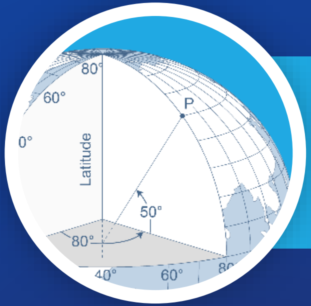
Coordinate Systems in ArcGIS

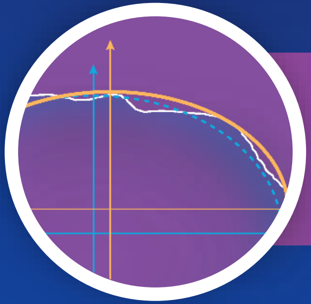
Melita Kennedy & Bojan Šavrič

SEE
WHAT
OTHERS
CAN'T



Coordinate Systems

Map Projections



Transformations

Map of the Gaslamp Quarter

My data is everywhere else except…

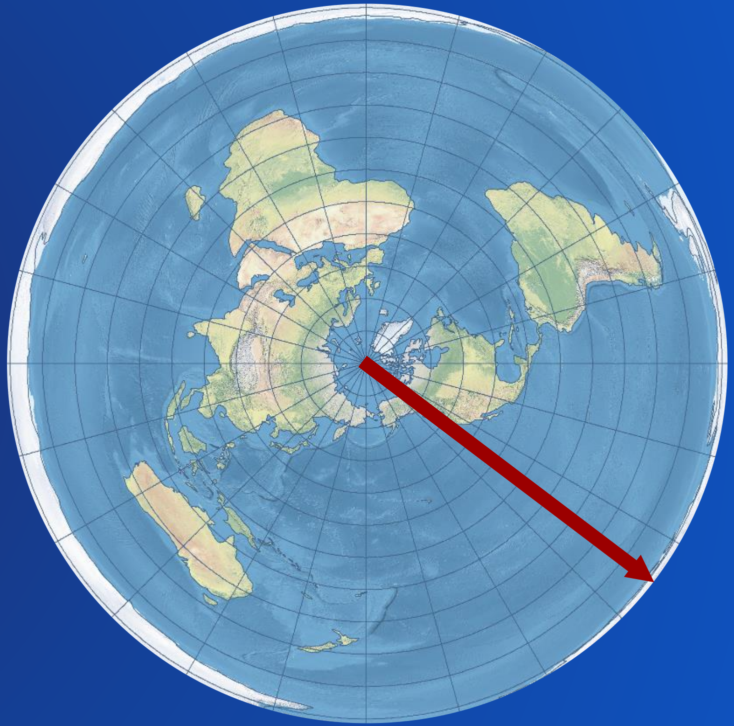
Horizontal Coordinate Systems

Geographic and Projected

What does a coordinate system tell us?

Distance

Location



Direction

Distance

Q: How far is it from San Francisco to Los Angeles?

352.34 miles

690.67 kilometers

567.03 kilometers

620111.549 yards

Distance

Q: How far is it from San Francisco to Los Angeles?

A: It depends on the coordinate system.

- 352.34 miles
- 690.67 kilometers
- 567.03 kilometers
- 620111.549 yards

Location

Q: What are the coordinates for Los Angeles?

(-118.25, 34.05)

(1276.333, 2421.545)

(2054060.514, 3897101.109)

(-13163527.521, 4035514.817)

Location

Q: What are the coordinates for Los Angeles?

A: It depends on the coordinate system.

(-118.25, 34.05)

(1276.333, 2421.545)

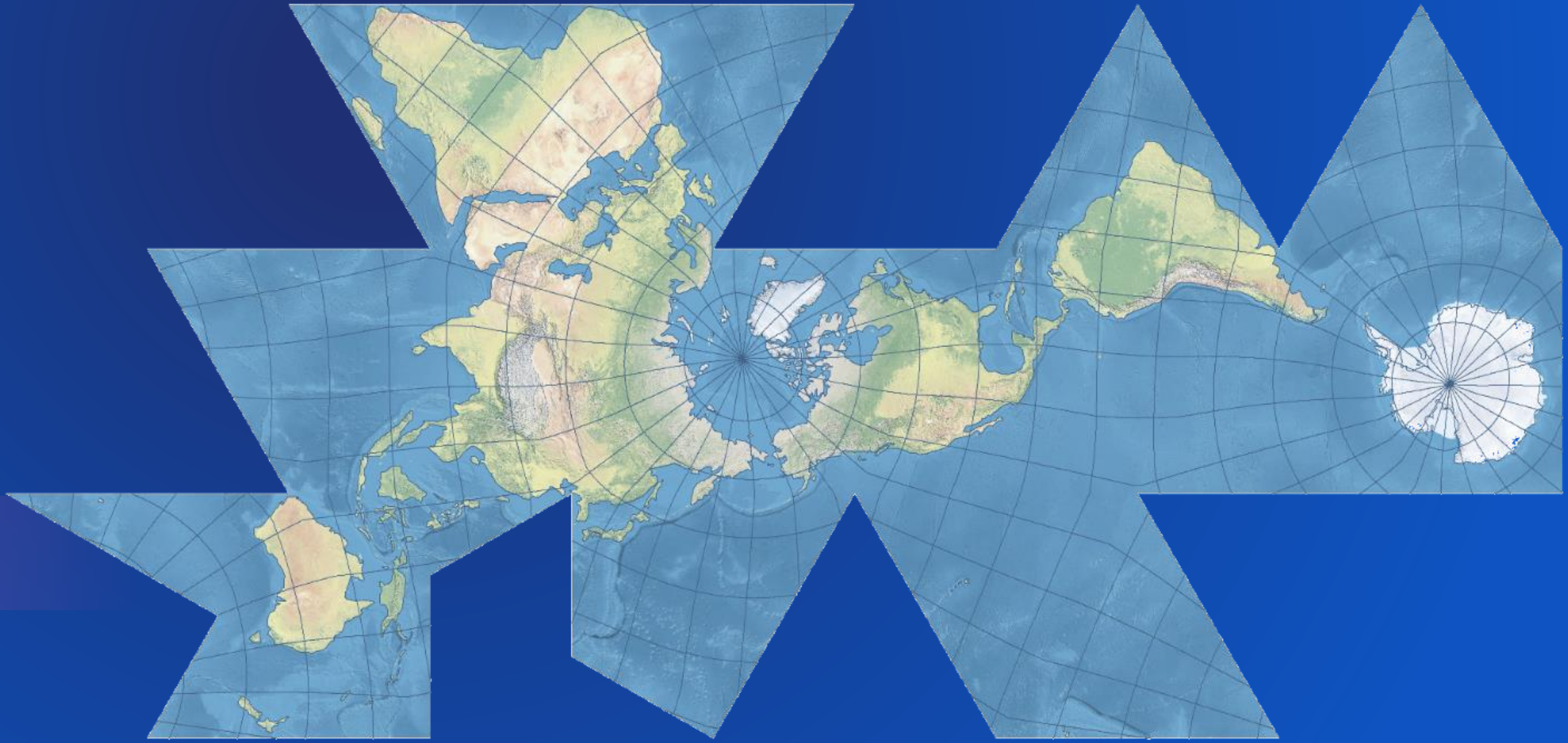
(2054060.514, 3897101.109)

(-13163527.521, 4035514.817)

Direction

Q: In which direction is the North Pole?

- Down
- To the right
- Up
- Can’t, not on the map



Direction

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- To the right
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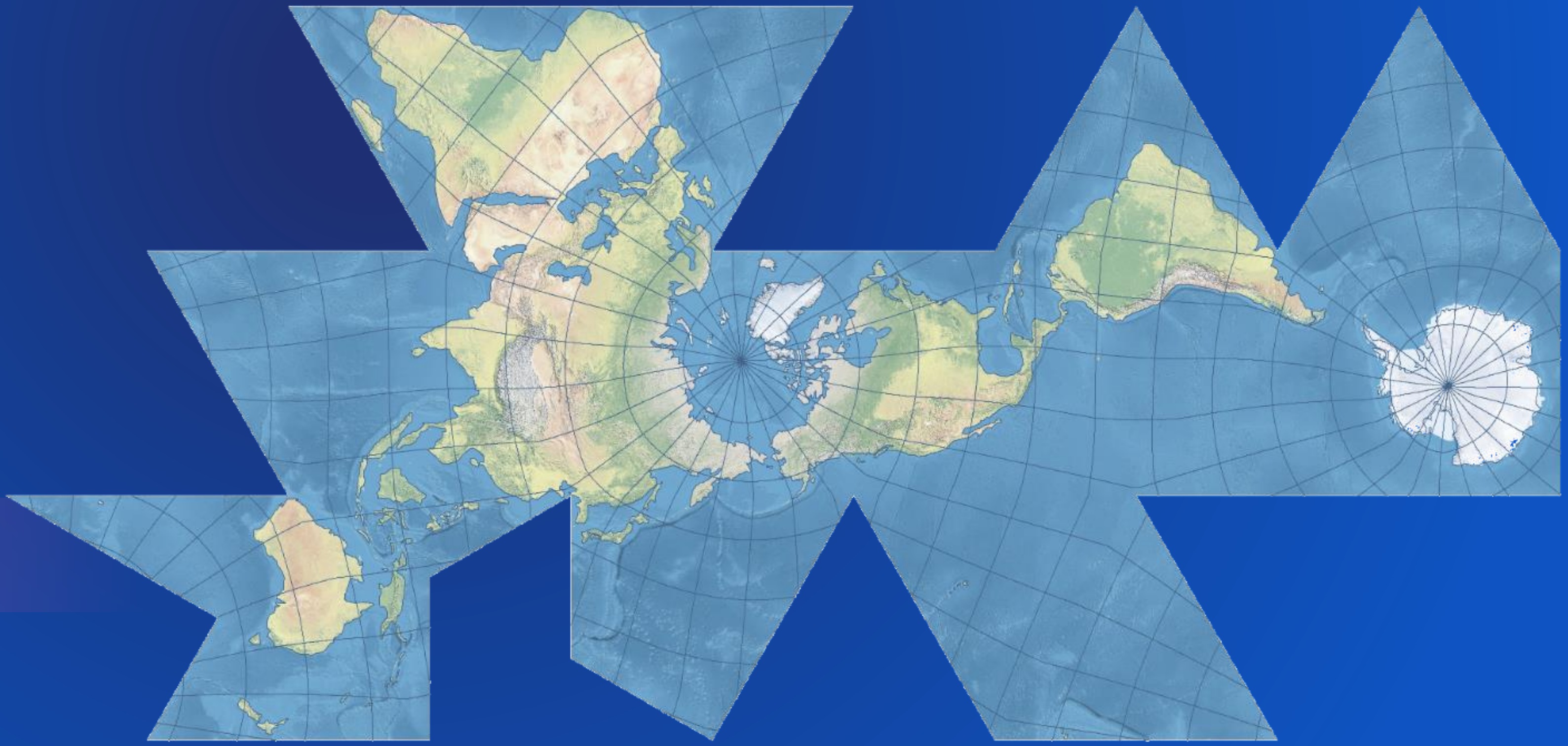


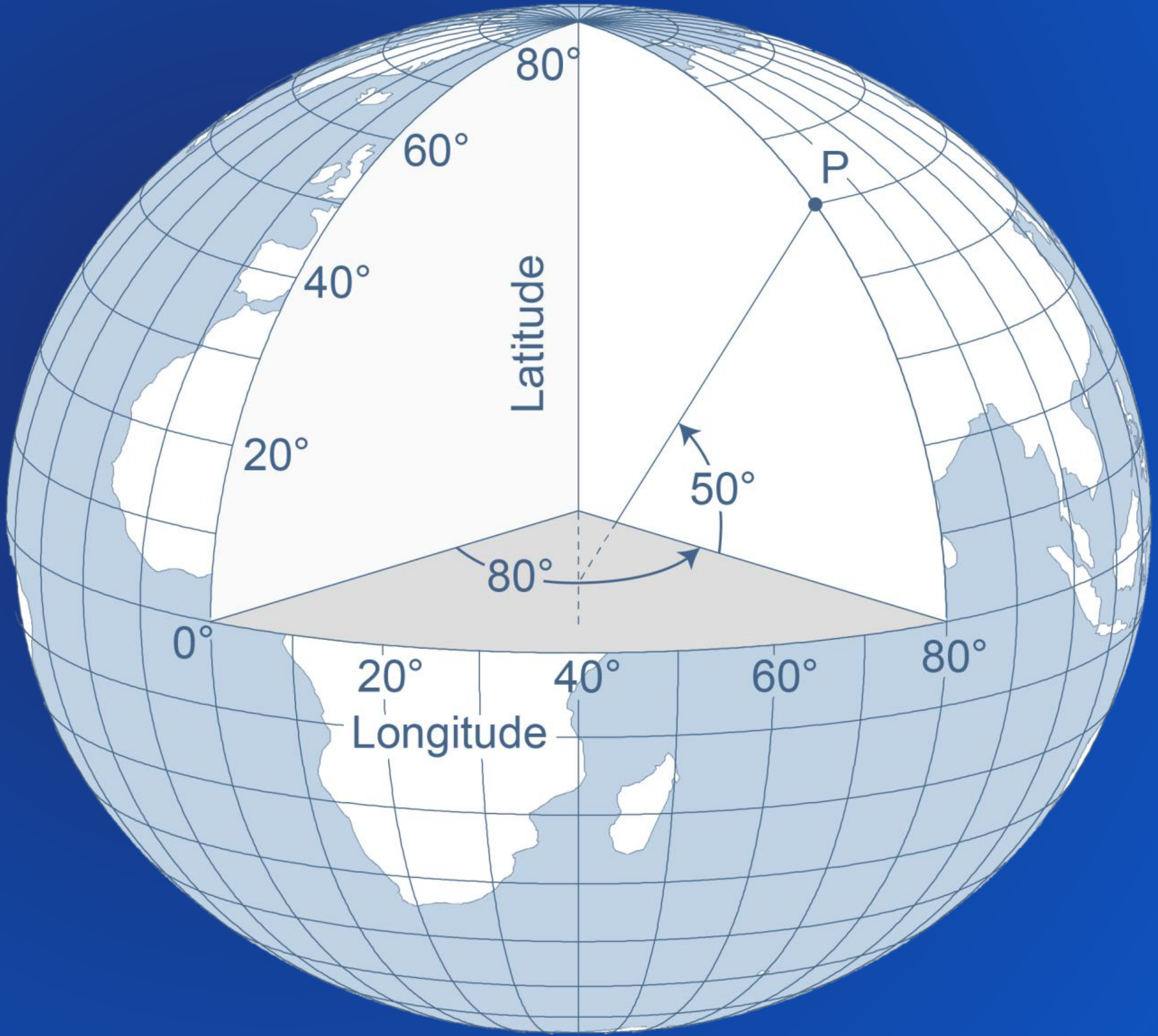
Two Kinds of Horizontal Coordinate Systems

Geographic coordinate system

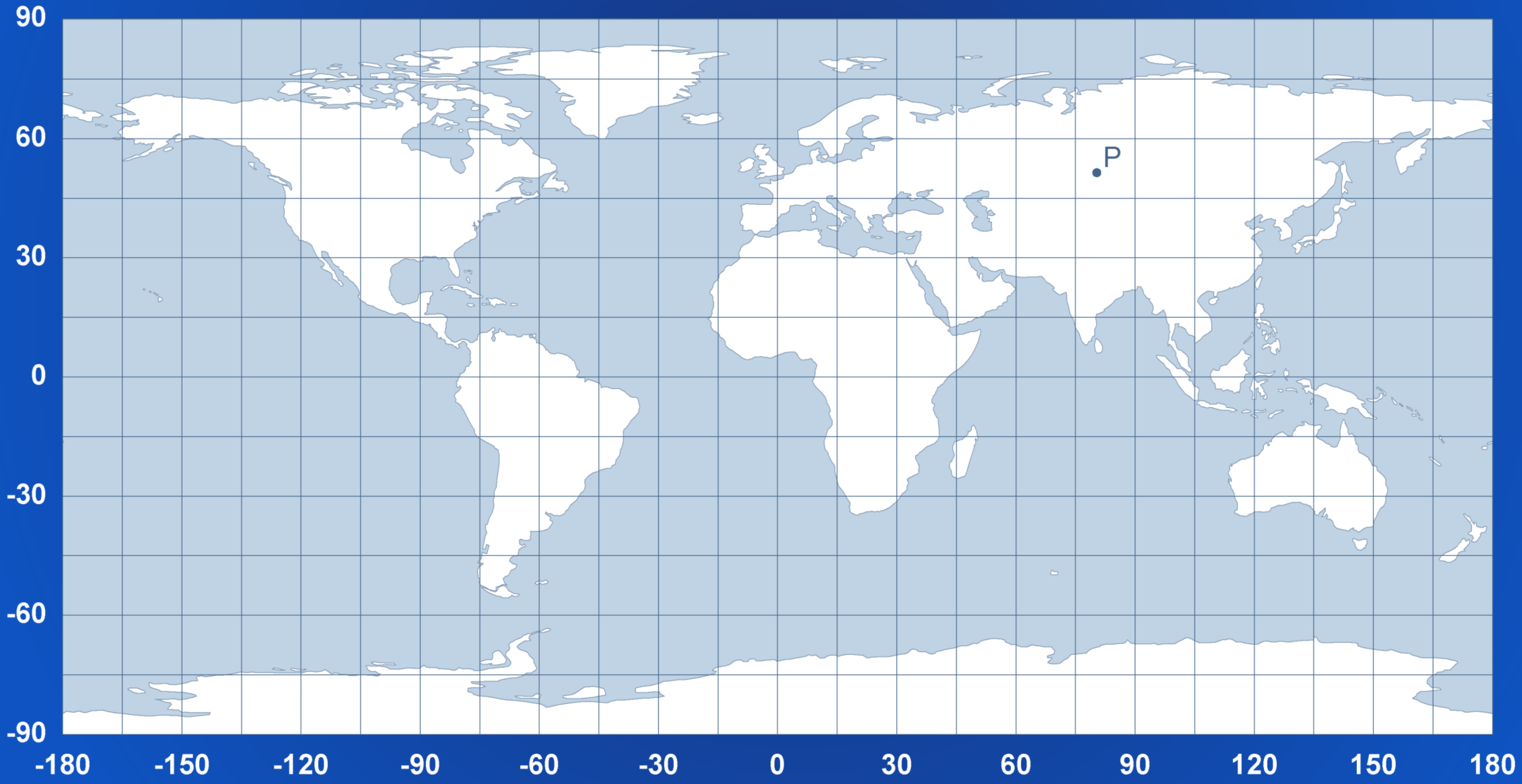
Projected coordinate system

Geographic Coordinate System (GCS)

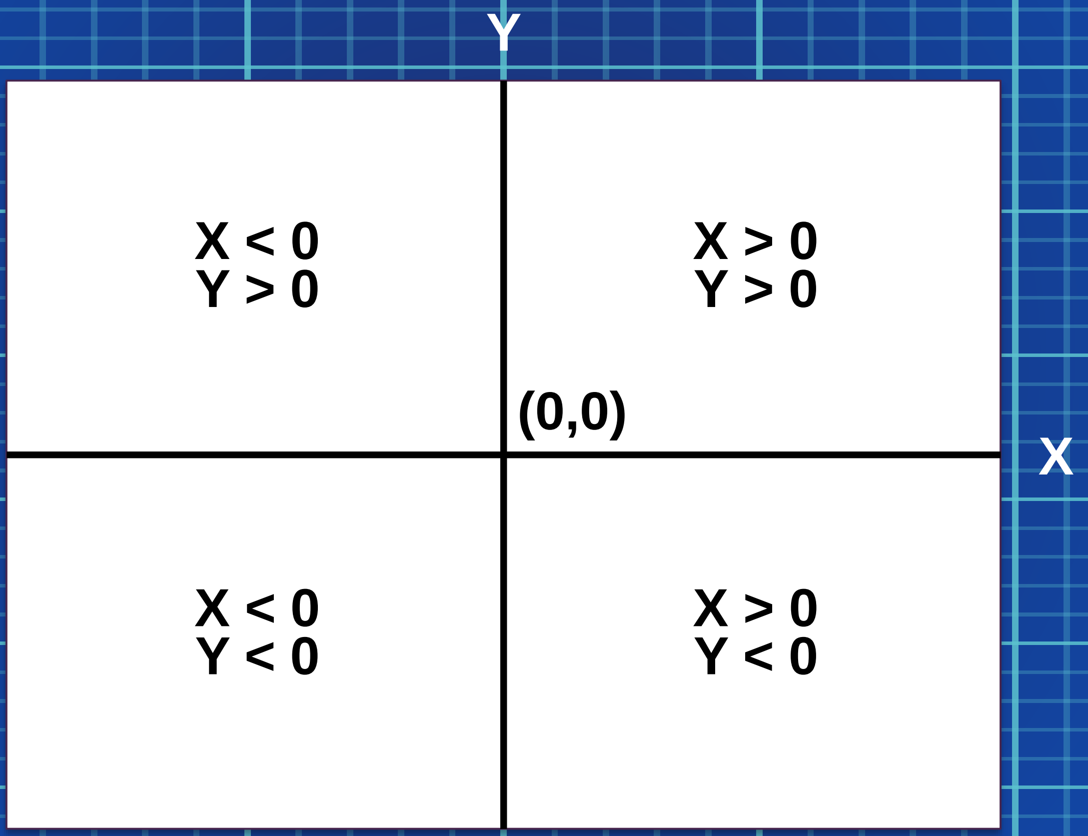
- 3D ellipsoidal surface
- Point P has:
  - Longitude – 80º E
  - Latitude – 50º N



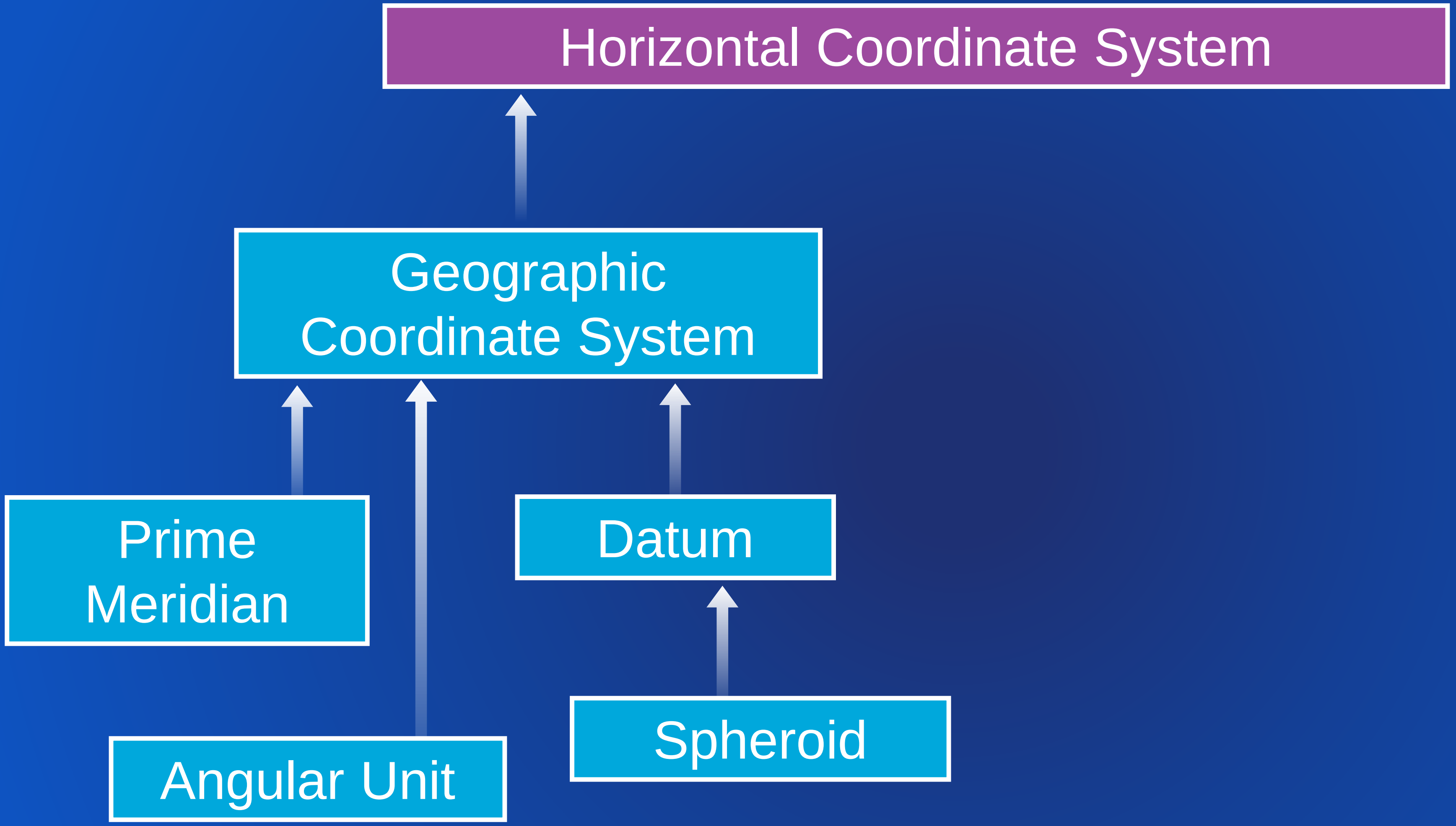
Geographic Coordinate System (GCS)

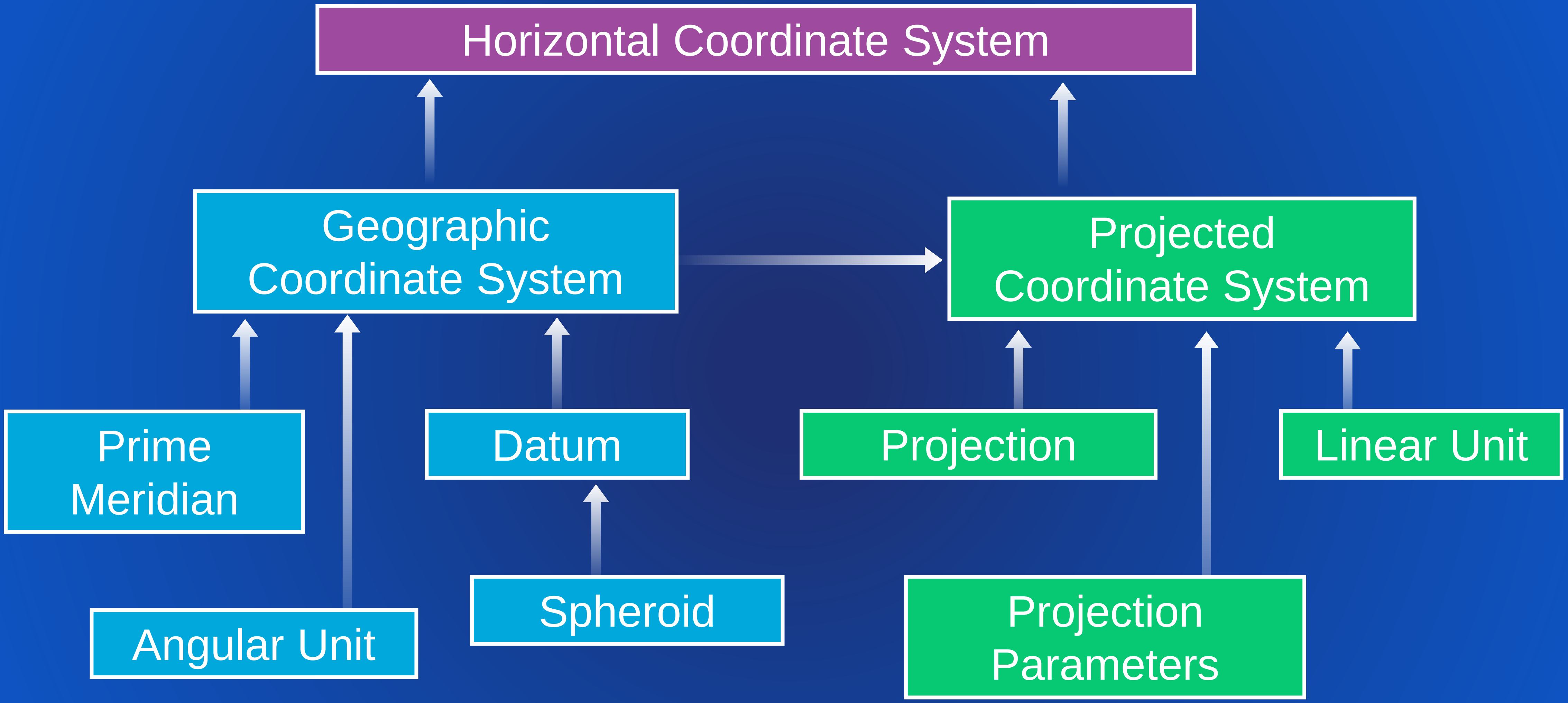


Projected Coordinate System (PCS)



Horizontal Coordinate System


Horizontal Coordinate System
Geographic Coordinate System
Prime Meridian
Angular Unit
Datum
Spheroid


Horizontal Coordinate System
Geographic Coordinate System
Projected Coordinate System
Prime Meridian
Angular Unit
Datum
Spheroid
Projection
Projection Parameters
Linear Unit

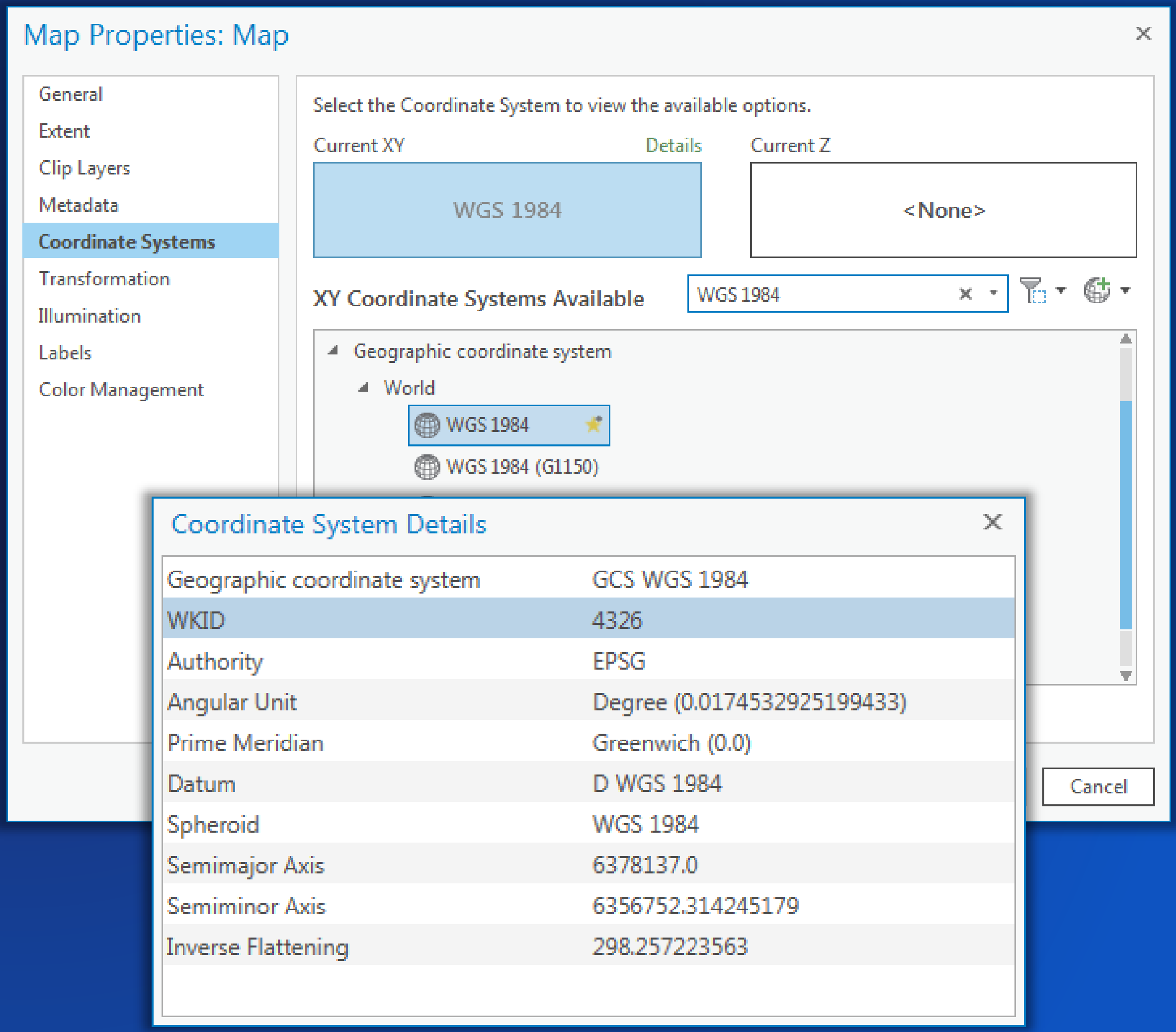
Two Ways to Specify a Coordinate System

Well-known ID

Well-known text

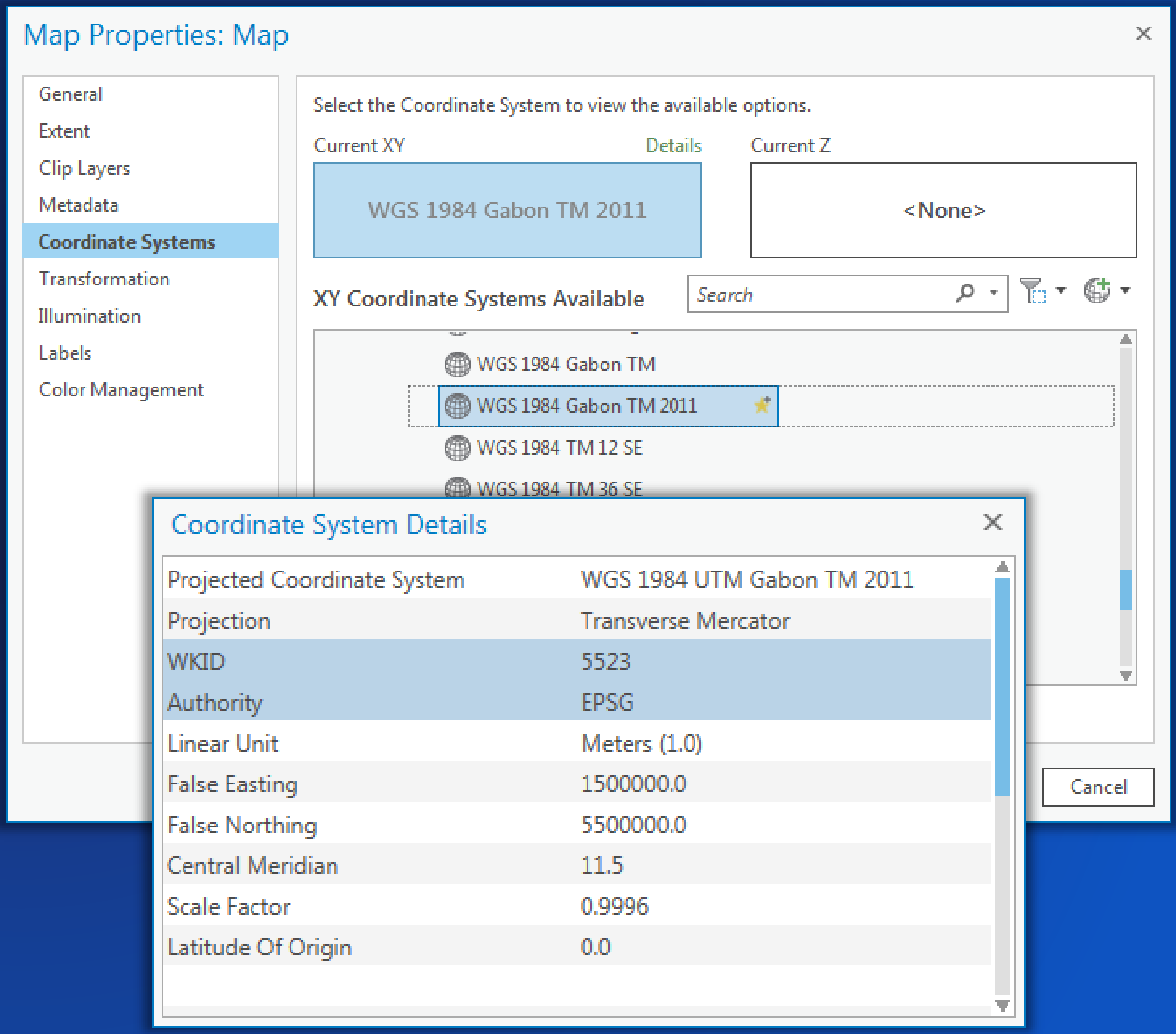
Well-Known ID (WKID)

- All predefined coordinate systems have a WKID



Well-Known ID (WKID)

- WKID ≤ 32767: EPSG
  - EPSG Geodetic Parameter Dataset
  - http://www.epsg-registry.org/



Well-Known ID (WKID)

- WKID ≤ 32767: EPSG
  - EPSG Geodetic Parameter Dataset
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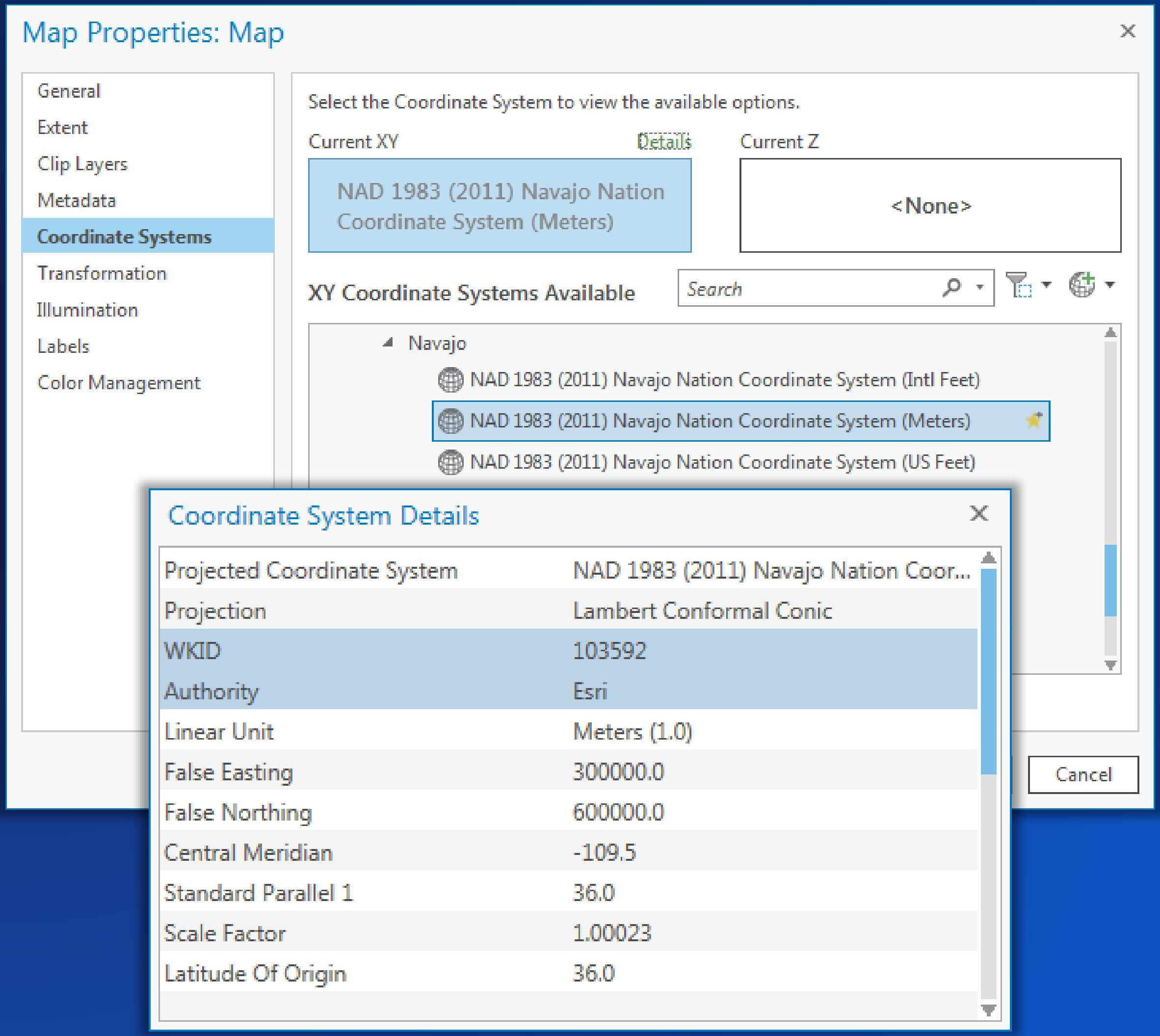
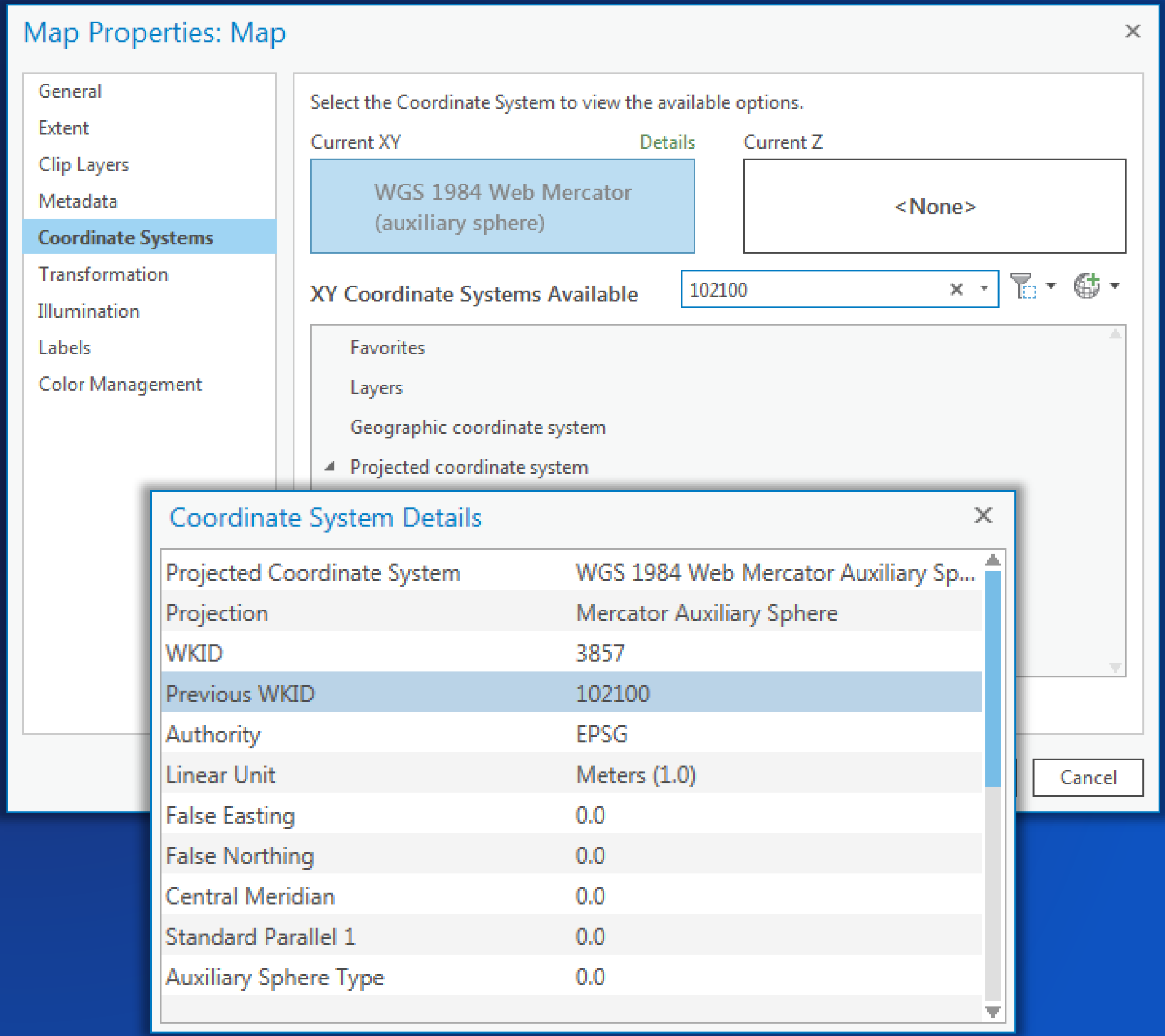
- WKID > 32767: Esri



Well-Known ID (WKID)

- WKID ≤ 32767: EPSG
  - EPSG Geodetic Parameter Dataset
  - http://www.epsg-registry.org/
- WKID > 32767: Esri
- Any WKID may change



Well-Known Text (WKT)

```
GEOGCS["GCS_ETRS_1989",
    DATUM["D_ETRS_1989",
        SPHEROID["GRS_1980",6378137.0,298.257222101]],
    PRIMEM["Greenwich",0.0],
    UNIT["Degree",0.0174532925199433]]
```

Geographic coordinate system

Well-Known Text (WKT)

```
PROJCS["ETRS_1989_UTM_Zone_32N",
  GEOGCS["GCS_ETRS_1989",
    DATUM["D_ETRS_1989",
      SPHEROID["GRS_1980",6378137.0,298.257222101]],
    PRIMEM["Greenwich",0.0],
    UNIT["Degree",0.0174532925199433]],
  PROJECTION["Transverse_Mercator"],
  PARAMETER["False_Easting",500000.0],
  PARAMETER["False_Northing",0.0],
  PARAMETER["Central_Meridian",9.0],
  PARAMETER["Scale_Factor",0.9996],
  PARAMETER["Latitude_Of_Origin",0.0],
  UNIT["Meter",1.0]]
```

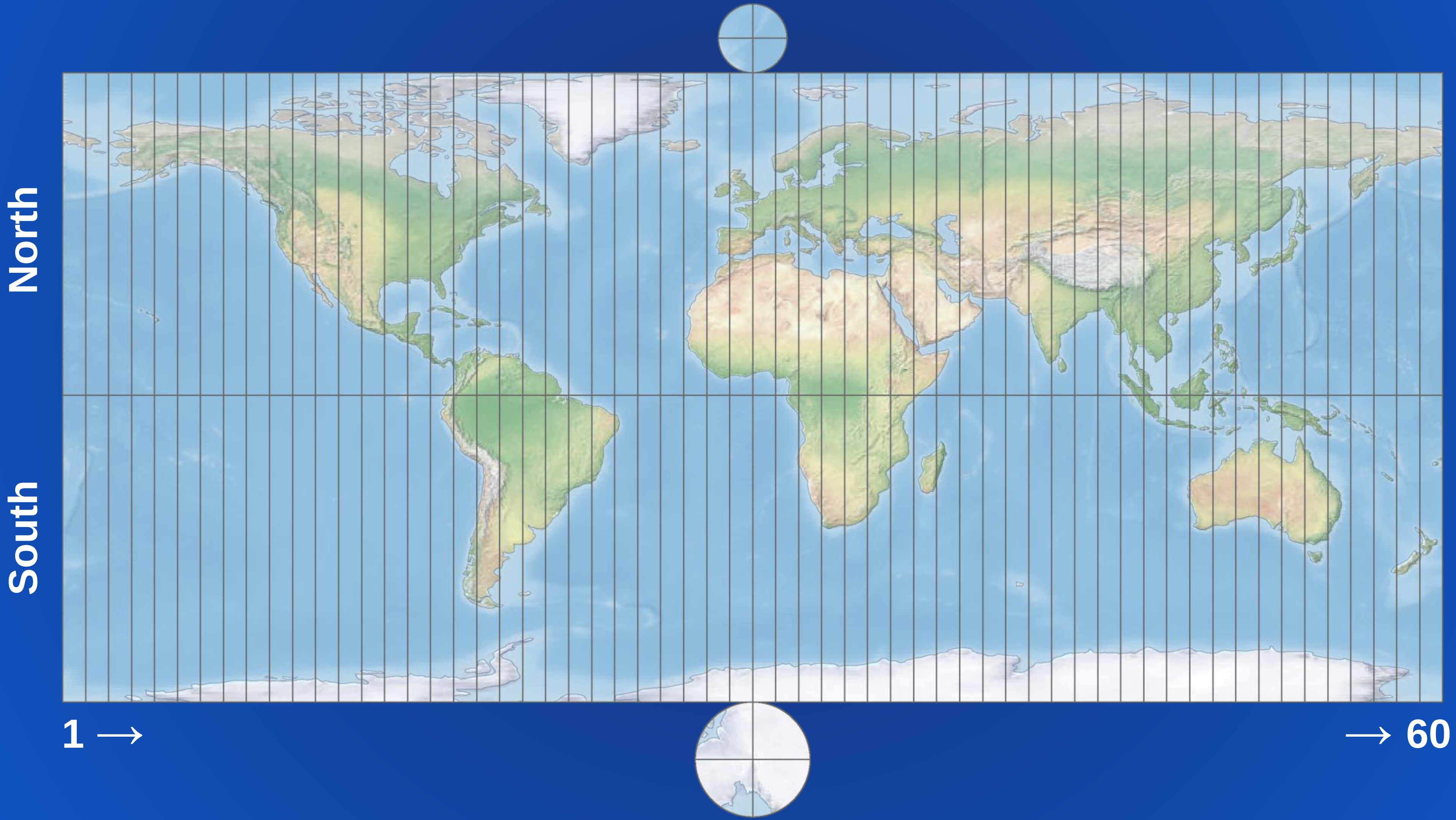
Projected coordinate system

Universal Transverse Mercator (UTM)

- Series of projected coordinate systems

Area of Use	world
Zones	60 zones, 6º wide
Projection	transverse Mercator
Scale Factor	0.9996
Central Meridian	$[(\#zone - 0.5) \times 6 - 180]^{\circ}$
False Easting	500 000 m
False Northing	0 m or 10 000 000 m for southern hemisphere

Universal Transverse Mercator (UTM)



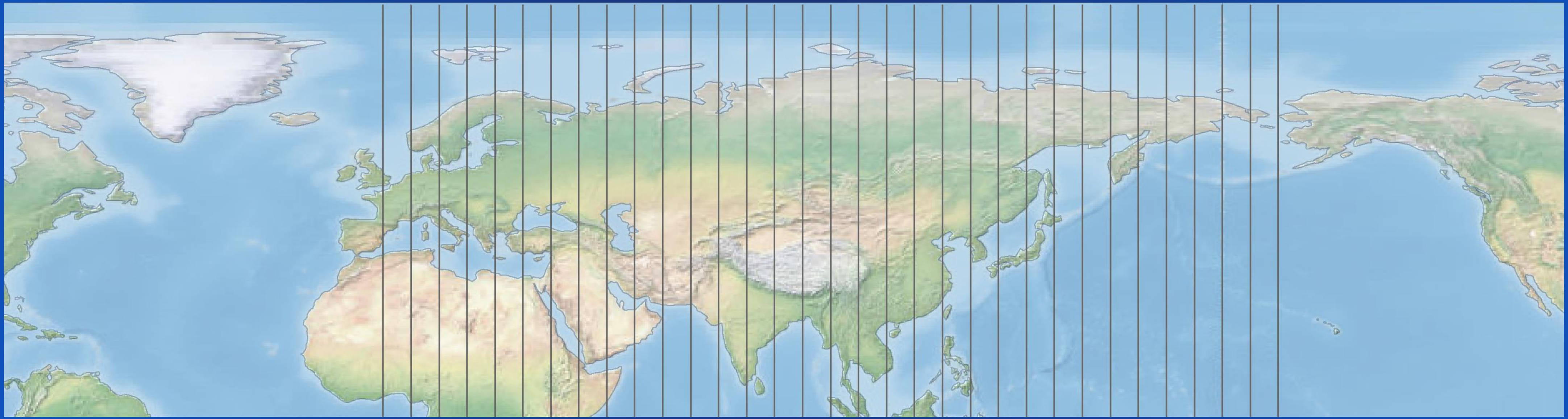
Gauss-Krüger (GK)

- Series of projected coordinate systems

Area of Use	countries in Europe & Asia
Zones	3º or 6º wide zones
Projection	transverse Mercator
Scale Factor	1.0
Central Meridian	$[\ (\#zone - 0.5) \times width\ ]^{\circ}$
False Easting	500 000 m or $[\ (\#zone + 0.5) \times 10^6\ ]$ m
False Northing	0 m

Gauss-Krüger (GK)

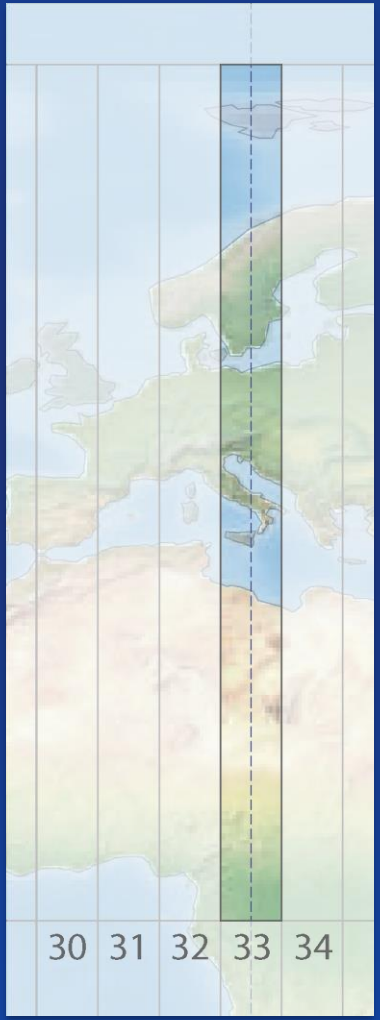
- Series of projected systems 6º wide



1 → → 32

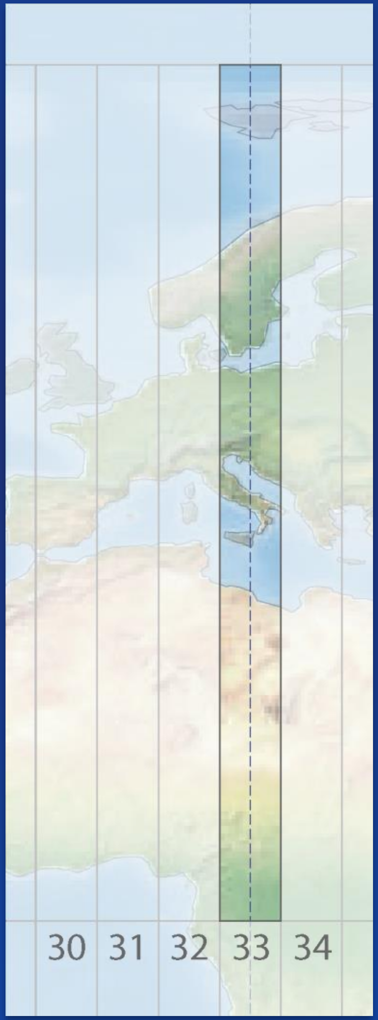
6º Wide Zone Along Meridian 15º East

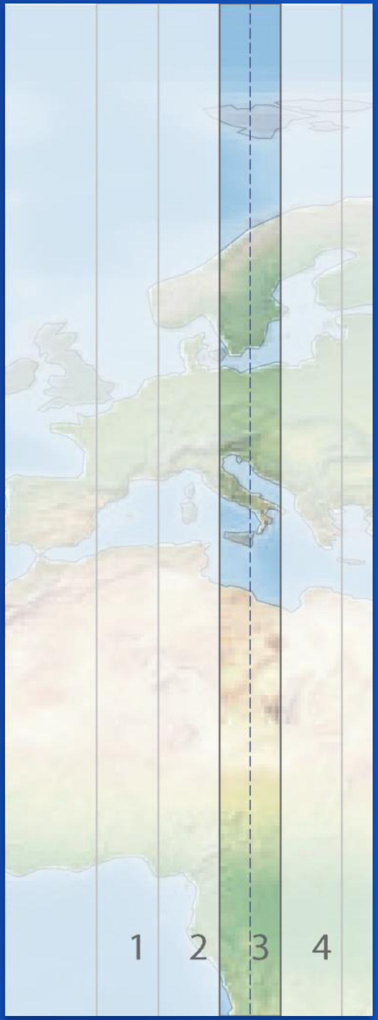
	UTM
Zone	33 N
Central Meridian	15º E
Scale Factor	0.9996
False Easting	500 000 m
False Northing	0 m



6º Wide Zone Along Meridian 15º East

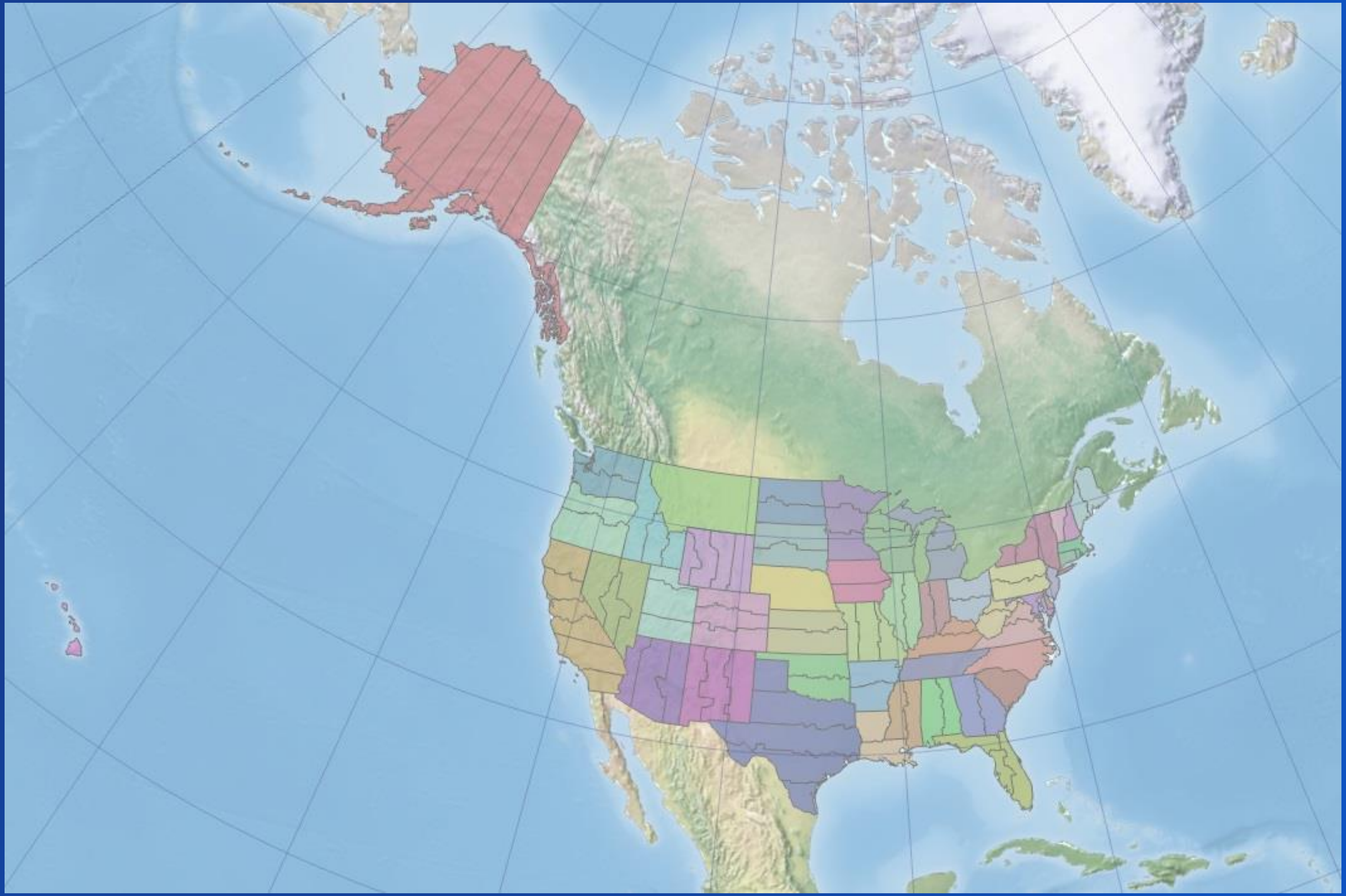
	UTM	GK
Zone	33 N	**3**
Central Meridian	15º E	15º E
Scale Factor	0.9996	1.0
False Easting	500 000 m	**3** 500 000 m
False Northing	0 m	0 m





State Plane Coordinate Systems

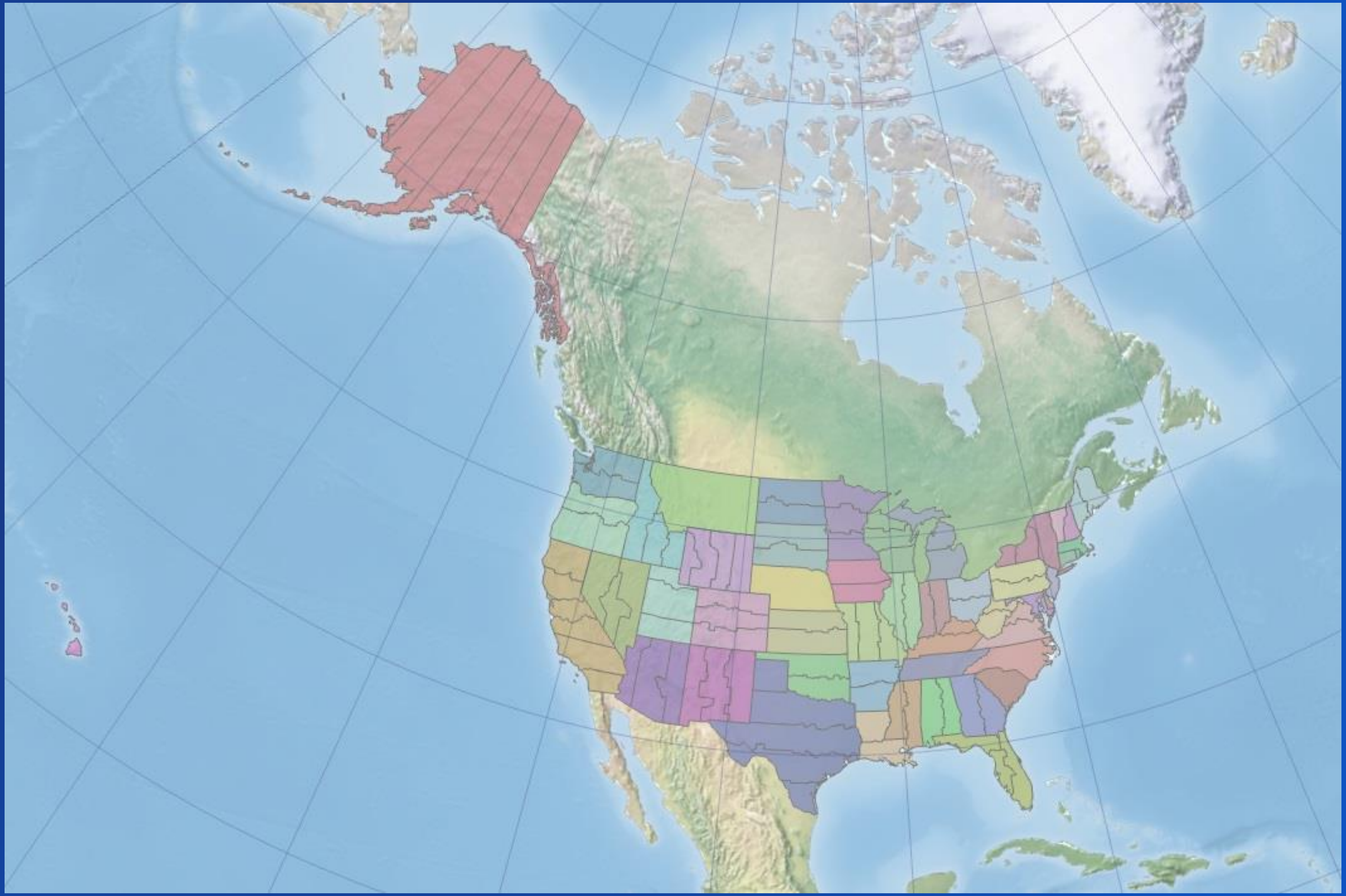
- Projected CS in US
- Each state has 1 or more zones
- Defined on
  - NAD27
  - NAD83 variants



State Plane Coordinate Systems

- Projections
  - Lambert conic
  - Transverse Mercator
  - Oblique Mercator

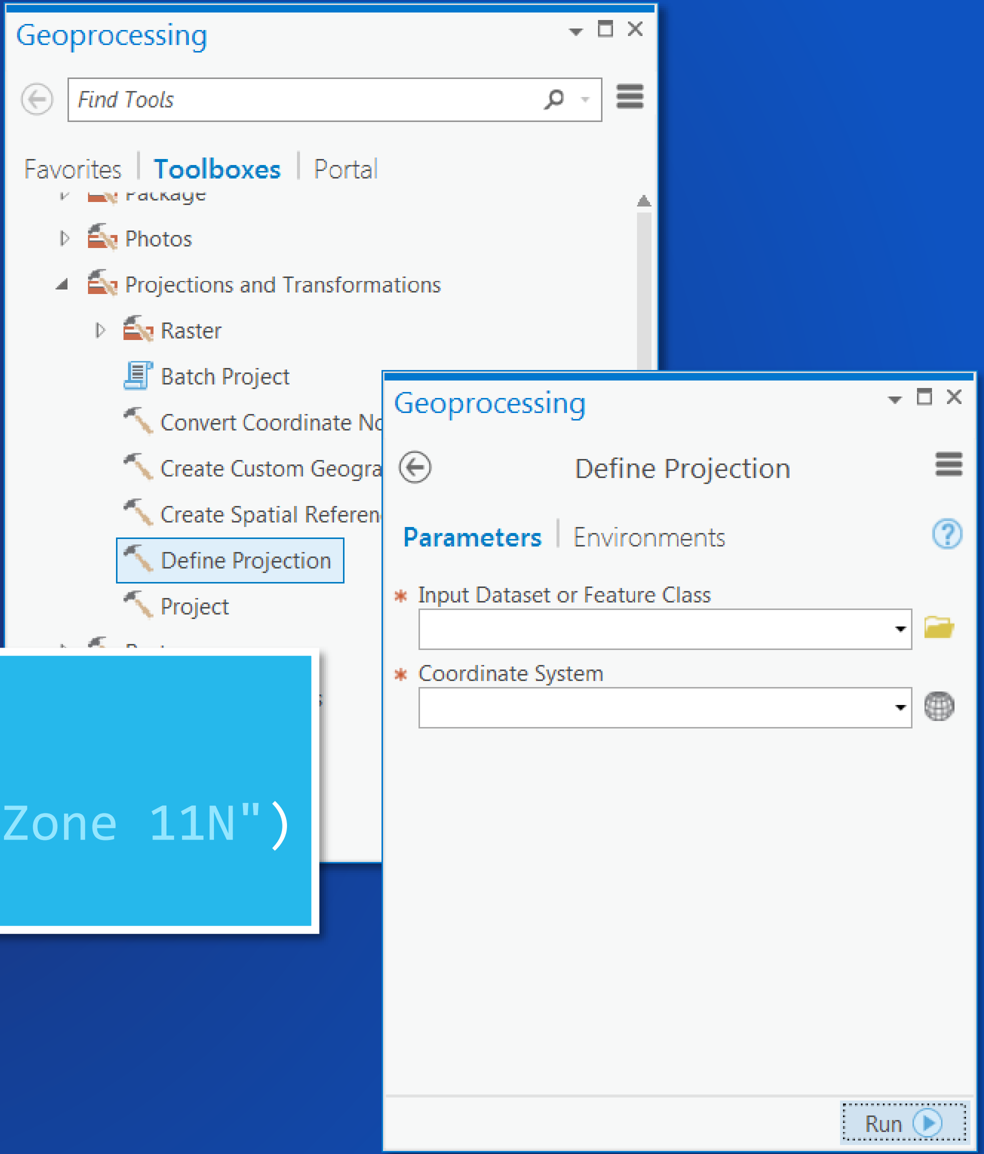
- Expected also for NATRF 2022



Define Projection Tool

- Overwrites the coordinate system info of a dataset
- When it is unknown or incorrect

```
import arcpy
infc = r"C:\data\My_Data.shp"
sr   = arcpy.SpatialReference("NAD 1983 UTM Zone 11N")
arcpy.DefineProjection_management(infc, sr)
```



Map of the Gaslamp Quarter

Fixing coordinate system definitions…

Vertical Coordinate Systems

Ellipsoidal and Gravity-related

Height

Q: How high is Mount Everest?

- 8844.43 meters
- 29029 feet
- 8.850 kilometers
- 29017.16 feet

Height

Q: How high is Mount Everest?

A: It depends on the vertical coordinate system.

8844.43 meters

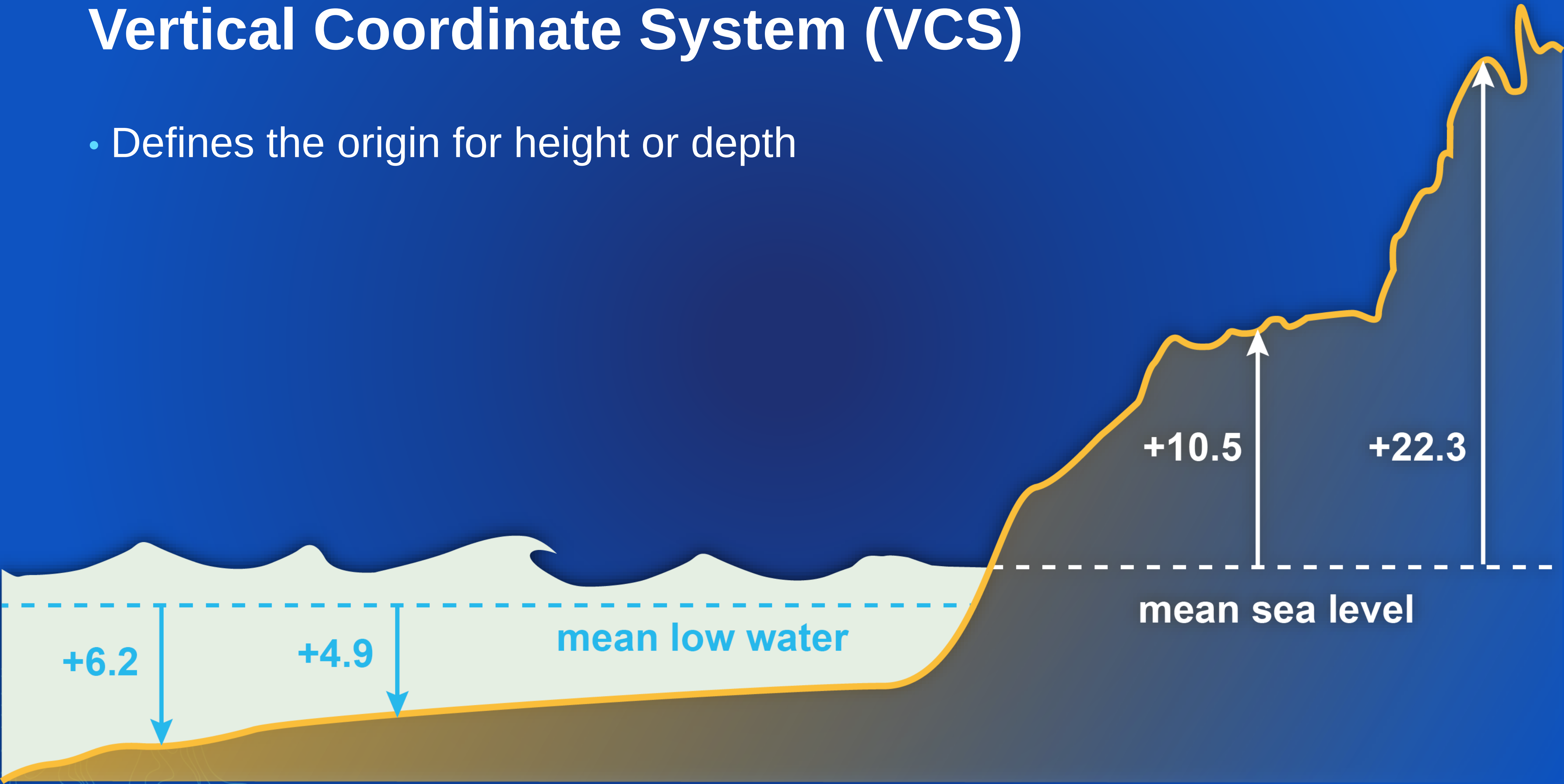
29029 feet

8.850 kilometers

29017.16 feet

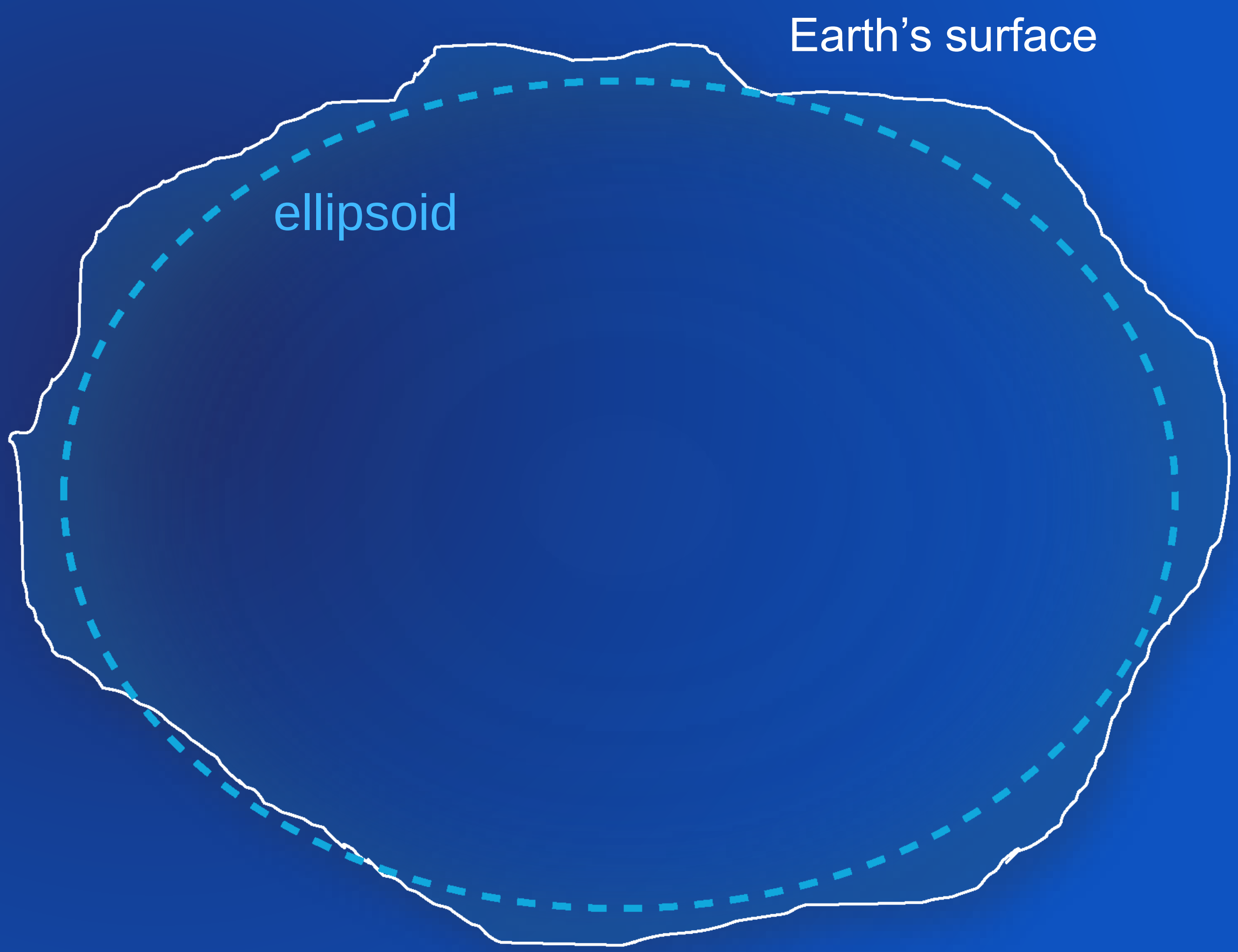
Vertical Coordinate System (VCS)

- Defines the origin for height or depth



The Origin for Height or Depth

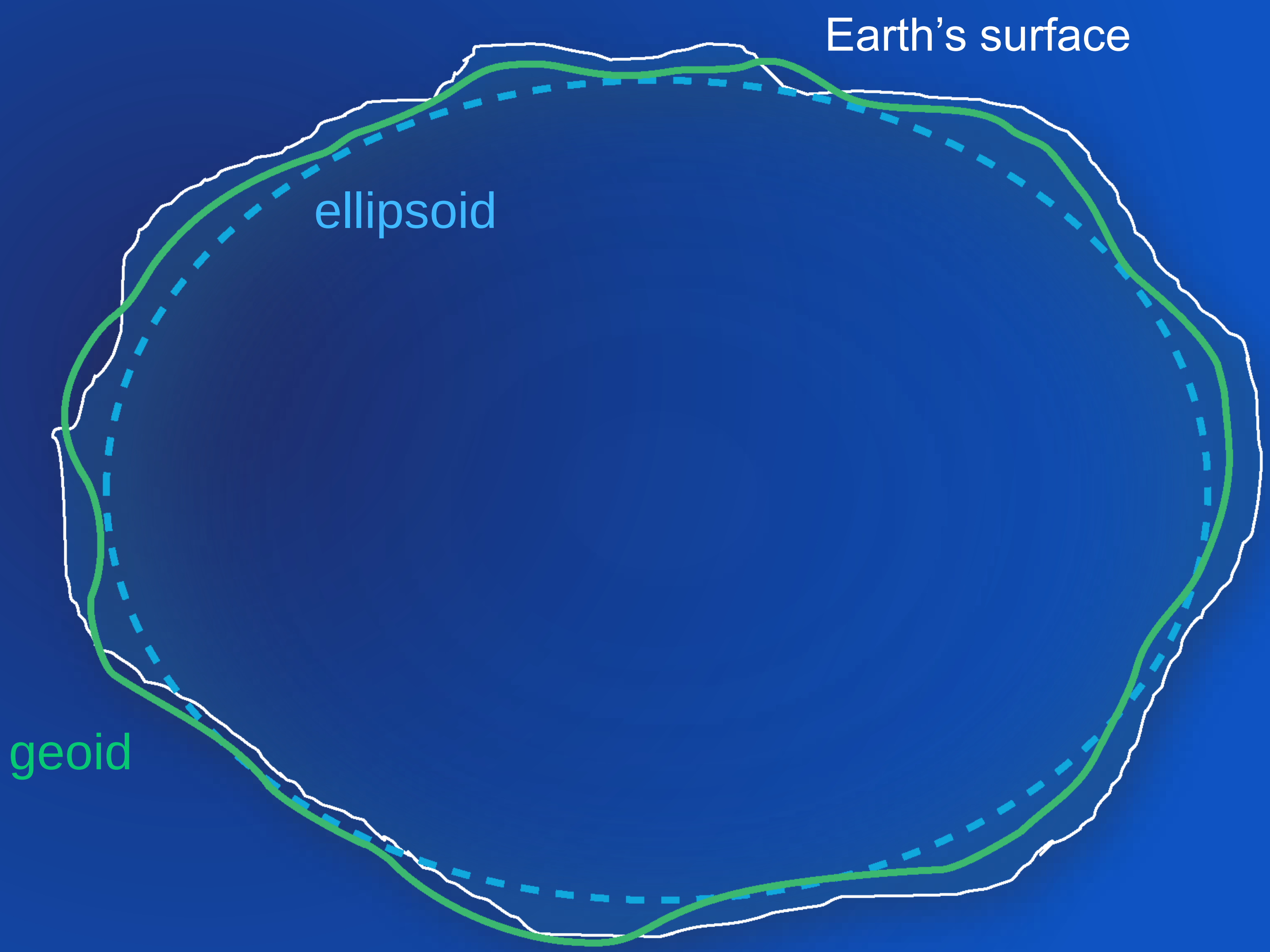
Geometric model



The Origin for Height or Depth

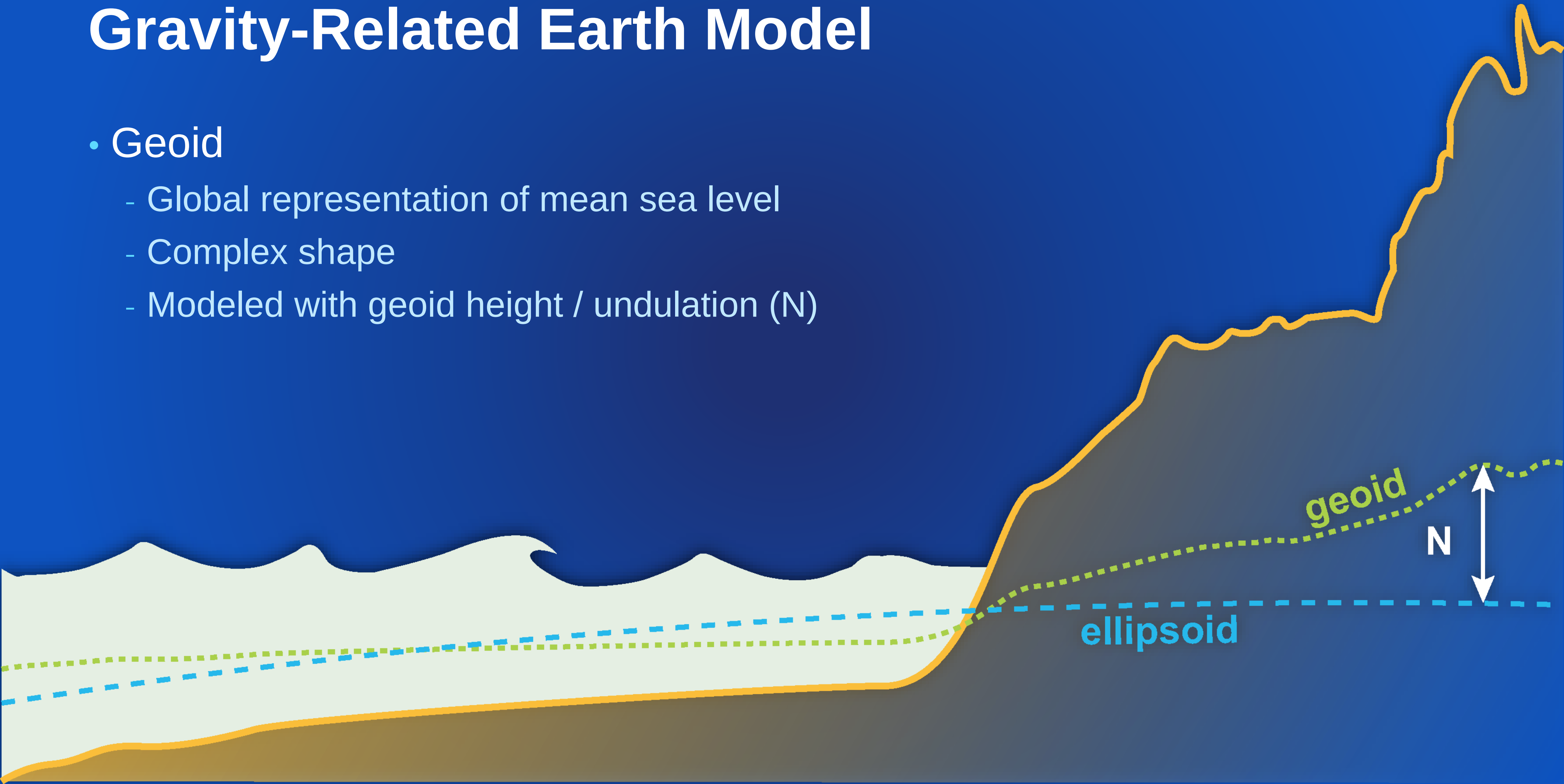
Geometric model

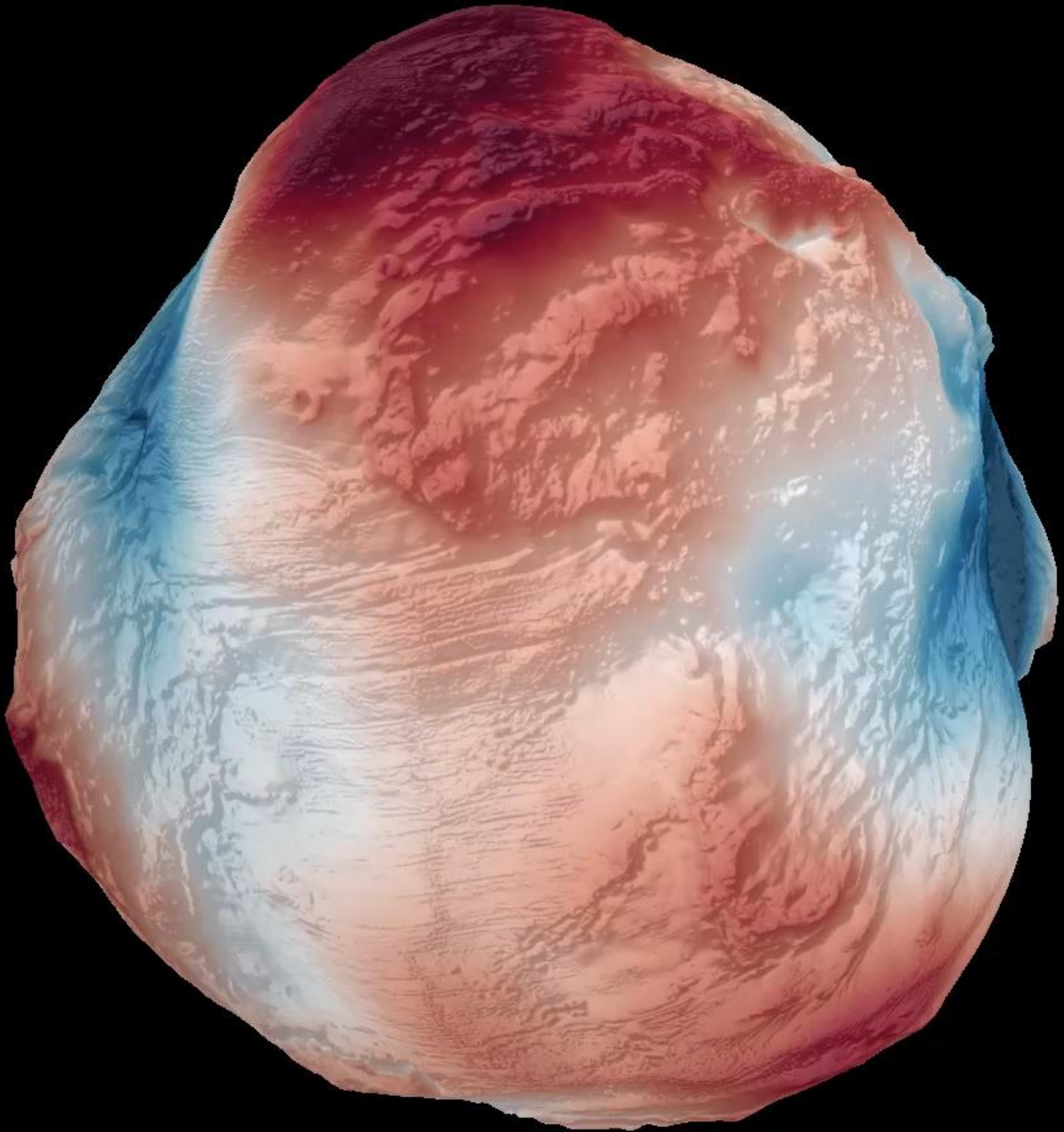
Gravity-related model



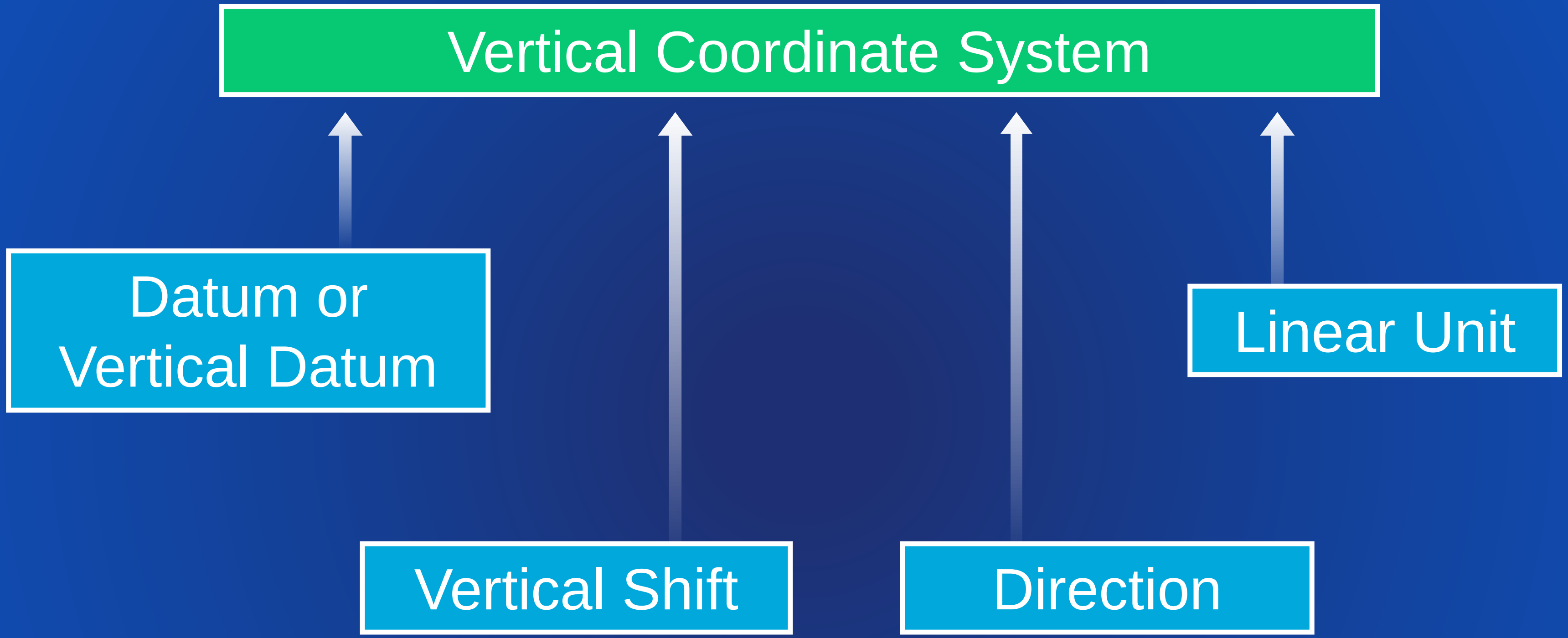
Gravity-Related Earth Model

- Geoid
  - Global representation of mean sea level
  - Complex shape
  - Modeled with geoid height / undulation (N)



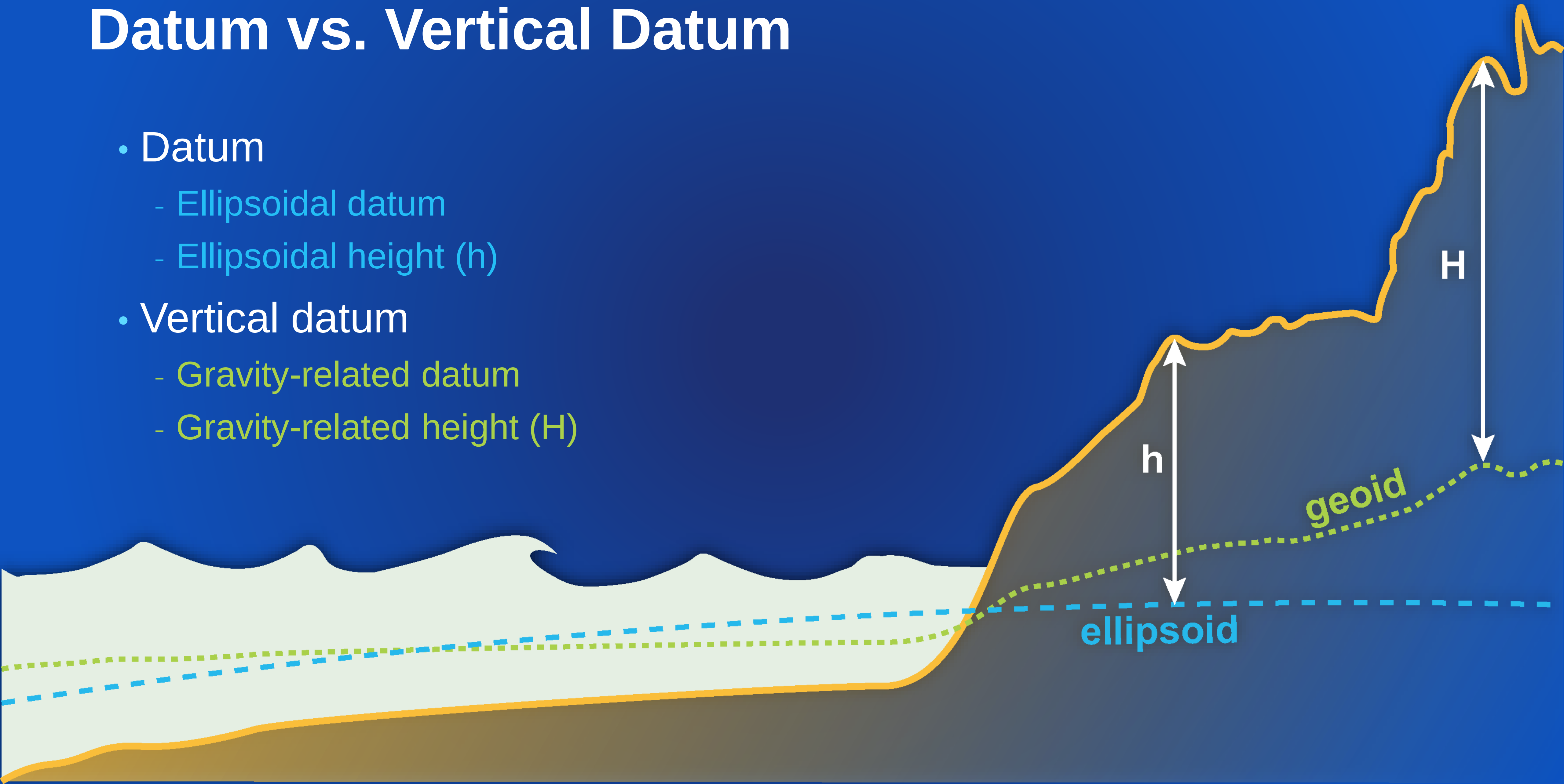


Vertical Coordinate System


Vertical Coordinate System
Datum or
Vertical Datum
Vertical Shift
Direction
Linear Unit

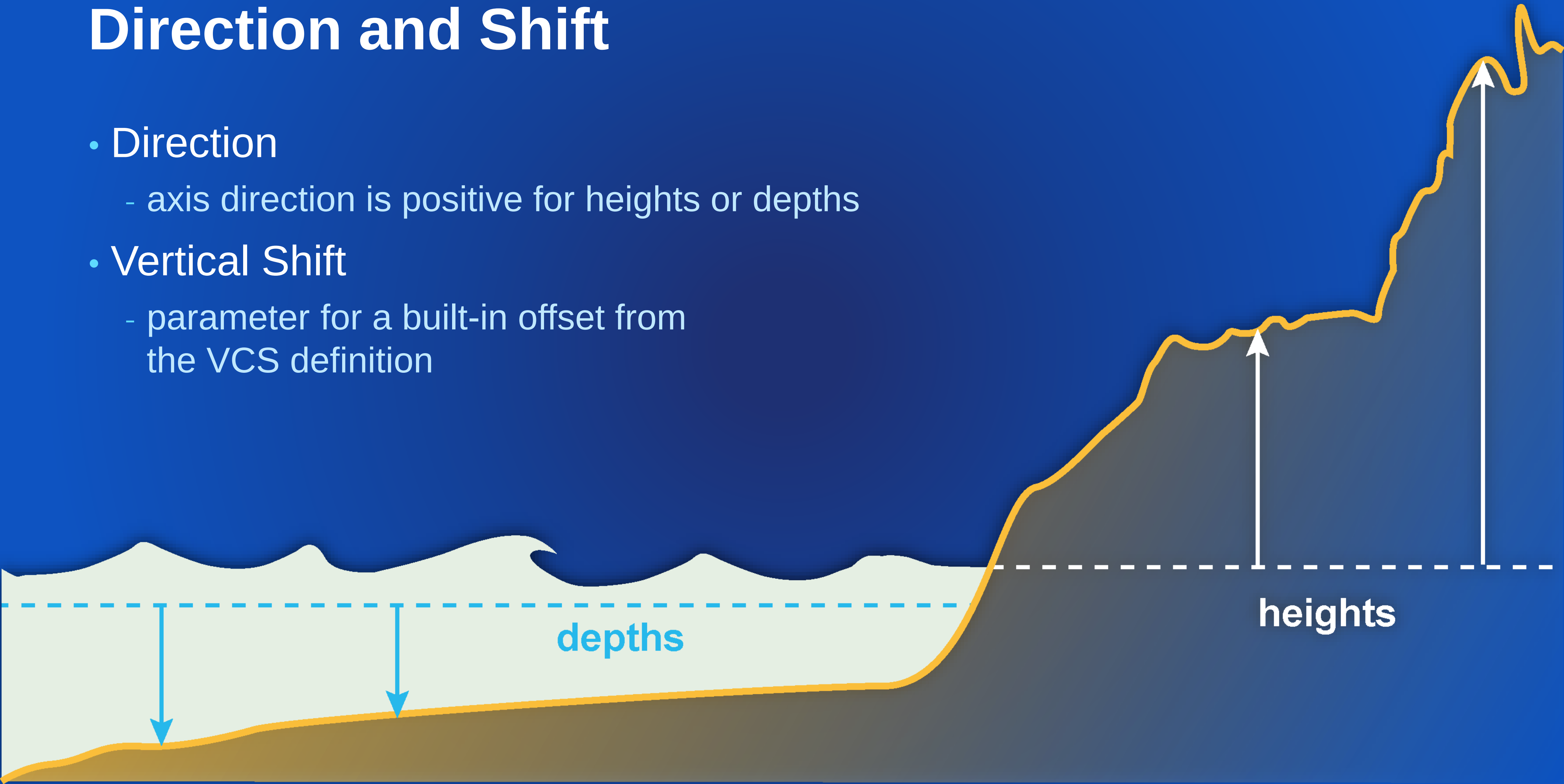
Datum vs. Vertical Datum

- Datum
  - Ellipsoidal datum
  - Ellipsoidal height (h)
- Vertical datum
  - Gravity-related datum
  - Gravity-related height (H)



Direction and Shift

- Direction
  - axis direction is positive for heights or depths
- Vertical Shift
  - parameter for a built-in offset from the VCS definition



Well-Known Text and ID

- WKT:

```
VERTCS["NAVD_1988",
    VDATUM["North_American_Vertical_Datum_1988"],
    PARAMETER["Vertical_Shift",0.0],
    PARAMETER["Direction",1.0],
    UNIT["Meter",1.0]]
```

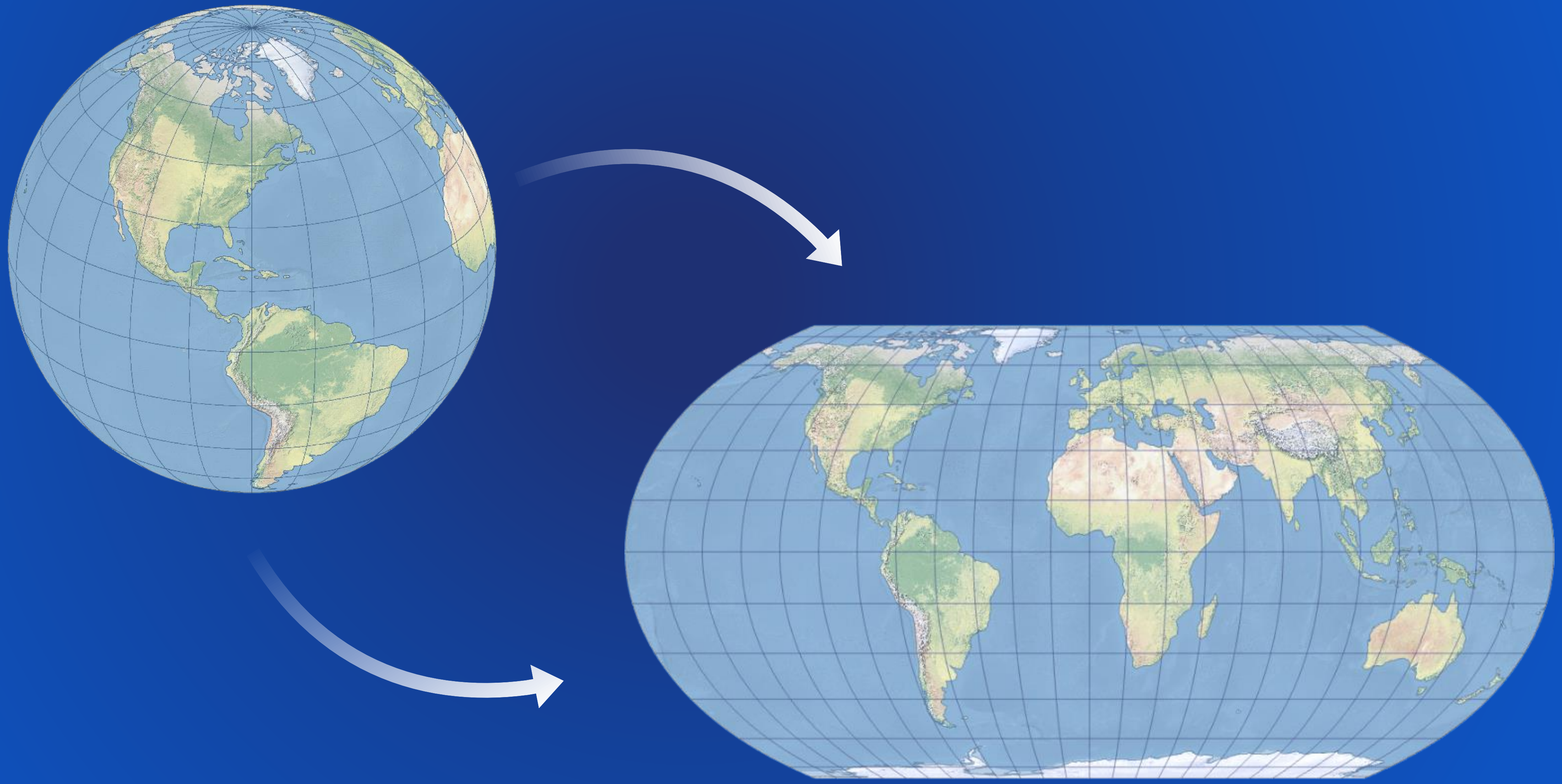
Vertical coordinate system

- WKID: **EPSG:5703**

Map Projections

From a Spheroid to a Plane

Projecting to a Different Coordinate System



Map Projections in Esri Software

Aitoff
Albers
Aspect-adaptive
Azimuthal equidistant
Behrmann
Berghaus Star
Bonne
Cassini
Compact Miller
Craster parabolic
Cube
Cylindrical equal-area
Double stereographic
Eckert I
Eckert II
Eckert III
Eckert IV
Eckert V
Eckert VI
Eckert-Greifendorff
Equal Earth
Equidistant conic
Equidistant cylindrical
Fuller
Gall stereographic
Gauss-Krüger
Geostationary satellite
Gnomonic
Goode homolosine
Hammer
Hotine oblique Mercator
IGAC Plano Cartesiano
Krovak
Laborde oblique Mercator
Lambert azimuthal equal-area
Lambert conformal conic
Local
Loximuthal
McBryde-Thomas flat-polar quartic
Mercator
Miller cylindrical
Mollweide
Natural Earth
Natural Earth II
New Zealand map grid
Ney modified conic
Orthographic
Patterson
Peirce quincuncial
Plate Carrée
Polyconic
Quartic authalic
Rectified skew orthomorphic
Robinson
Sinusoidal
Stereographic
Times
Transverse cylindrical equal-area
Transverse Mercator
Two point equidistant
Van der Grinten I
Vertical near side perspective
Wagner IV
Wagner V
Wagner VII
Winkel I
Winkel II
Winkel Tripel

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Eckert V

Eckert VI
Eckert-Greifendorff
Equal Earth
Equidistant conic
Equidistant cylindrical
Fuller

Hotine Oblique Mercator

Hotine Oblique Mercator Azimuth Center
Hotine Oblique Mercator Azimuth Natural Origin
Hotine Oblique Mercator Two Point Center
Hotine Oblique Mercator Two Point Natural Origin

IGAC Plano Cartesiano
Krovak
Laborde oblique Mercator
Lambert azimuthal equal-area
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Winkel II
Winkel Tripel

Every Map Projection Deforms Something

- Shape
- Area
- Direction
- Angle
- Distance

Illustration by Charles Preppernau, geolographer.xyz

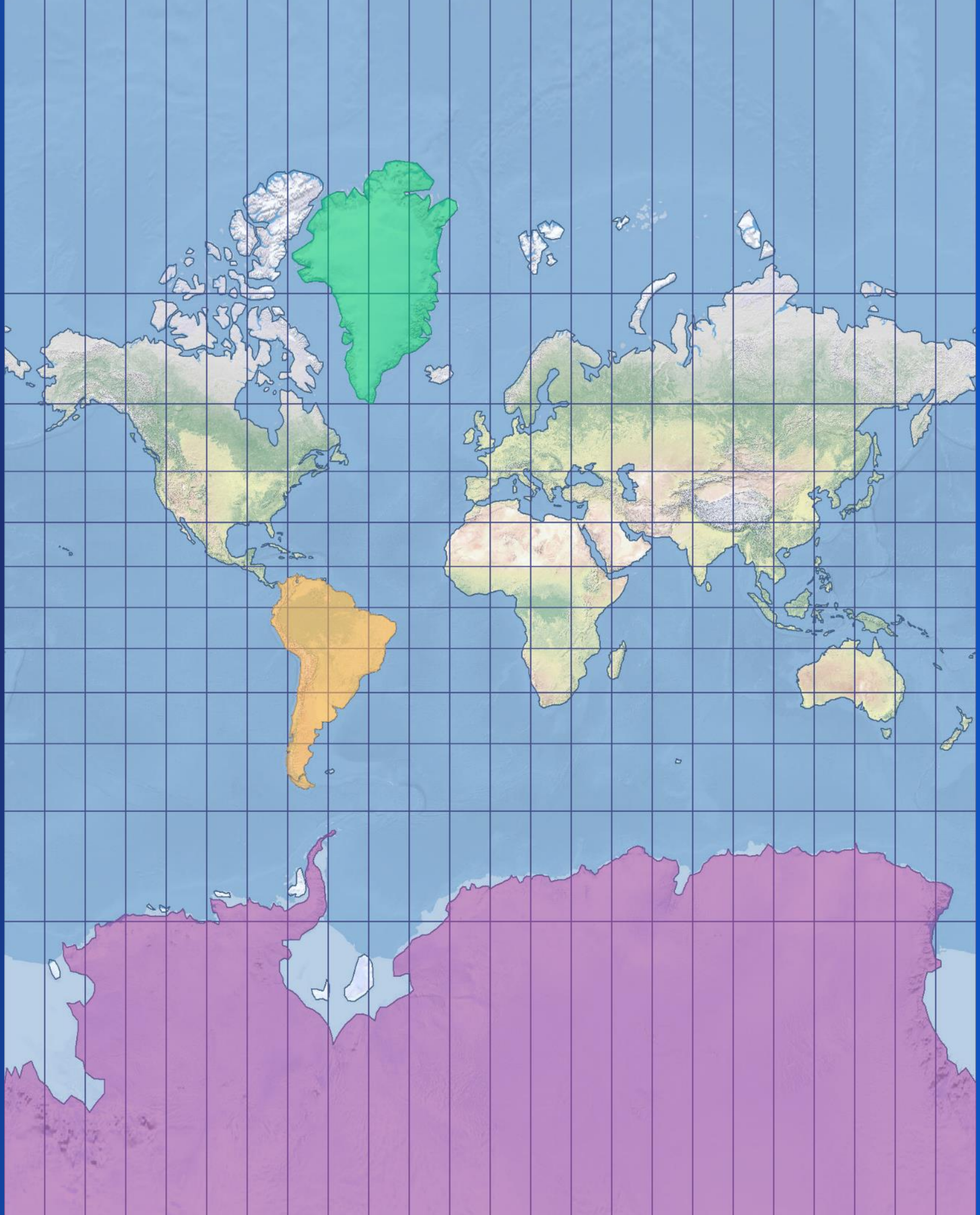
Web Mercator Projection

Q: Which is bigger?

Greenland

South America

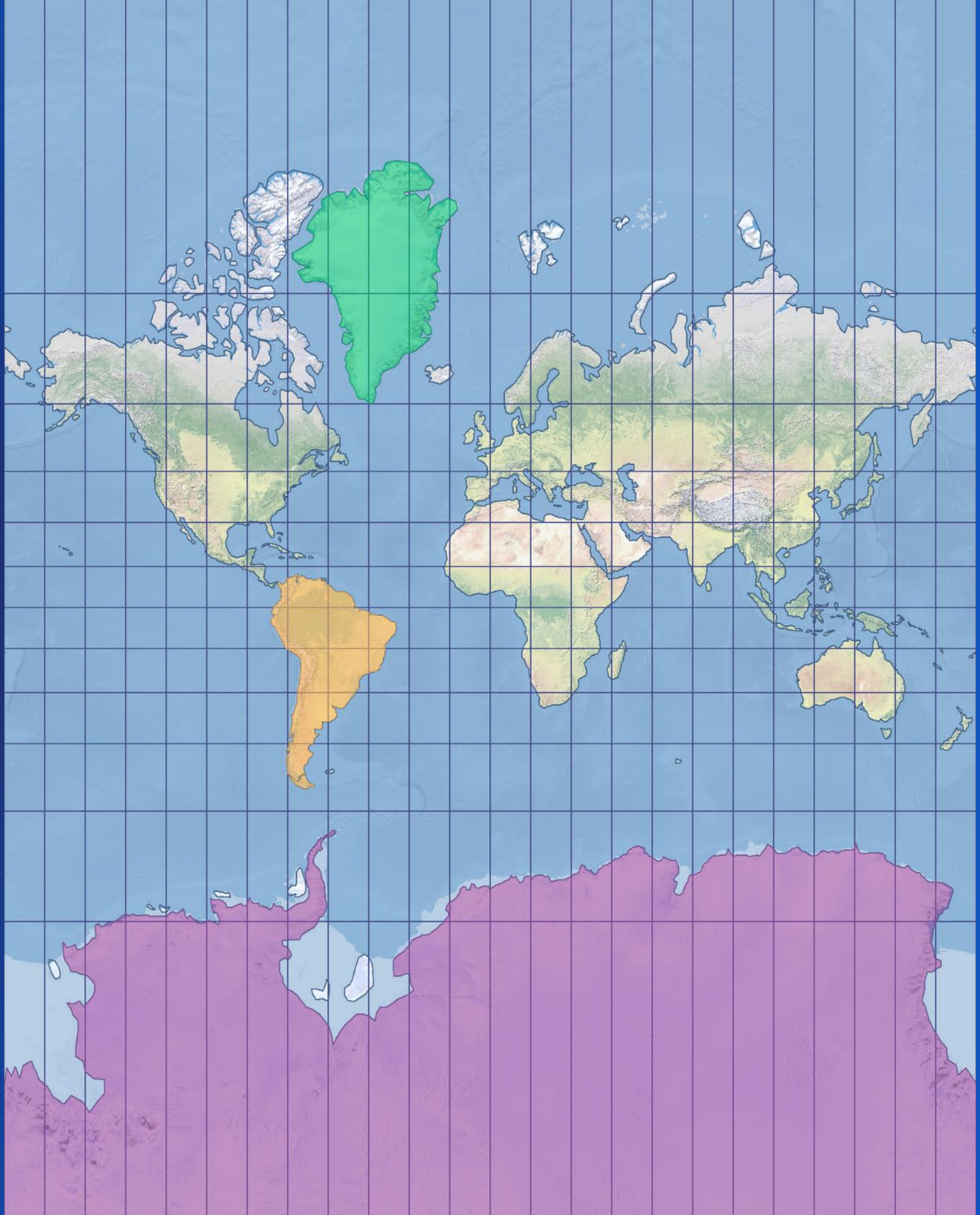
Antarctica



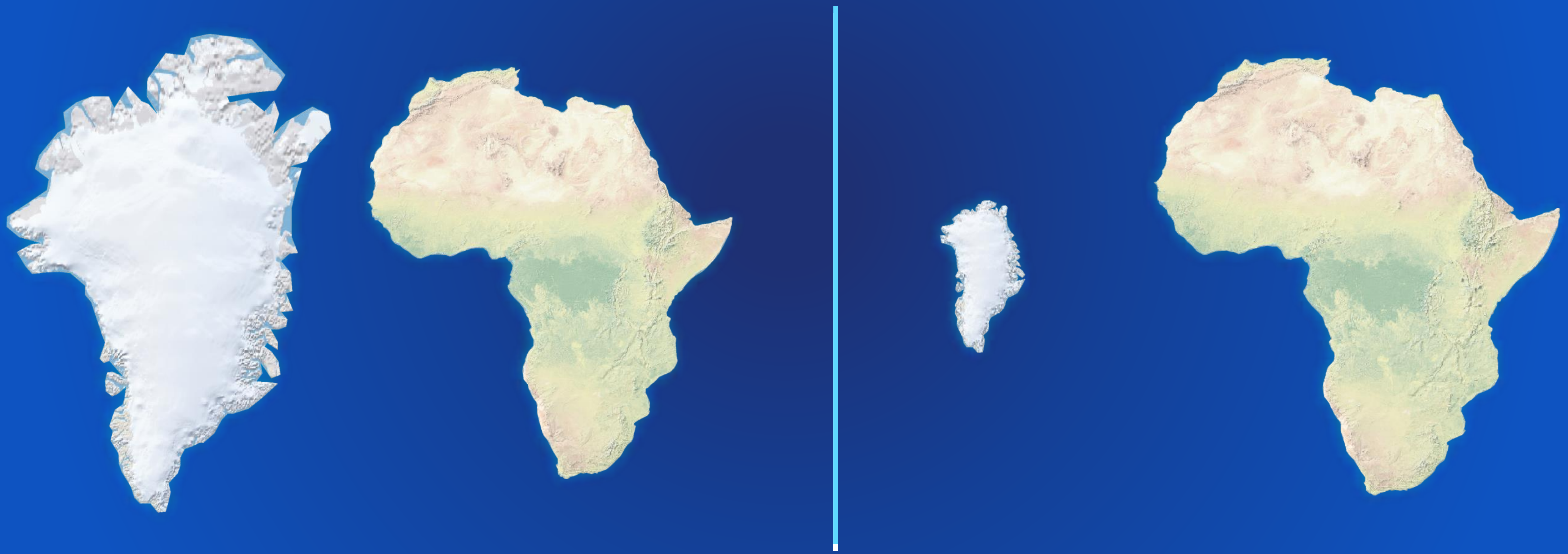
Web Mercator Projection

Q: Which is bigger?

Greenland	~	2 166 000 km^2
South America	~	17 840 000 km^2
Antarctica	~	14 000 000 km^2



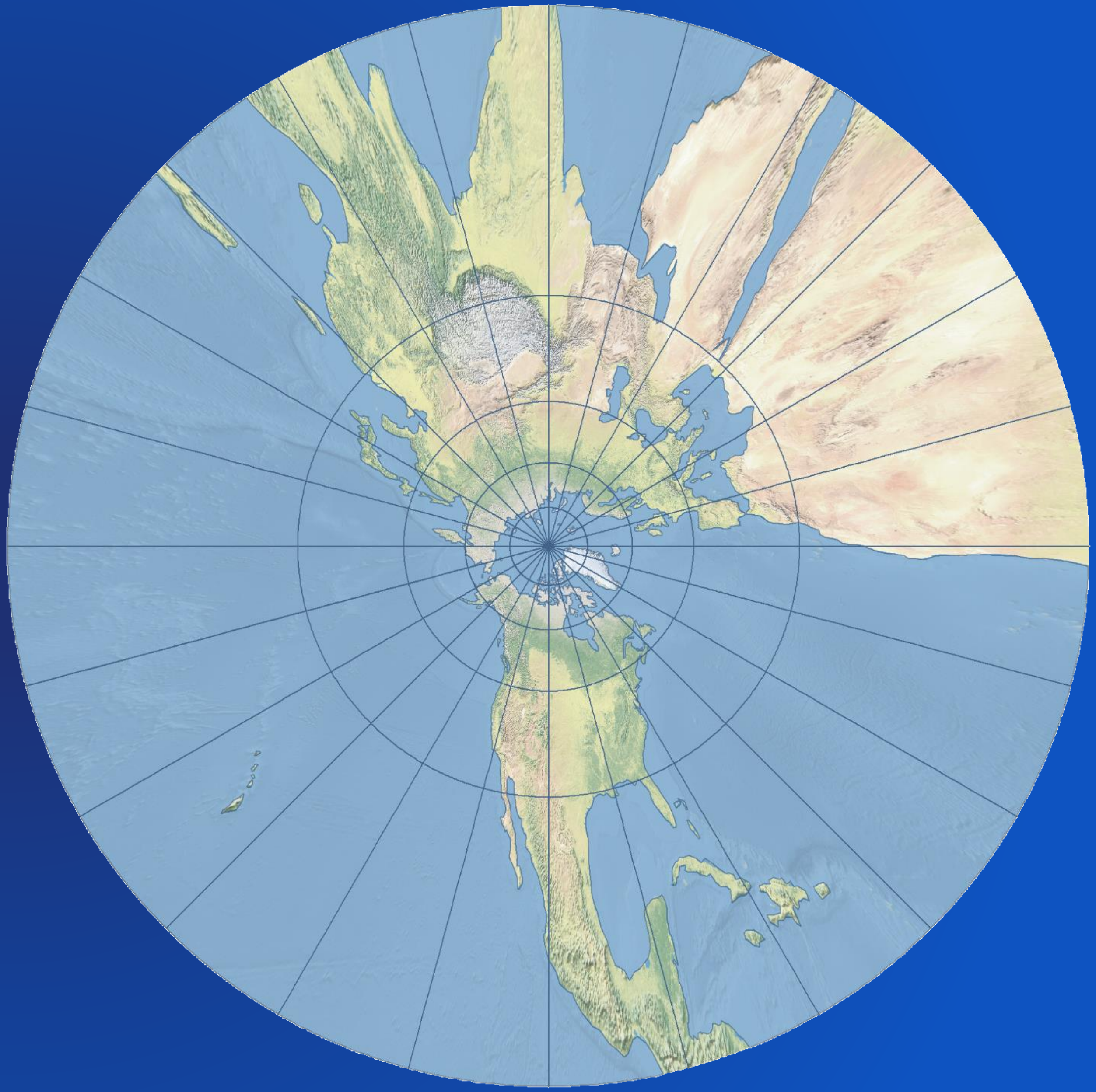
Web Mercator Projection vs. Reality



Selection

Q: Which projection is the best?

- Albers equal-area
- Stereographic
- Azimuthal equidistant
- Transverse Mercator

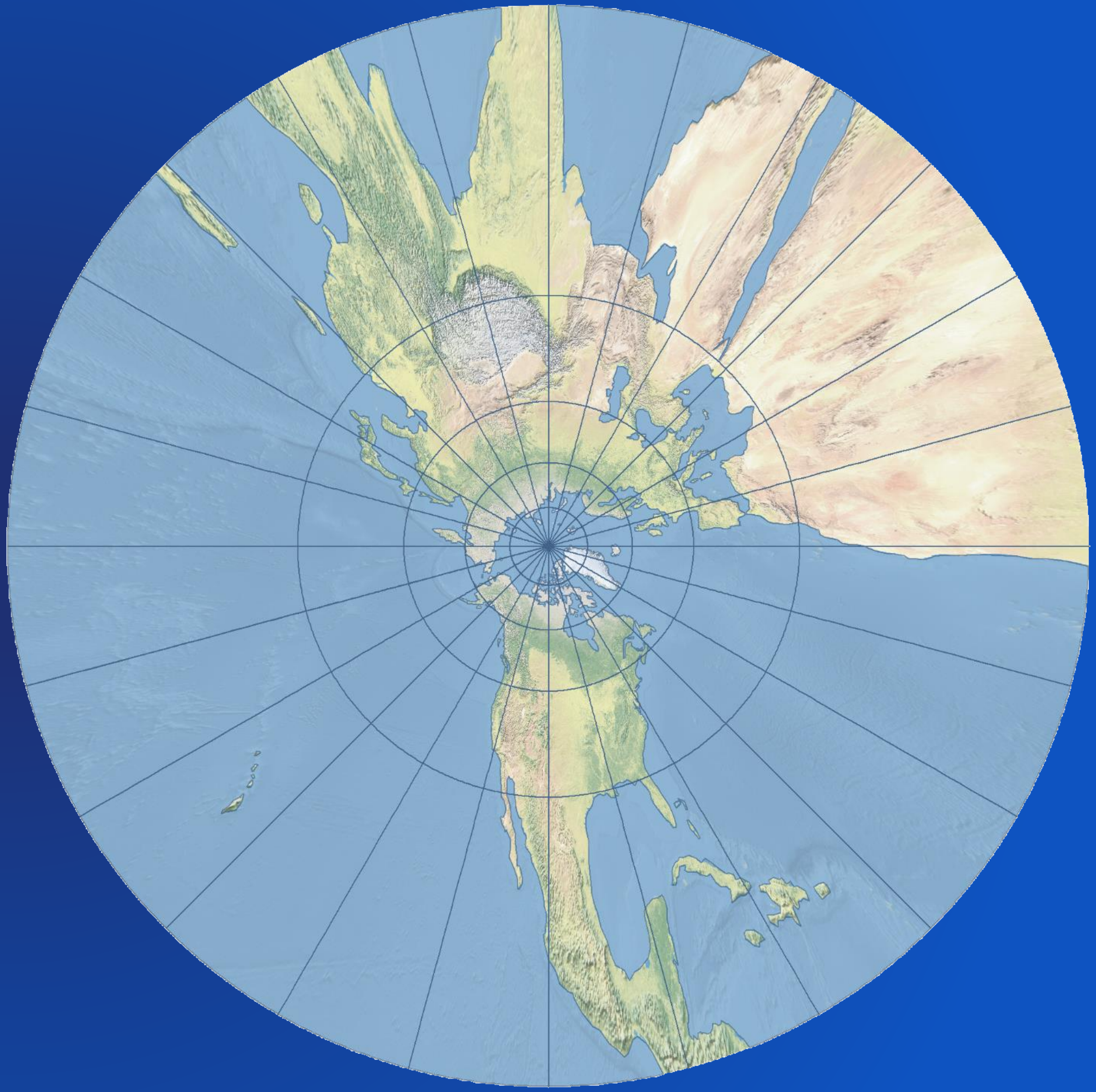


Selection

Q: Which projection is the best?

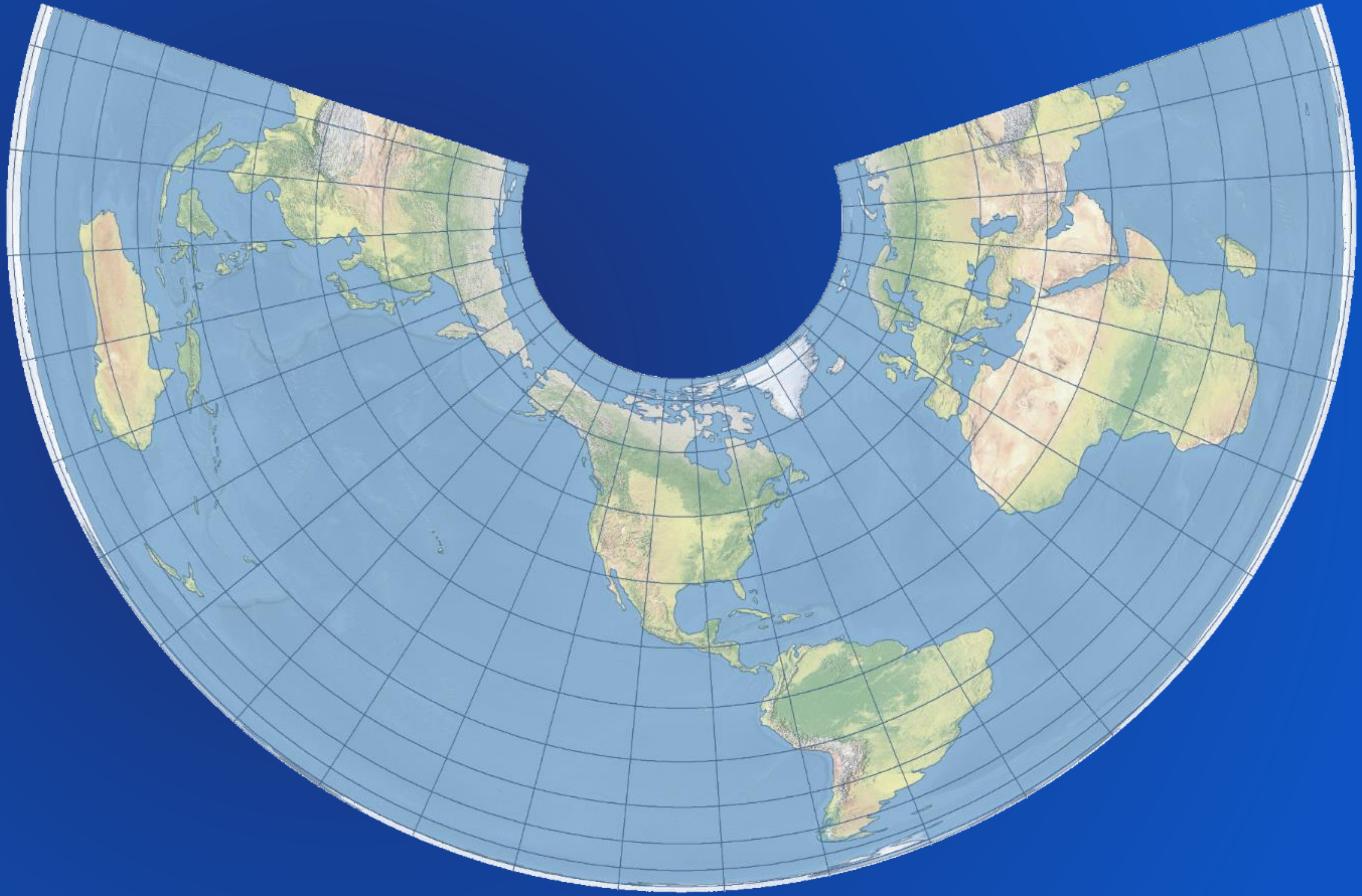
A: It depends on what you are doing.

- Albers equal-area
- Stereographic
- Azimuthal equidistant
- Transverse Mercator



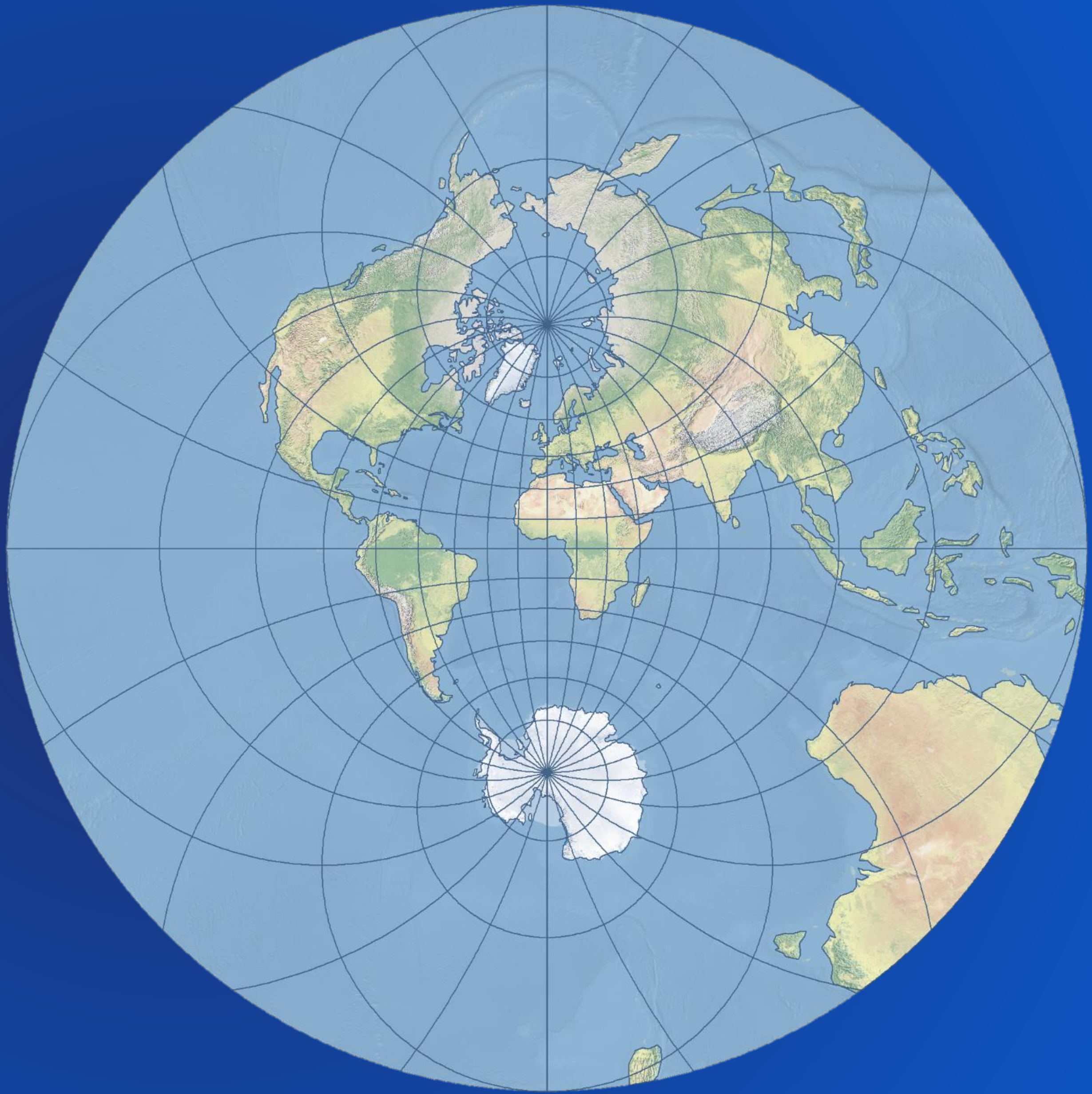
Preserve Areas

- Albers conic equal-area



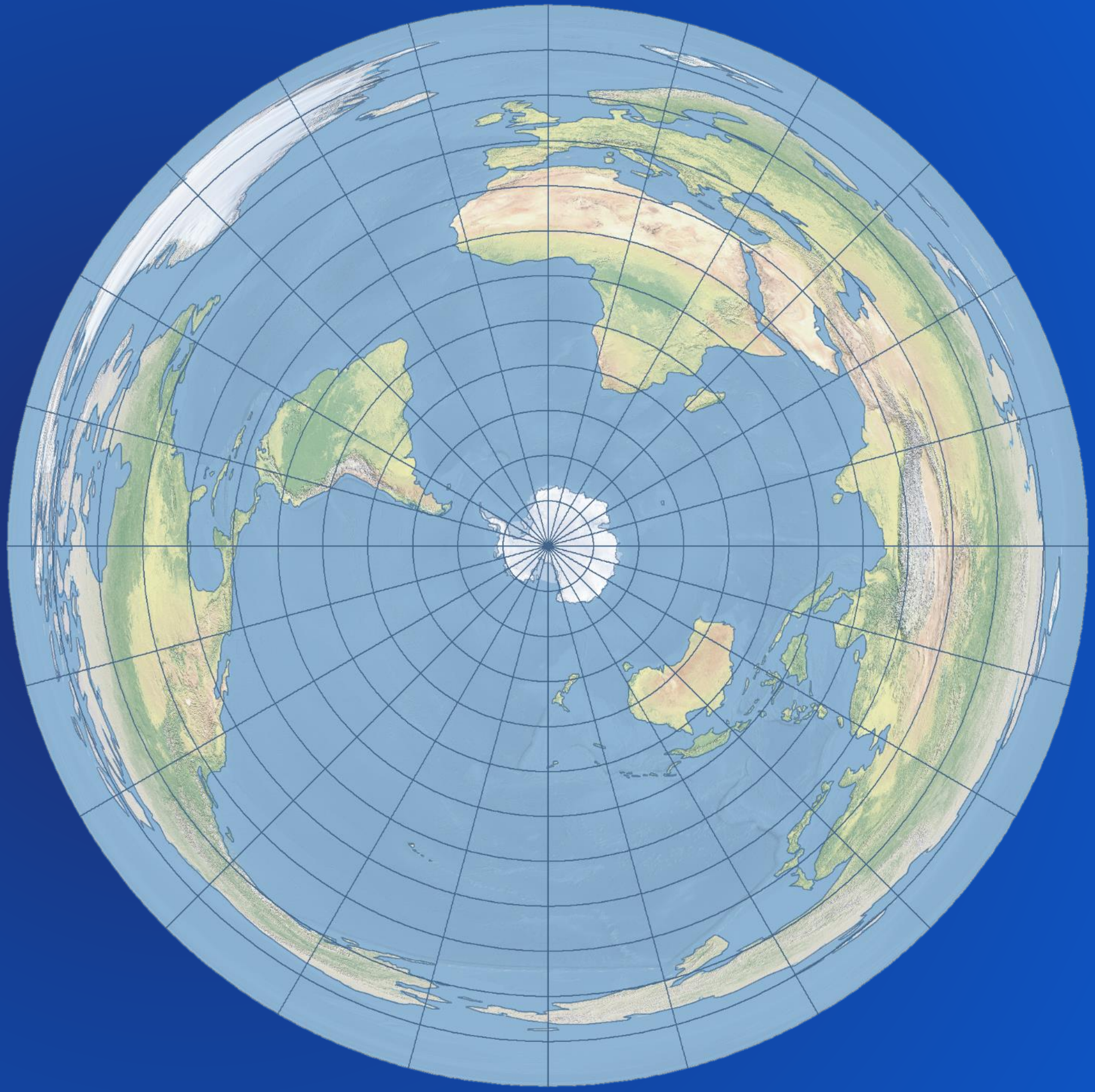
Preserve Angles

- Stereographic
  - Only at infinitesimal scale



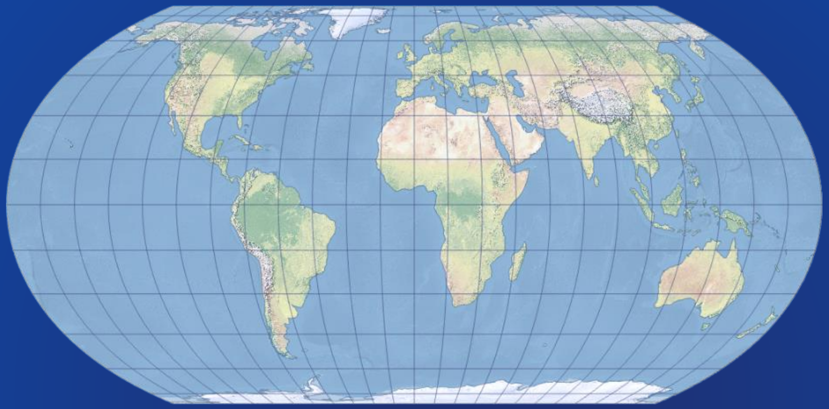
Preserve Directions and Distances

- Azimuthal equidistant
  - Only from the center

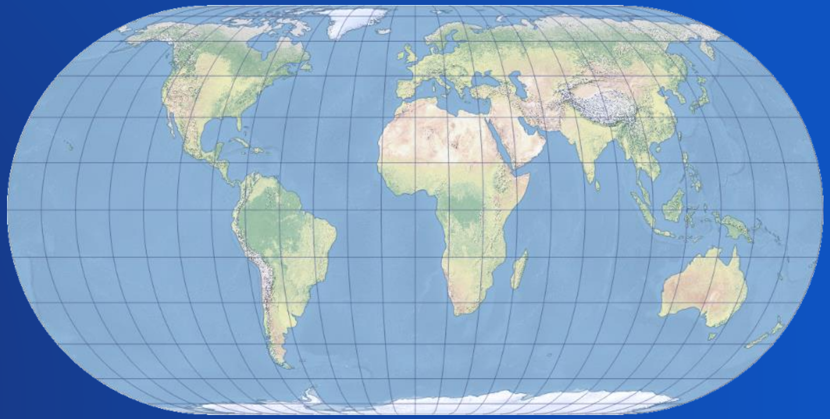


Appropriate for World Maps

- Pseudocylindrical
  - Equal-area (thematic maps)



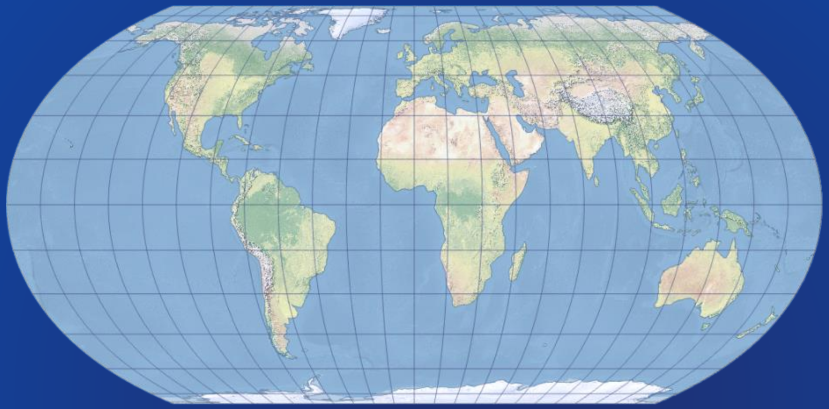
Equal Earth



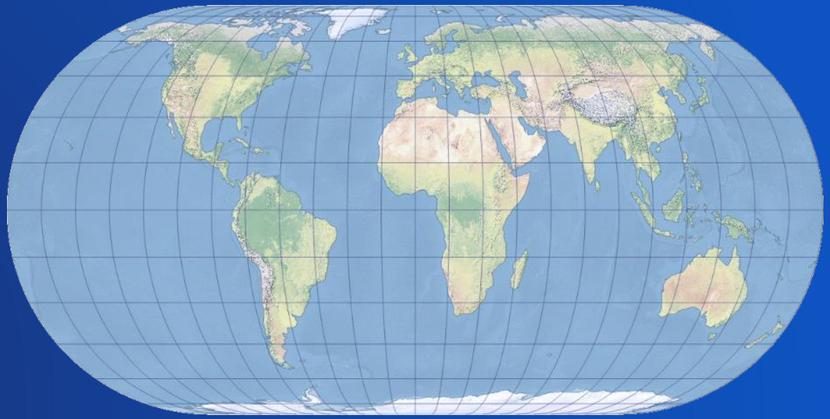
Eckert IV

Appropriate for World Maps

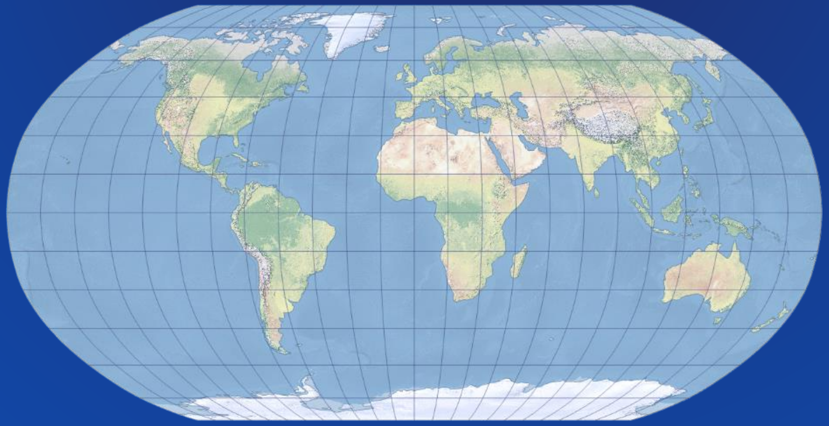
- Pseudocylindrical
  - Equal-area (thematic maps)
  - Compromise (general maps)



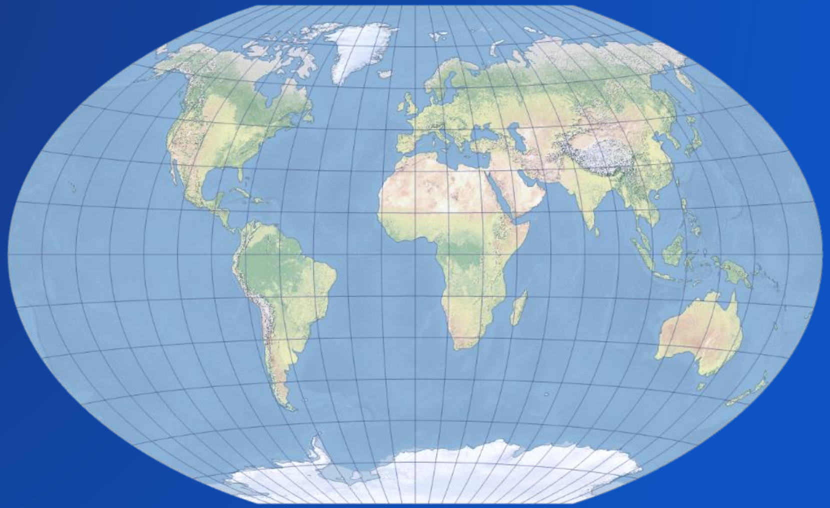
Equal Earth



Eckert IV



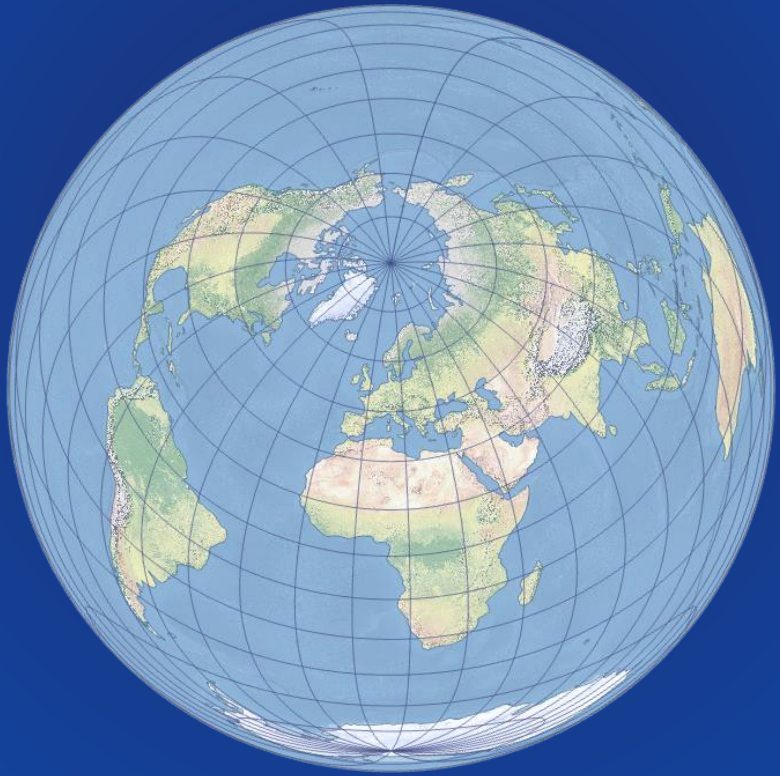
Robinson



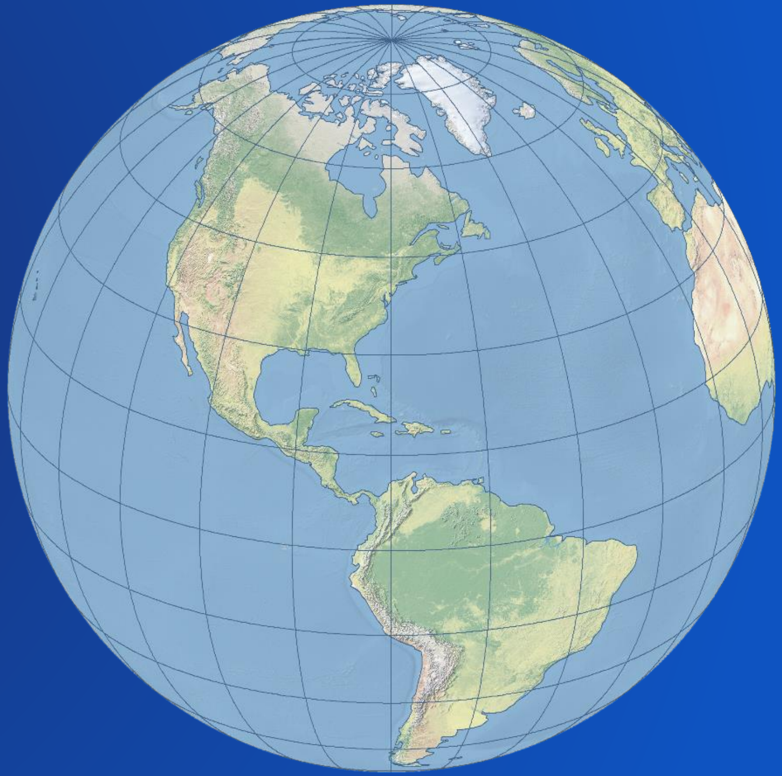
Winkel Tripel

Appropriate for Hemisphere Maps

- Azimuthal projections
  - Stereographic
  - Azimuthal equidistant
  - Lambert equal-area
  - Orthographic



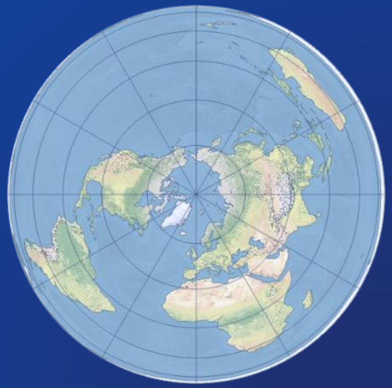
Lambert azimuthal equal-area



Orthographic

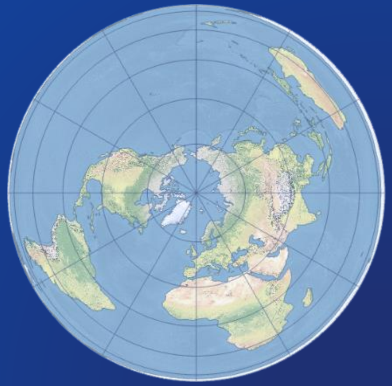
Appropriate for Large-scale Maps

- Azimuthal
  - Polar areas



Appropriate for Large-scale Maps

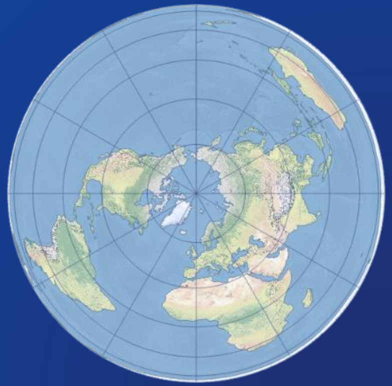
- Azimuthal
  - Polar areas



- Conic
  - Mid-latitudes

Appropriate for Large-scale Maps

- Azimuthal
  - Polar areas

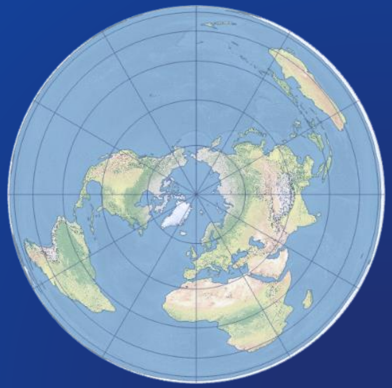


- Conic
  - Mid-latitudes

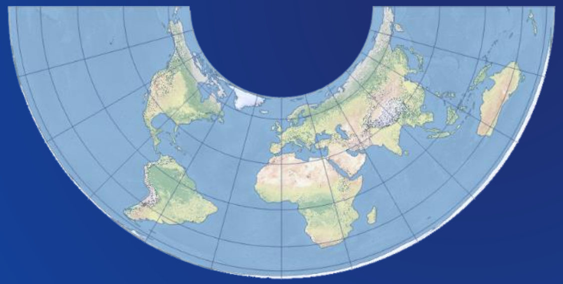
- Cylindrical
  - Equatorial areas

Appropriate for Large-scale Maps

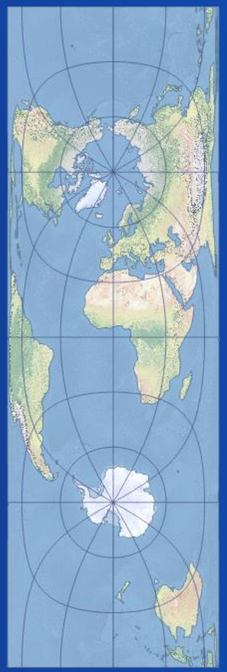
- Azimuthal
  - Polar areas



- Conic
  - Mid-latitudes



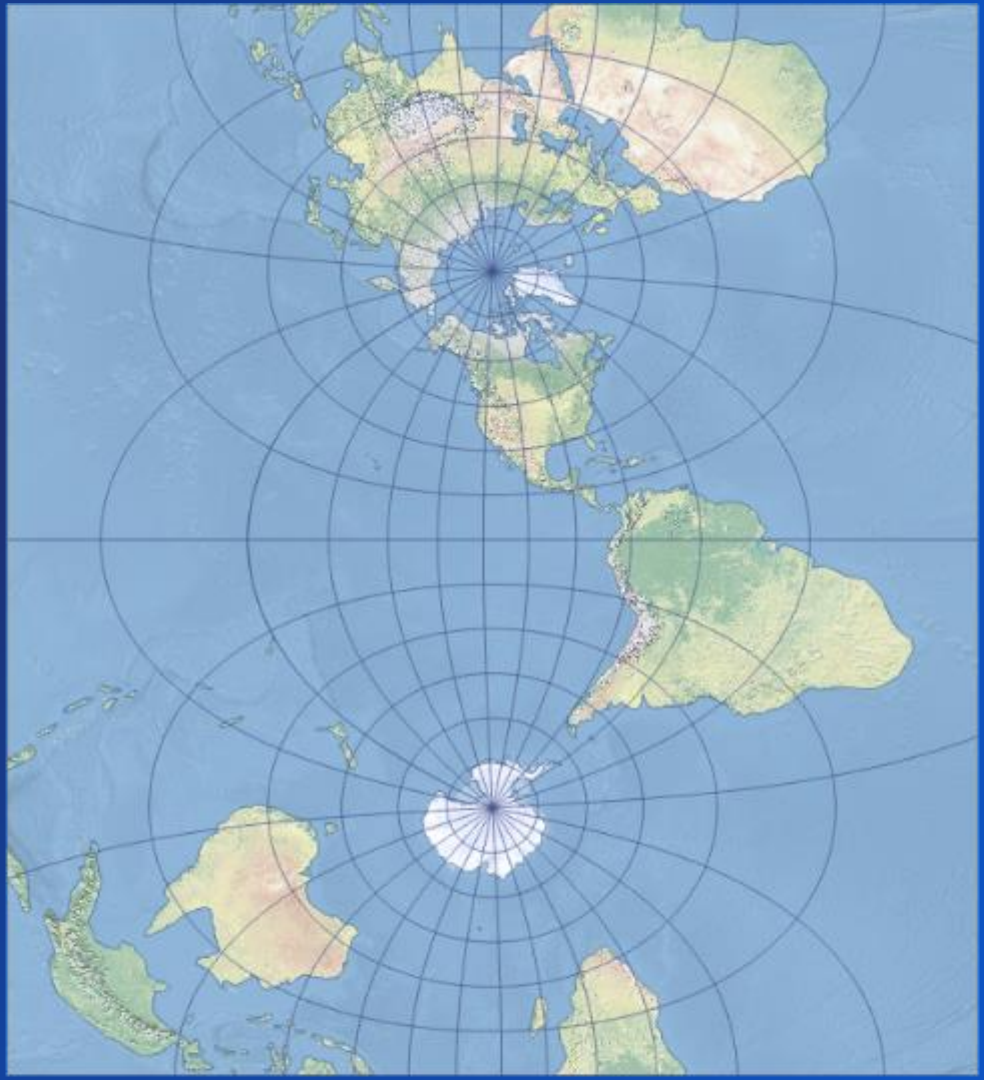
- Cylindrical
  - Equatorial areas



- Transverse cylindrical
  - North to south extents

Appropriate for Topographic Maps

- Transverse cylindrical
  - Transverse Mercator
  - Transverse cylindrical equal-area
  - Cassini

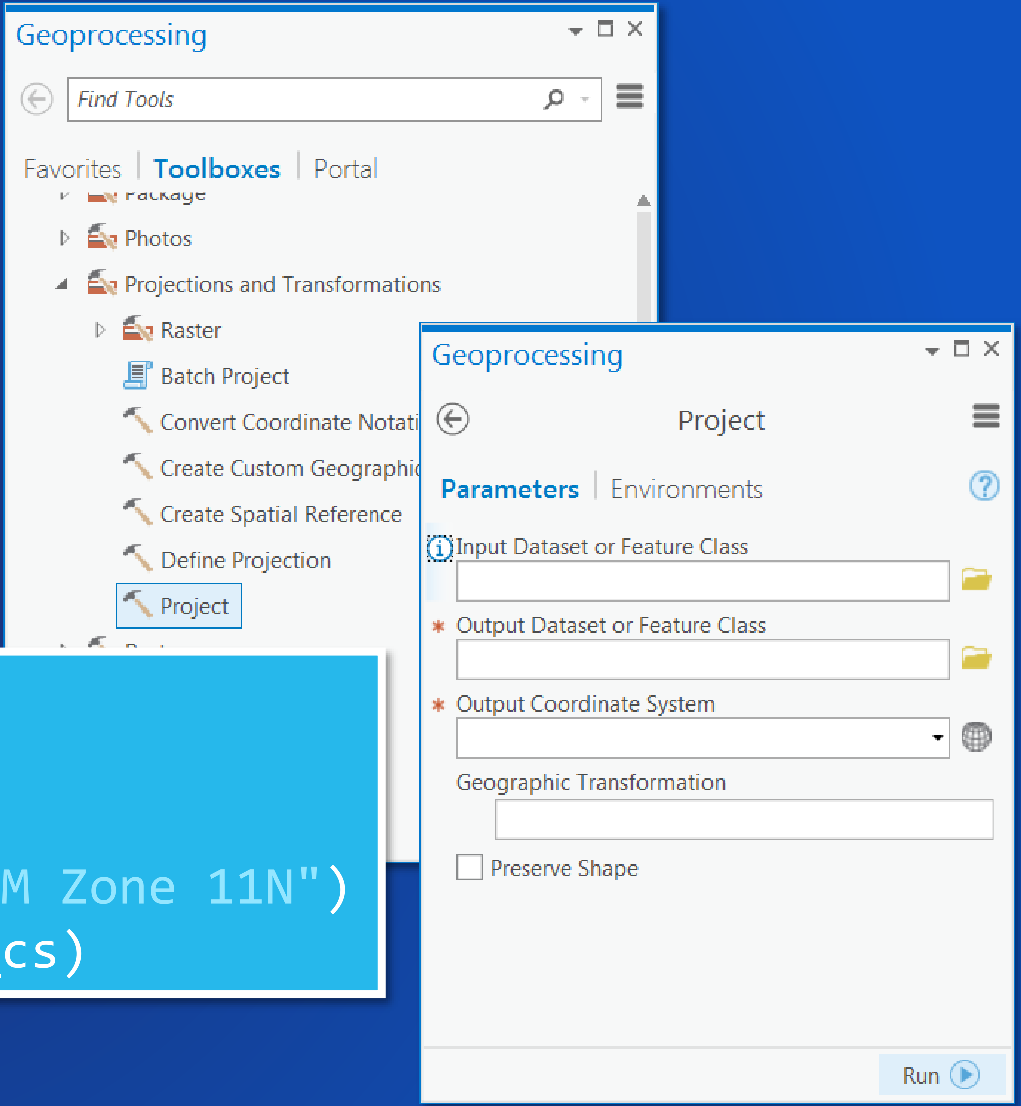


Transverse Mercator,
used in UTM, State Plane, etc.

Project Tool

- Projects spatial data from one coordinate system to another
- Changes data's coordinates

```
import arcpy
input  = r"C:\data\My_Data.shp"
output = r"C:\data\My_Data_Project.shp"
out_cs = arcpy.SpatialReference("NAD 1983 UTM Zone 11N")
arcpy.Project_management(input, output, out_cs)
```



What is happening when we project data?

- Case 1: Both PCSs contain the same GCS

(x, y) PCS A1

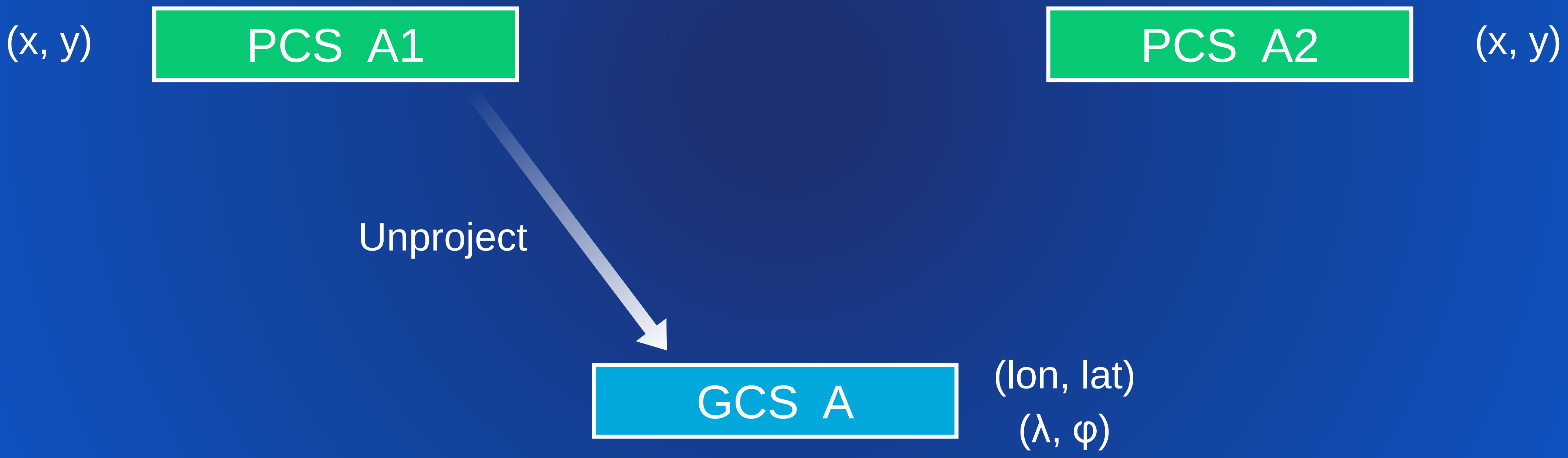
PCS A2 (x, y)

GCS A (lon, lat)

(λ, φ)

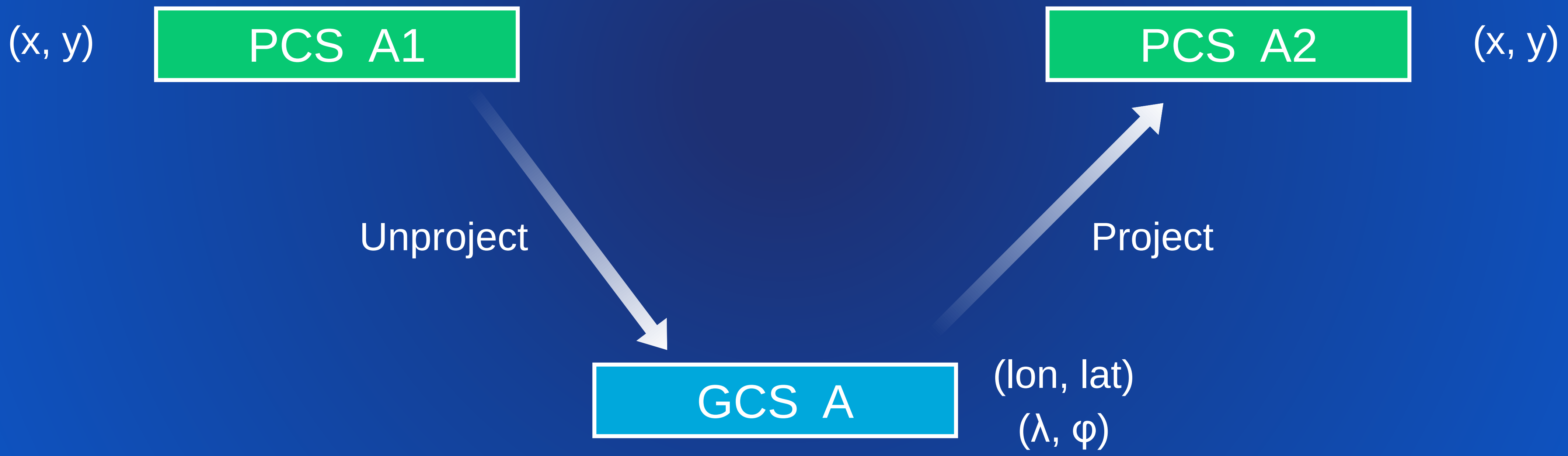
What is happening when we project data?

- Case 1: Both PCSs contain the same GCS



What is happening when we project data?

- Case 1: Both PCSs contain the same GCS



What is happening when we project data?

- Case 2: Each PCS contains a different GCS

(x, y) PCS A1

PCS B2 (x, y)

(lon, lat)
(λ, φ) GCS A

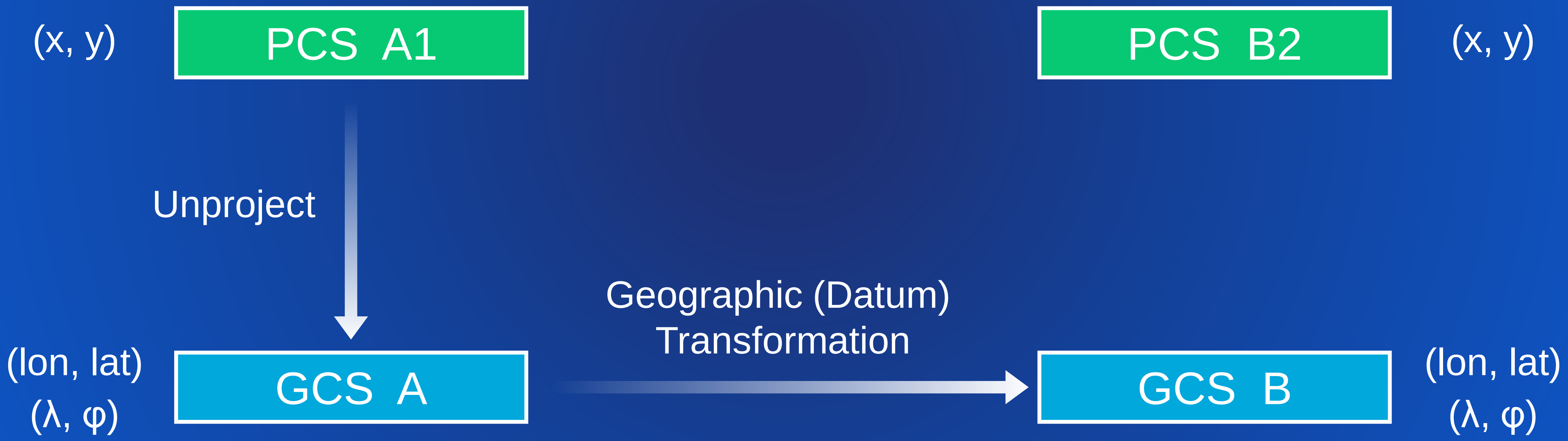
GCS B (lon, lat)
(λ, φ)

What is happening when we project data?

- Case 2: Each PCS contains a different GCS

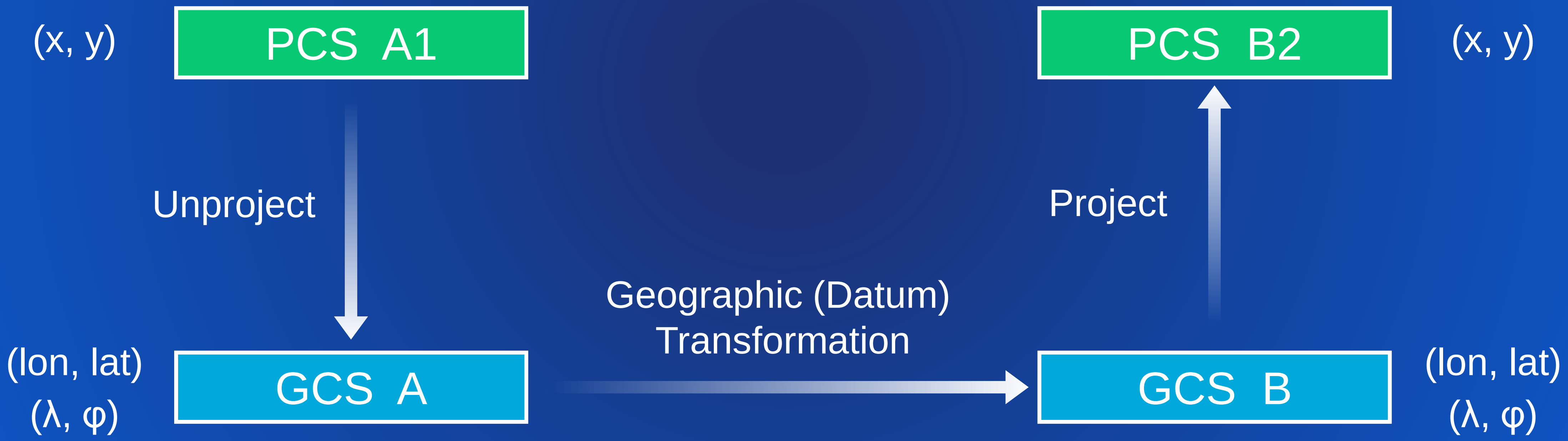
What is happening when we project data?

- Case 2: Each PCS contains a different GCS



What is happening when we project data?

- Case 2: Each PCS contains a different GCS



Datum Transformations

Geographic and Vertical

Why do we need to transform our data?

WGS 1984

ED 1950

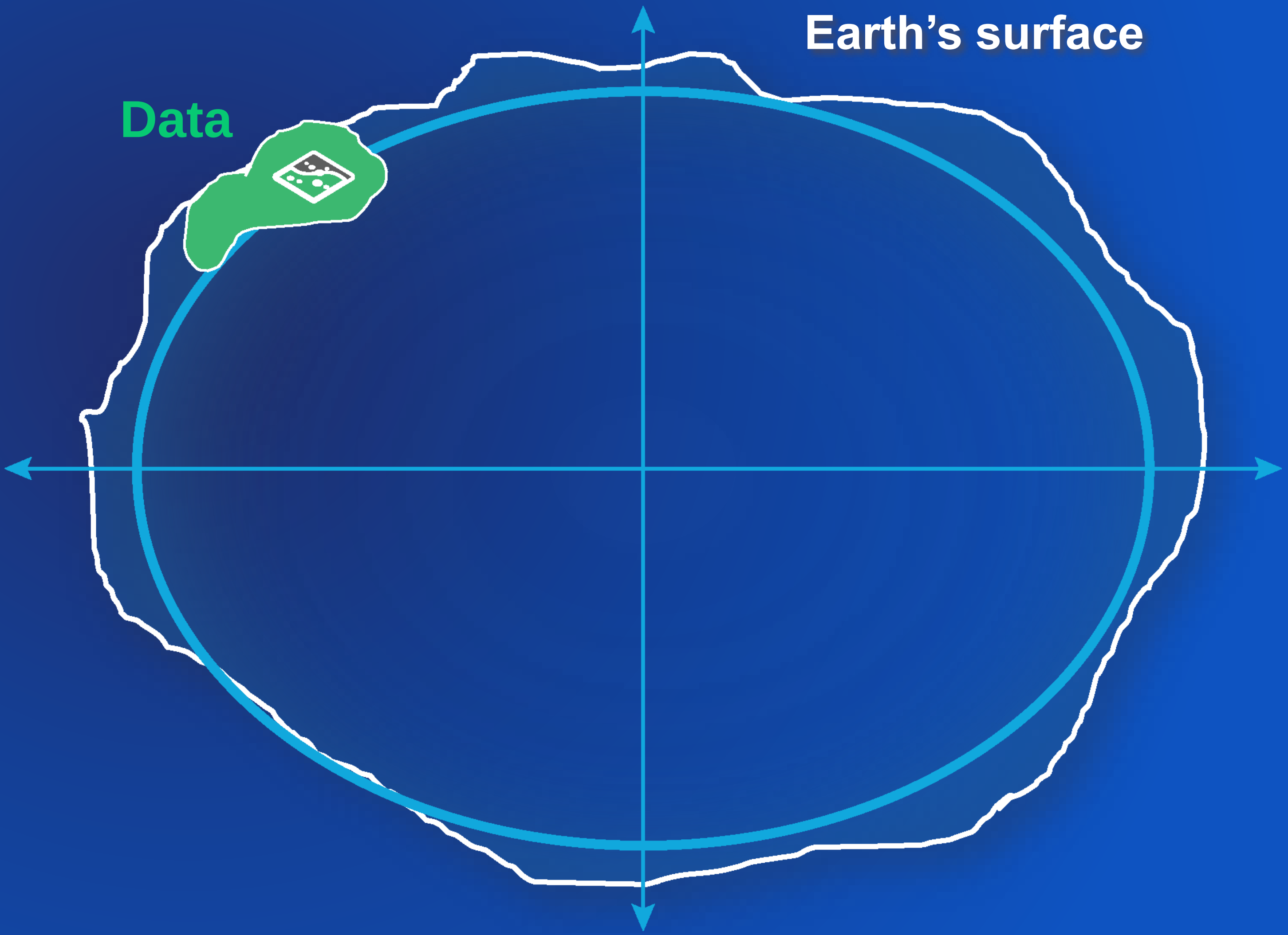
Why do we need to transform our data?

WGS 1984

ED 1950

Transforming Means Changing Datum

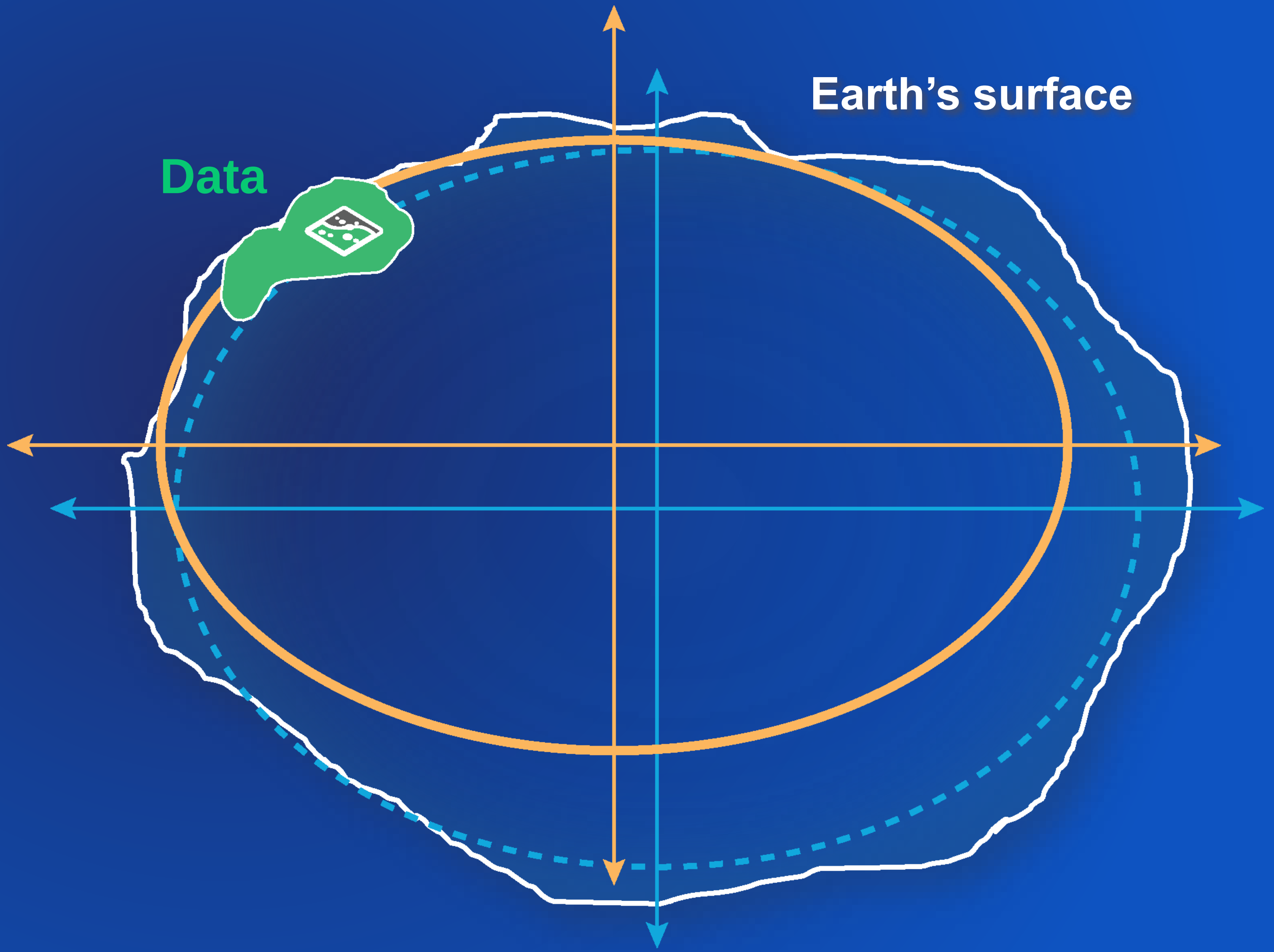
Earth-centered datum (WGS 1984)



Transforming Means Changing Datum

Earth-centered datum (WGS 1984)

Local datum (ED 1950)



Two Kinds of Transformations

Geographic (datum) transformation

Vertical transformation

Geographic (Datum) Transformation

- Between two geographic coordinate systems:

ED 1950 $\xrightarrow{\text{ED\_1950\_To\_WGS\_1984\_1}}$ WGS 1984

Geographic (Datum) Transformation

- Between two geographic coordinate systems:

Defined for Certain Area

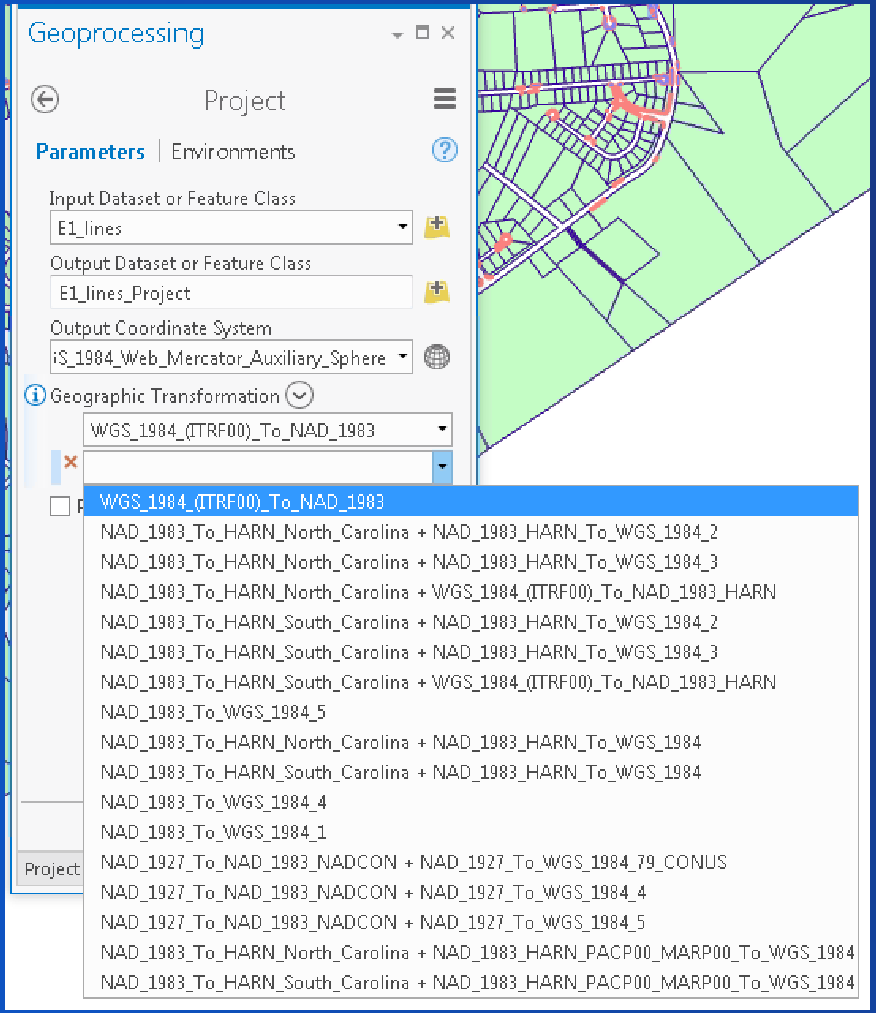
- Multiple transformations
  - Various areas, extents
  - Different accuracies

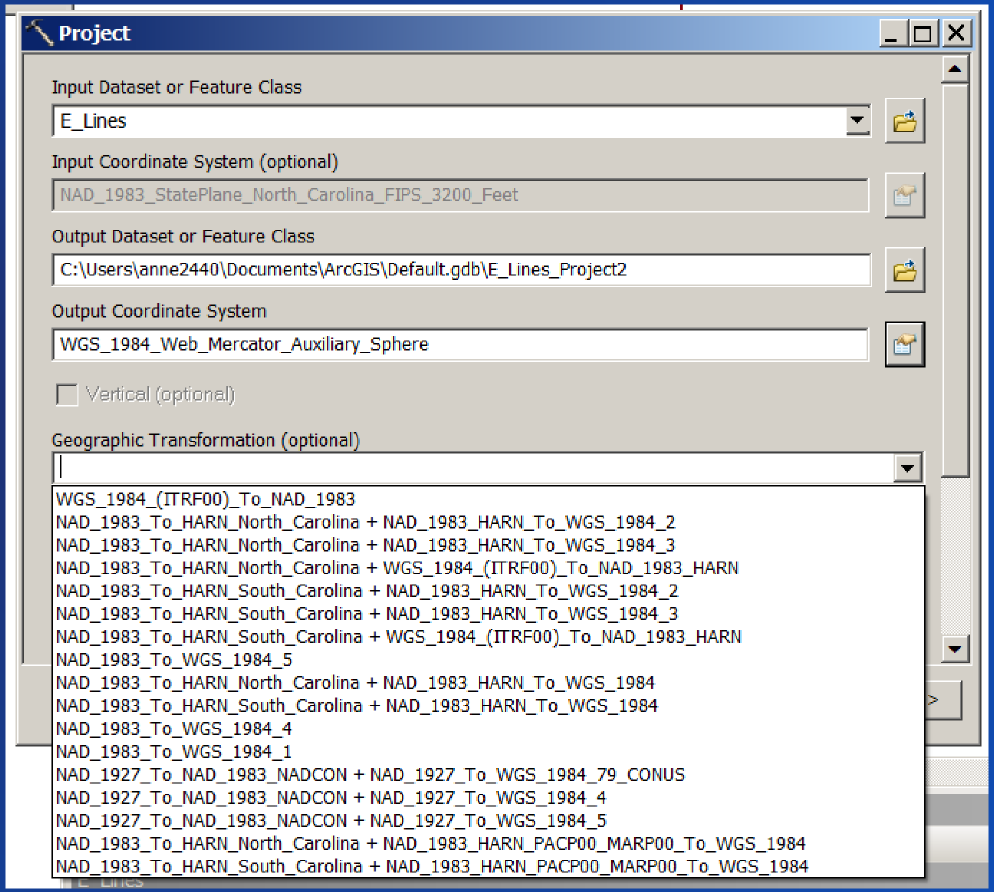
WGS 1984

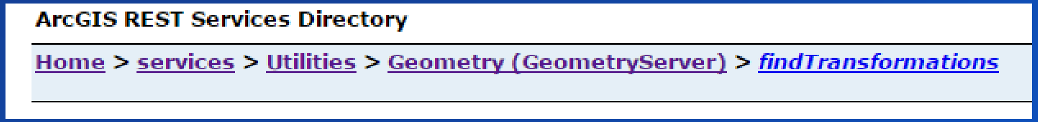
↕ 24 transformations

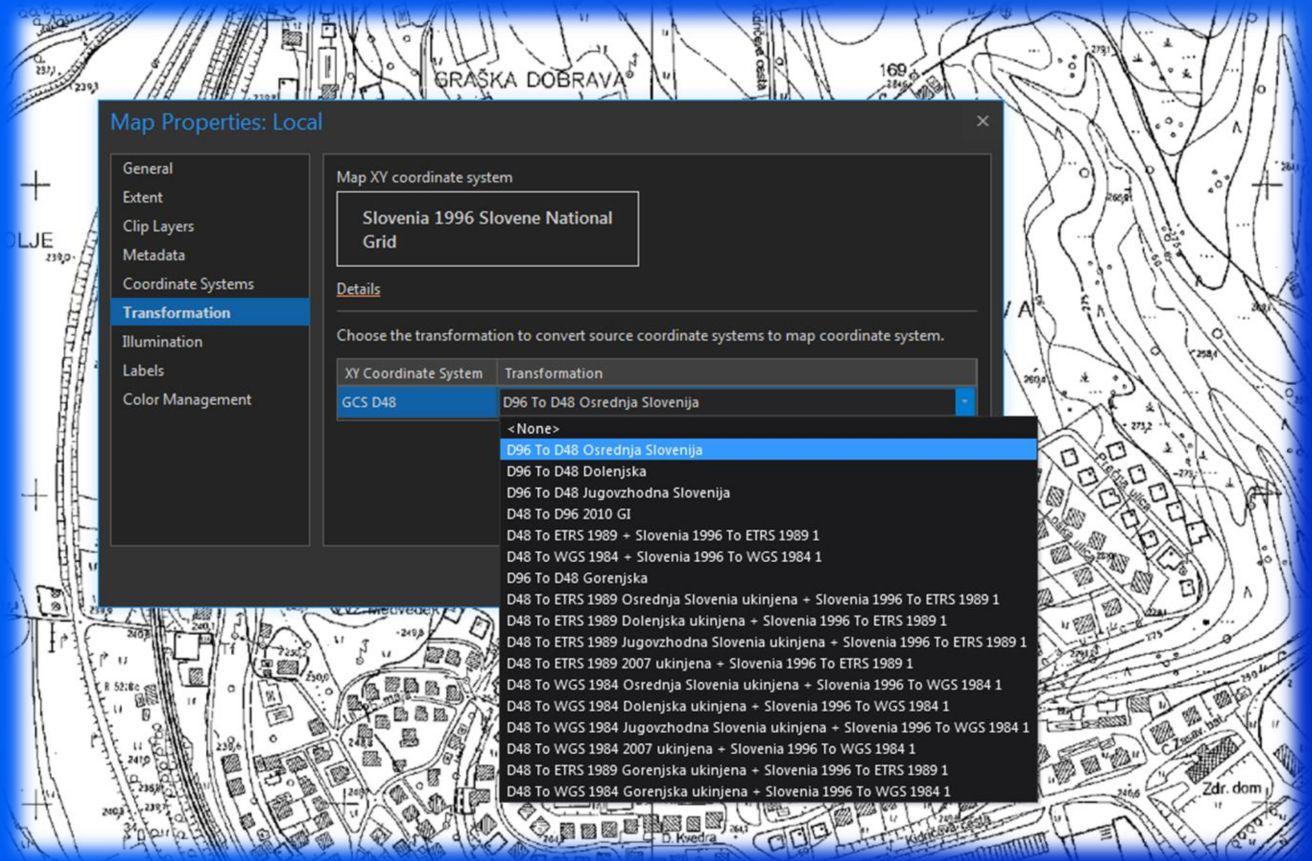
ED 1950

How do I find transformations?



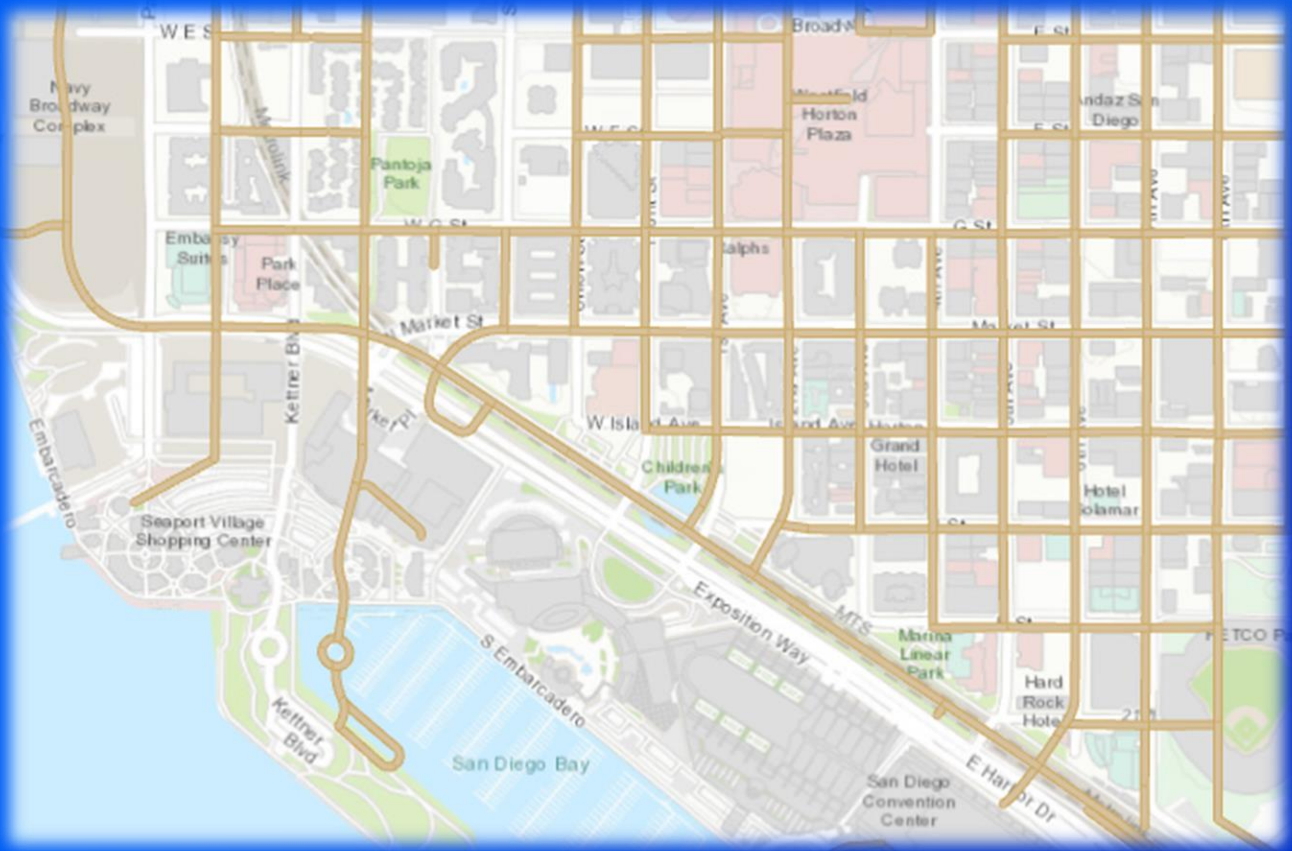






Deep Dive into Transformations

Today, 1:00 pm – 2:00 pm
Room 32 A/B



Map of the Gaslamp Quarter

Fixing datum transformations…

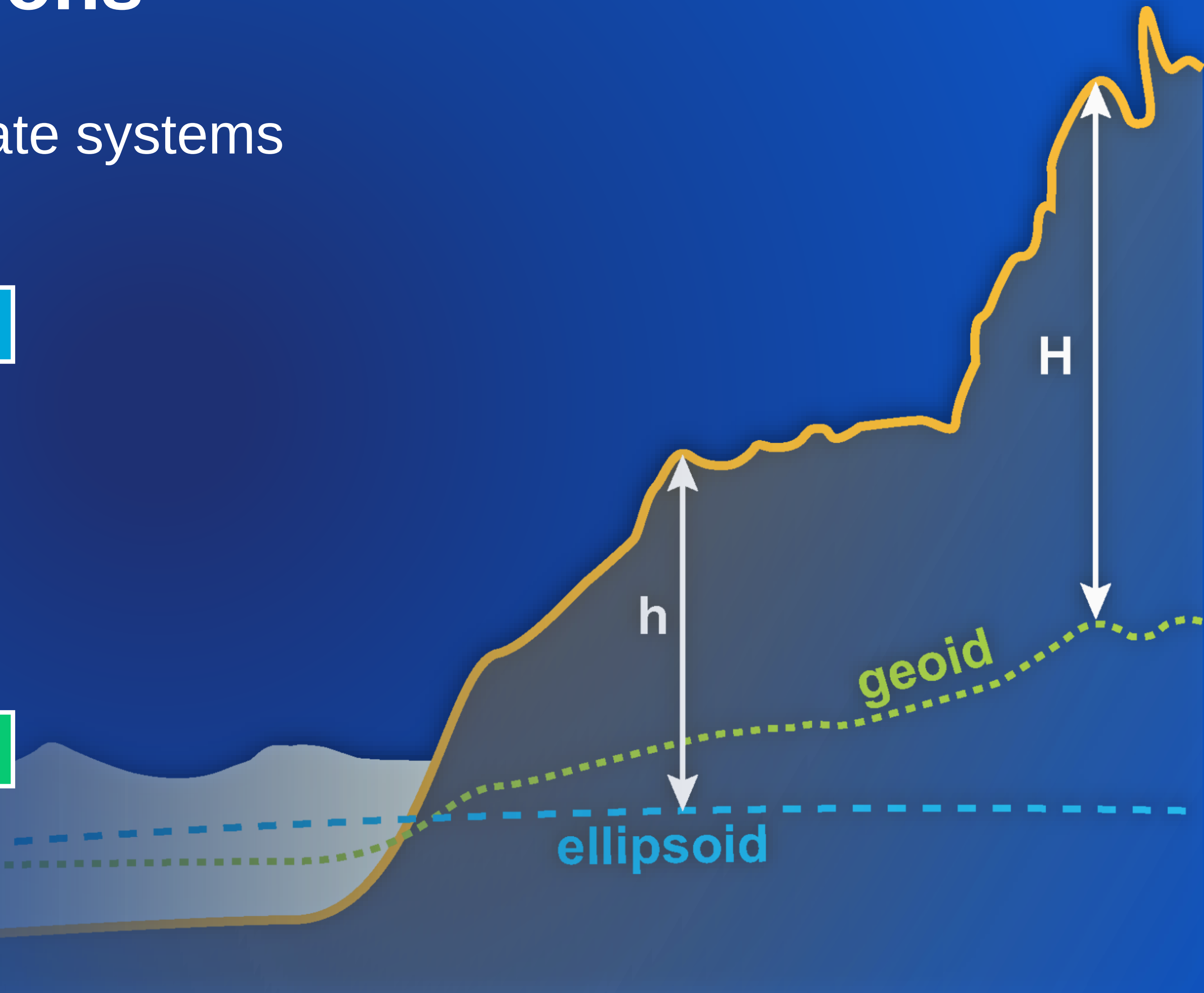
Vertical Transformations

- Between two vertical coordinate systems

Ellipsoidal Heights (NAD83)

NAD_1983_To_NAVD88_
CONUS_GEOID12B_Height

Orthometric Heights (NAVD 88)



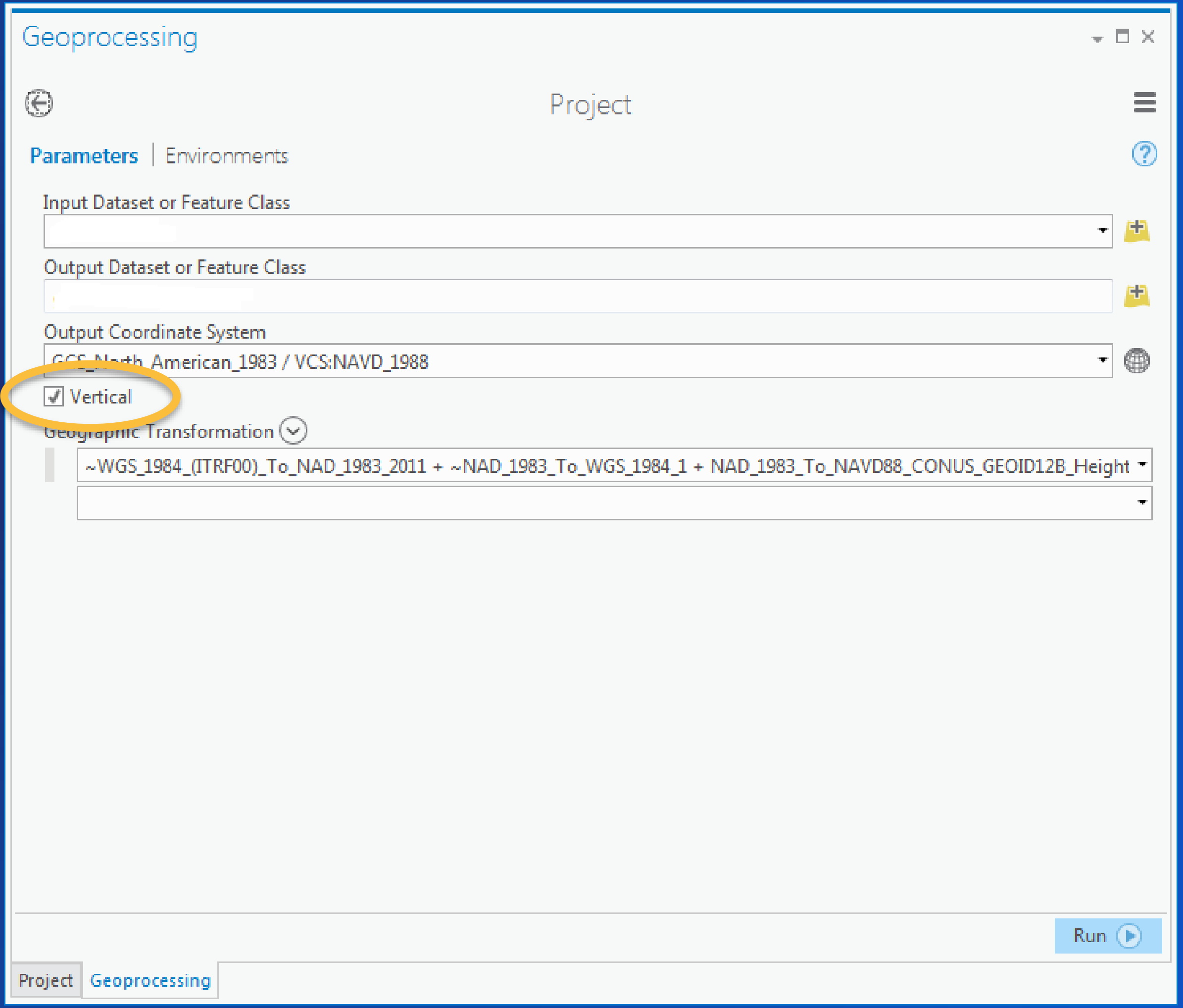
Vertical Transformations

- Project tool option

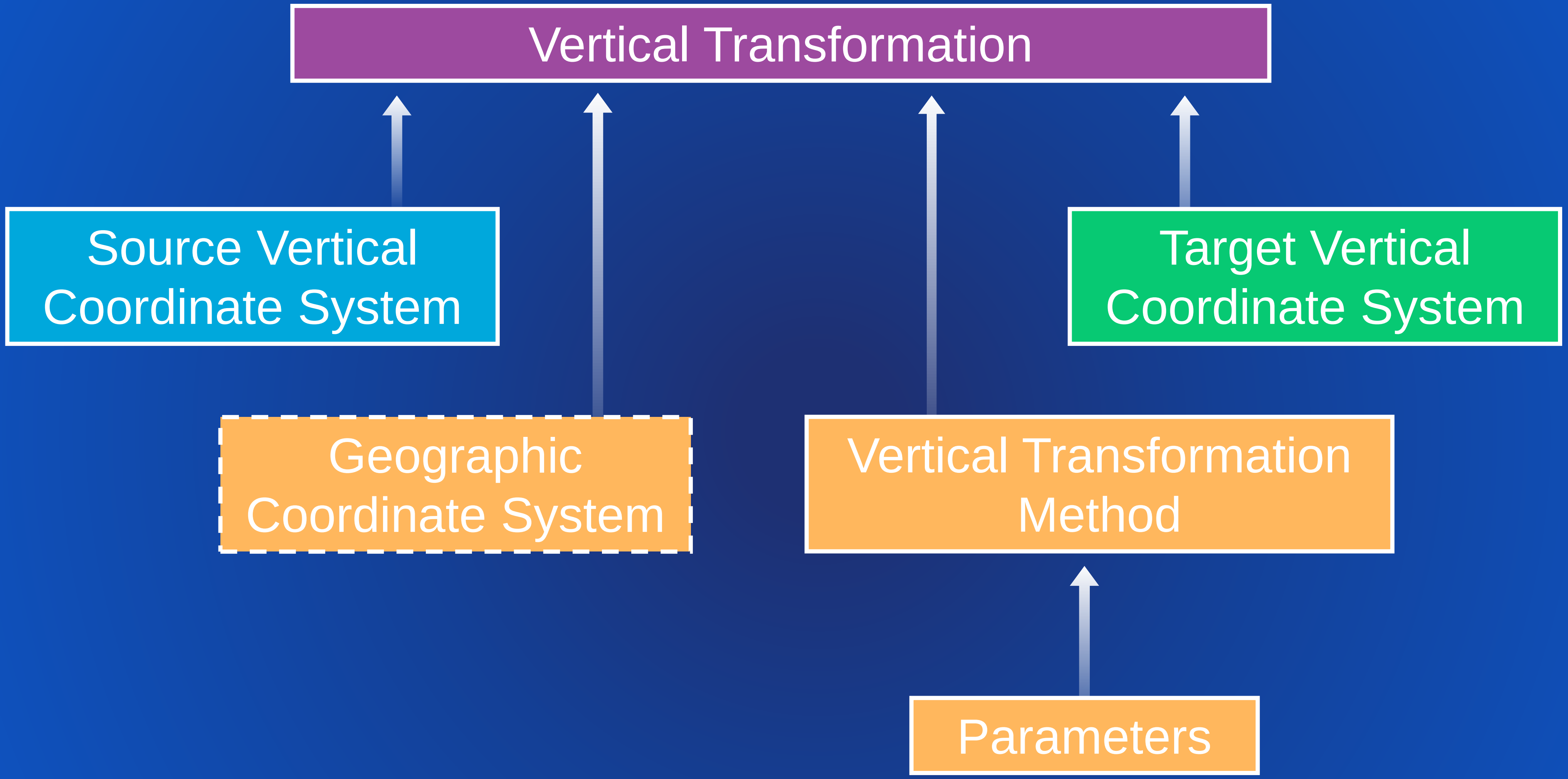
Ellipsoidal Heights (NAD83)

NAD_1983_To_NAVD88_
CONUS_GEOID12B_Height

Orthometric Heights (NAVD 88)




Vertical Transformation
Source Vertical Coordinate System
Target Vertical Coordinate System


Vertical Transformation
Source Vertical Coordinate System
Target Vertical Coordinate System
Geographic Coordinate System
Vertical Transformation Method
Parameters

Vertical Transformation Methods

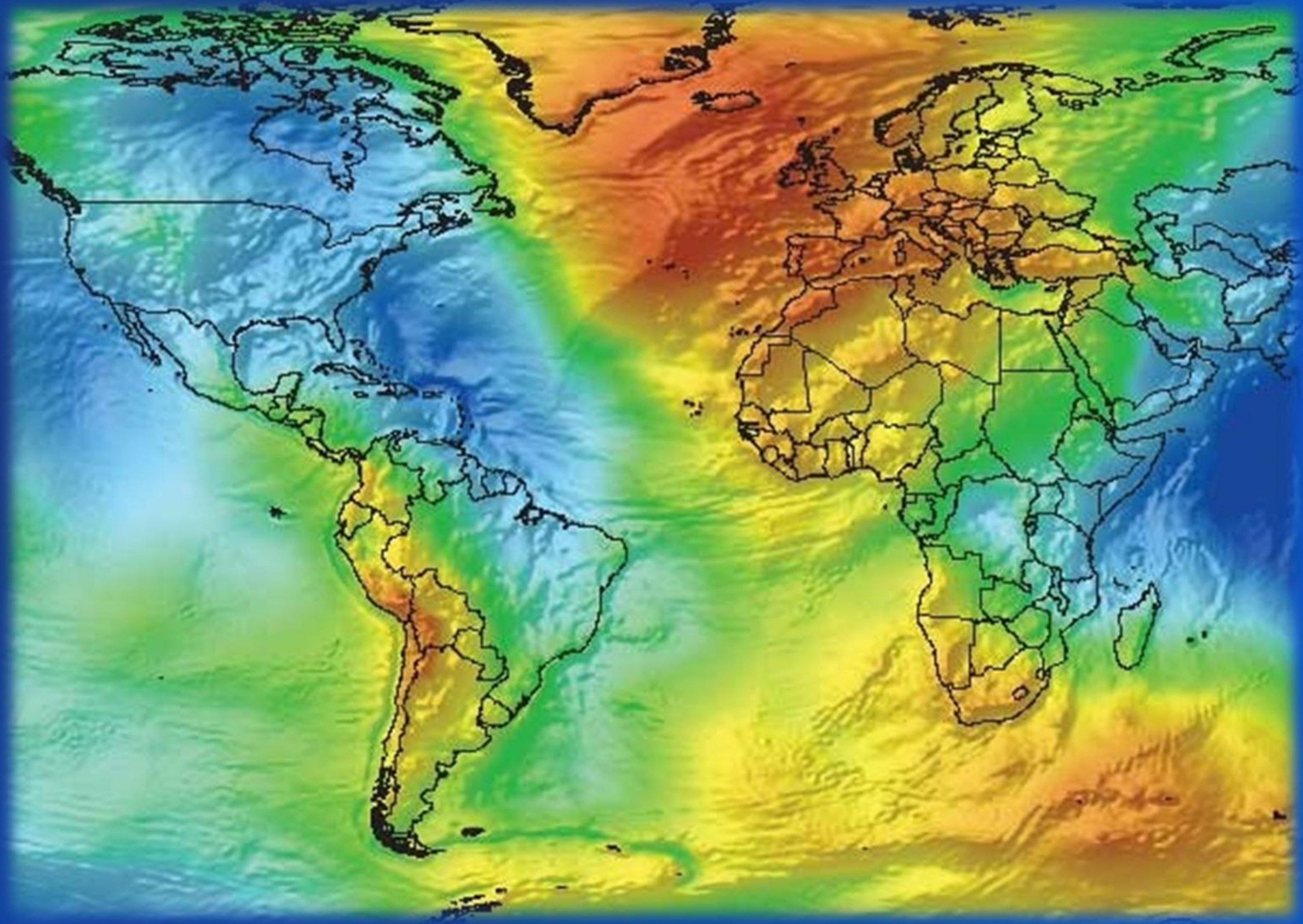
Geoid model formats

- EGM2008
- EGM84 and EGM96
- GEOID12B

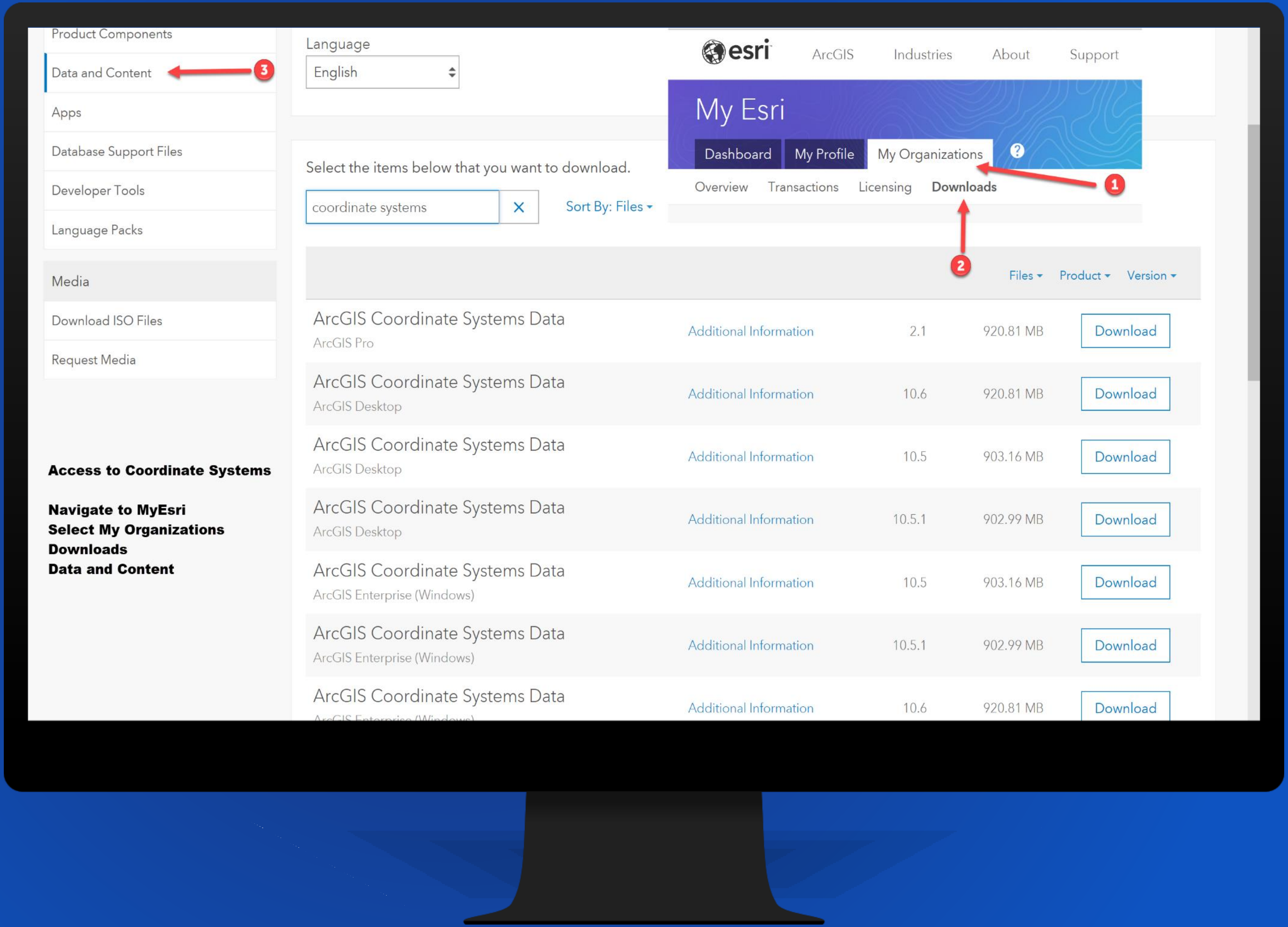
VERTCON

Vertical offset

Vertical offset and slope



ArcGIS Coordinate Systems Data



ArcGIS Coordinate Systems Data

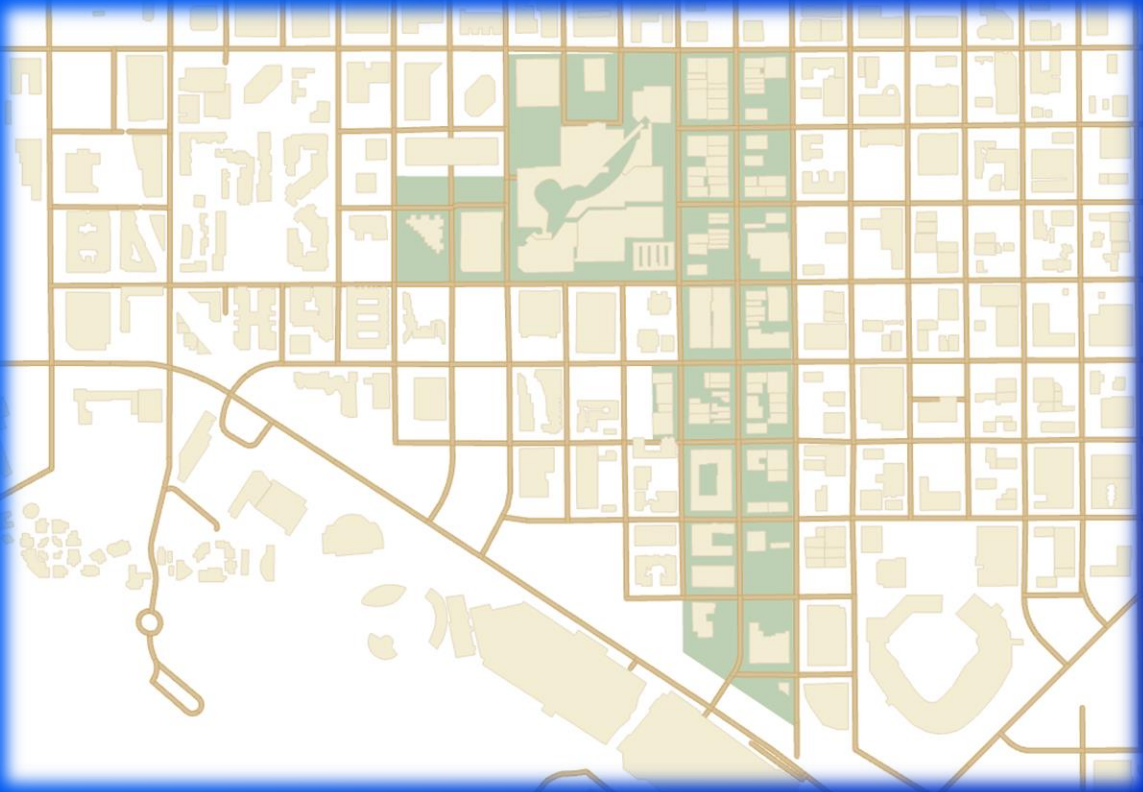
- 1.6 GB additional data install

- GEOCON v1.0 (USA)
- NTv2 (AU, BE, CA, ES, CH, UK)
- NADCON (SK)

Geographic Transformations

- VERTCON / GEOID12B (USA)
- Geoids (JP, NZ, CH)
- EGM2008 (world)

Vertical Transformations

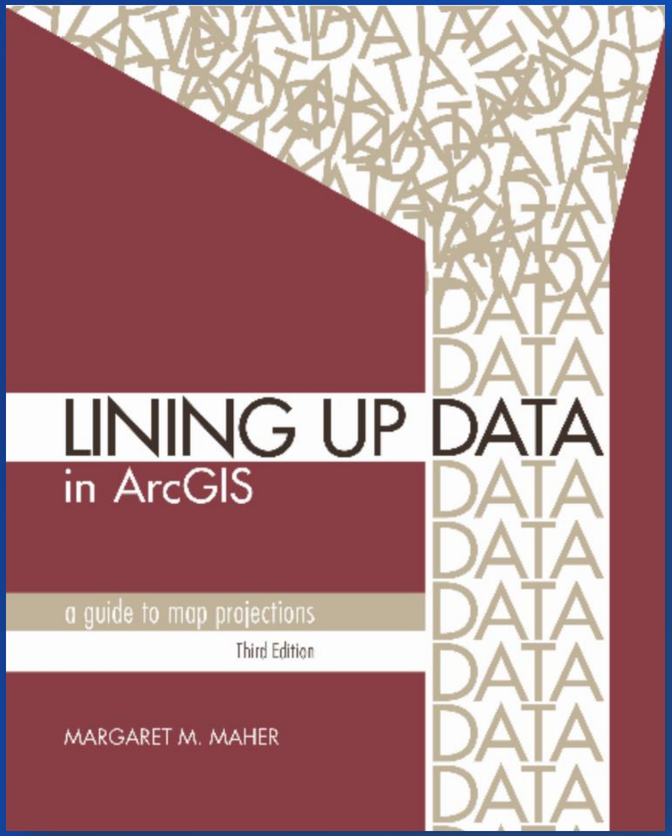


Map of the Gaslamp Quarter

A custom projection for the map…

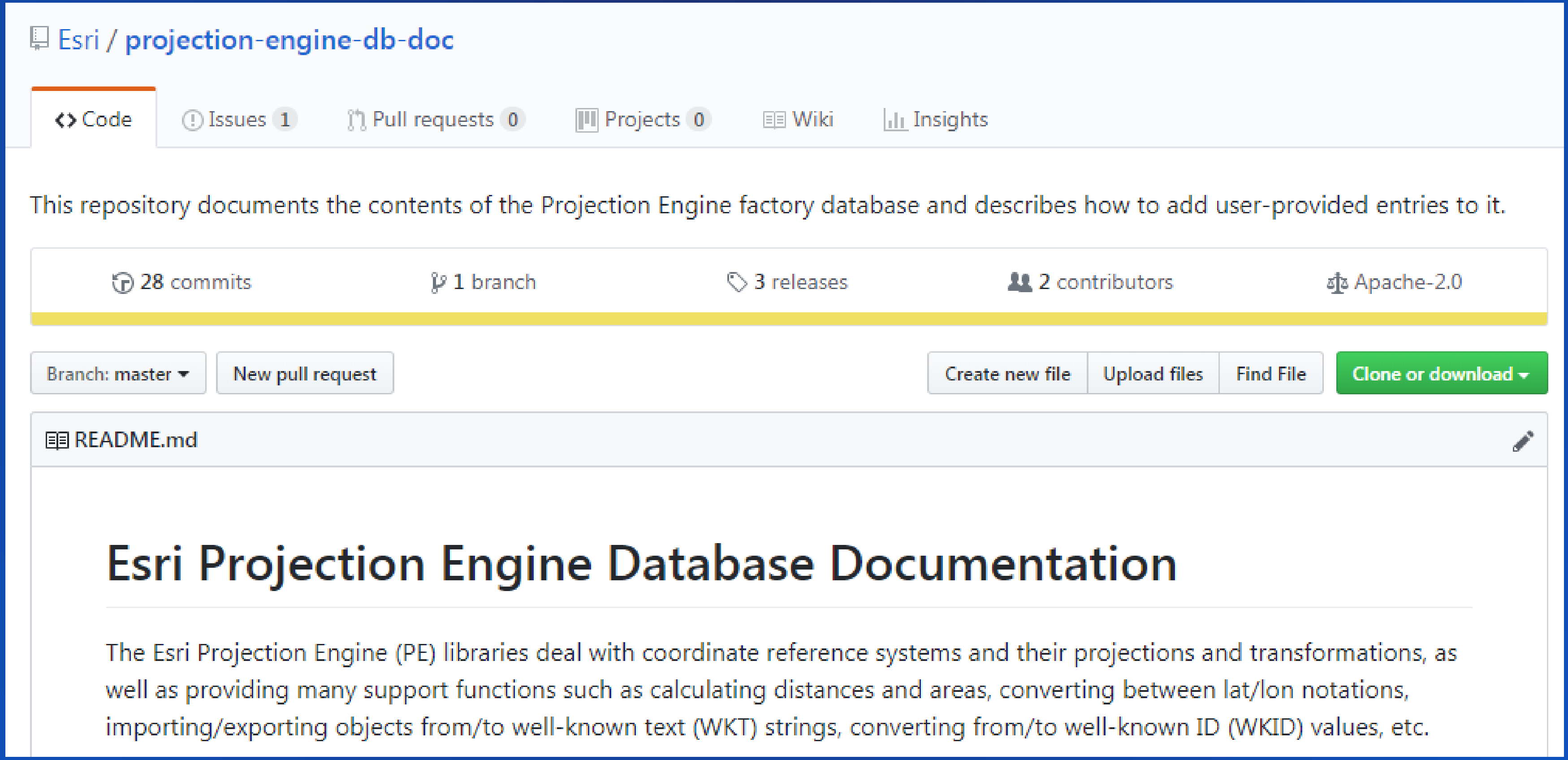
Resources

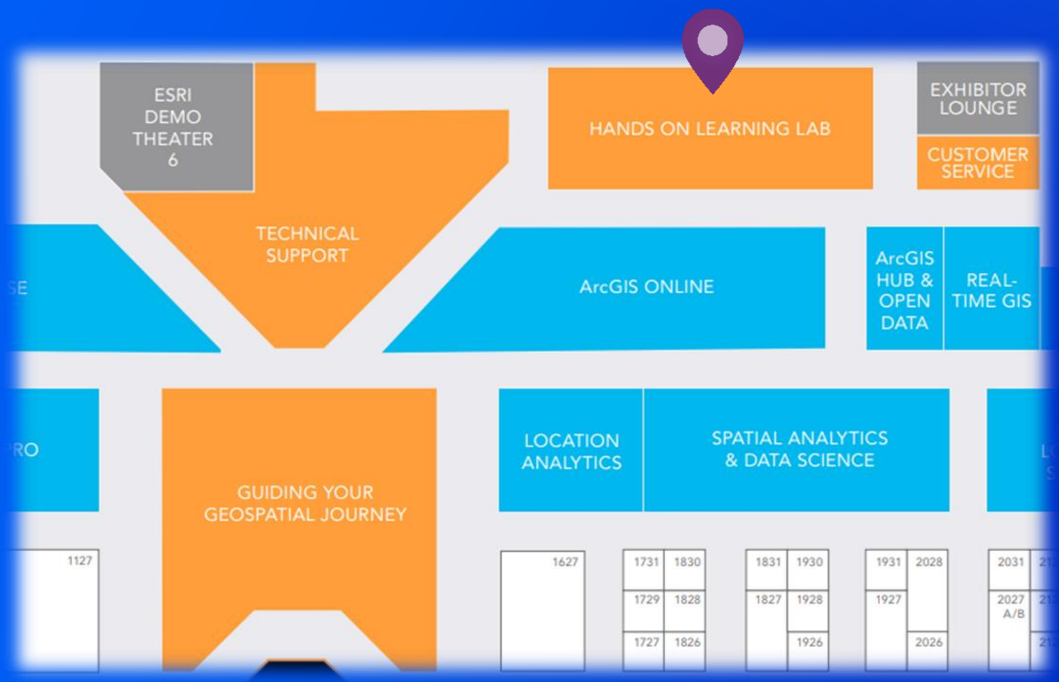
- Don't forget the Knowledge Base / Technical Articles!
  - http://esriurl.com/11518
- Esri forums for user-to-user help
  - http://geonet.esri.com
- EPSG (epsg-registry.org)
  - Database of coordinate systems & datums
  - *Guidance Note 7-2*
- Lining Up Data in ArcGIS, *Margaret Maher*



Resources

- Esri Projection Engine Database Documentation
  - https://github.com/Esri/projection-engine-db-doc/

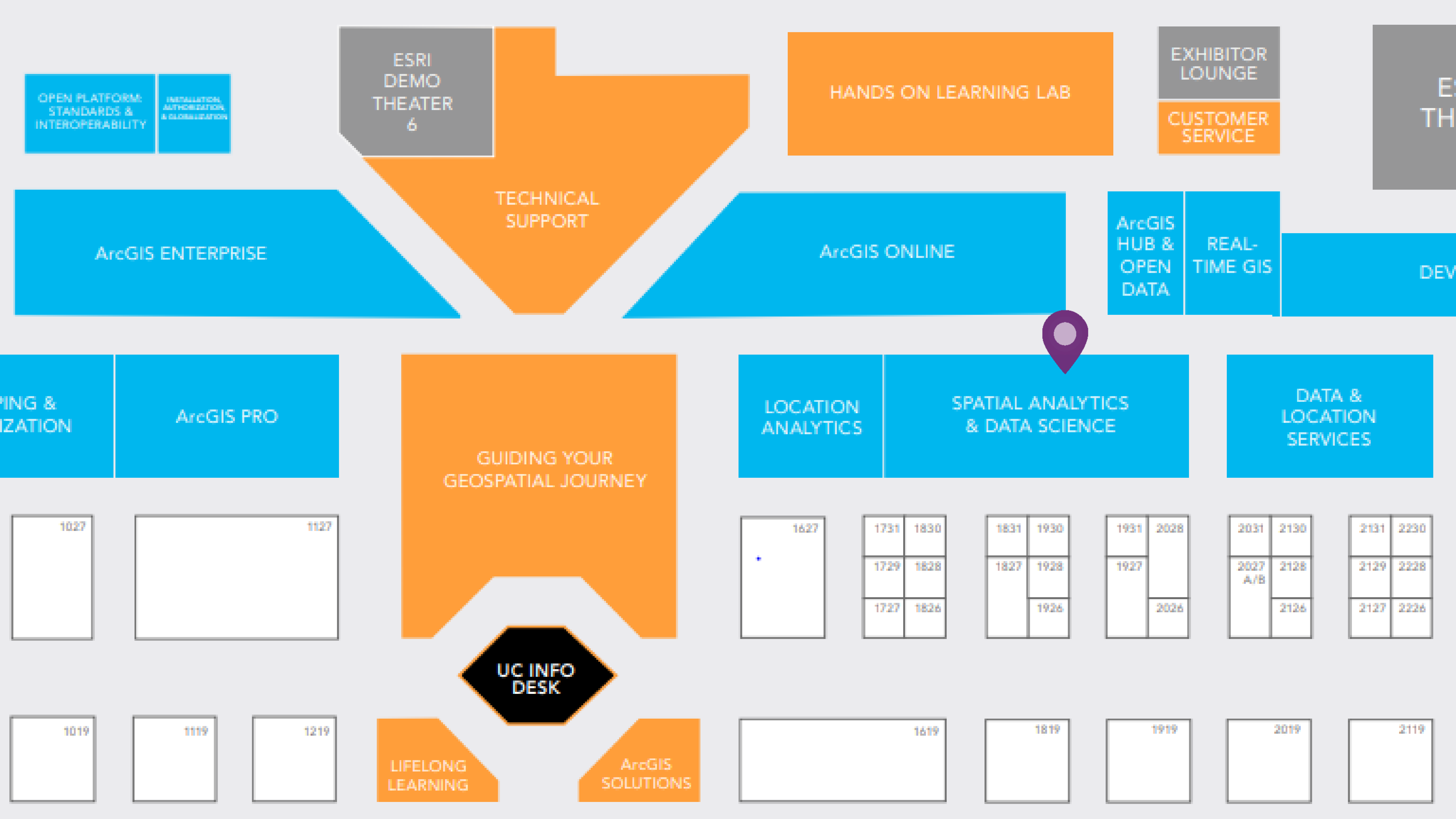




Spatial Reference and Data Alignment **Lesson**

Hands-on Learning Lab, Exhibit Hall A

Today, 9:00 am – 4:00 pm


OPEN PLATFORM: STANDARDS & INTEROPERABILITY
ESRI DEMO THEATER 6
TECHNICAL SUPPORT
HANDS ON LEARNING LAB
EXHIBITOR LOUNGE
CUSTOMER SERVICE
ArcGIS ENTERPRISE
ArcGIS ONLINE
ArcGIS HUB & OPEN DATA
REAL-TIME GIS
ArcGIS PRO
GUIDING YOUR GEOSPATIAL JOURNEY
LOCATION ANALYTICS
SPATIAL ANALYTICS & DATA SCIENCE
DATA & LOCATION SERVICES
1027
1127
1627
1731
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1729
1828
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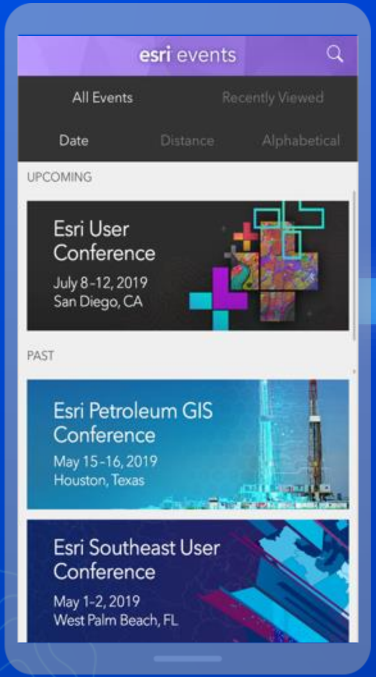
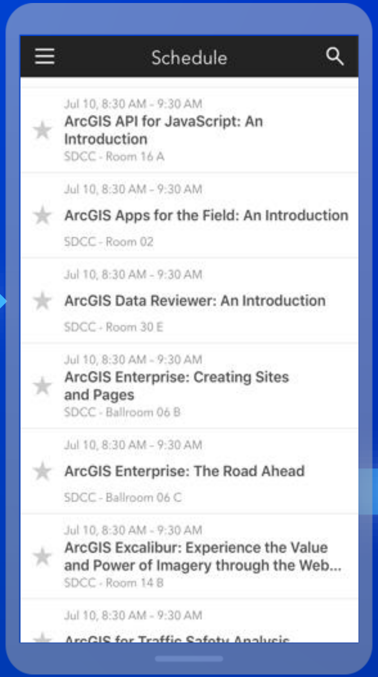
2026
2031
2130
2027 A/B
2128
2126
2131
2230
2129
2228
2127
2226
UC INFO DESK
1019
1119
1219
LIFELONG LEARNING
ArcGIS SOLUTIONS
1619
1819
1919
2019
2119

Please Share Your Feedback in the App

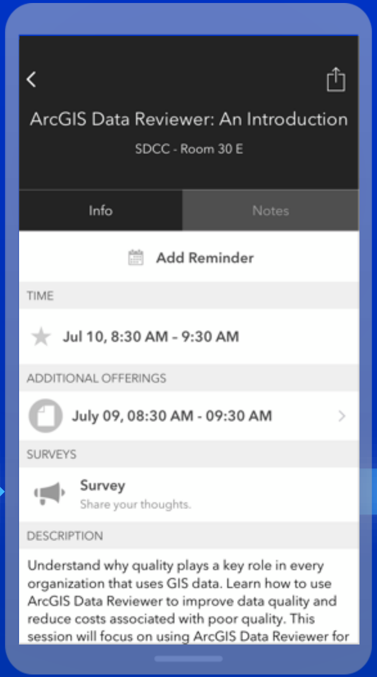
Download the Esri Events app and find your event



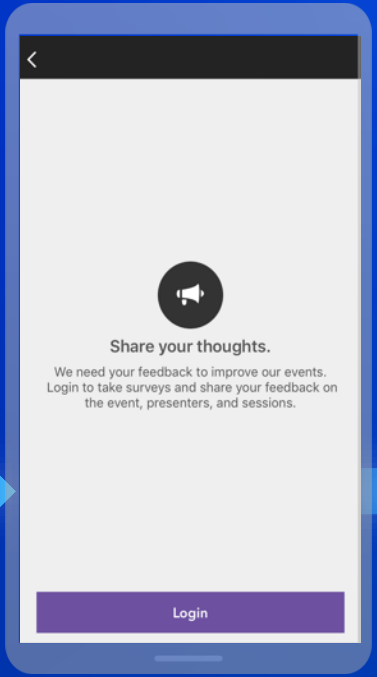
Select the session you attended



Scroll down to "Survey"



Log in to access the survey



Complete the survey and select "Submit"