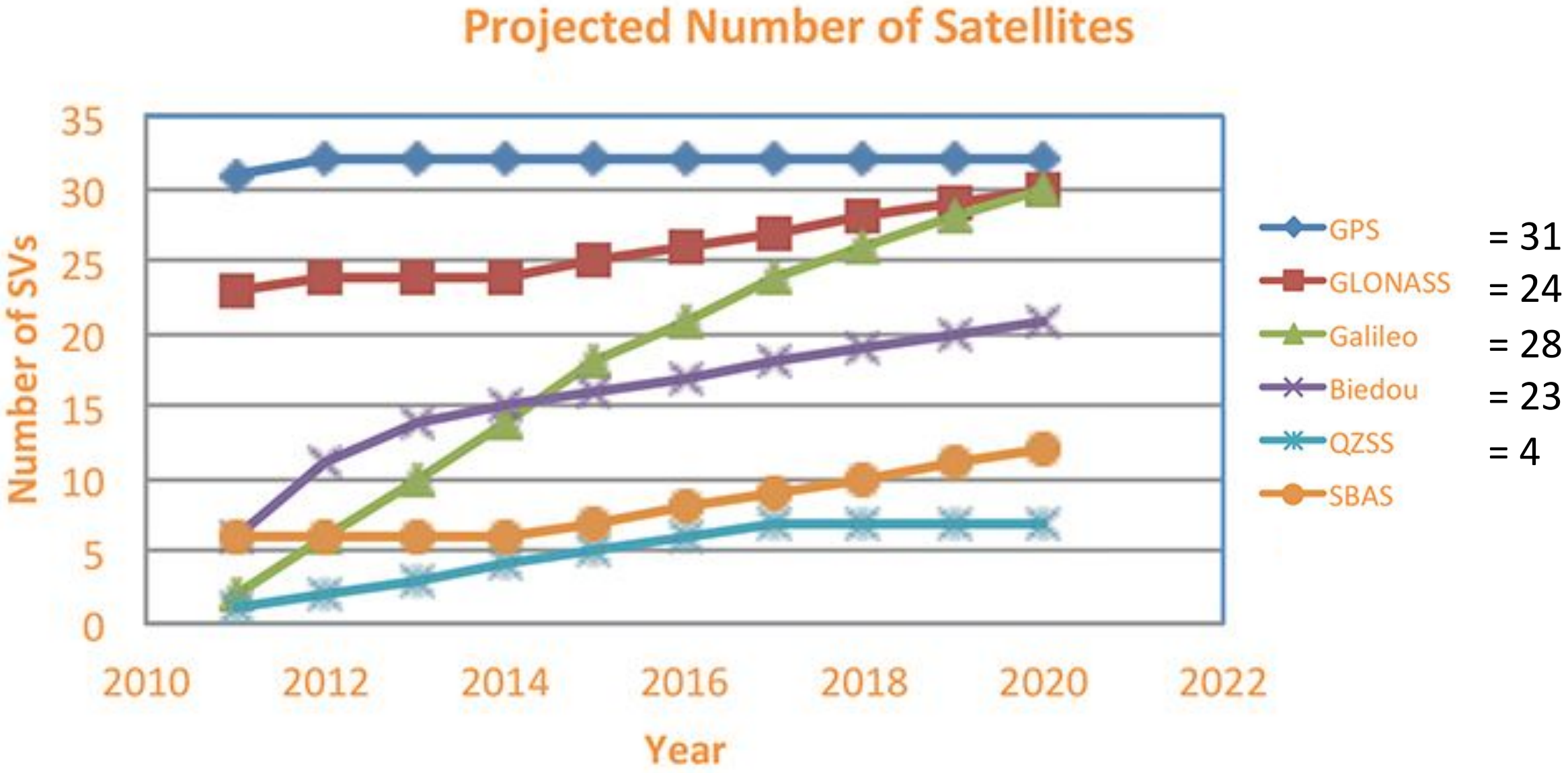








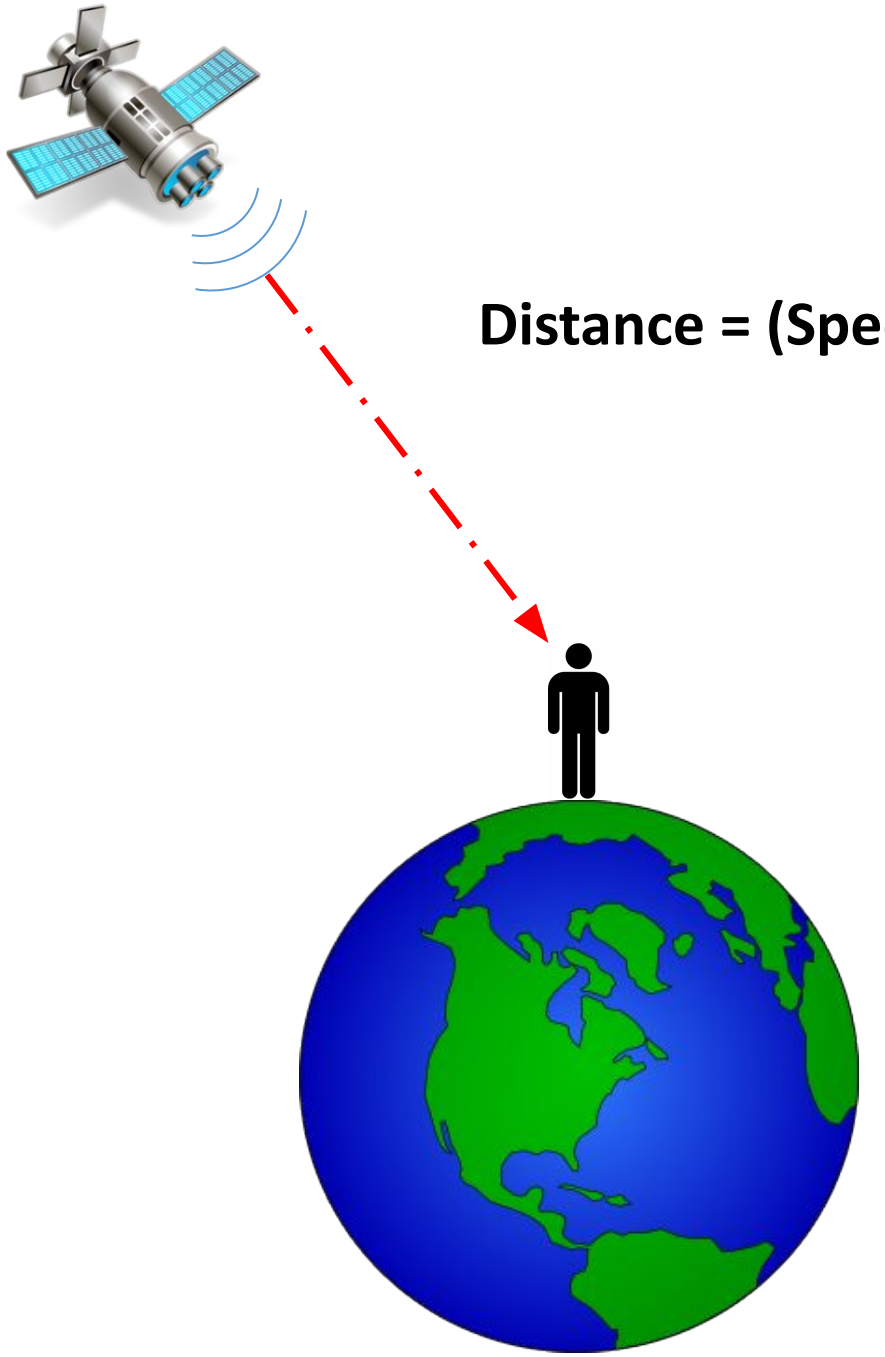
http://www.agi.com/news/blog/june-2017/don%E2%80%99t-have-consternation-about-your-gnss-constella



http://www.gpsworld.com/wp-content/uploads/2013/05/Fig1_chart_01.jpg

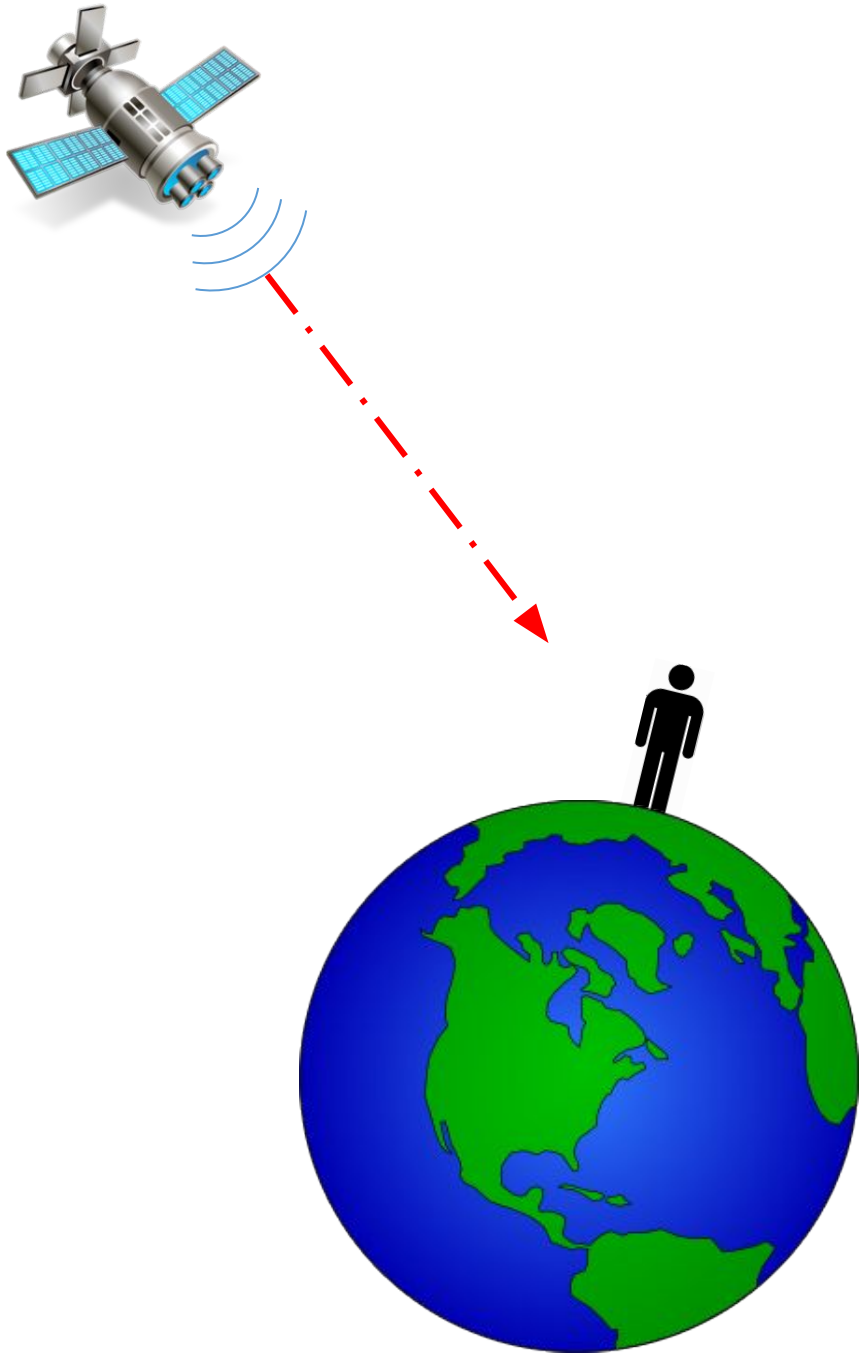
$$d = v * t$$

Where d = distance, v = speed of light (mph or m), and t = signal transit time



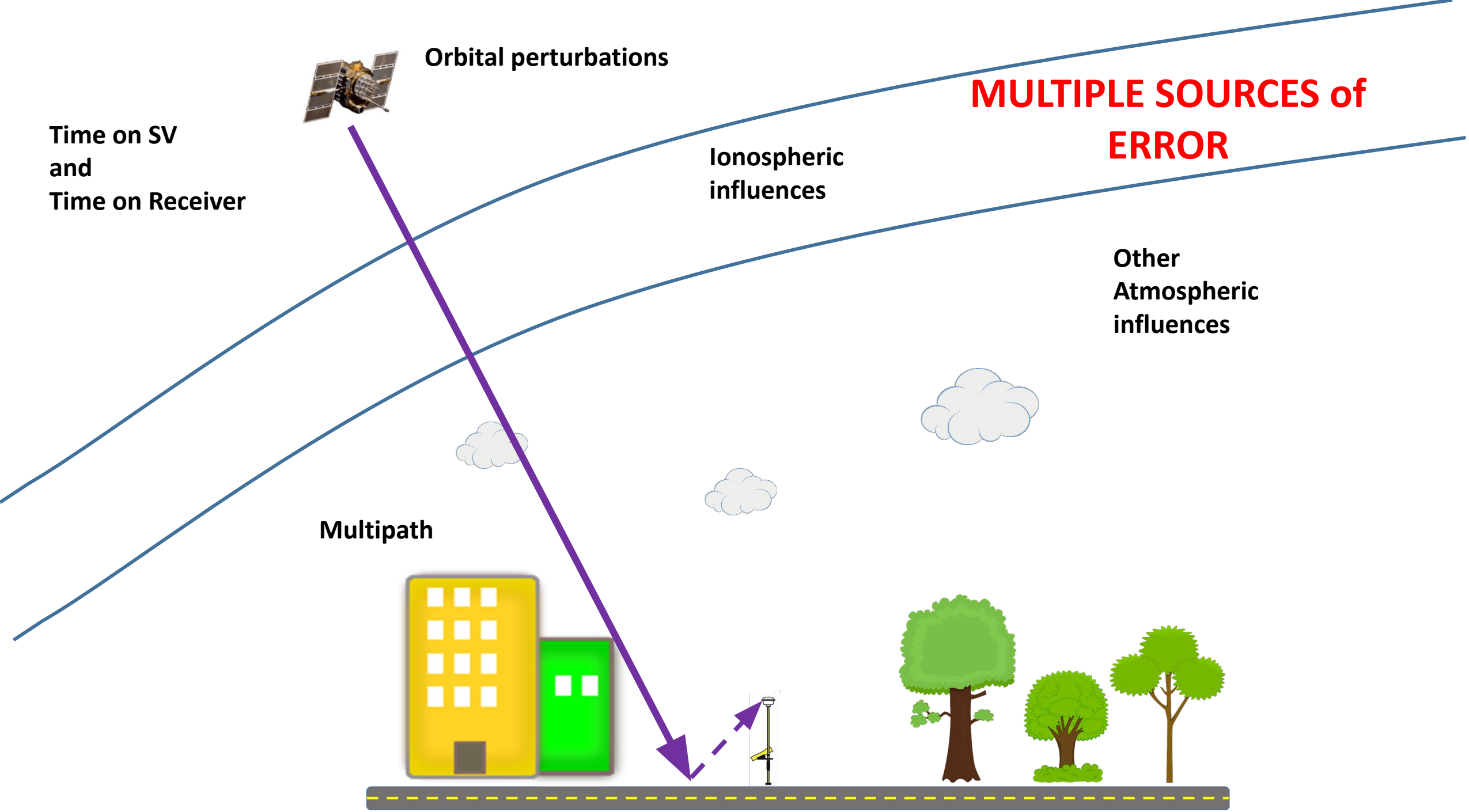
$$d = v * t$$

$$\text{Distance} = (\text{Speed of light}) * (GPS_{receiverTime} - GPS_{svTime})$$



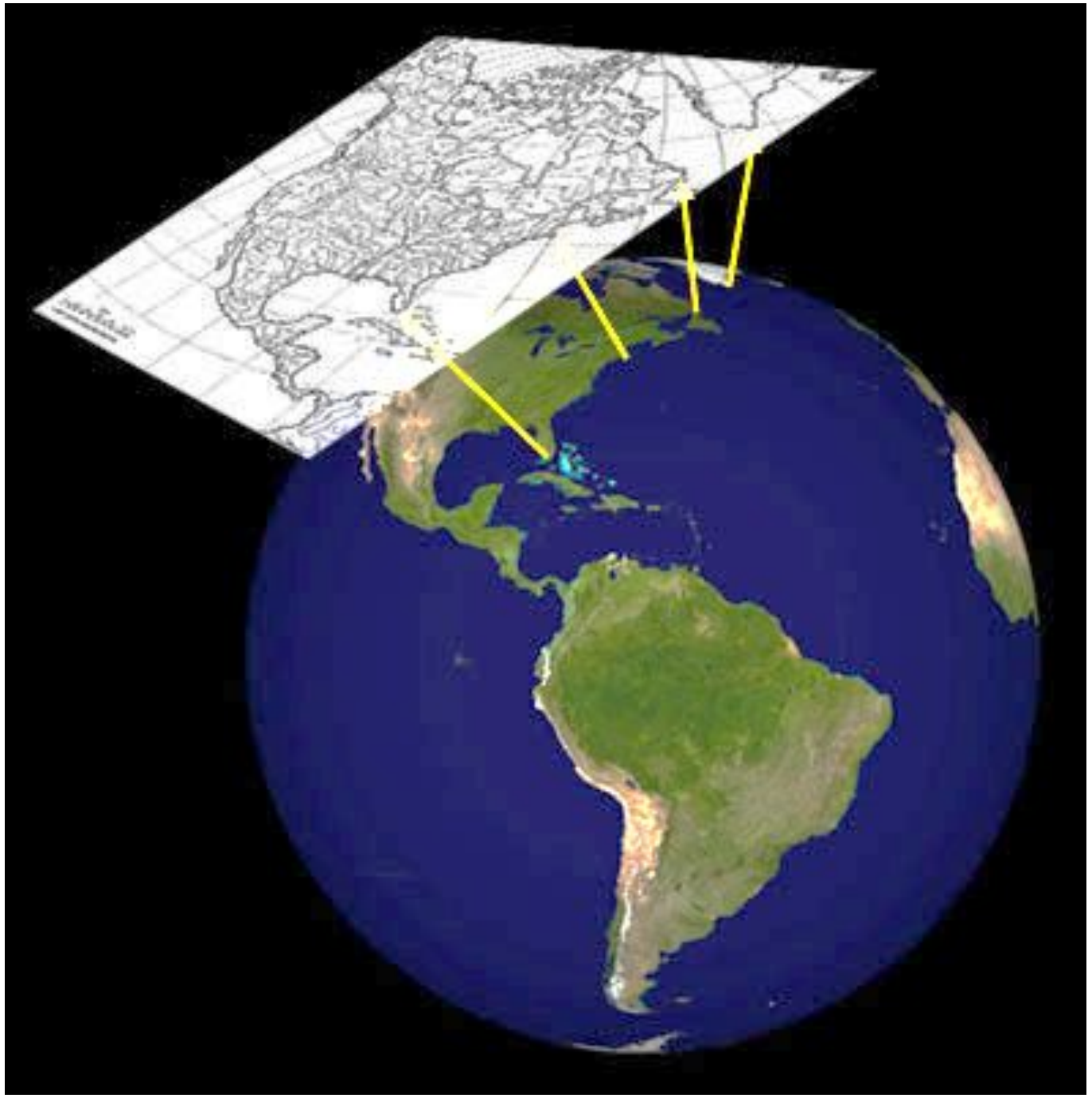
Because of the importance to time, it is essential that the SV's and receivers carry very accurate clocks that are synchronized

MULTIPLE SOURCES of ERROR



What happens when we try to make a flat map from a round surface?

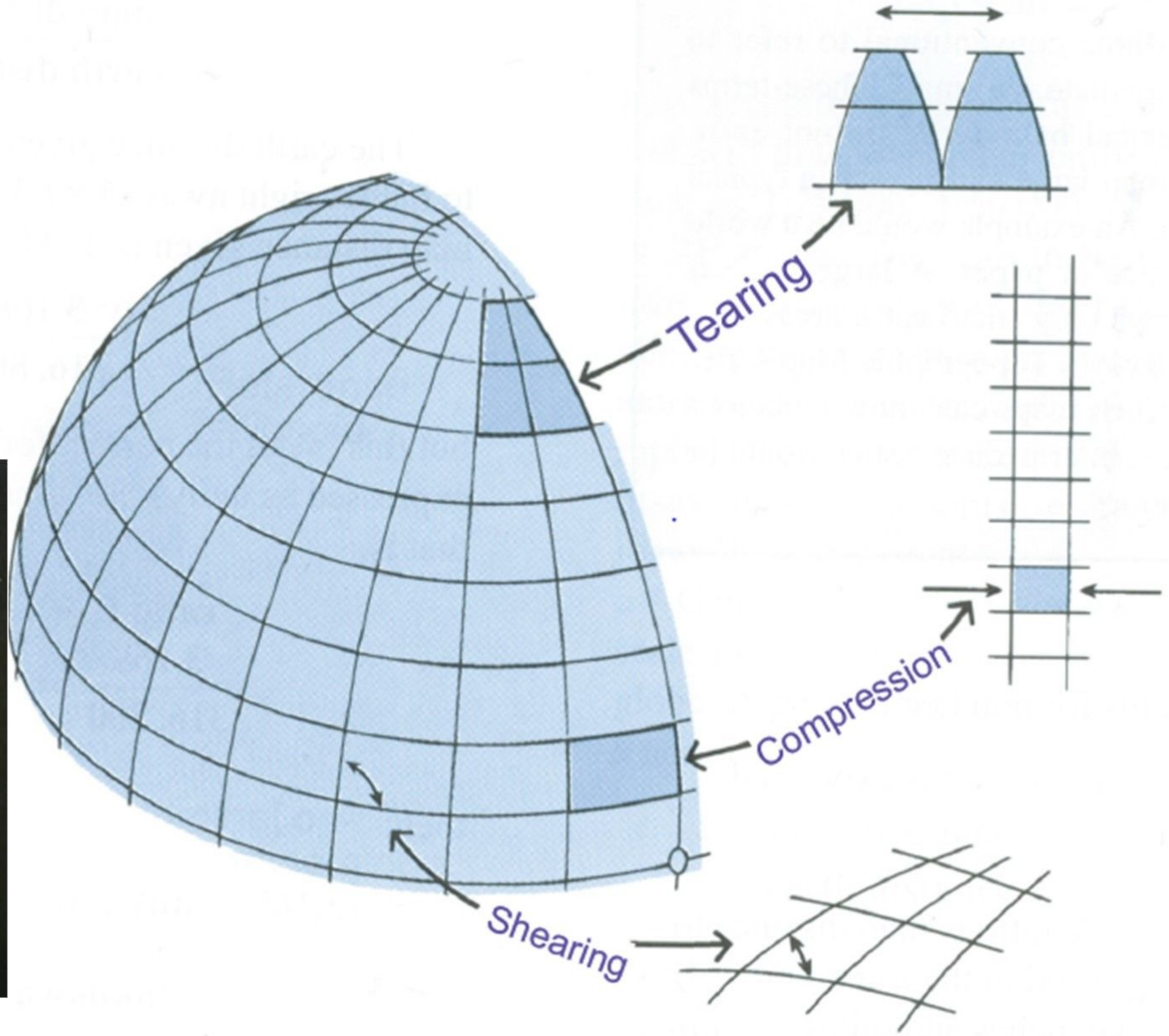
https://www.e-education.psu.edu/geog862/node/1808



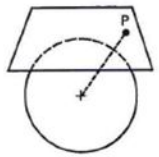
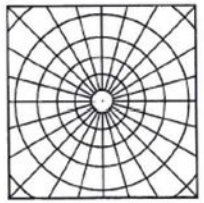
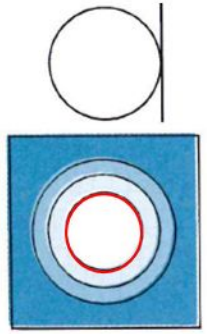
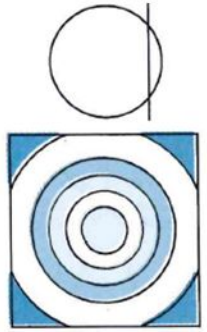
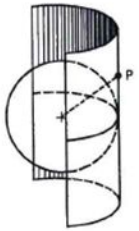
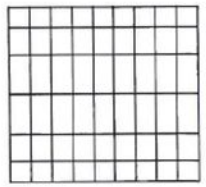
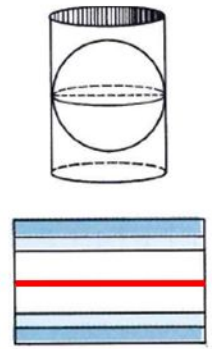
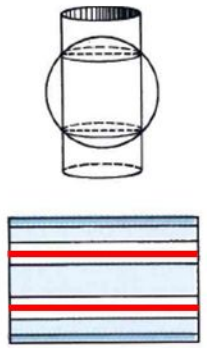
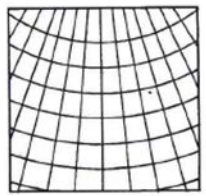
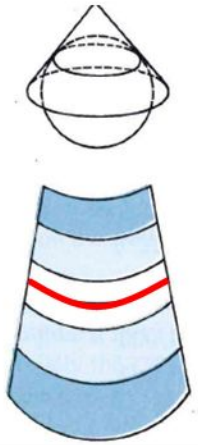
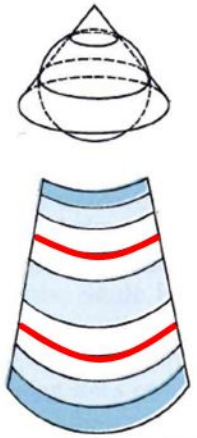
Making the World Flat Leads to

different sources of ***Distortion***

https://www.e-education.psu.edu/geog862/node/1808



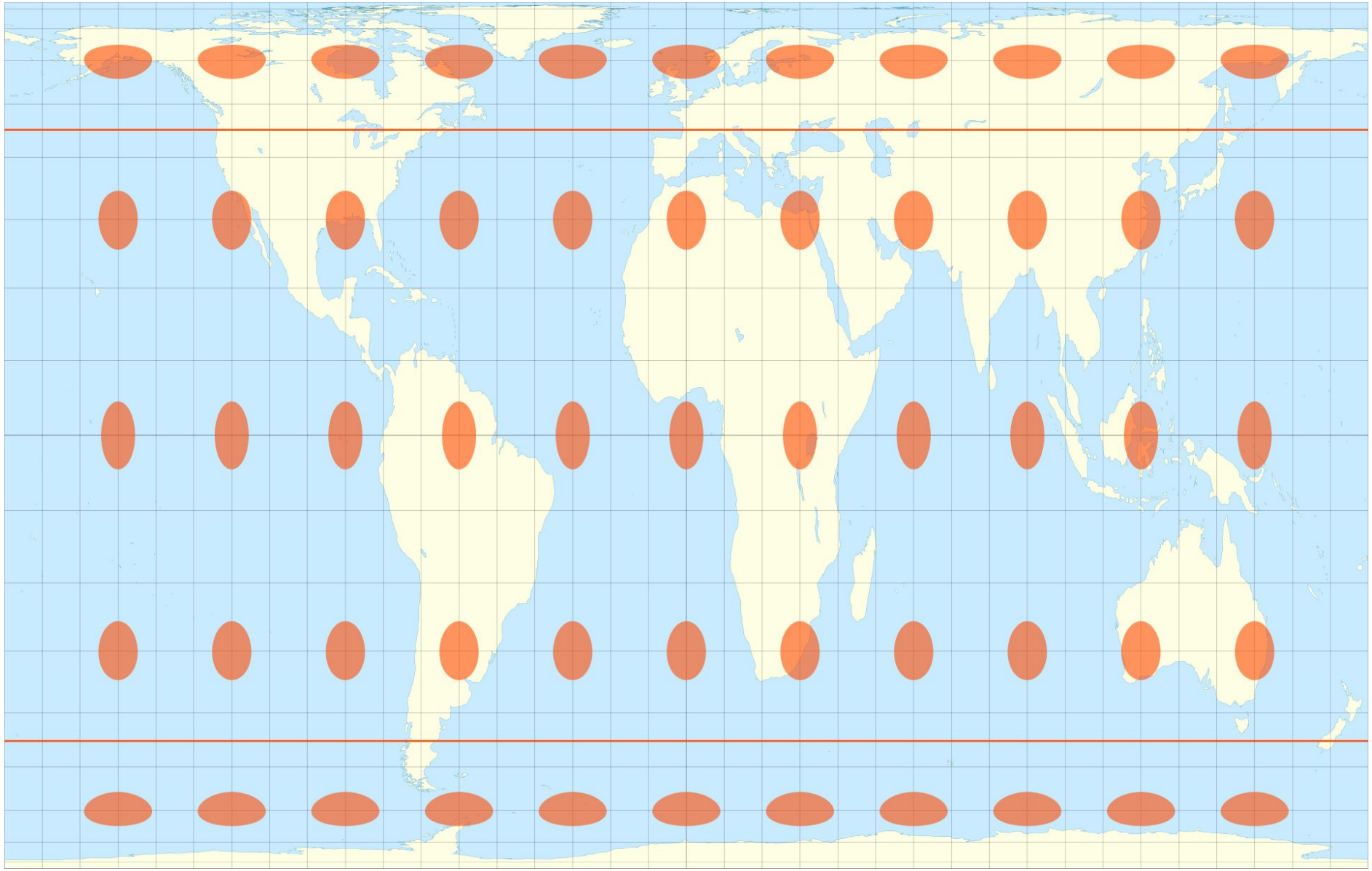
From: Dent, 1999, Cartography: Thematic Map Design (pg 38)

		Gird View	Tangent Case	Secant Case	
Azimuthal					• Parallels are concentric circles • Meridians extend from the center outward • Scale is correct at center but becomes distorted the further away from the center
Cylindrical					• Generally used for portraying the whole world • Areas of least distortion are areas parallel to the line of tangency • Meridians and parallels cross at right angles
Conic					• Meridians converge at a point, which may or may not be a pole • Meridians are straight lines • Parallels are curves; ‘arcs of a circle’

From: Dent, Cartography (pg 42)

Types of ***Distortion***

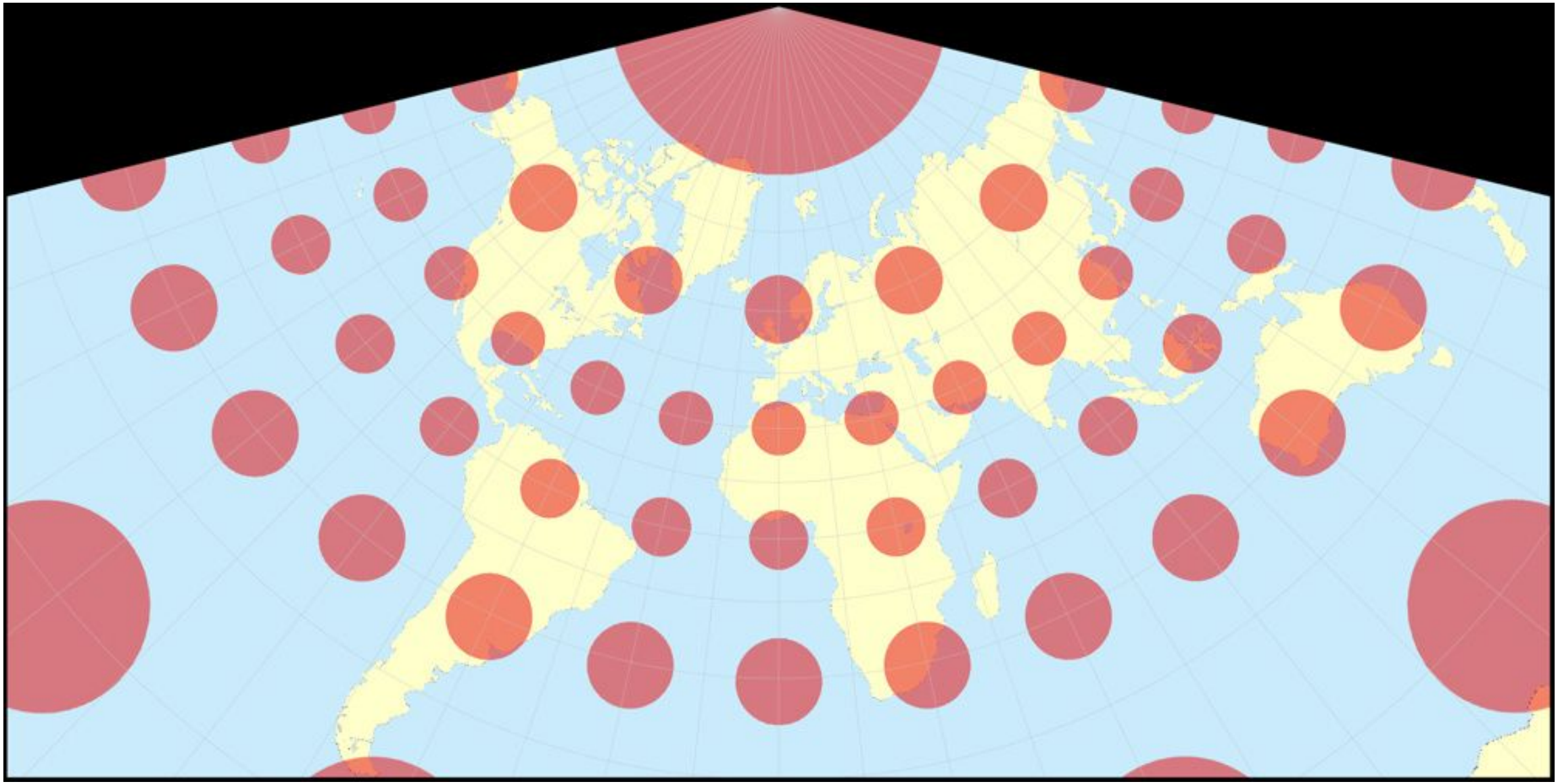
Gall-Peters Projection
(Equal Area—area is preserved)



https://en.wikipedia.org/wiki/Gall%E2%80%93Peters_projection#/media/File:Tissot_indicatrix_world_map_Gall-Peters_equal-area_proj.svg

Types of ***Distortion***

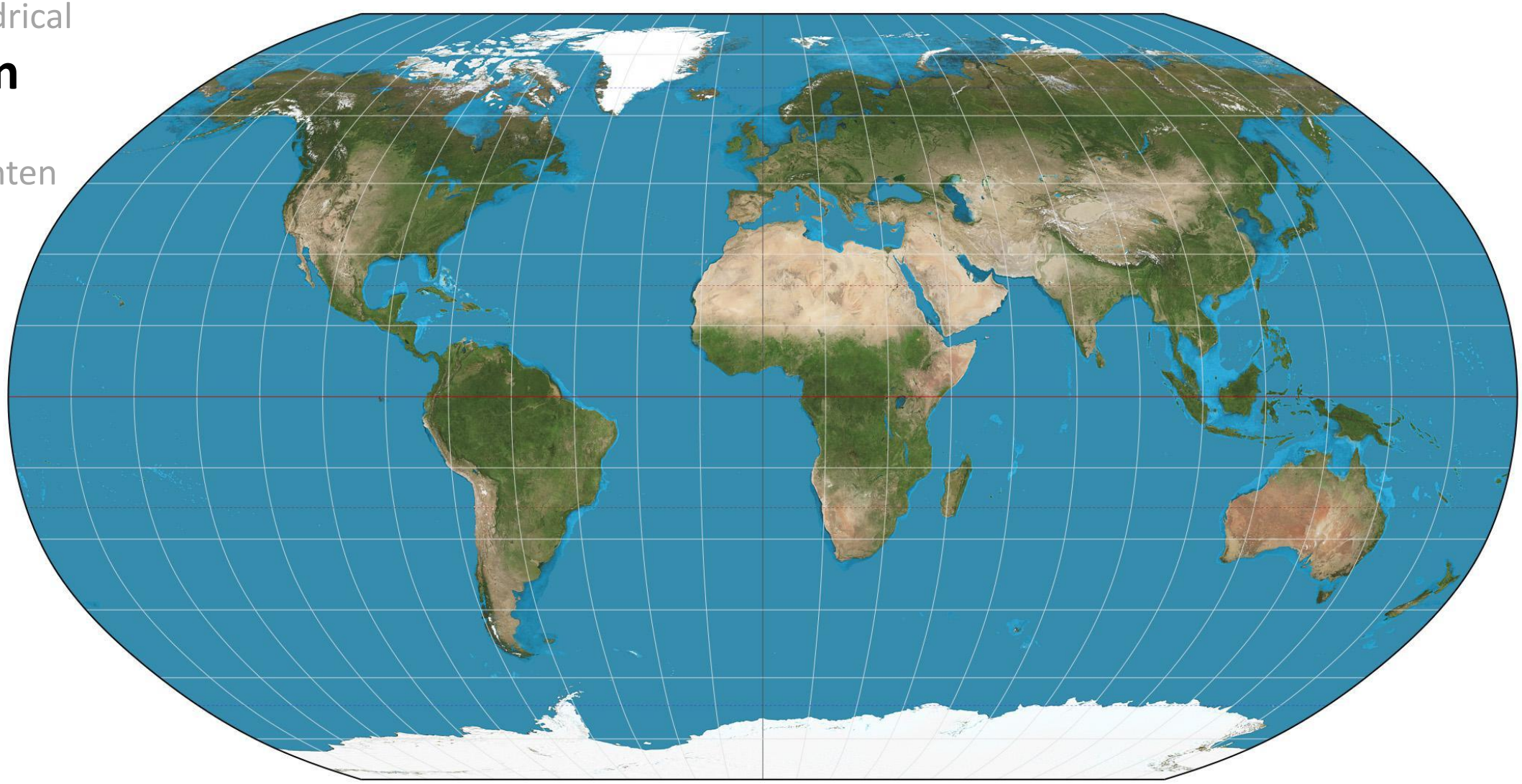
Lambert Conformal Conic Projection
(Equidistant—distance is preserved)



http://map-projections.net/img/tissot-30/lambert-conformal-conic.jpg

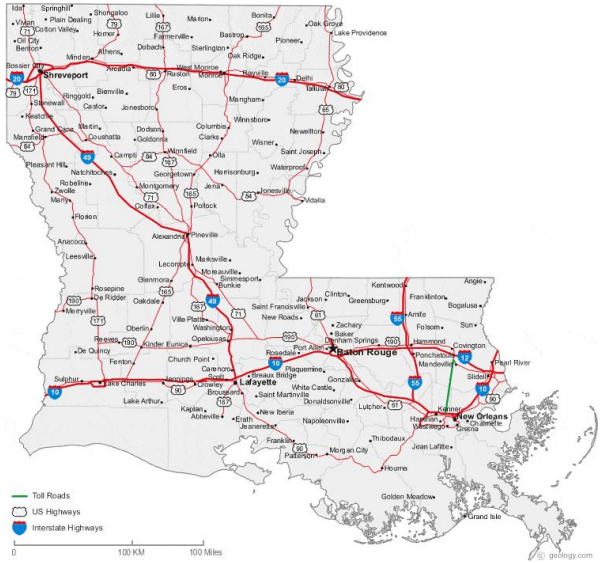
- World Equidistant Cylindrical
- World Lambert-Conformal Conic
- Mercator
- Miller Cylindrical
- **Robinson**
- Sinusoidal
- Van der Grinten

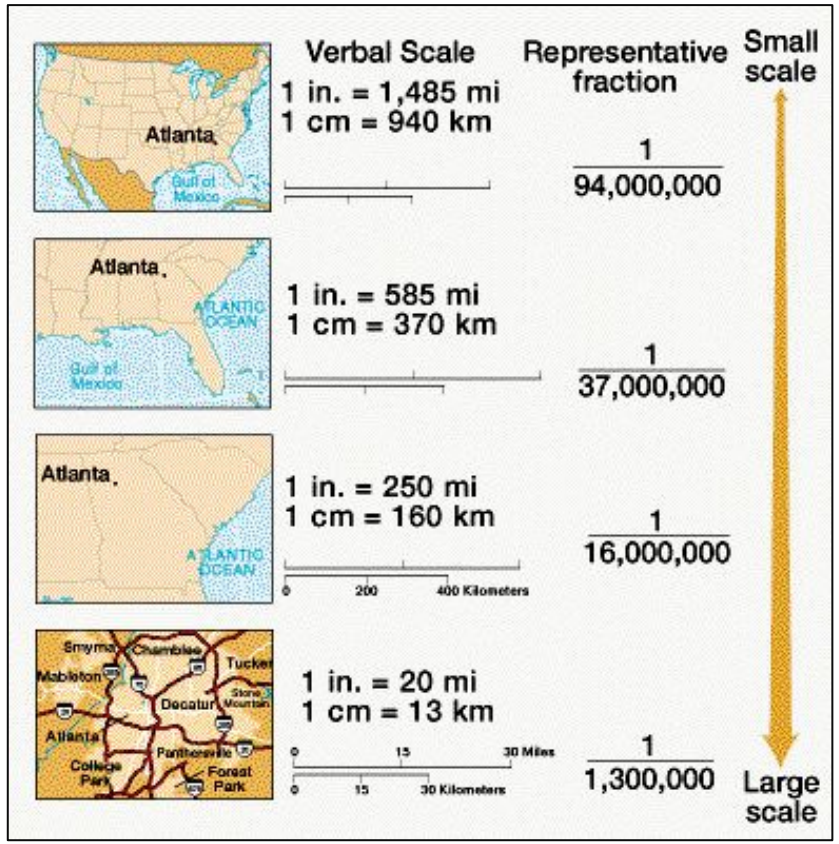
shows the entire world at once. It was specifically created in an attempt to find **a good compromise to the problem of readily showing the whole globe as a flat image.**



Cartographic Fundamentals

Large	**Scale**	Small
Small	**Mapped Area**	Large
More	**Information**	Less
Less generalized	**Symbolism**	More generalized





SCALE 1:24 000

1 0.5 0 KILOMETERS 1 2

1000 500 0 METERS 1000 2000

1 0.5 0 1

MILES

1000 0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000

FEET

CONTOUR INTERVAL 40 FEET
NORTH AMERICAN VERTICAL DATUM OF 1988

SCALE 1:100 000

1 0 1 2 3 4 5 6 7 8 9 10

KILOMETRES

1 0 1 2 3 4 5

MILES

5000 0 5000 10000 15000 20000 25000

FEET

CONTOUR INTERVAL 50 METRES
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Scale classification

Small scale	**= 1:24000 or smaller**
Medium scale	**= 1:10000 to 1:24000**
Large scale	**= 1:1000 to 1:10000**
Very large scale	**= 1:1000 and larger**

Small scale: objects on map are small

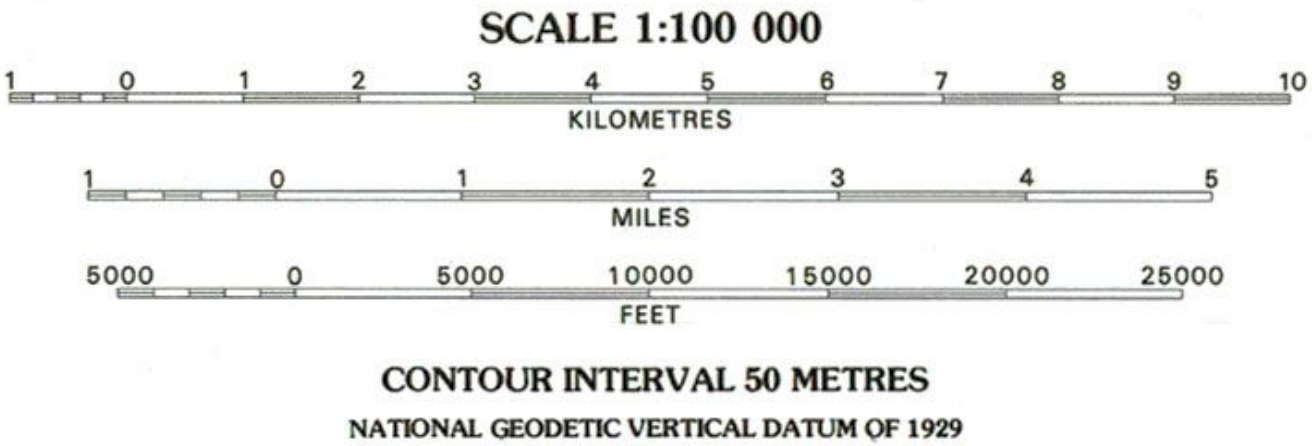
Large scale: objects on map are large

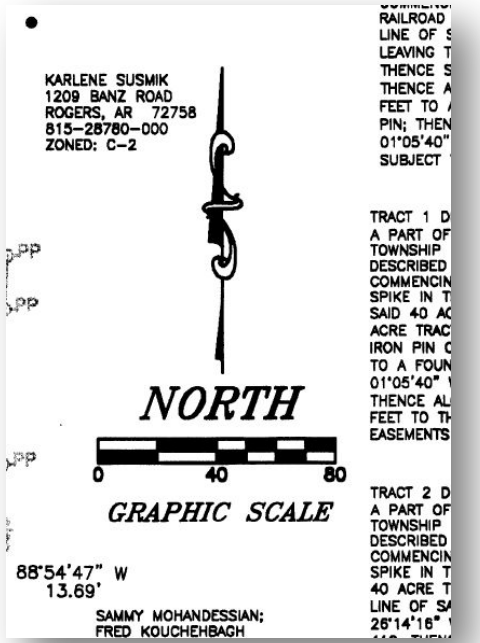
Scale

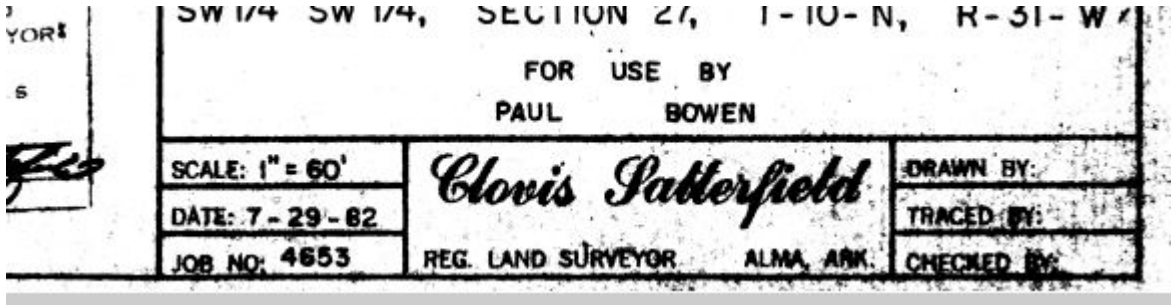
- **Scale is the ratio of a distance on the map with a distance on the ground**

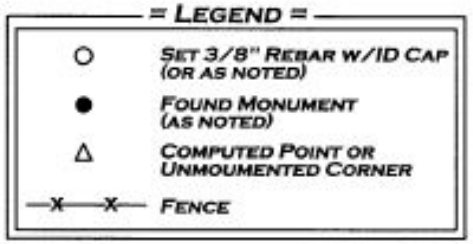
- **Three types of scale**

  1) **Ratio or Representative Fraction (RF)**
  2) **Verbal (aka equivalent scale)**
  3) **Bar (graphic)**



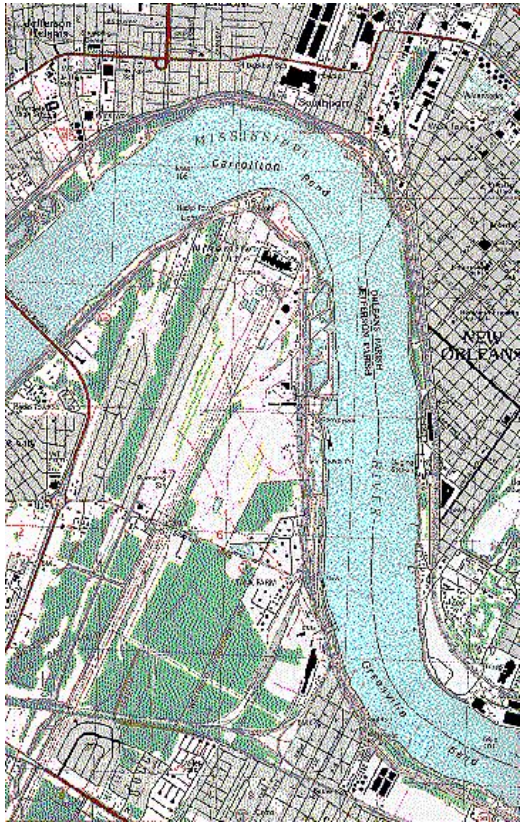






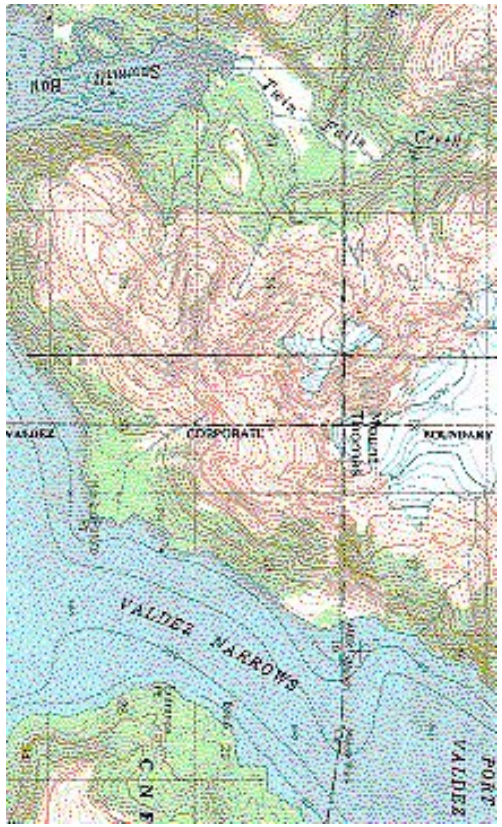
DATE:	01-25-2018
SCALE:	1" = 200'
DRAWN BY:	Jeff Harness
JOB NO.:	59810
SHEET	1 OF 1

USGS Topographic Maps



1:24,000 scale

1 inch = 2000 ft



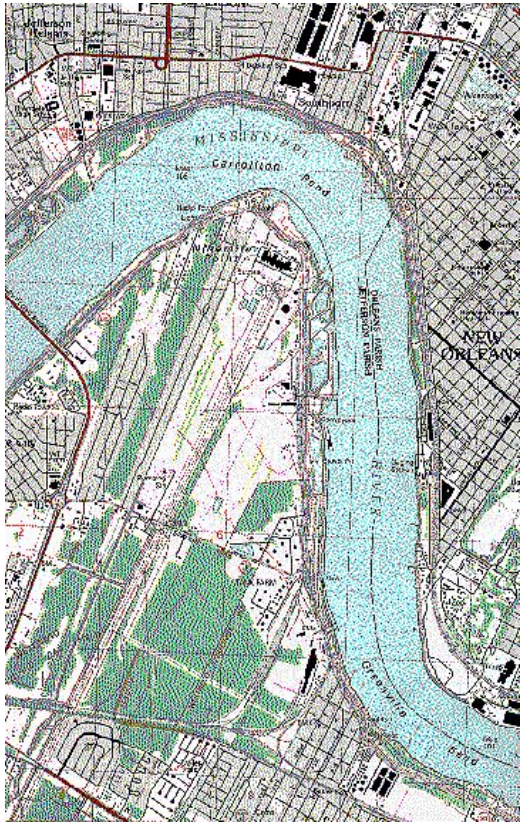
1:63,360 scale

1 inch =

1:100,000 scale

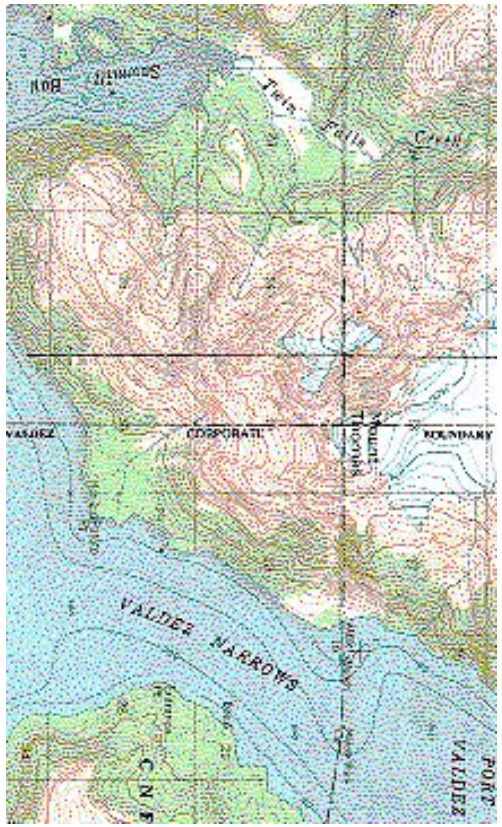
1 inch ≈

USGS Topographic Maps



1:24,000 scale

1 inch = 2000 ft



1:63,360 scale

1 inch = 5280 ft

1:100,000 scale

1 inch ≈ 8333 ft
(1.6 miles)

Scale

USGS Topographic Maps

Scale	Series	1 inch represents	1 centimeter represents	Standard quadrangle size (latitude-longitude)	Quadrangle area (square miles)
1:20,000	Puerto Rico 7.5 minute	1,667 feet (about)	200 meters	7.5 × 7.5 min.	71
1:24,000	7.5 minute	2,000 feet	240 meters	7.5 × 7.5 min.	49 to 70
1:25,000	7.5 × 15 minute	2,083 feet (about)	250 meters	7.5 × 15 min.	98 to 140
1:50,000	Intermediate	.8 mile (about)	500 meters	NA	county
1:62,500	15 minute	1 mile (about)	625 meters	15 × 15 min.	197 to 282
1:63,360	Alaska 1:63,360	1 mile	634 meters (about)	15 × 20 to 36 min.	207 to 281
1:100,000	Intermediate	1.6 miles (about)	1 kilometer	30 × 60 min.	1,568 to 2,240
1:100,000	Intermediate	1.6 miles (about)	1 kilometer	NA	county
1:125,000	30 minute	2 miles (about)	1.25 kilometers	30 × 30 min.	788 to 1,128
1:250,000	United States	4 miles (about)	2.5 kilometers	1° × 2° or 3°	4,580 to 8,669
1:250,000	Antarctica	4 miles (about)	2.5 kilometers	1° × 3° to 15°	4,089 to 8,336
1:500,000	Antarctica	8 miles (about)	5 kilometers	2° × 7.5°	28,174 to 30,462
1:500,000	State maps	8 miles (about)	5 kilometers	NA	NA
1:1,000,000	United States	16 miles (about)	10 kilometers	4° × 6°	73,734 to 102,759

Scale

USGS Topographic Maps

Scale	Series	1 inch represents	1 centimeter represents	Standard quadrangle size (latitude-longitude)	Quadrangle area (square miles)
1:20,000	Puerto Rico 7.5 minute	1,667 feet (about)	200 meters	7.5 × 7.5 min.	71
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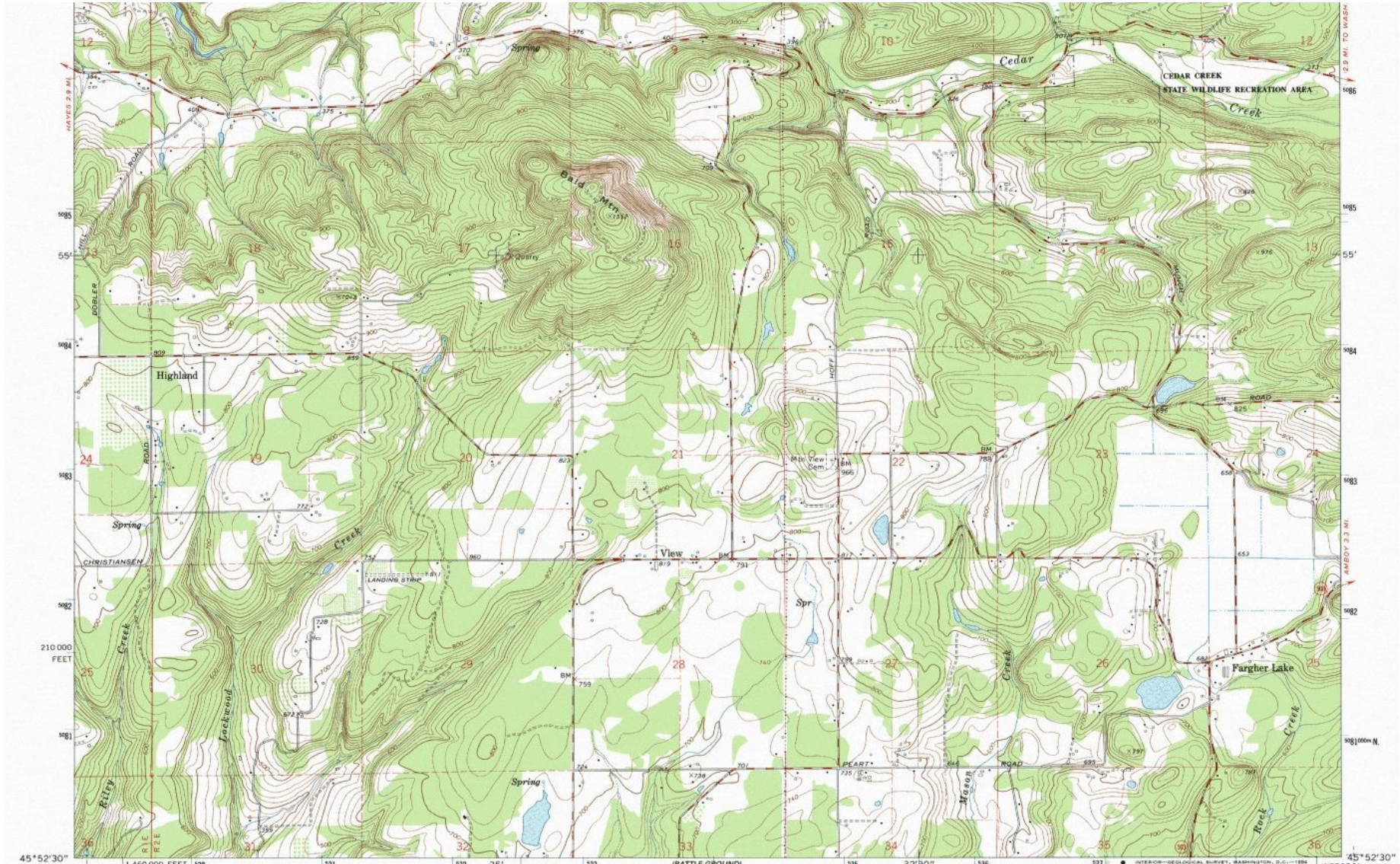
1:50,000	Intermediate	.8 mile (about)	500 meters	NA	county
1:62,500	15 minute	1 mile (about)	625 meters	15 × 15 min.	197 to 282
1:63,360	Alaska 1:63,360	1 mile	634 meters (about)	15 × 20 to 36 min.	207 to 281
1:100,000	Intermediate	1.6 miles (about)	1 kilometer	30 × 60 min.	1,568 to 2,240
1:100,000	Intermediate	1.6 miles (about)	1 kilometer	NA	county
1:125,000	30 minute	2 miles (about)	1.25 kilometers	30 × 30 min.	788 to 1,128
1:250,000	United States	4 miles (about)	2.5 kilometers	1° × 2° or 3°	4,580 to 8,669
1:250,000	Antarctica	4 miles (about)	2.5 kilometers	1° × 3° to 15°	4,089 to 8,336
1:500,000	Antarctica	8 miles (about)	5 kilometers	2° × 7.5°	28,174 to 30,462
1:500,000	State maps	8 miles (about)	5 kilometers	NA	NA
1:1,000,000	United States	16 miles (about)	10 kilometers	4° × 6°	73,734 to 102,759

Commonly used

Commonly used

Commonly used



Produced by the United States Geological Survey

Control by USGS and NOS/NOAA

Compiled from aerial photographs taken 1951 and 1970. Field checked 1971. Map edited 1994

North American Datum of 1927 (NAD 27). Projection and 10 000-foot ticks: Washington Coordinate System, south zone (Lambert Conformal Conic)
Blue 1000-meter Universal Transverse Mercator ticks, zone 10

North American Datum of 1983 (NAD 83) is shown by dashed corner ticks. The values of the shift between NAD 27 and NAD 83 for 7.5-minute intersections are obtainable from National Geodetic Survey NADCON software

There may be private inholdings within the boundaries of the National or State reservations shown on this map

Fine red dashed lines indicate selected fence lines

Photoinspected from 1990 source; no major culture or drainage changes observed. Names verified 1994

GN MN
0°19' 6 MILS
18½° 329 MILS
UTM GRID AND 1994 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

1 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY
DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

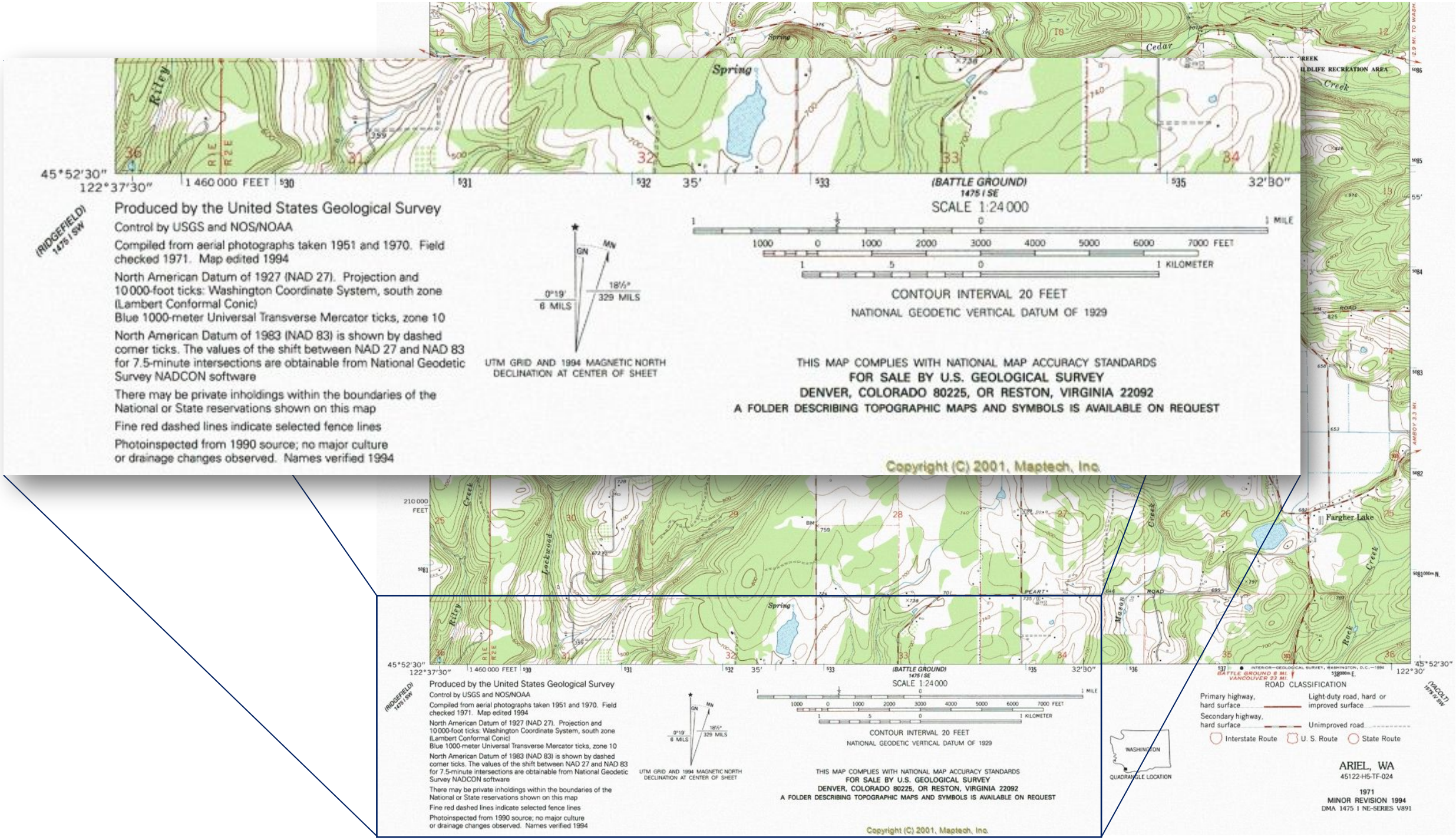
WASHINGTON
QUADRANGLE LOCATION

ROAD CLASSIFICATION

Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route
U. S. Route
State Route

ARIEL, WA
45122-H5-TF-024

1971
MINOR REVISION 1994
DMA 1475 I NE-SERIES V891


Spring
Riley
Cedar
Creek
45°52'30"
122°37'30"
1 460 000 FEET
35'
32'30"
(BATTLE GROUND)
1475 I SE
SCALE 1:24 000
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER
CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929
(RIDGEFIELD)
1475 I SW
Produced by the United States Geological Survey
Control by USGS and NOS/NOAA
Compiled from aerial photographs taken 1951 and 1970. Field checked 1971. Map edited 1994
North American Datum of 1927 (NAD 27). Projection and 10 000-foot ticks: Washington Coordinate System, south zone (Lambert Conformal Conic)
Blue 1000-meter Universal Transverse Mercator ticks, zone 10
North American Datum of 1983 (NAD 83) is shown by dashed corner ticks. The values of the shift between NAD 27 and NAD 83 for 7.5-minute intersections are obtainable from National Geodetic Survey NADCON software
There may be private inholdings within the boundaries of the National or State reservations shown on this map
Fine red dashed lines indicate selected fence lines
Photoinspected from 1990 source; no major culture or drainage changes observed. Names verified 1994
GN
MN
0°19'
6 MILS
18½°
329 MILS
UTM GRID AND 1994 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET
THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY
DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST
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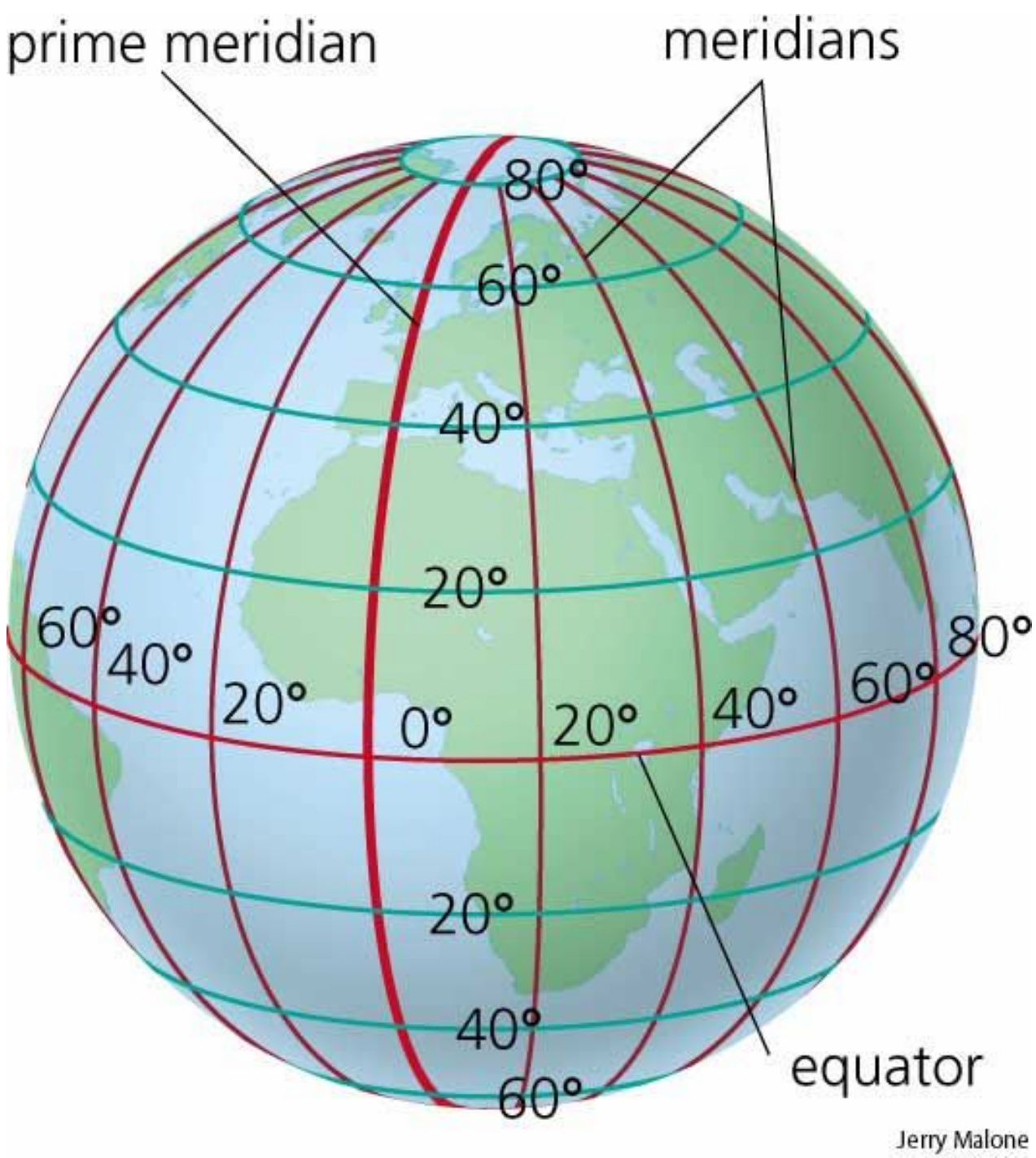
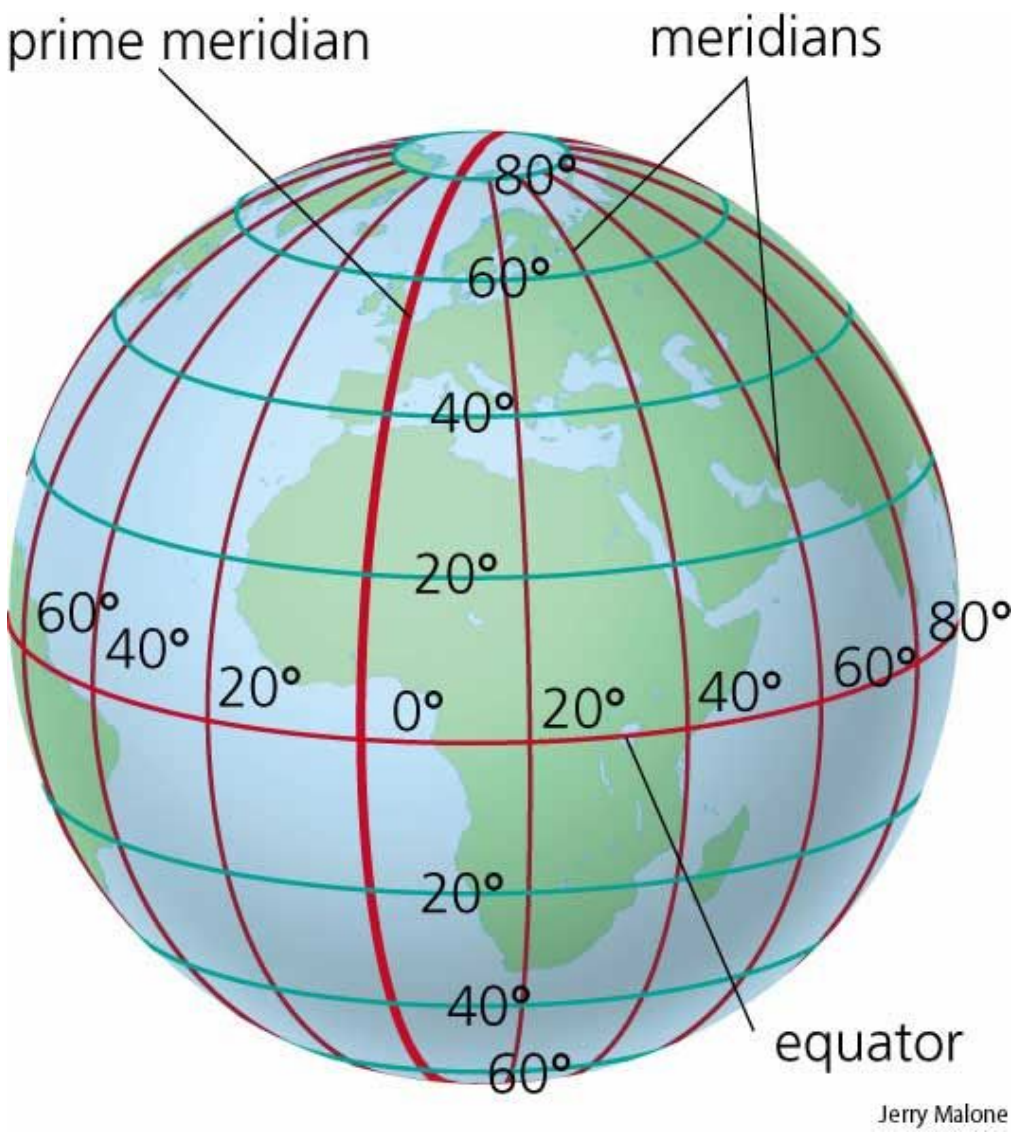
Fargher Lake
Lockwood
Creek
Rock
Mason
ROAD
ROAD CLASSIFICATION
Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route
U. S. Route
State Route
WASHINGTON
QUADRANGLE LOCATION
ARIEL, WA
45122-H5-TF-024
1971
MINOR REVISION 1994
DMA 1475 I NE-SERIES V891


prime meridian
meridians
80°
60°
40°
20°
60°
40°
20°
0°
20°
40°
60°
80°
20°
40°
60°
equator
Jerry Malone

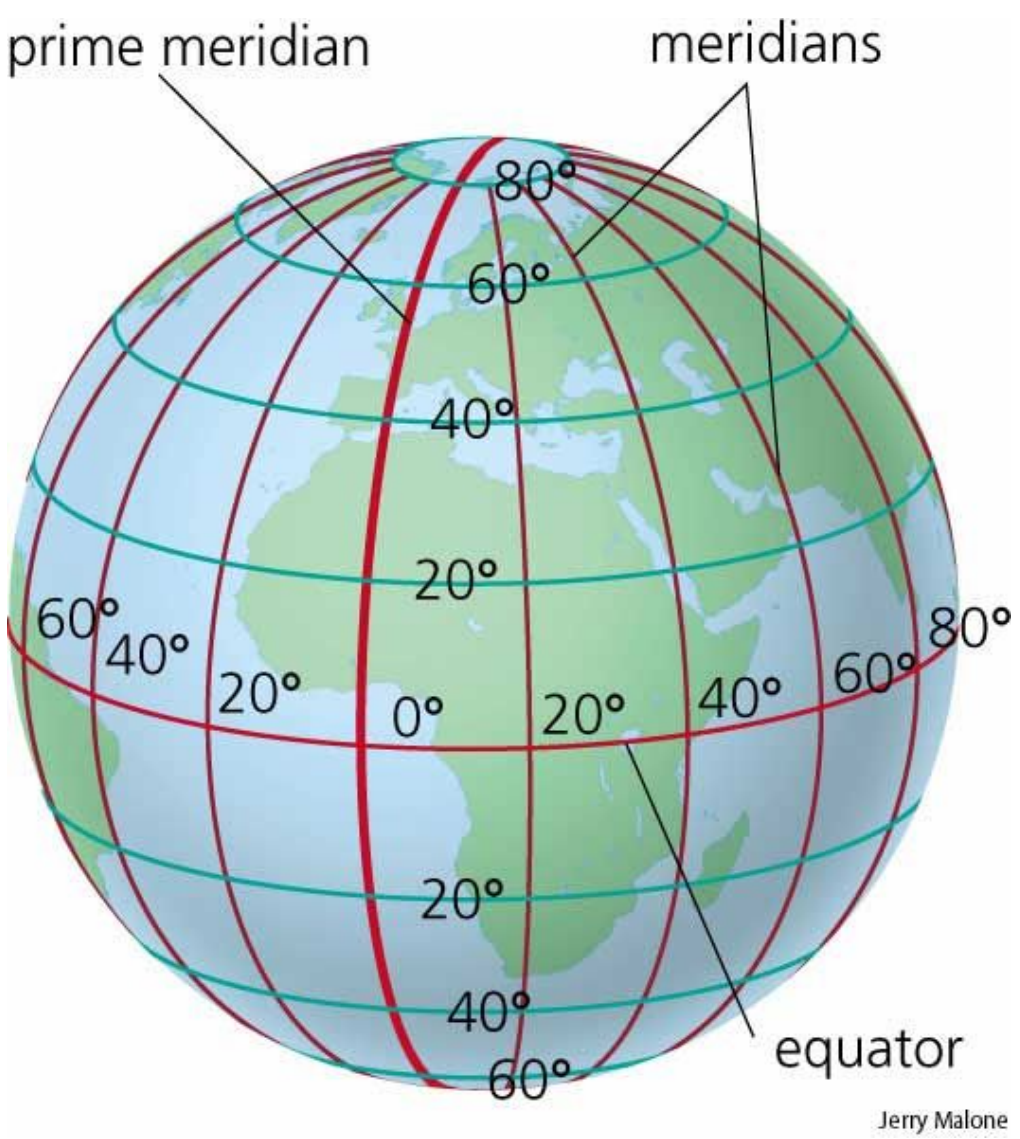
Geographic Grid

- Meridians
  - Lines of longitude.
  - Prime Meridian = 0°
  - Ranges –180° to + 180°
  - 0° to + 180°, east
  - -180° to 0°, west

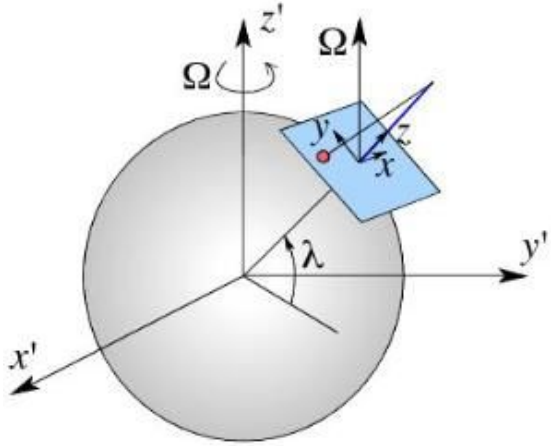


Geographic Grid

- Parallels
  - Lines of latitude.
  - Equator = 0°
  - Ranges –90° to + 90°
  - 0° to +90°, north
  - -90° to 0°, south

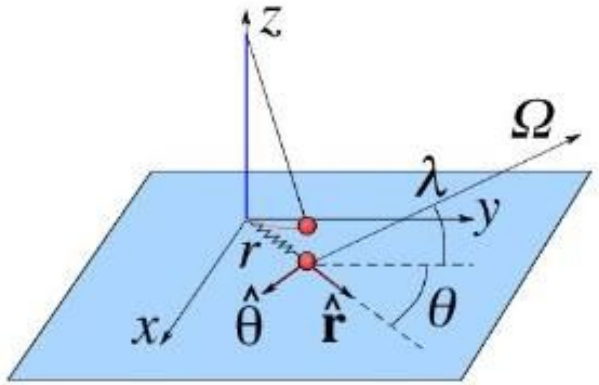


Projected Coordinate Systems



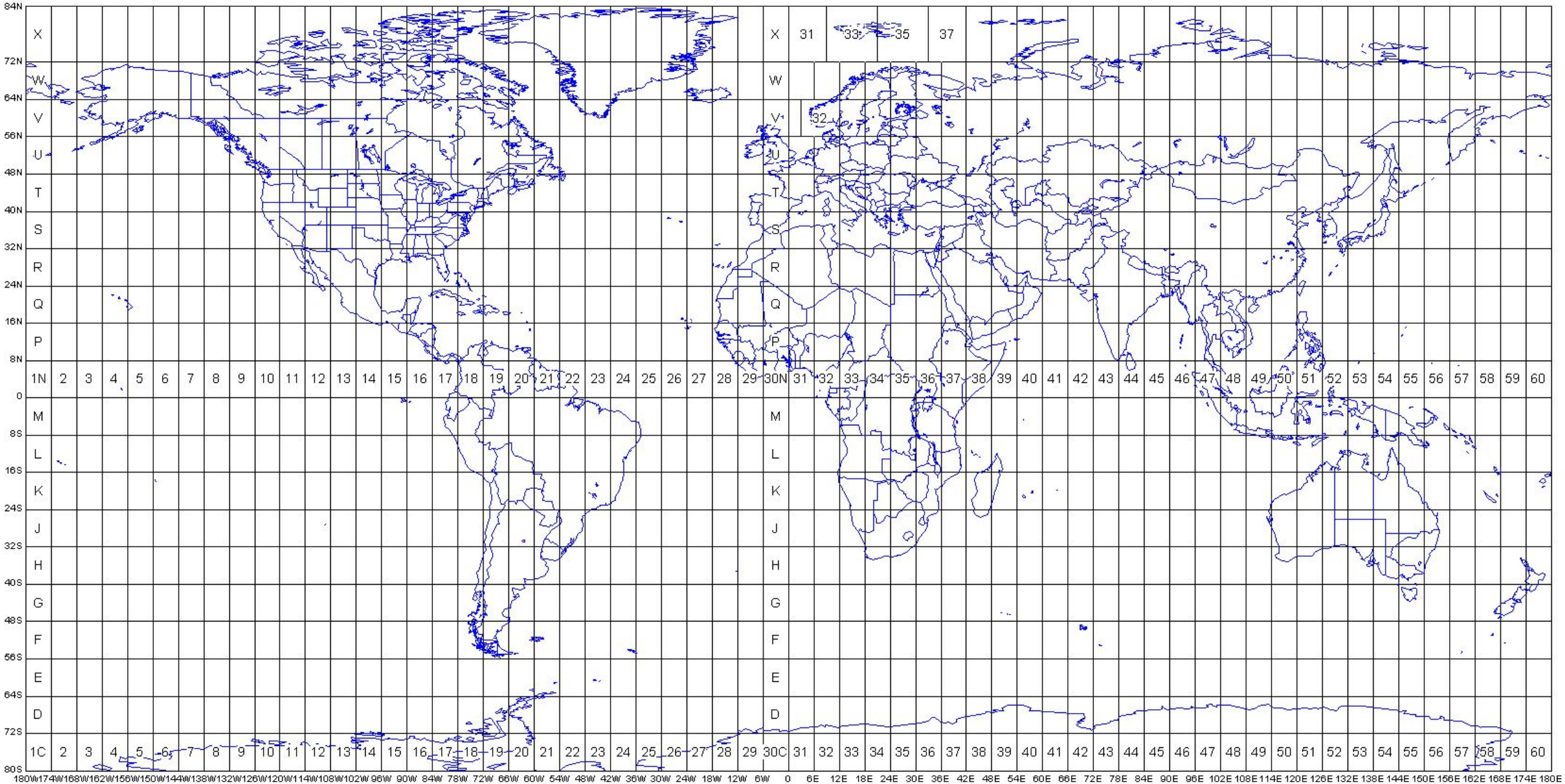
4 Common Systems

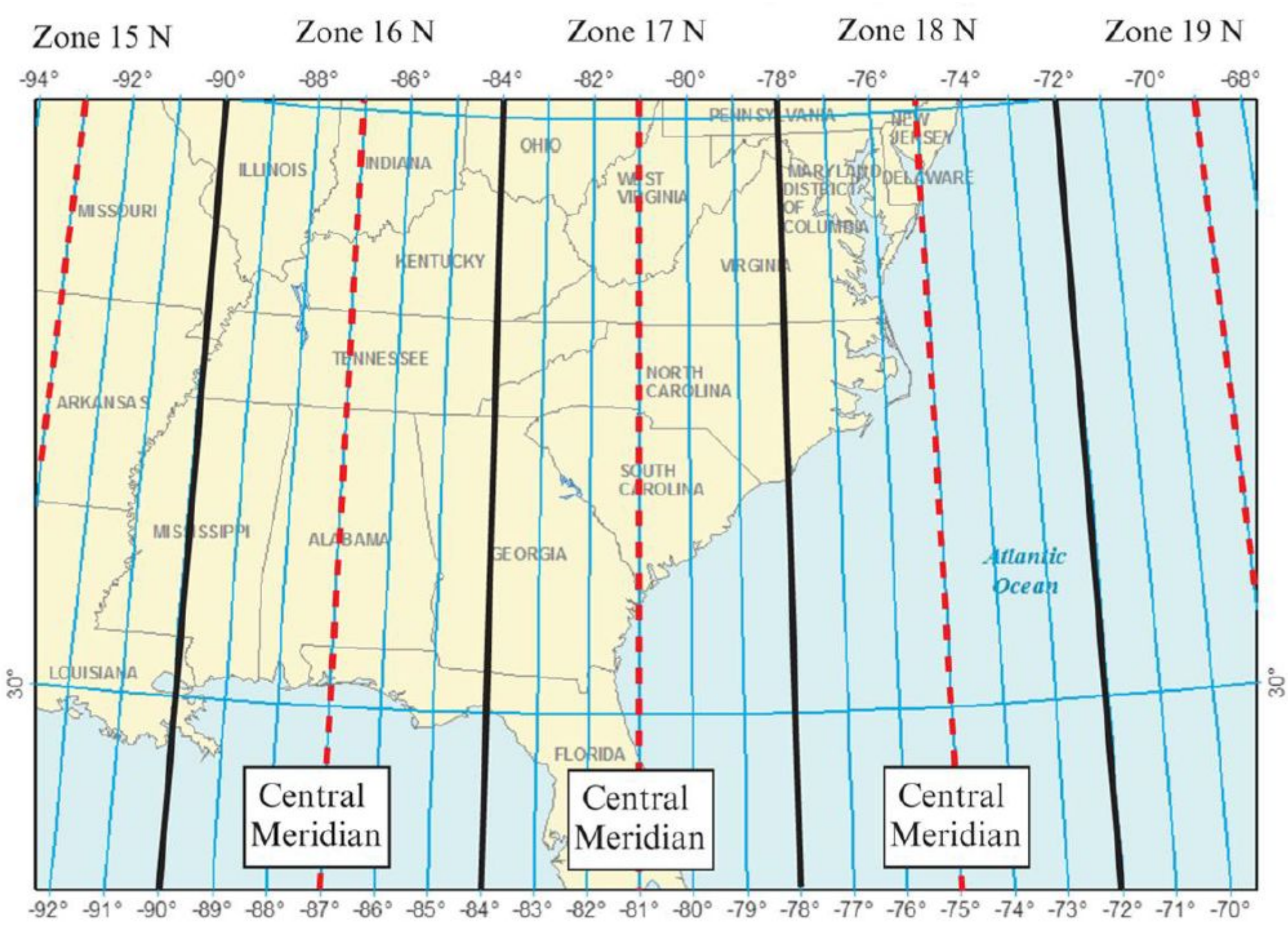
1. Universal Transverse Mercator (UTM)
2. Universal Polar Stereographic (UPS)
3. State Plane Coordinate System (SPC)
4. Public Land Survey System (PLSS)



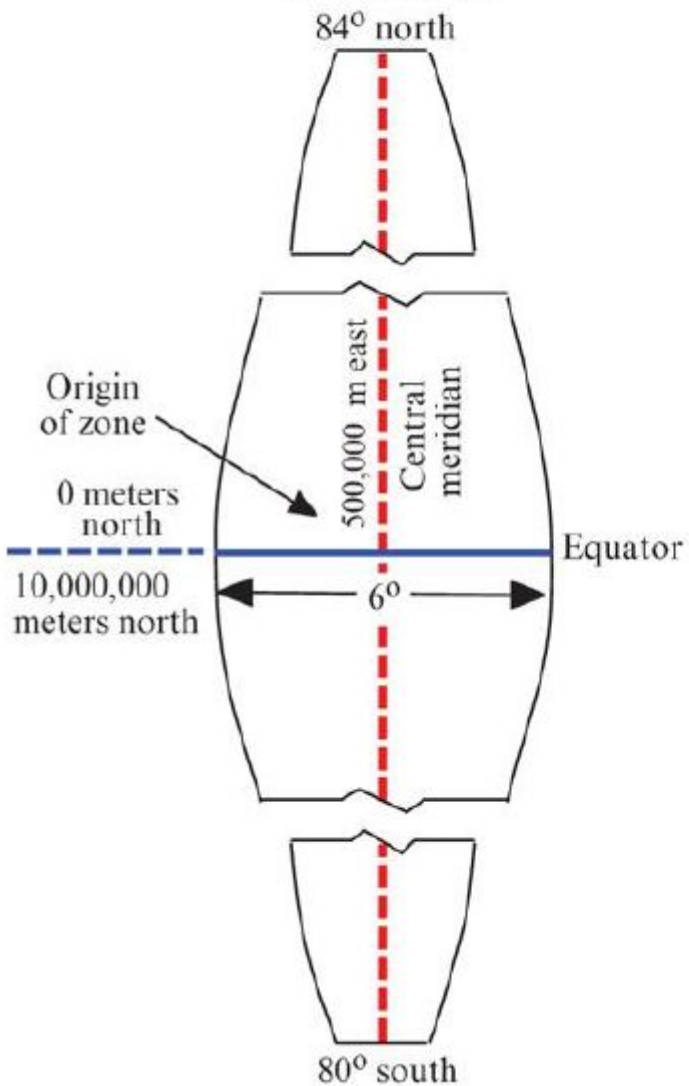
UTM Coordinate System

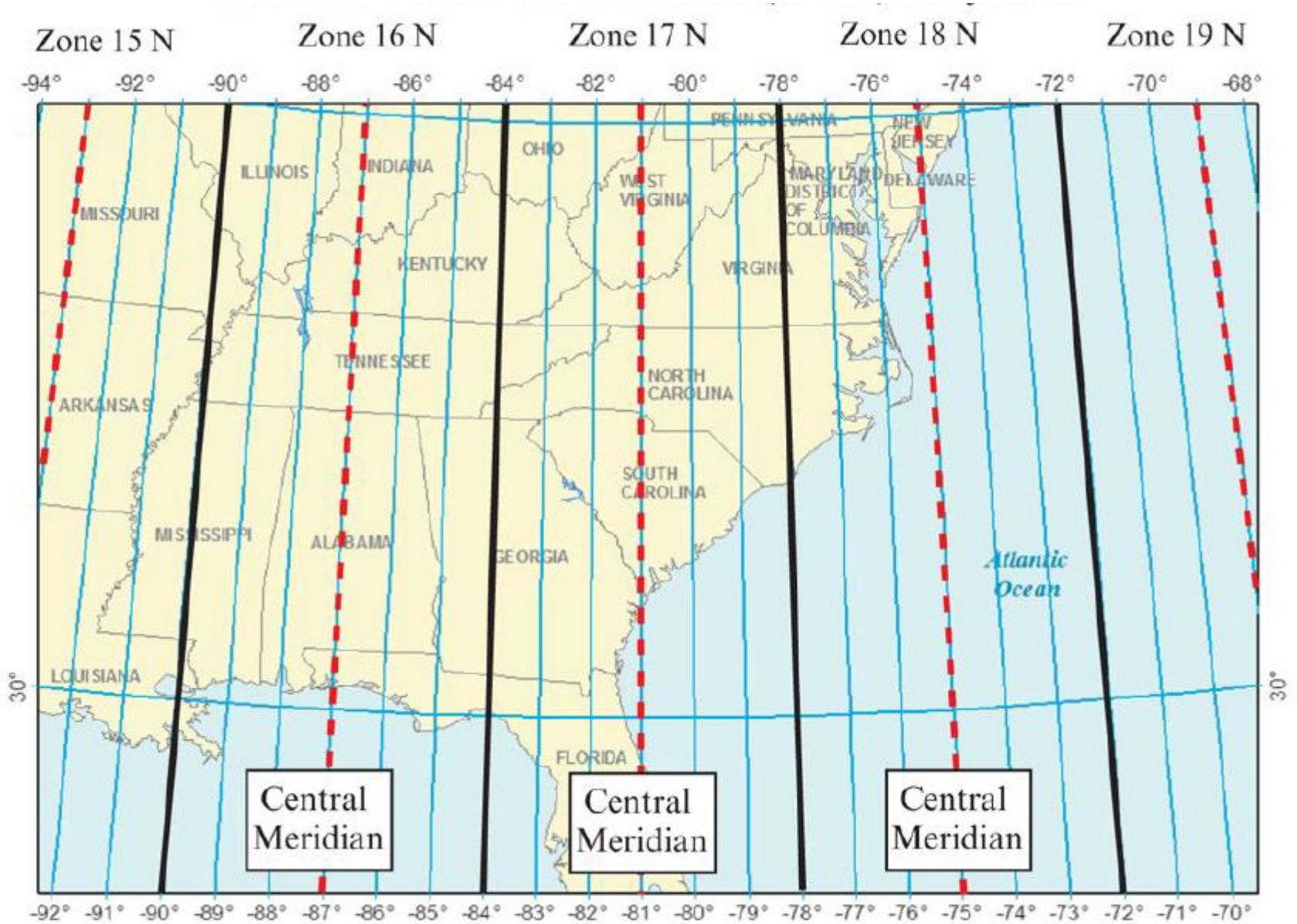
- UTM
- 84° N to 80° S.
- 60 zones, 6° each; which are we in?
- Uses Transverse Mercator projection.
- Scale factor = 0.9996
- Y-shift = 0, measured from equator in northern hemisphere; x-shift = 500,000 m from central meridian.
- In southern hemisphere, y-shift = 10,000,000 m at equator and x-shift of 500,000 m from central meridian.


84N
72N
64N
56N
48N
40N
32N
24N
16N
8N
0
8S
16S
24S
32S
40S
48S
56S
64S
72S
80S
X
W
V
U
T
S
R
Q
P
M
L
K
J
H
G
F
E
D
1N 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30N 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60
1C 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30C 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60
180W 174W 168W 162W 156W 150W 144W 138W 132W 126W 120W 114W 108W 102W 96W 90W 84W 78W 72W 66W 60W 54W 48W 42W 36W 30W 24W 18W 12W 6W 0 6E 12E 18E 24E 30E 36E 42E 48E 54E 60E 66E 72E 78E 84E 90E 96E 102E 108E 114E 120E 126E 132E 138E 144E 150E 156E 162E 168E 174E 180E



Jensen and Jensen, 2013





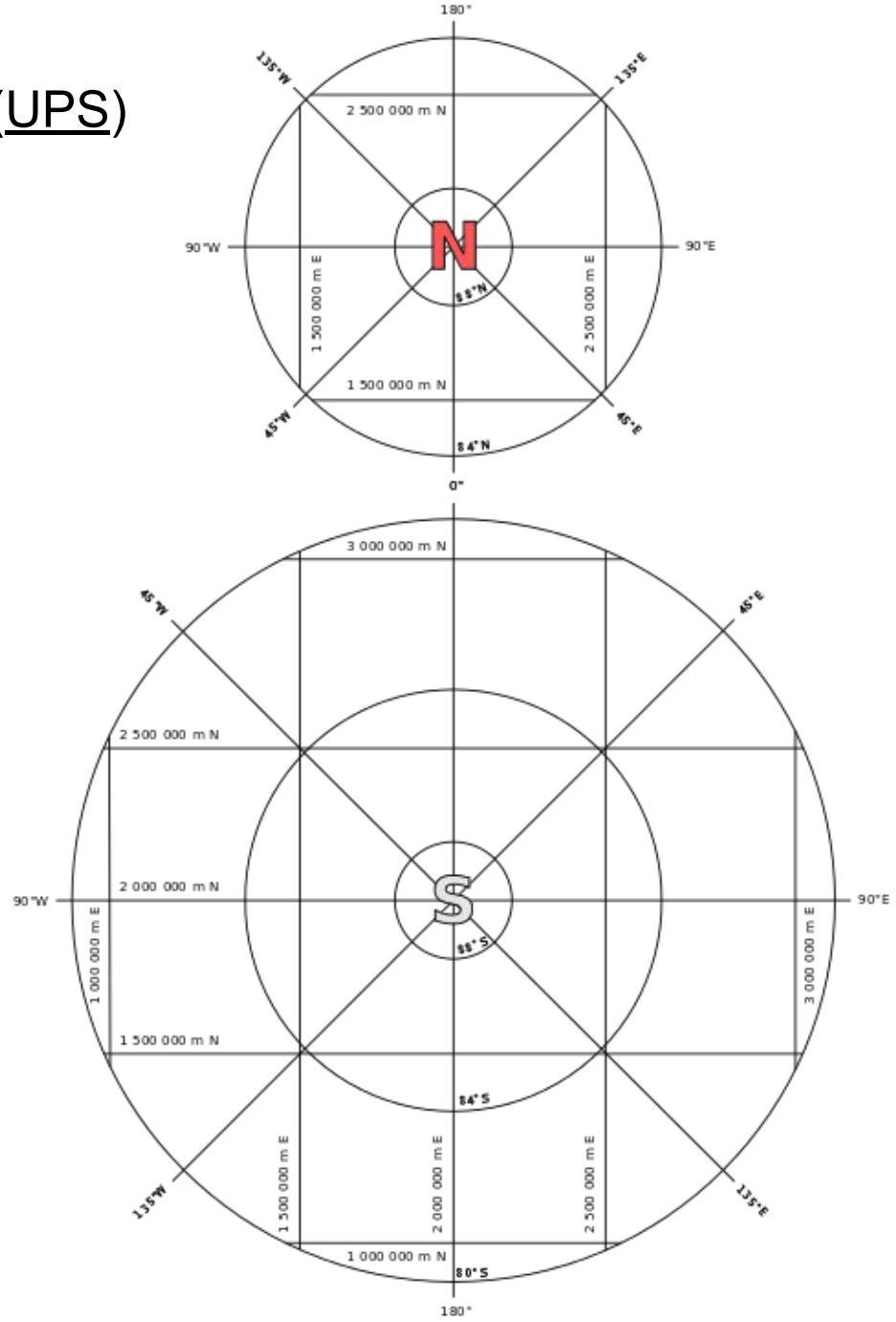
Jensen and Jensen, 2013

When Coordinates go Wrong

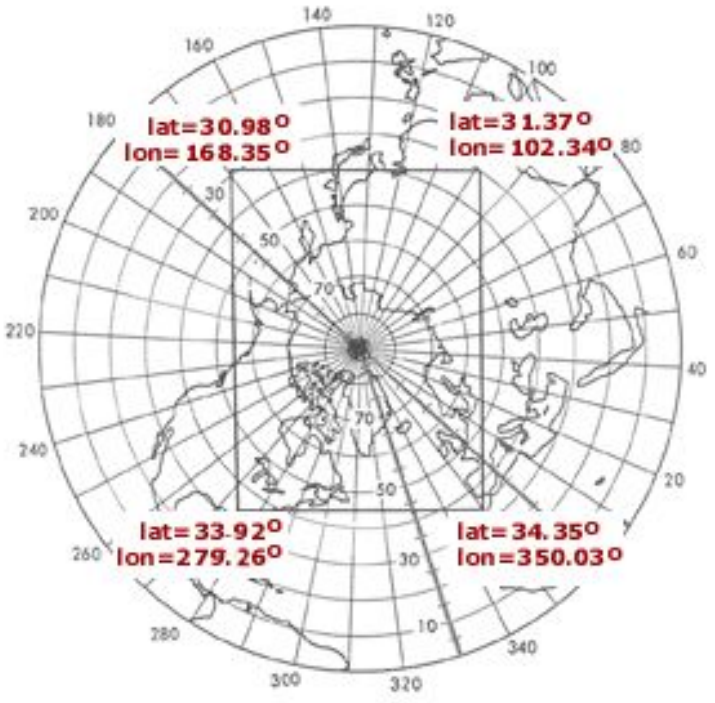
Lake Peigneur and the Salt Dome

Due to an incorrect or misinterpreted coordinate reference system (the drill-rig was positioned as if the coordinates were in the Universal Transverse Mercator coordinate system when, in actuality, they were in transverse Mercator projection), a 200 foot lake was accidentally created.

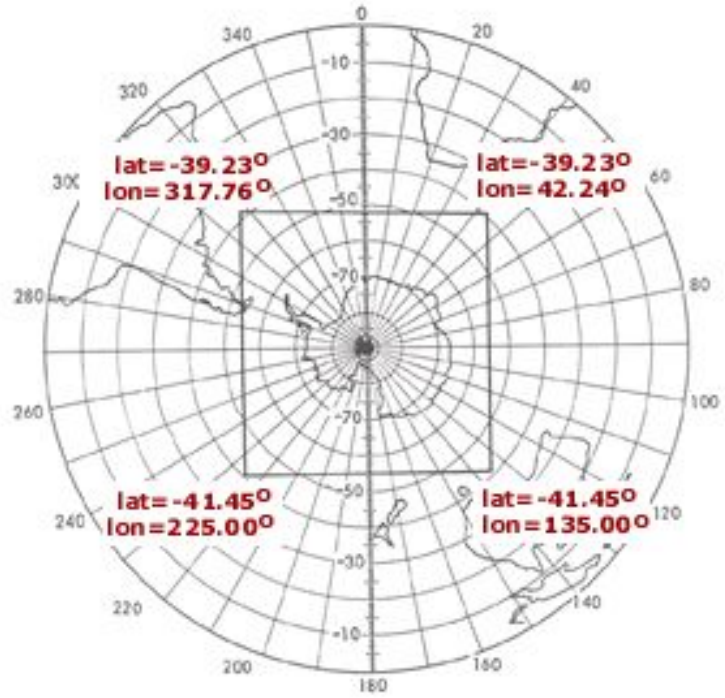
Universal Polar Stereographic (UPS)



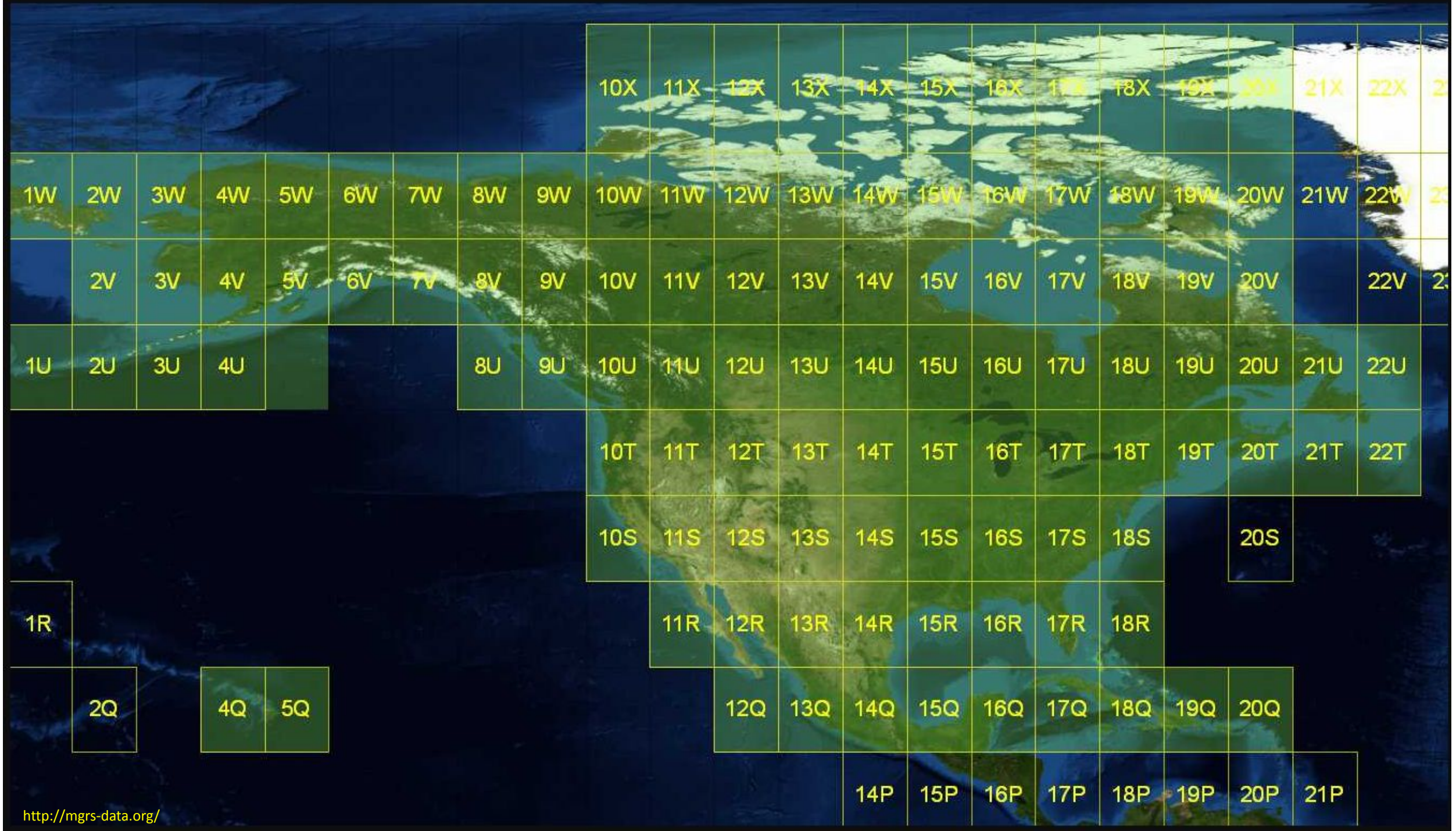
Universal Polar Stereographic (UPS)



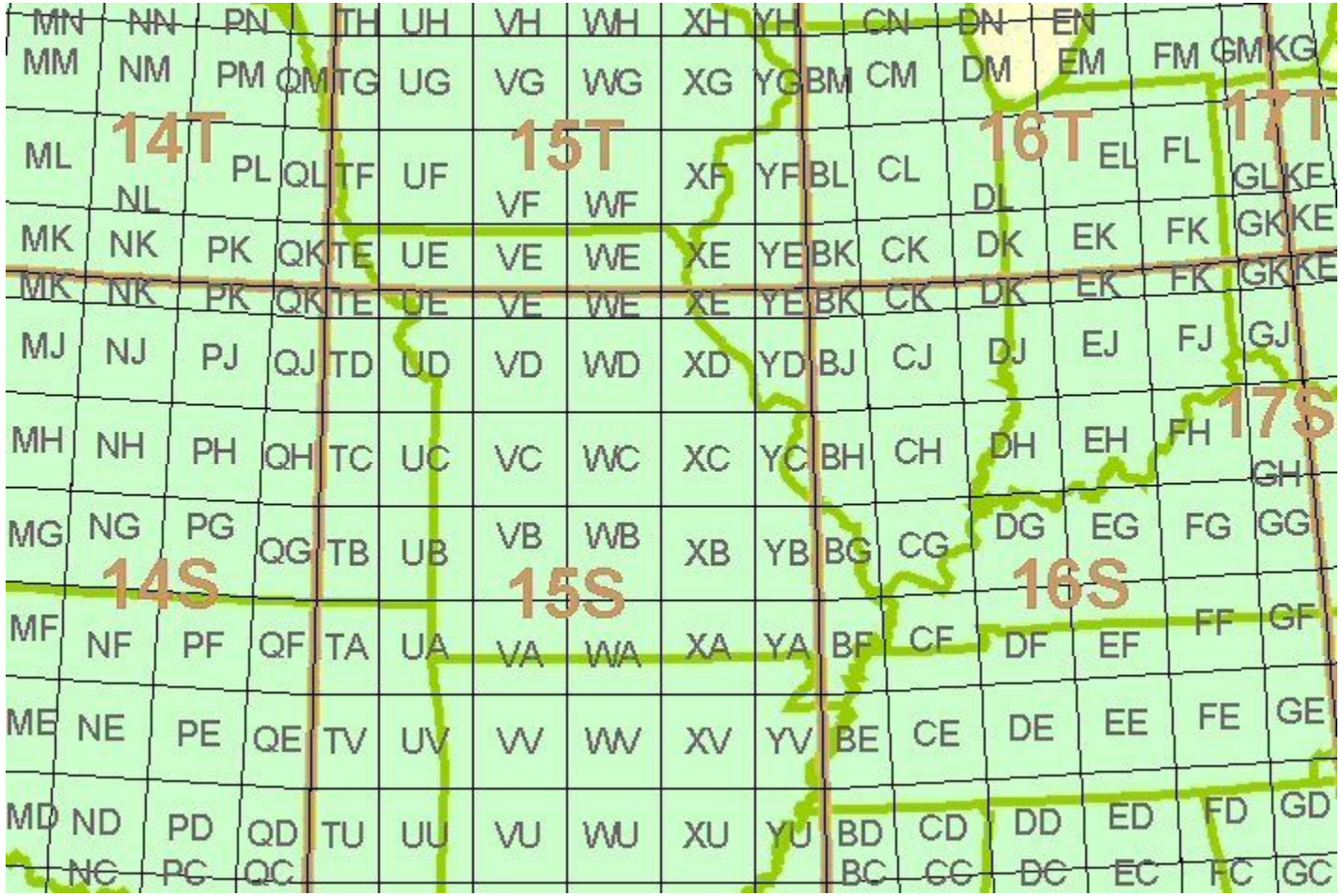
Northern Hemisphere

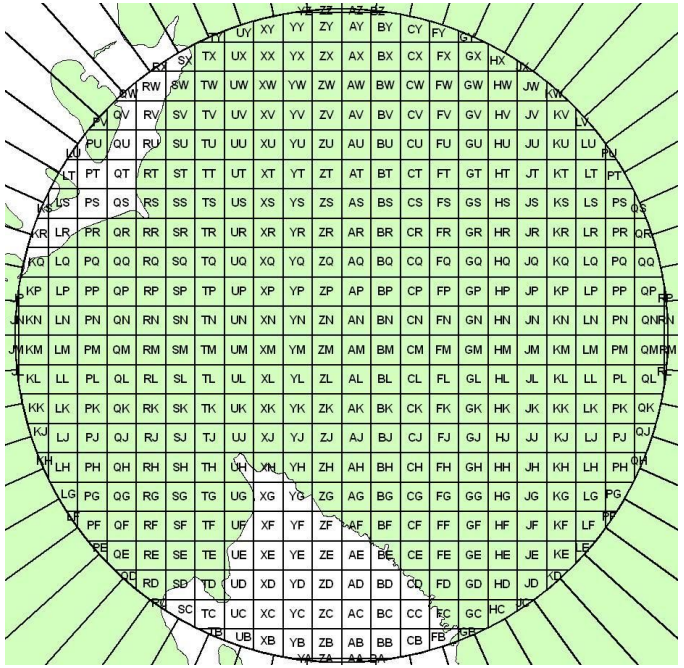


Southern Hemisphere

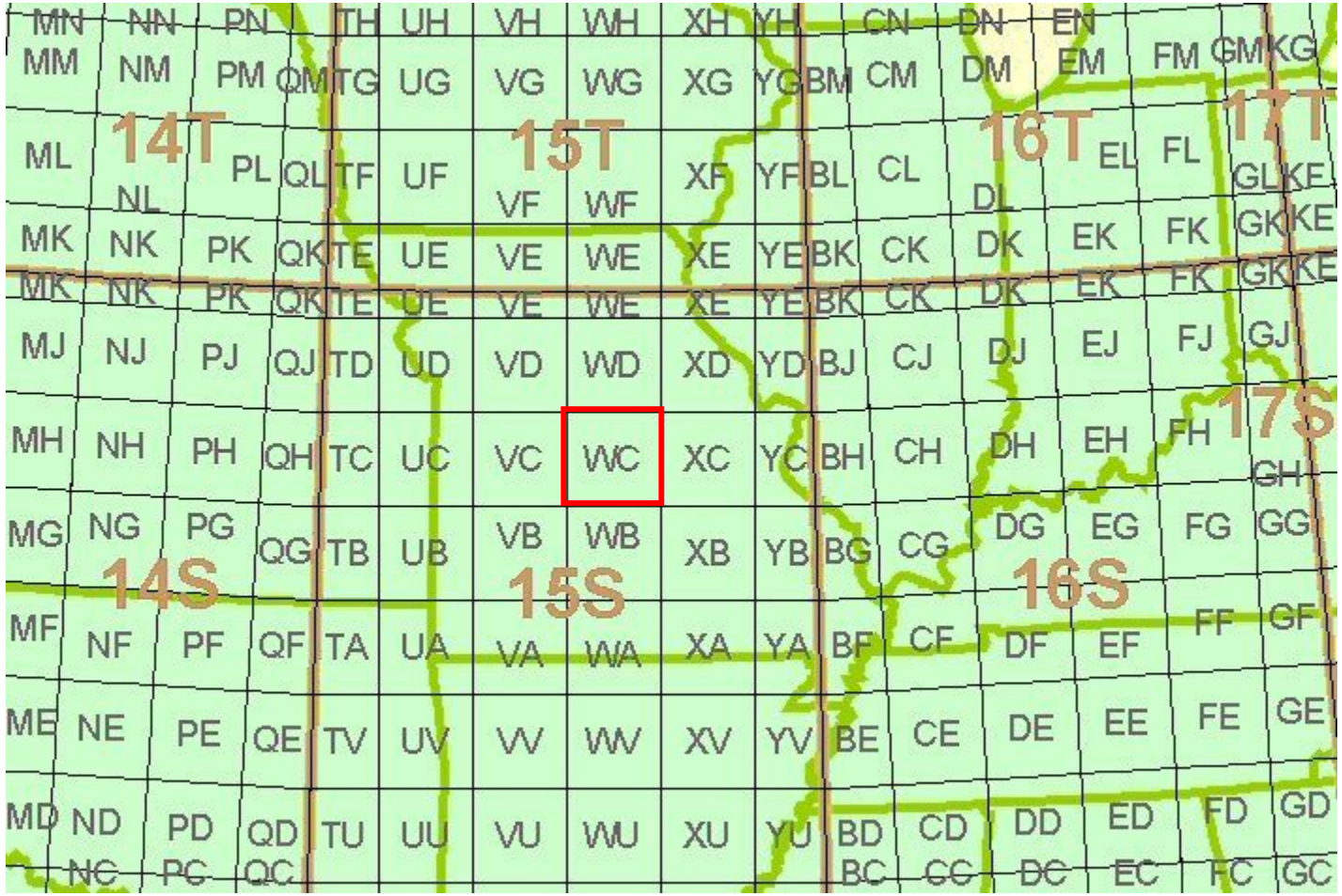

10X 11X 12X 13X 14X 15X 16X 17X 18X 19X 20X 21X 22X
1W 2W 3W 4W 5W 6W 7W 8W 9W 10W 11W 12W 13W 14W 15W 16W 17W 18W 19W 20W 21W 22W
2V 3V 4V 5V 6V 7V 8V 9V 10V 11V 12V 13V 14V 15V 16V 17V 18V 19V 20V 22V
1U 2U 3U 4U 8U 9U 10U 11U 12U 13U 14U 15U 16U 17U 18U 19U 20U 21U 22U
10T 11T 12T 13T 14T 15T 16T 17T 18T 19T 20T 21T 22T
10S 11S 12S 13S 14S 15S 16S 17S 18S 20S
1R 11R 12R 13R 14R 15R 16R 17R 18R
2Q 4Q 5Q 12Q 13Q 14Q 15Q 16Q 17Q 18Q 19Q 20Q
14P 15P 16P 17P 18P 19P 20P 21P
http://mgrs-data.org/

Military Grid Reference System (MGRS)

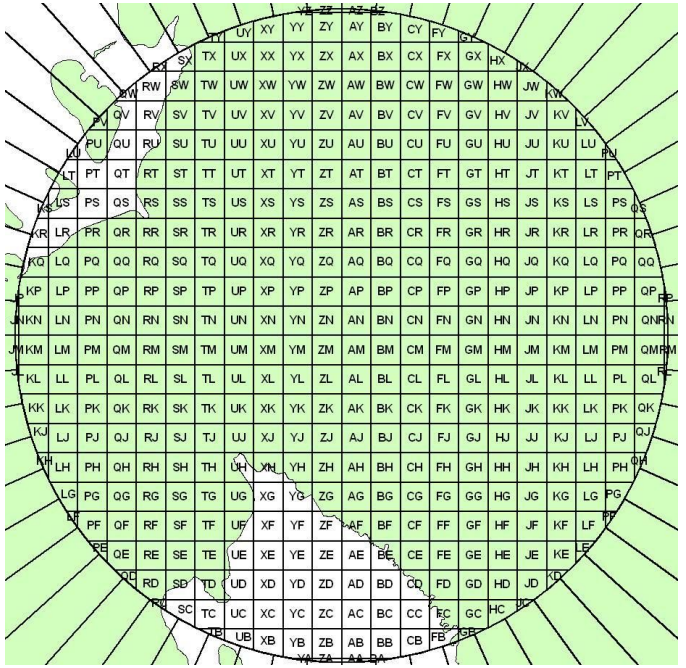




http://earth-info.nga.mil/GandG/coordsys/grids/universal_grid_system.html#zz10



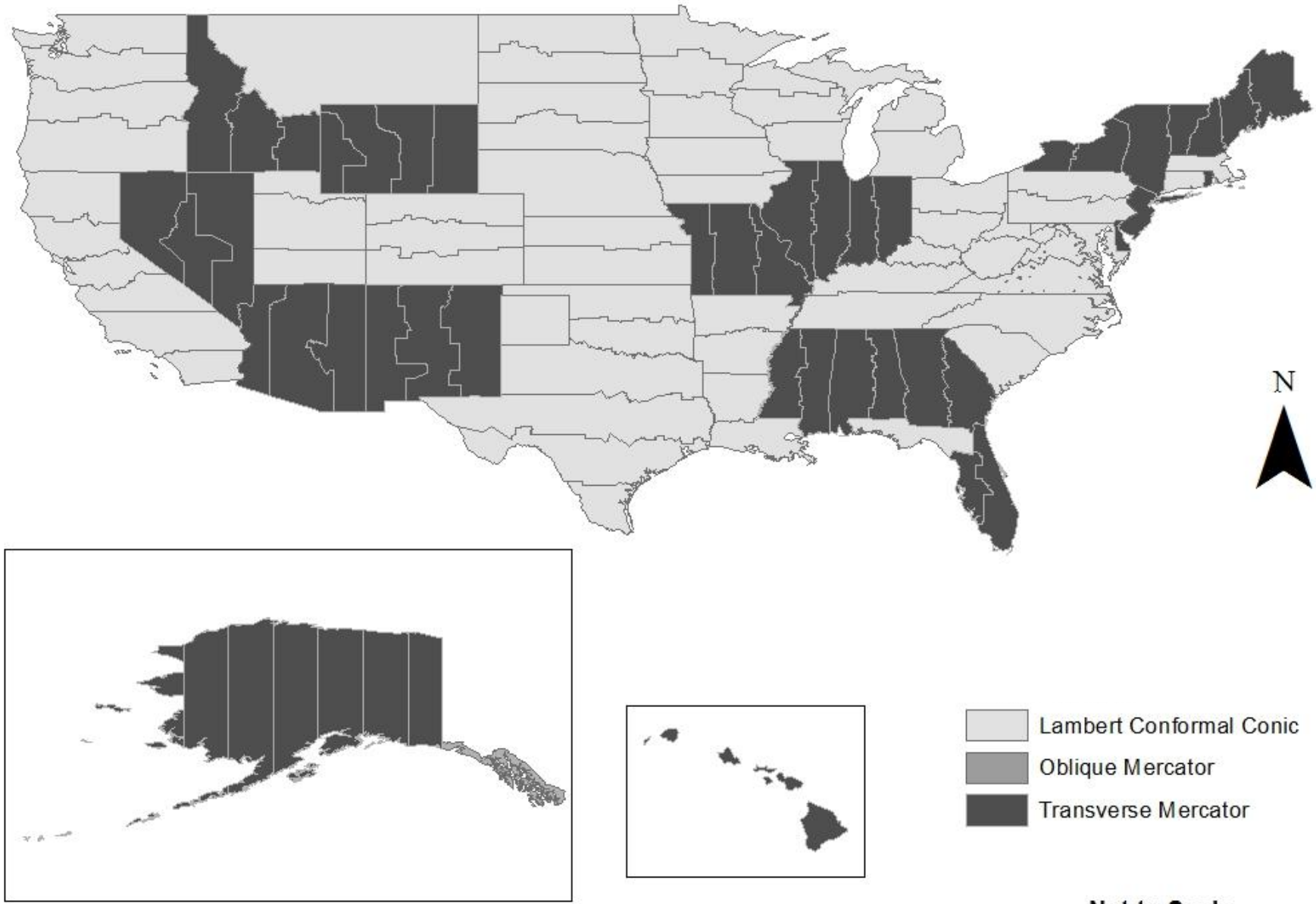
Military Grid Reference System (MGRS)



- **15SWC** is at the 100,000-meter refinement
- **15SWC8151** is at 1000-meter refinement.
- **15SWC808512** is at 100-meter refinement.
- **15SWC80825121** is at 10-meter refinement.
- **15SWC8081751205** is at 1-meter refinement.

http://earth-info.nga.mil/GandG/coordsys/grids/universal_grid_system.html#zz10

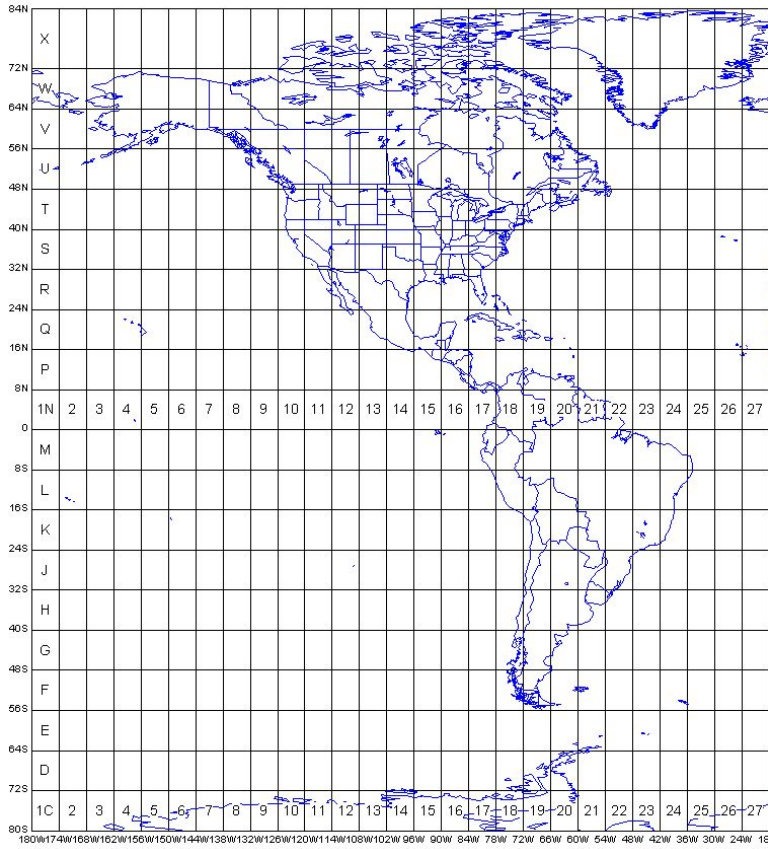
State Plane Coordinate Systems



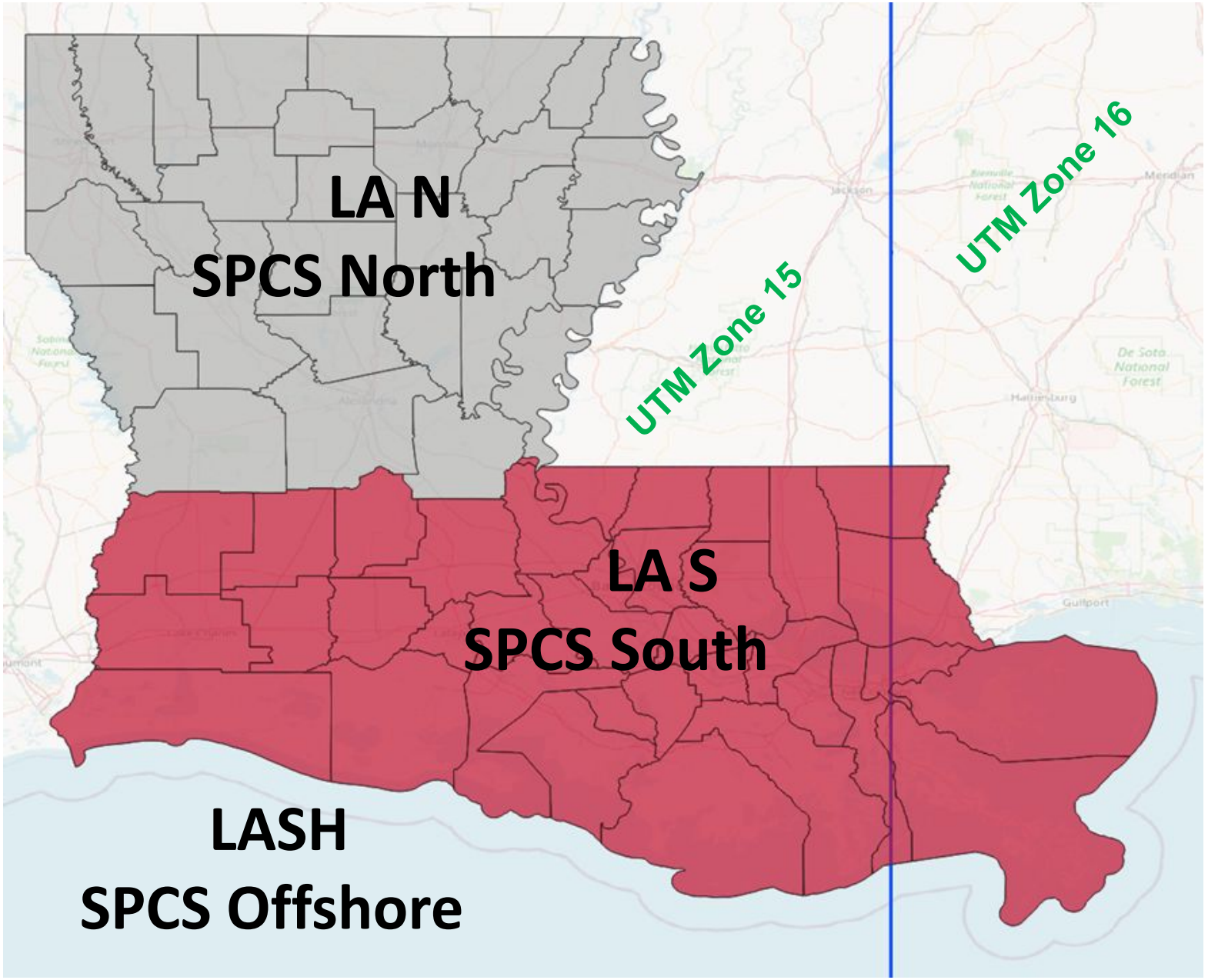
Grid North

State Plane Coordinate System (SPCS)

Universal Transverse Mercator (UTM)



http://www.dmap.co.uk/utmworld.htm



- **Understanding GNSS and GPS:**
  - https://www.gps.gov/students/
  - http://www.gpsprimer.net/

- **Understanding Distortion and Map Projections:**
  - https://www.e-education.psu.edu/geog862/node/1808
  - https://www.esri.com/arcgis-blog/products/arcgis-pro/education/earth-peel/

- **Understanding UTM Map Coordinates:**
  - https://www.maptools.com/tutorials/utm/quick_guide