Use Literally Anything but Web Mercator

Bojan Šavrič & Melita Kennedy

2021 ESRI DEVELOPER SUMMIT

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Software Development Engineer

Projection Engine Team

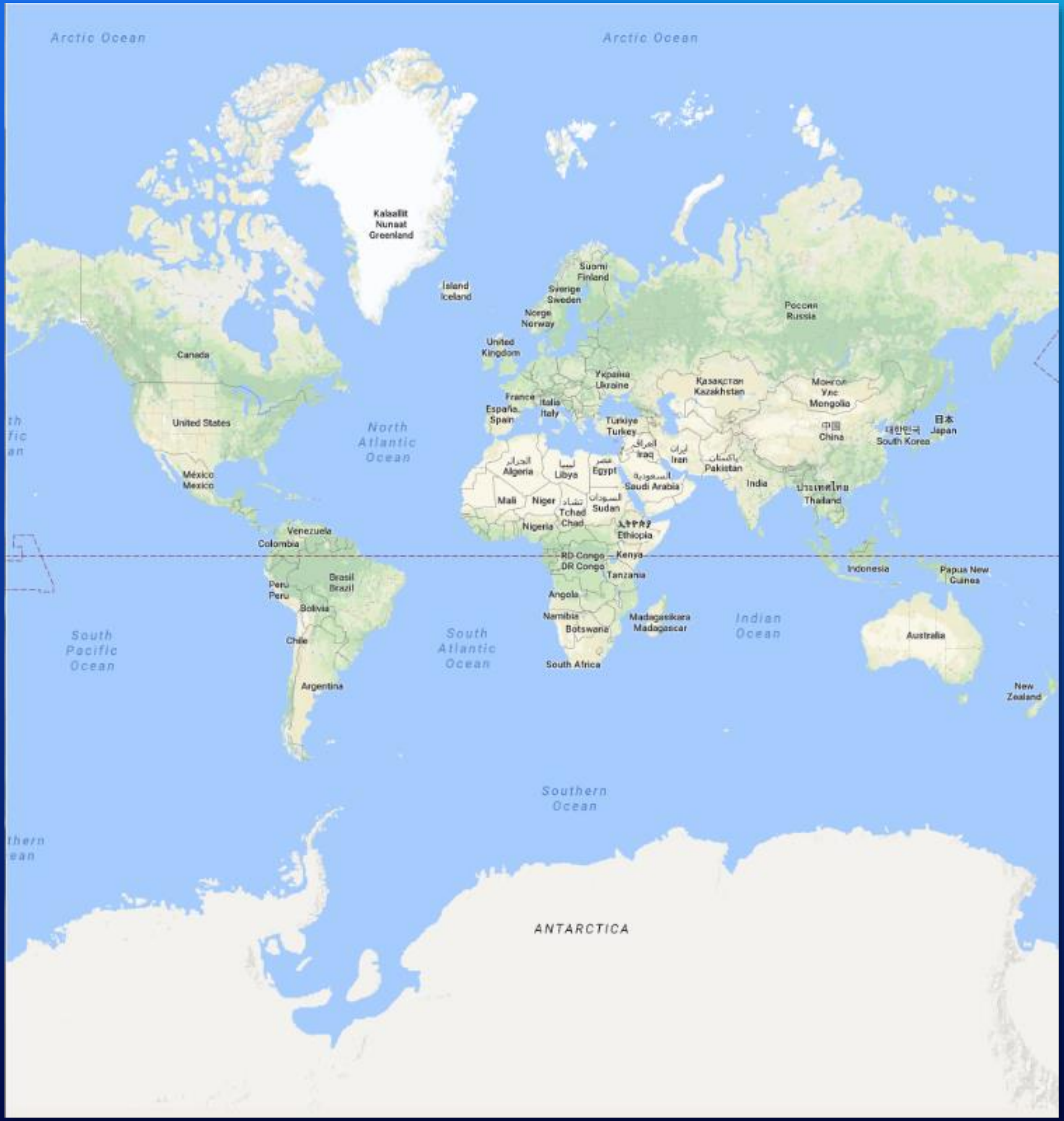
Melita Kennedy

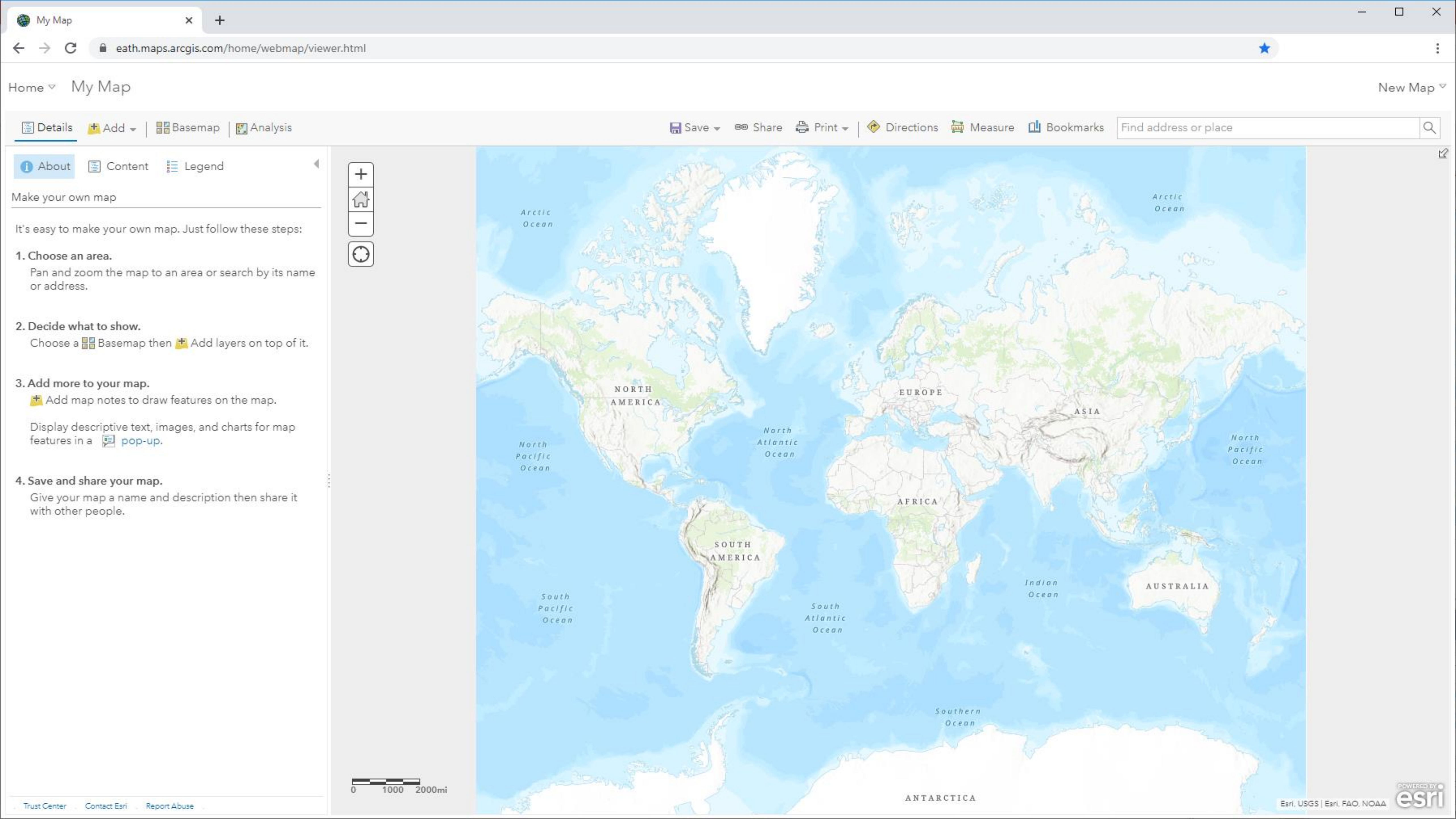
Principal Product Engineer

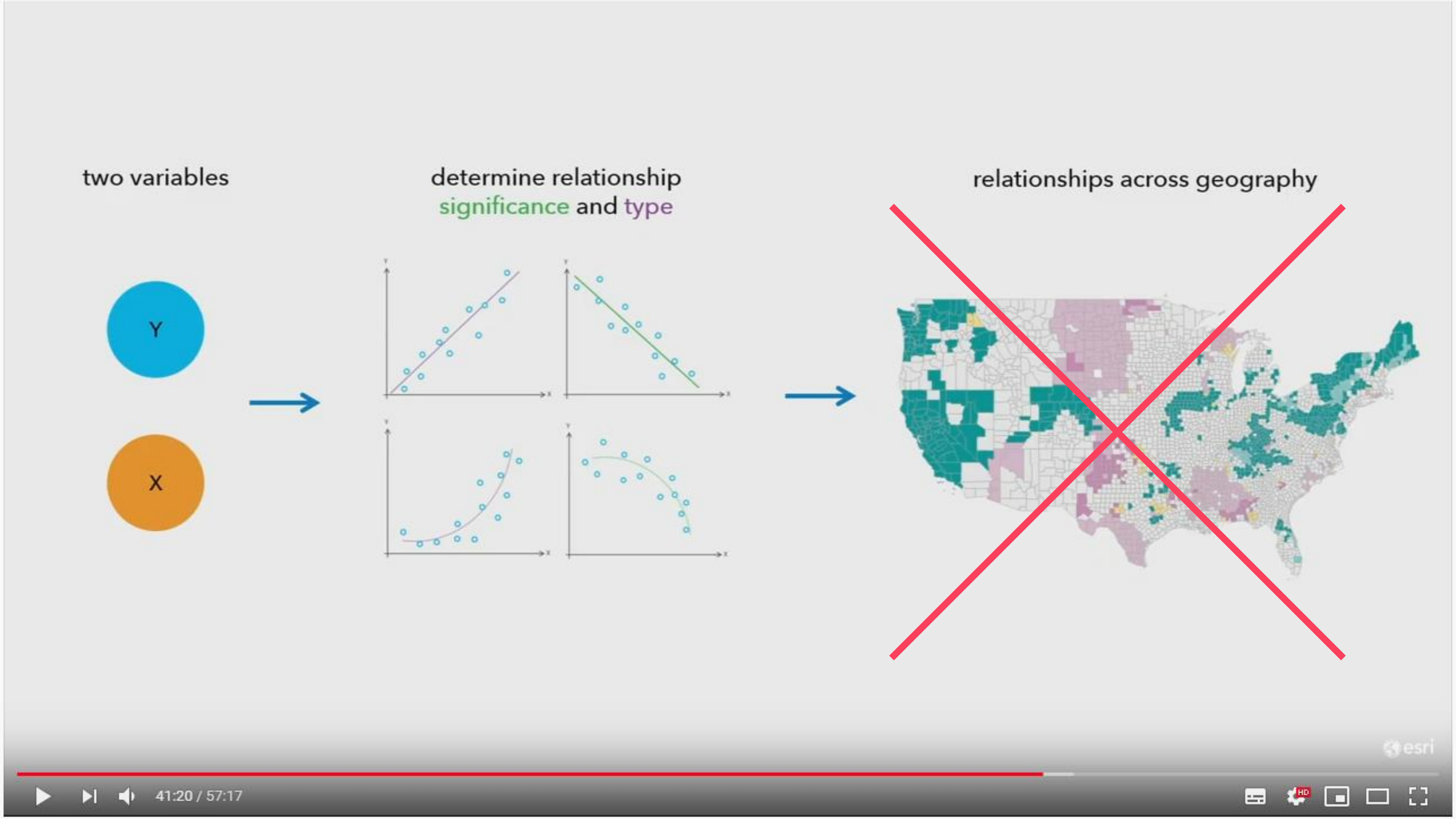
Projection Engine Team

Web Mercator

- It is everywhere!
- Started when Google Maps was introduced in 2005




My Map
eath.maps.arcgis.com/home/webmap/viewer.html
Home
My Map
New Map
Details
Add
Basemap
Analysis
Save
Share
Print
Directions
Measure
Bookmarks
Find address or place
About
Content
Legend
Make your own map
It's easy to make your own map. Just follow these steps:
1. Choose an area.
Pan and zoom the map to an area or search by its name or address.
2. Decide what to show.
Choose a Basemap then Add layers on top of it.
3. Add more to your map.
Add map notes to draw features on the map.
Display descriptive text, images, and charts for map features in a pop-up.
4. Save and share your map.
Give your map a name and description then share it with other people.
Trust Center
Contact Esri
Report Abuse
Arctic Ocean
Arctic Ocean
NORTH AMERICA
EUROPE
ASIA
North Atlantic Ocean
North Pacific Ocean
North Pacific Ocean
AFRICA
SOUTH AMERICA
Indian Ocean
AUSTRALIA
South Pacific Ocean
South Atlantic Ocean
Southern Ocean
ANTARCTICA
0 1000 2000mi
Esri, USGS | Esri, FAO, NOAA
esri

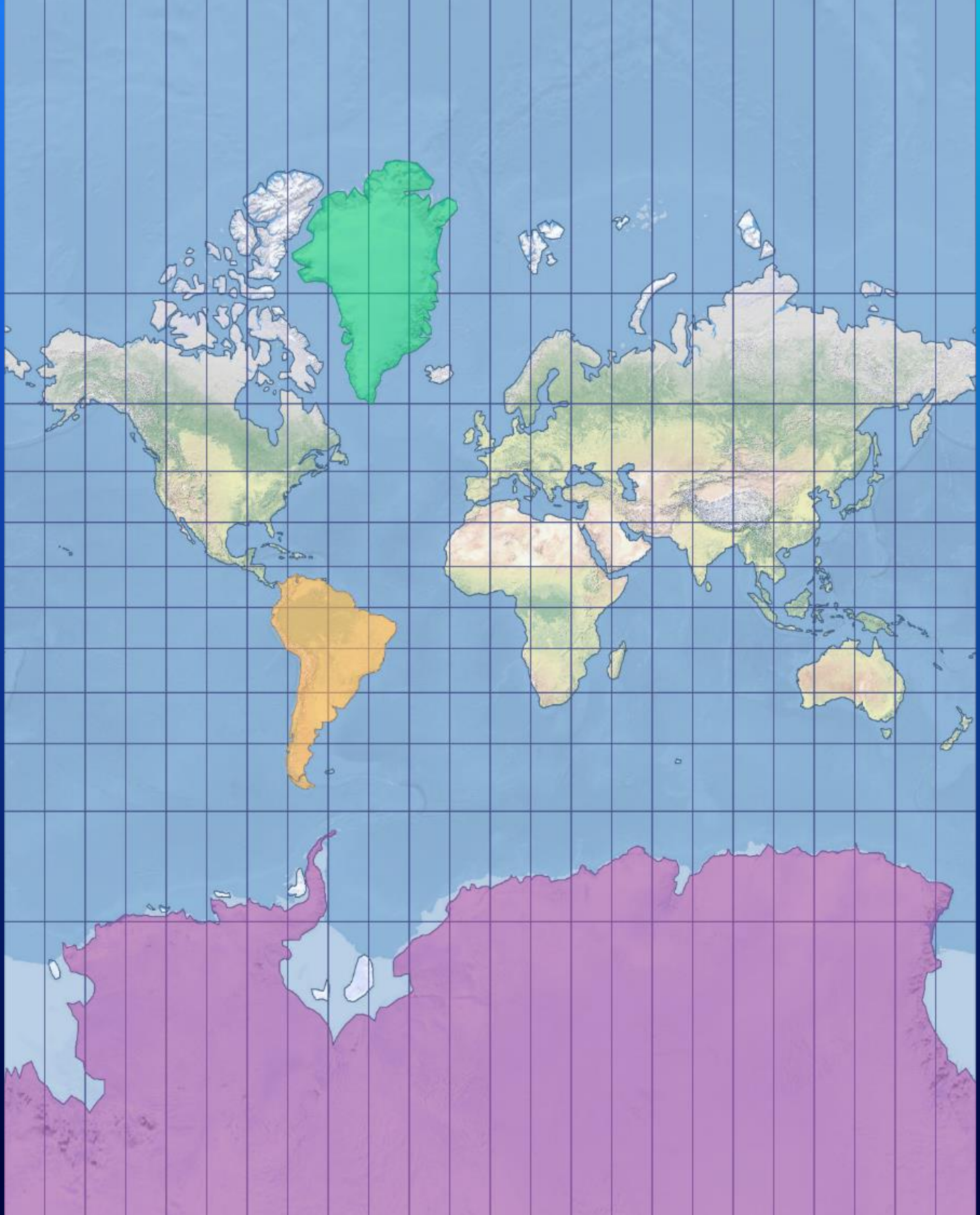


Beyond Where: Modeling Spatial Relationships and Making Predictions

Web Mercator

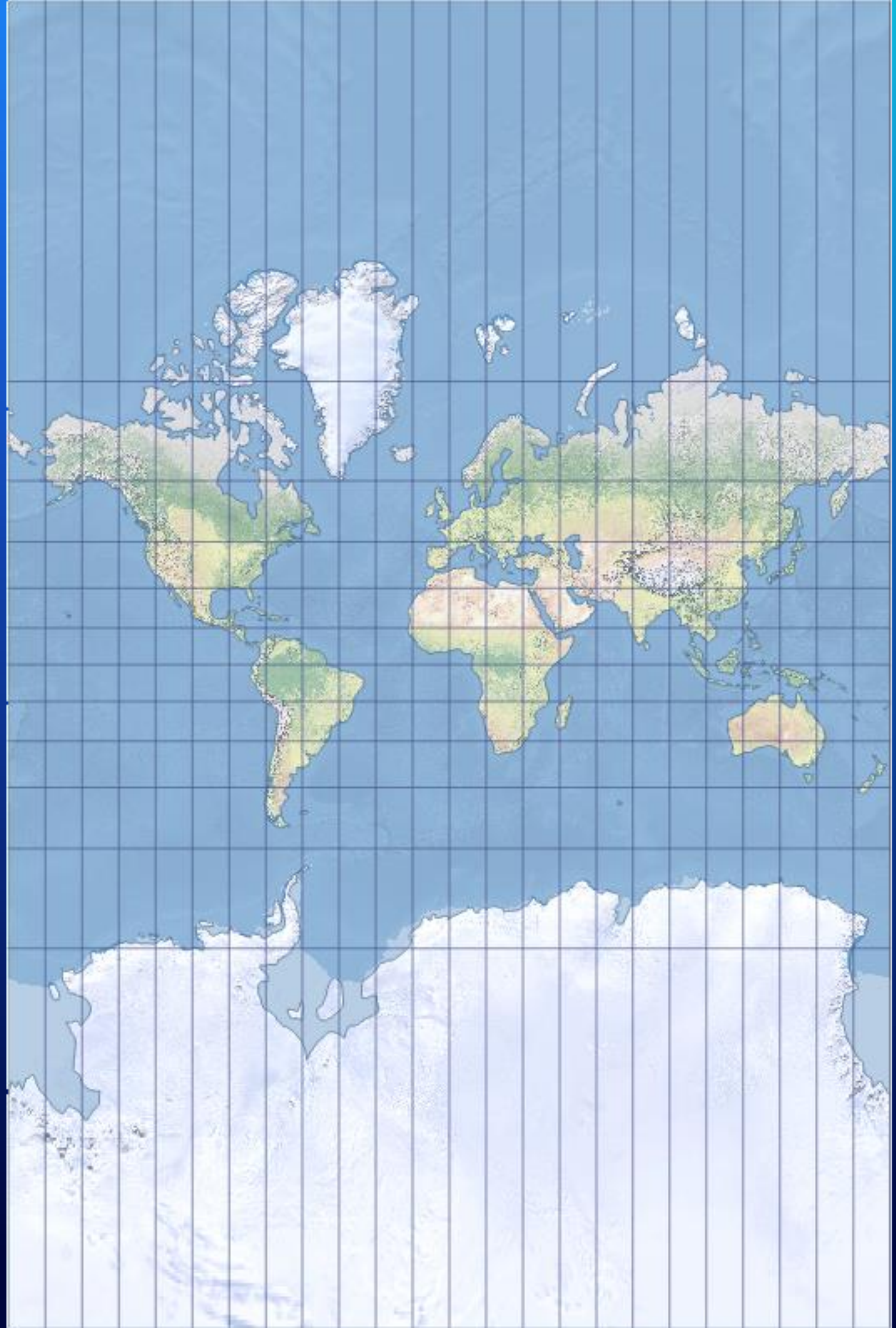
Q: Which is bigger?

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



Why not Web Mercator?

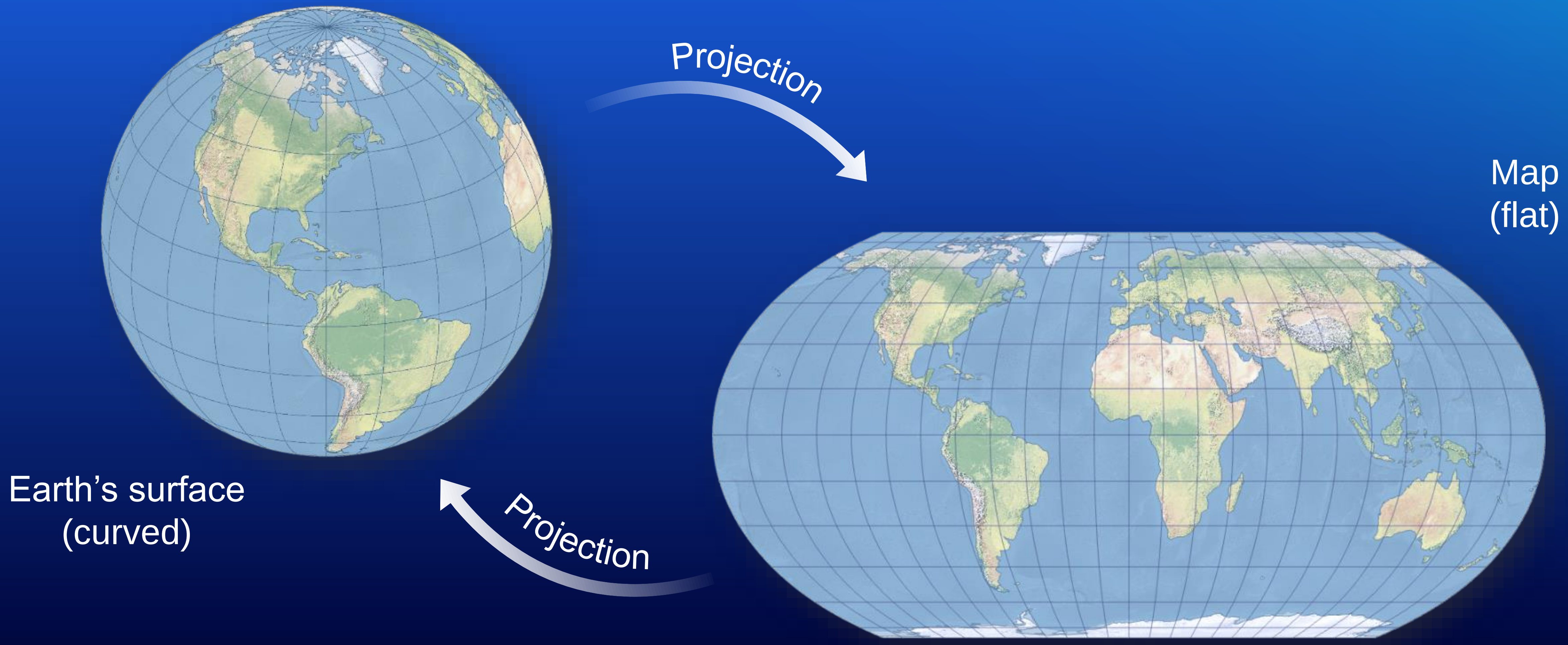
- Shows areas with enormous distortion
- Impossible to display poles (infinite scale at poles)
- Rectangular shape gives an impression that our world is flat



Addressing Common Misconceptions

1. Web Mercator is a projected coordinate system, not a projection

From a Spheroid to a Plane



```
PROJCS["WGS_1984_Web_Mercator_Auxiliary_Sphere",
  GEOGCS["GCS_WGS_1984",
    DATUM["D_WGS_1984",
        SPHEROID["WGS_1984",6378137.0,298.257223563]],
    PRIMEM["Greenwich",0.0],
    UNIT["Degree",0.0174532925199433]],
  PROJECTION["Mercator_Auxiliary_Sphere"],
  PARAMETER["False_Easting",0.0],
  PARAMETER["False_Northing",0.0],
  PARAMETER["Central_Meridian",0.0],
  PARAMETER["Standard_Parallel_1",0.0],
  PARAMETER["Auxiliary_Sphere_Type",0.0],
  UNIT["Meter",1.0]]
```

Web Mercator Projected Coordinate System

Addressing Common Misconceptions

1. Web Mercator is a projected coordinate system, not a projection

2. Web Mercator does not preserve shape

   - There is no projection that preserves correct shapes

Web Mercator Projection vs. Reality

Addressing Common Misconceptions

1. Web Mercator is a projected coordinate system, not a projection
2. Web Mercator does not preserve shape
3. Web Mercator does not preserve local angles (not conformal)

Geographic Coordinates

- Longitude (λ), Latitude (ϕ)

- Defined on a curved 2D surface
  - Ellipsoid (most data)
  - Sphere (very rarely)

Field, K. (2018) Cartography., p. 361

Projection Equations

- A projection can have a pair of equations for both models
  - Mercator projection for a sphere

$$x = R \cdot (\lambda - \lambda_0) \qquad y = \frac{R}{2} \cdot \ln\left[\frac{1 + \sin\phi}{1 - \sin\phi}\right]$$

  - Mercator projection for an ellipsoid

$$x = a \cdot (\lambda - \lambda_0) \qquad y = \frac{a}{2} \cdot \ln\left[\left(\frac{1 + \sin\phi}{1 - \sin\phi}\right)\left(\frac{1 + e \cdot \sin\phi}{1 - e \cdot \sin\phi}\right)^{e}\right]$$

Geographic Coordinates + Projection Equations

Earth		Projection		Map property
Sphere	+	Mercator for spheres	→	Conformal ✓
Ellipsoid	+	Mercator for ellipsoids	→	Conformal ✓
Ellipsoid	+	Web Mercator: Mercator for spheres	→	Conformal ✗

Web Mercator

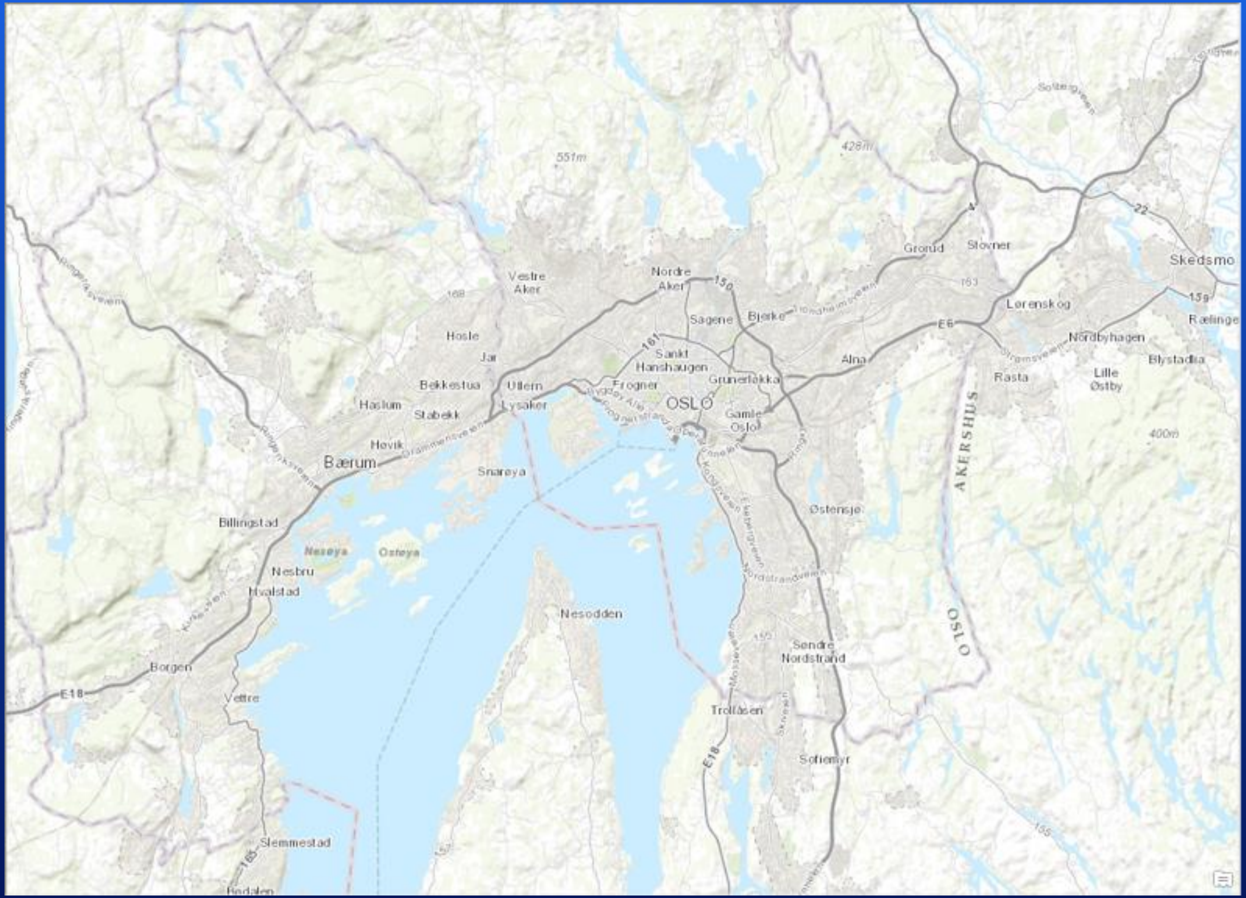
> “The Web Mercator is an engineering mistake that went out of control!

Web Mercator

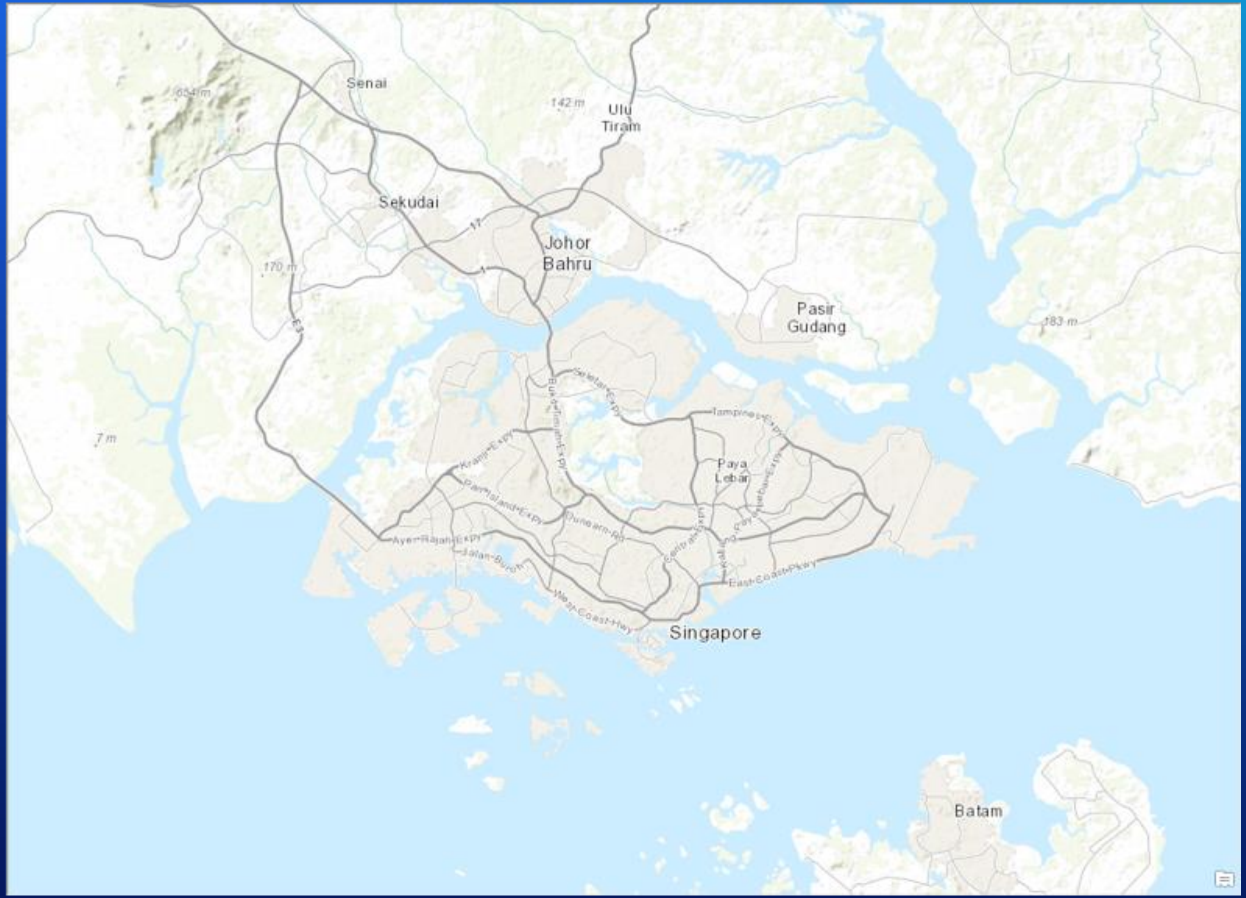
- It distorts everything
  - Shapes
  - Angles
  - Areas
  - Distances
  - Directions
  - Rhumb lines
  - Compass bearings
  - Etc.

Addressing Common Misconceptions

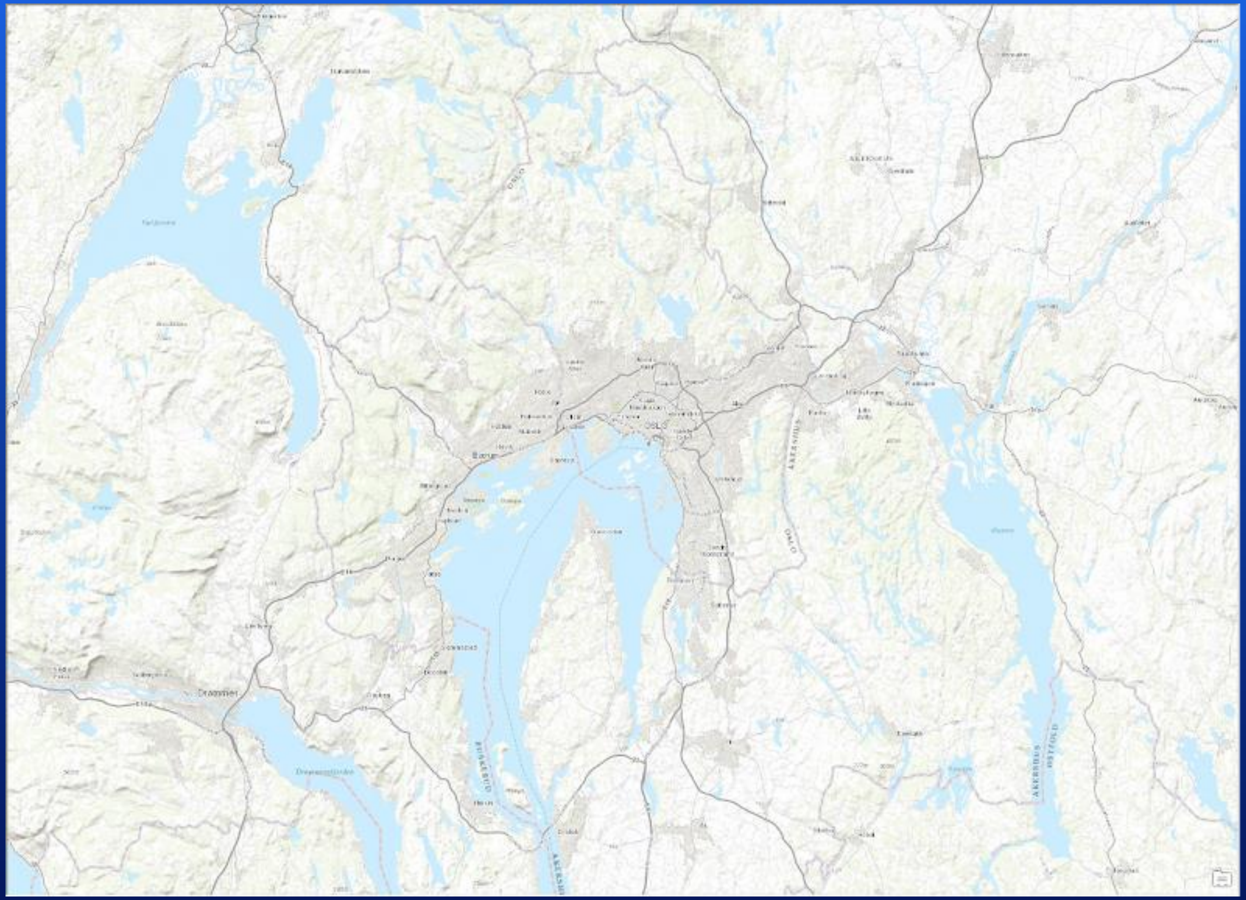
1. Web Mercator is a projected coordinate system, not a projection
2. Web Mercator does not preserve shape
3. Web Mercator does not preserve local angles (not conformal)
4. Web Mercator is also not appropriate at large scales
   - It still requires scale adjustment at large scales



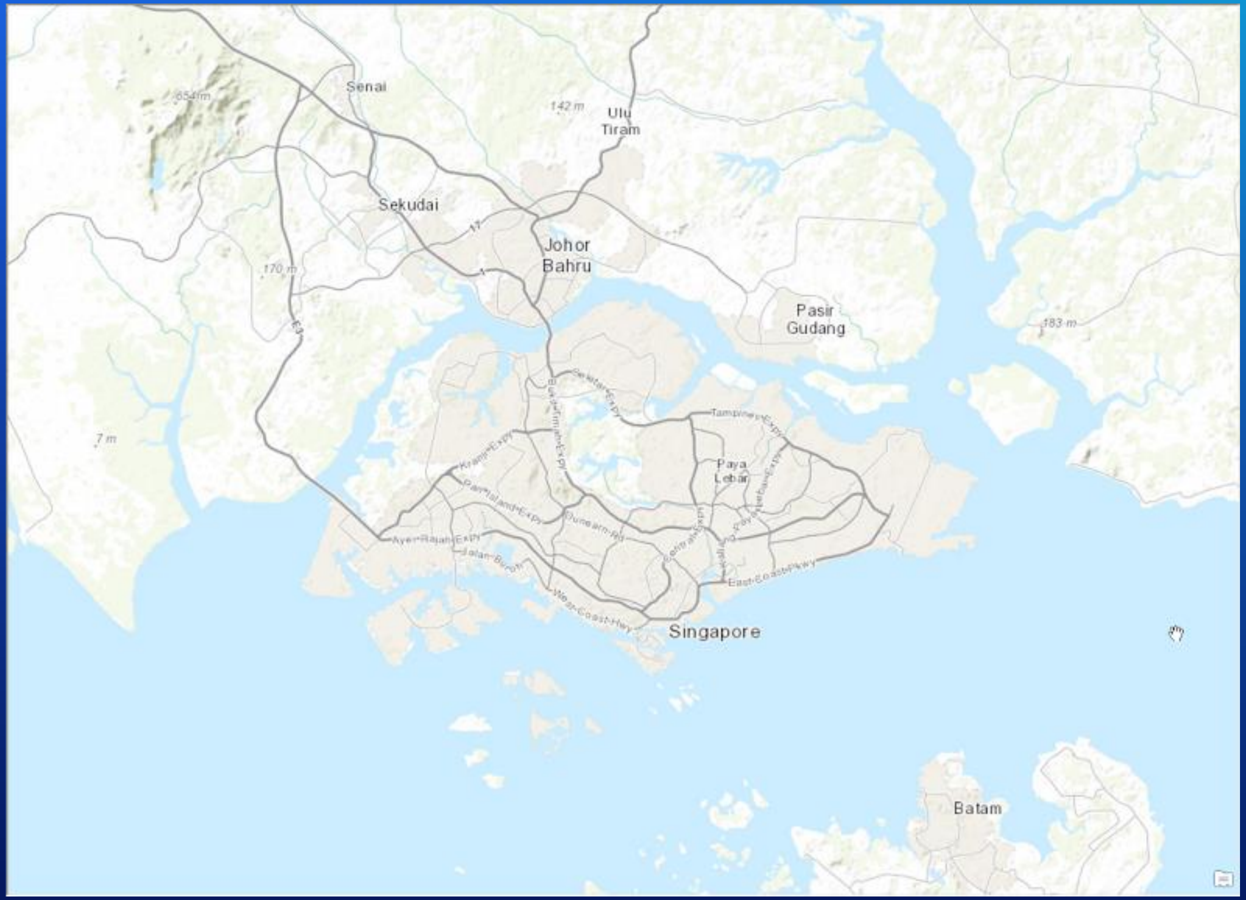
Oslo, Norway



Singapore



Oslo, Norway



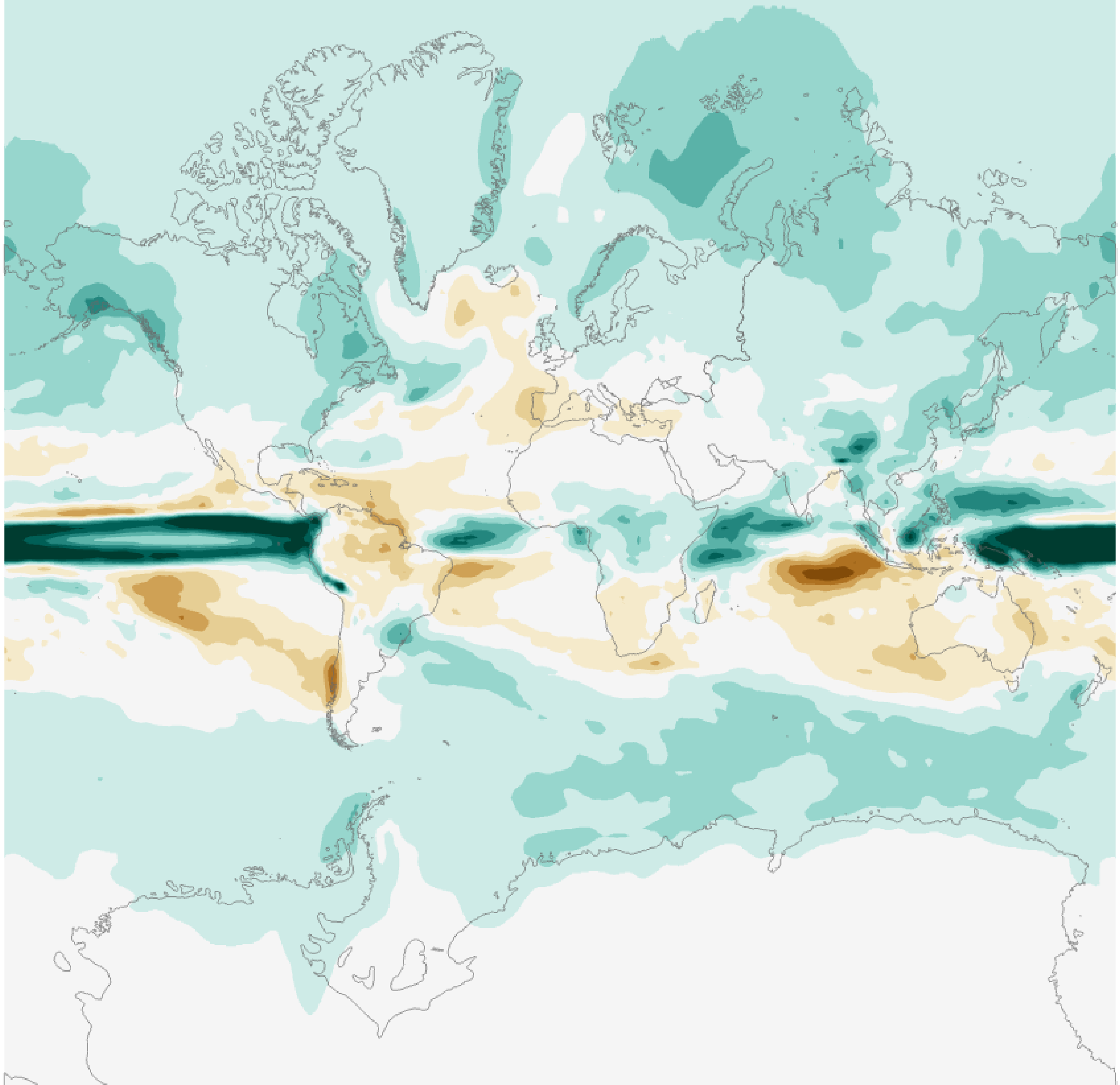
Singapore

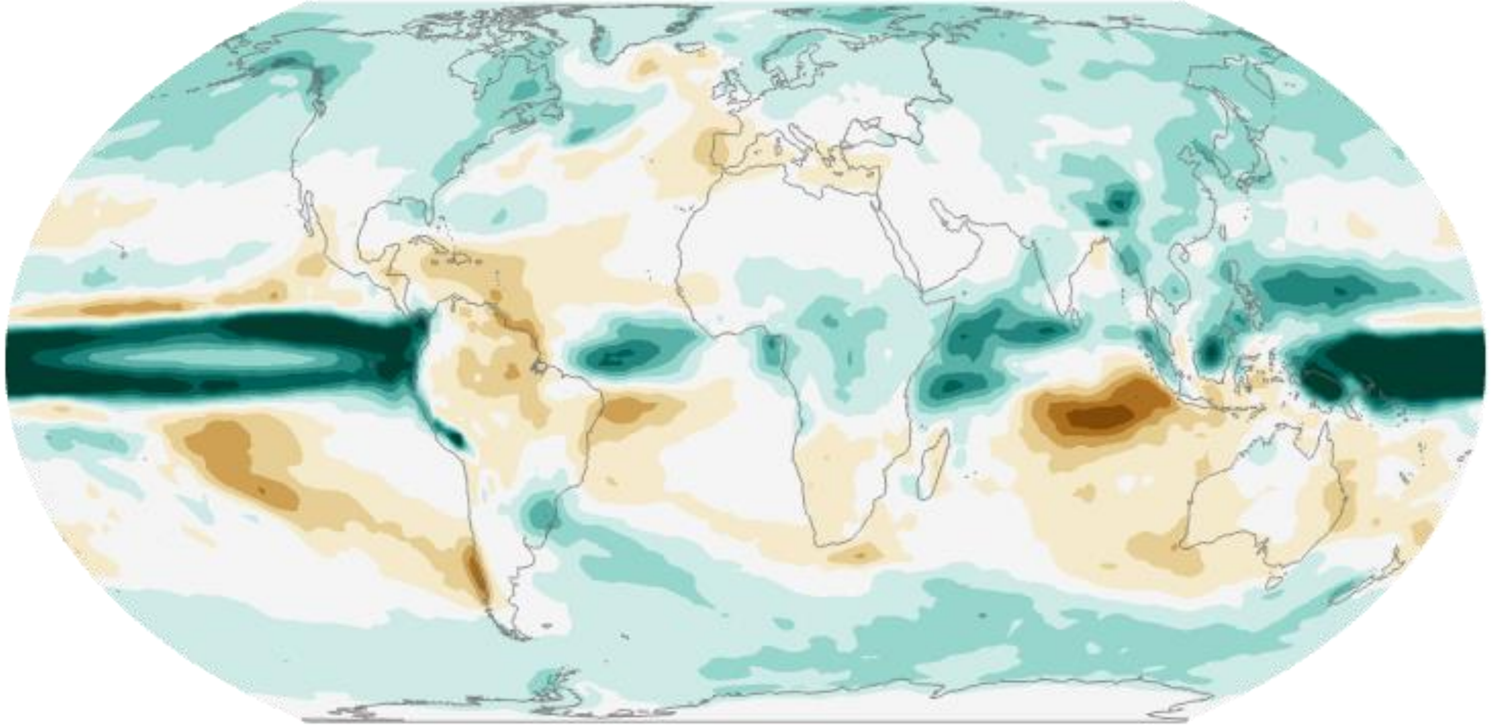
Addressing Common Misconceptions

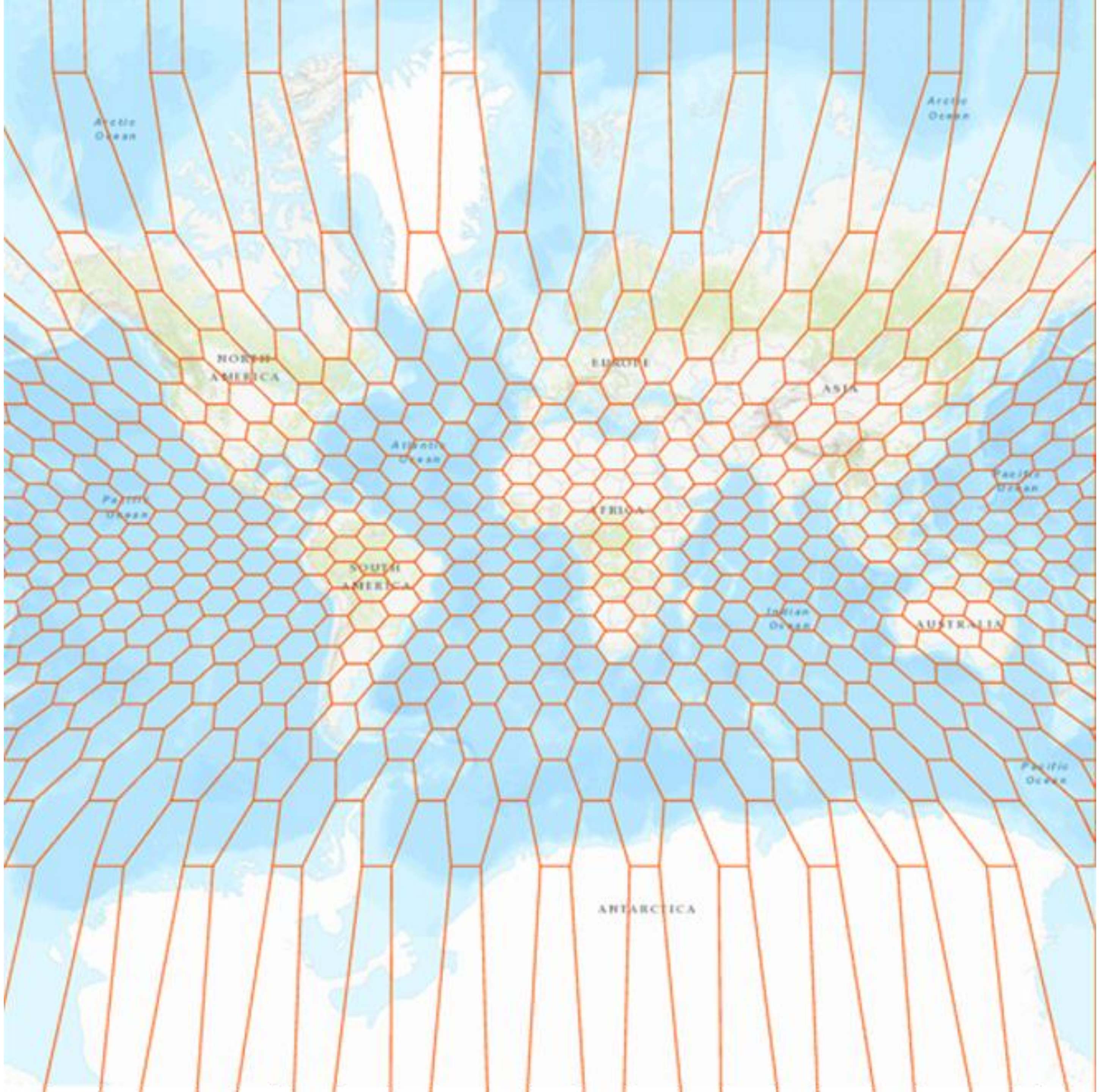
1. Web Mercator is a projected coordinate system, not a projection
2. Web Mercator does not preserve shape
3. Web Mercator does not preserve local angles (not conformal)
4. Web Mercator is also not appropriate at large scales

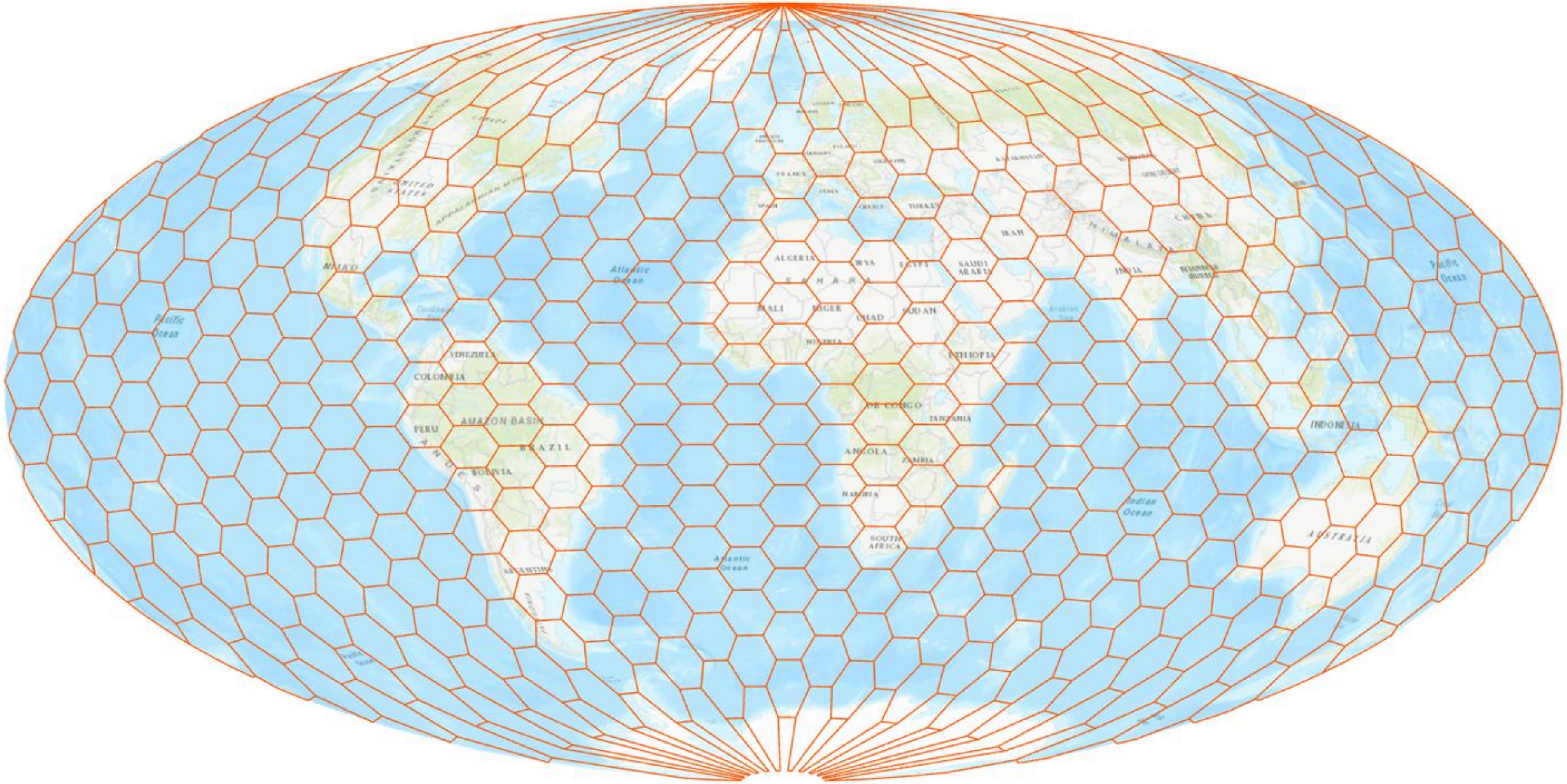
Addressing Common Misconceptions

5. The results of geodesic-based analysis are not presented correctly in Web Mercator
   - Even when the analysis is performed accurately behind the scenes, it is still important to display the results correctly






Arctic Ocean
NORTH AMERICA
EUROPE
ASIA
Atlantic Ocean
Pacific Ocean
AFRICA
SOUTH AMERICA
Indian Ocean
AUSTRALIA
ANTARCTICA



Pacific Ocean
MEXICO
Atlantic Ocean
VENEZUELA
COLOMBIA
AMAZON BASIN
PERU
BRAZIL
BOLIVIA
FRANCE
SPAIN
TURKEY
ALGERIA
EGYPT
SAUDI ARABIA
IRAN
INDIA
CHINA
MALI
NIGER
CHAD
SUDAN
NIGERIA
ETHIOPIA
DR CONGO
TANZANIA
ANGOLA
ZAMBIA
NAMIBIA
SOUTH AFRICA
Indian Ocean
INDONESIA

Addressing Common Misconceptions

5. The results of geodesic-based analysis are not presented correctly in Web Mercator

6. WGS 1984 Web Mercator is not a static coordinate system
   - With time, geographic data in Web Mercator moves

Misalignments in WGS 1984

Misalignments in WGS 1984

Misalignments in WGS 1984

Misalignments in WGS 1984

Misalignments in WGS 1984

No Misalignments in GDA

Addressing Common Misconceptions

5. The results of geodesic-based analysis are not presented correctly in Web Mercator

6. WGS 1984 Web Mercator is not a static coordinate system

7. Web maps are not limited to Web Mercator
   - A web map can be in any projected coordinate system

Custom coordinate systems
Bojan Šavrič

Save | Settings | Change View

HTML

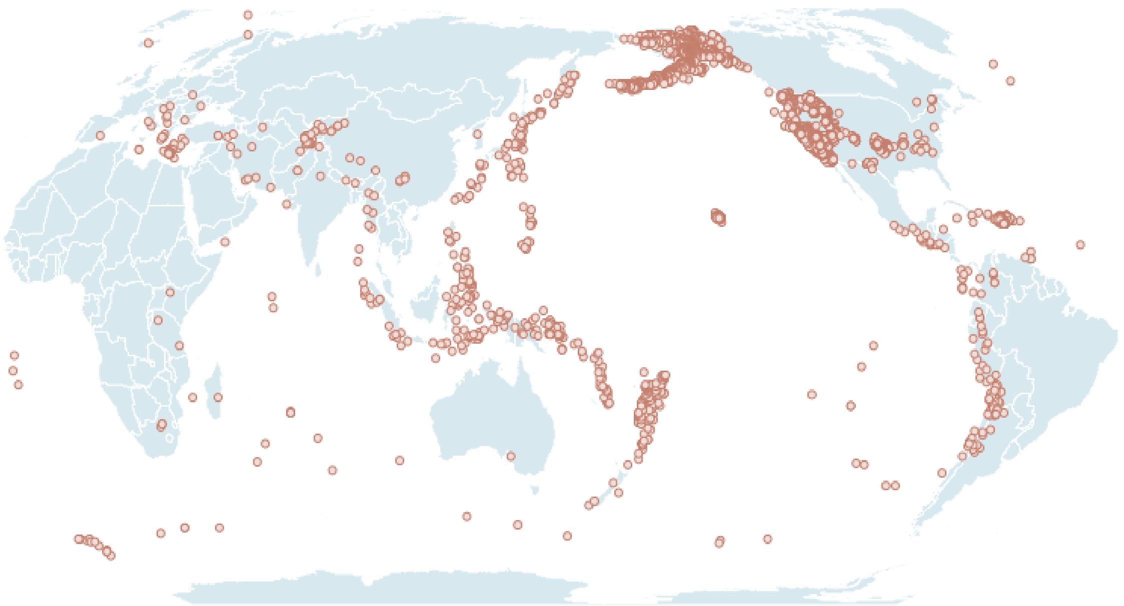
CSS

JS

```
  "esri/views/MapView"
], (Map, FeatureLayer, GeoJSONLayer, MapView) => {
  const map = new Map({↔});

  /* Setting spatial reference of your web map */
  const spatialReference = {
    wkid: 8859  //Equal Earth Asia-Pacific
    //wkid: 8857  //Equal Earth Greenwich
    //wkid: 54050 //Fuller world
    //wkt:
'PROJCS["Custom_Wagner_IV",GEOGCS["GCS_WGS_1984",DATUM["D_WGS_1984",SPHEROID["WGS_1984",6378137.0,298.257223563]],PRIMEM["Greenwich",0.0],UNIT["Degree",0.0174532925199433]],PROJECTION["Wagner_IV"],PARAMETER["False_Easting",0.0],PARAMETER["False_Northing",0.0],PARAMETER["Central_Meridian",-170.0],PARAMETER["Latitude_Of_Origin",15.0],UNIT["Meter",1.0]]'
  };

  const view = new MapView({
    container: "viewDiv",
    map: map,
    scale: 166418924,
    spatialReference,
    center: {
      x: 0,
      y: 0,
      spatialReference
    }
  });
});
```



https://codepen.io/BSavric/pen/jObZYLB?editors=0010

https://codepen.io/BSavric/pen/eYpVyrM?editors=0010

USGS Earthquakes

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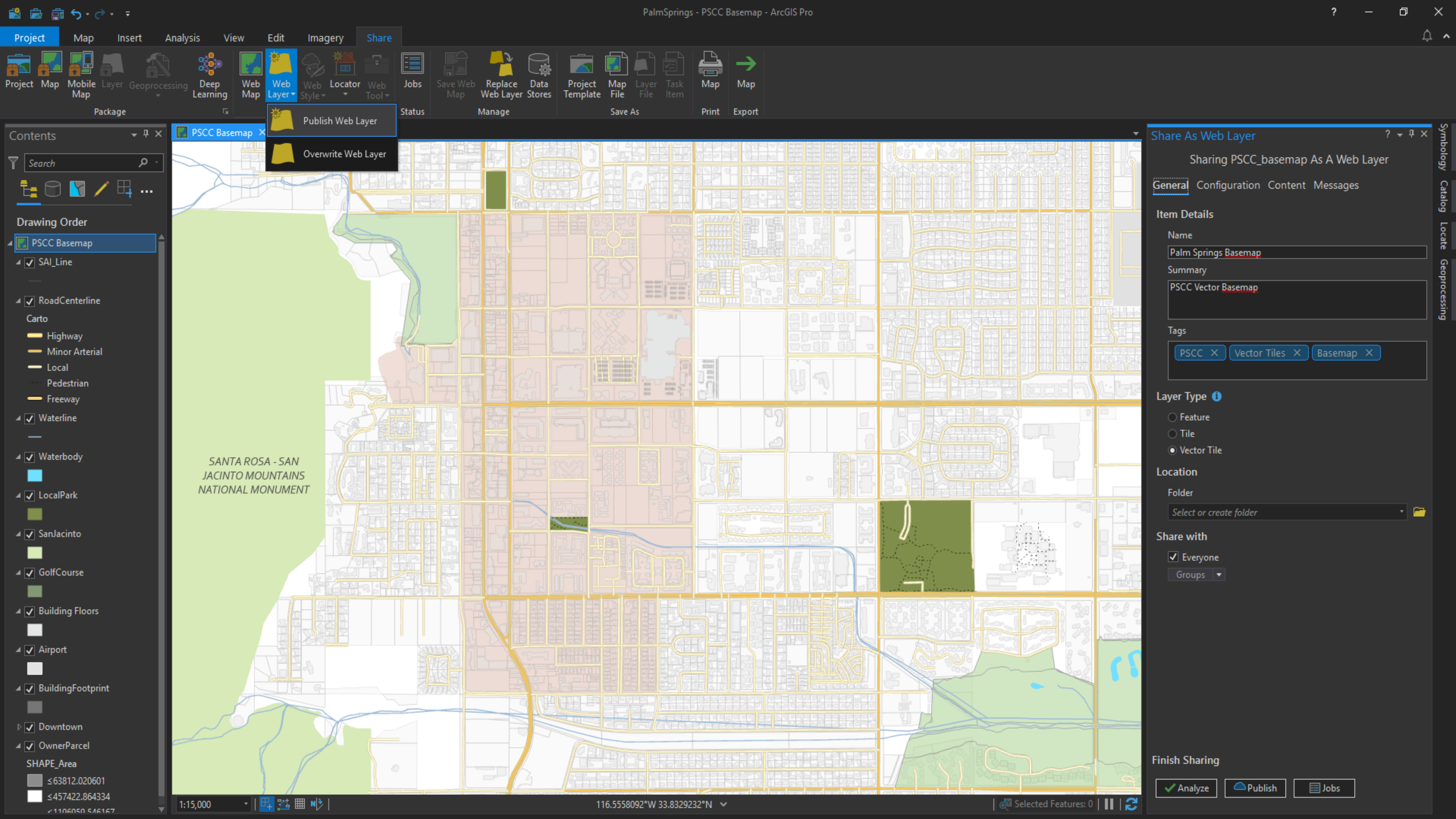
Console | Assets | Comments | Shortcuts

Last saved LESS THAN A MINUTE ago | Delete | Add to Collection | Fork | Embed | Export | Share


PalmSprings - PSCC Basemap - ArcGIS Pro
Project
Map
Insert
Analysis
View
Edit
Imagery
Share
Project
Map
Mobile Map
Layer
Geoprocessing
Deep Learning
Package
Web Map
Web Layer
Web Style
Locator
Web Tool
Publish Web Layer
Overwrite Web Layer
Jobs
Status
Save Web Map
Replace Web Layer
Data Stores
Manage
Project Template
Map File
Layer File
Task Item
Save As
Map
Print
Map
Export
Contents
Search
Drawing Order
PSCC Basemap
SAI_Line
RoadCenterline
Carto
Highway
Minor Arterial
Local
Pedestrian
Freeway
Waterline
Waterbody
LocalPark
SanJacinto
GolfCourse
Building Floors
Airport
BuildingFootprint
Downtown
OwnerParcel
SHAPE_Area
≤63812.020601
≤457422.864334
PSCC Basemap
SANTA ROSA - SAN JACINTO MOUNTAINS NATIONAL MONUMENT
1:15,000
116.5558092°W 33.8329232°N
Selected Features: 0
Share As Web Layer
Sharing PSCC_basemap As A Web Layer
General
Configuration
Content
Messages
Item Details
Name
Palm Springs Basemap
Summary
PSCC Vector Basemap
Tags
PSCC
Vector Tiles
Basemap
Layer Type
Feature
Tile
Vector Tile
Location
Folder
Select or create folder
Share with
Everyone
Groups
Finish Sharing
Analyze
Publish
Jobs
Symbology
Catalog
Locate
Geoprocessing

Home My Map New Map

Details | Add | Basemap | Analysis | Save | Share | Print | Directions | Measure | Bookmarks | Find address or place

About Content Legend

Make your own map

It's easy to make your own map. Just follow these steps:

1. Choose an area.

Pan and zoom the map to an area or search by its name or address.

2. Decide what to show.

Choose a Basemap then Add layers on top of it.

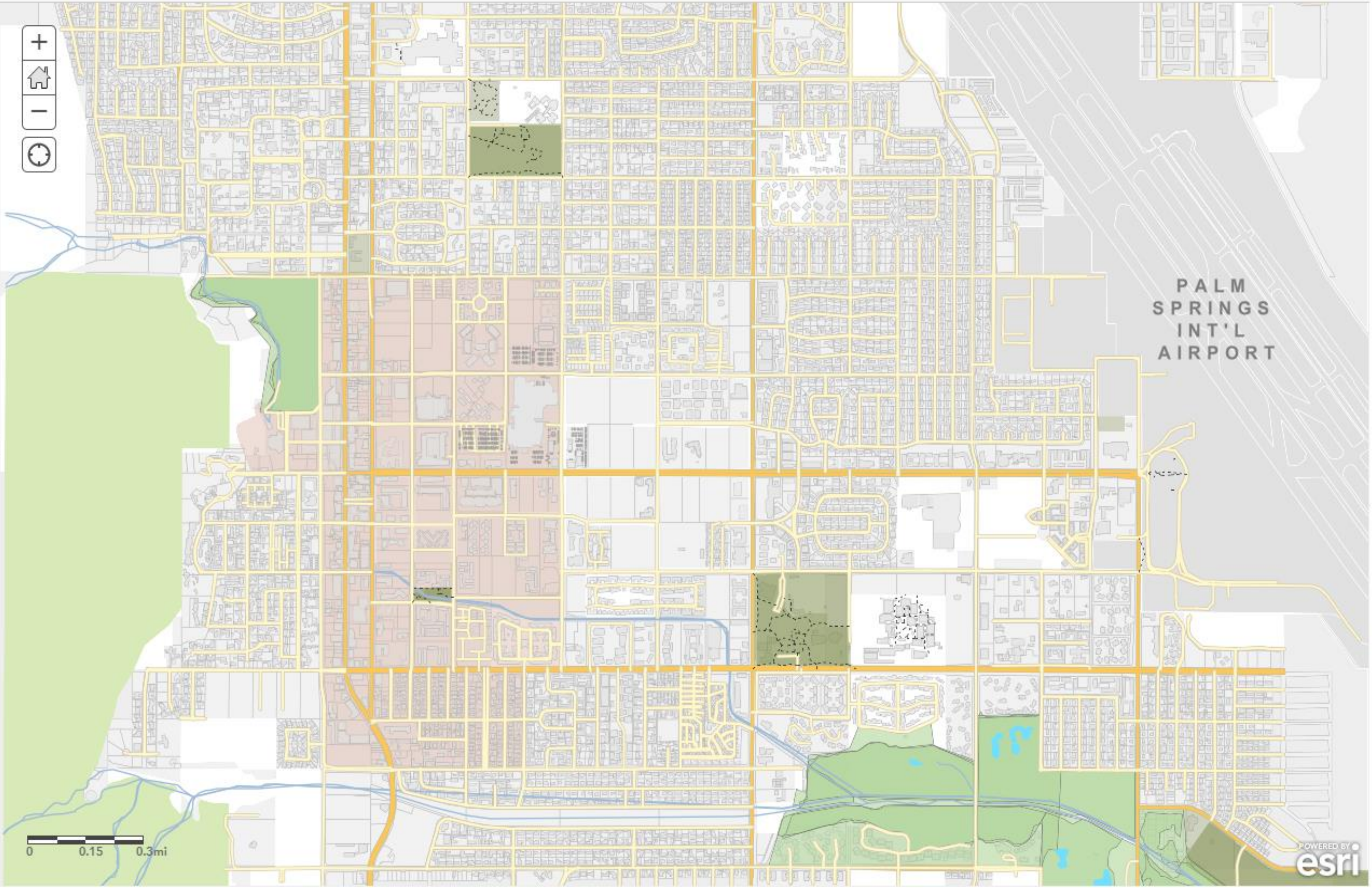
3. Add more to your map.

Add map notes to draw features on the map.

Display descriptive text, images, and charts for map features in a pop-up.

4. Save and share your map.

Give your map a name and description then share it with other people.



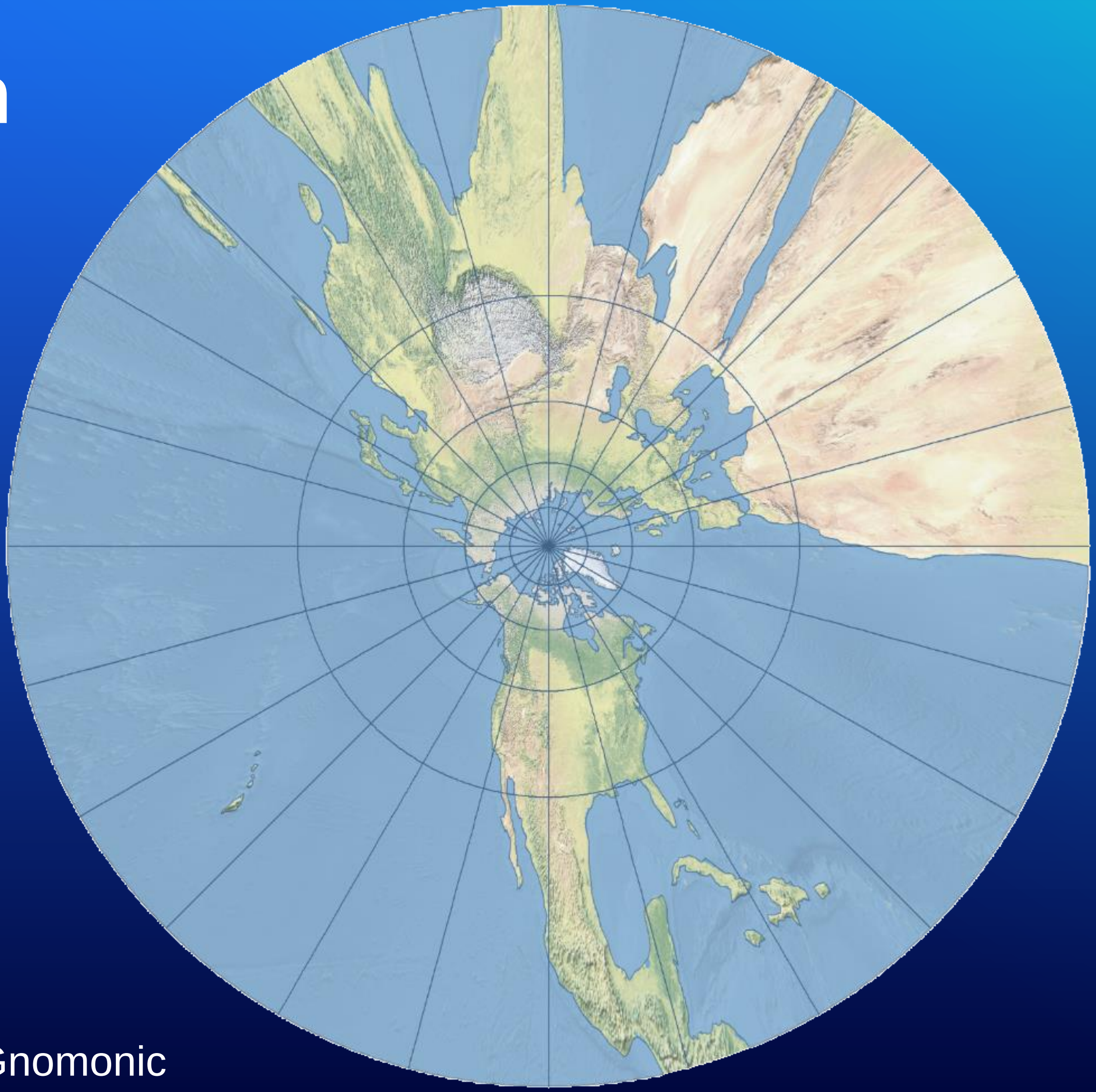
Map Projection Selection

Map Projection Selection

Q: Which projection is the best?

A: It depends on what you are doing.

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



Gnomonic

Map Projection Selection

> "Where projections are concerned there's really no good default. Every map should be considered on a case by case basis depending on where in the world you're mapping, the scale, purpose and content.
>
> (Kenneth Field, 2019)

Field, K. (2019) Mercator, it's not hip to be square.

John Snyder’s Selection Guideline

Snyder, J. P. (1987) Map Projections - A Working Manual., p. 33-35.

John Snyder’s Selection Guideline

- Map
  - World
  - Hemisphere
  - Continents, countries
    - Landscape
    - Portrait
    - Square
    - Oblique

Snyder, J. P. (1987) Map Projections - A Working Manual., p. 33-35.

Region mapped

1. World (Earth should be treated as a sphere)
   - A. Conformal (gross area distortion)
     - (1) Constant scale along Equator
       - Mercator
     - (2) Constant scale along meridian
       - Transverse Mercator
     - (3) Constant scale along oblique great circle
       - Oblique Mercator
     - (4) Entire Earth shown
       - Lagrange
       - August
       - Eisenlohr
   - B. Equal-Area
     - (1) Standard without interruption
       - Hammer
       - Mollweide
       - Eckert IV or VI
       - McBryde or McBryde-Thomas variations
       - Boggs Eumorphic
       - Sinusoidal
       - misc. pseudocylindricals
     - (2) Interrupted for land or ocean
       - any of above except Hammer
       - Goode Homolosine
     - (3) Oblique aspect to group continents
       - Briesemeister
       - Oblique Mollweide
   - C. Equidistant
     - (1) Centered on pole
       - Polar Azimuthal Equidistant
     - (2) Centered on a city
       - Oblique Azimuthal Equidistant
   - D. Straight rhumb lines
     - Mercator
   - E. Compromise distortion
     - Miller Cylindrical
     - Robinson

2. Hemisphere (Earth should be treated as a sphere)
   - A. Conformal
     - Stereographic (any aspect)
   - B. Equal-Area
     - Lambert Azimuthal Equal-Area (any aspect)
   - C. Equidistant
     - Azimuthal Equidistant (any aspect)
   - D. Global look
     - Orthographic (any aspect)

3. Continent, ocean, or smaller region (Earth should be treated as a sphere for larger continents and oceans and as an ellipsoid for smaller regions, especially at a larger scale)
   - A. Predominant east-west extent
     - (1) Along Equator
       - Conformal: Mercator
       - Equal-Area: Cylindrical Equal-Area
     - (2) Away from Equator
       - Conformal: Lambert Conformal Conic
       - Equal-Area: Albers Equal-Area Conic
   - B. Predominant north-south extent
     - Conformal: Transverse Mercator
     - Equal-Area: Transverse Cylindrical Equal-Area
   - C. Predominant oblique extent (for example: North America, South America, Atlantic Ocean)
     - Conformal: Oblique Mercator
     - Equal-Area: Oblique Cylindrical Equal-Area
   - D. Equal extent in all directions (for example: Europe, Africa, Asia, Australia, Antarctica, Pacific Ocean, Indian Ocean, Arctic Ocean, Antarctic Ocean)
     - (1) Center at pole
       - Conformal: Polar Stereographic
       - Equal-Area: Polar Lambert Azimuthal Equal-Area
     - (2) Center along Equator
       - Conformal: Equatorial Stereographic
       - Equal-Area: Equatorial Lambert Azimuthal Equal-Area
     - (3) Center away from pole or Equator
       - Conformal: Oblique Stereographic
       - Equal-Area: Oblique Lambert Azimuthal Equal-Area
   - E. Straight rhumb lines (principally for oceans)
     - Mercator
   - F. Straight great-circle routes
     - Gnomonic (for less than hemisphere)
   - G. Correct scale along meridians
     - (1) Center at pole
       - Polar Azimuthal Equidistant
     - (2) Center along Equator
       - Plate Carrée (Equidistant Cylindrical)
     - (3) Center away from pole or Equator
       - Equidistant Conic

Snyder, J. P. (1987) Map Projections - A Working Manual., p. 33-35.

Appropriate for World Maps

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

Equal Earth

Eckert IV

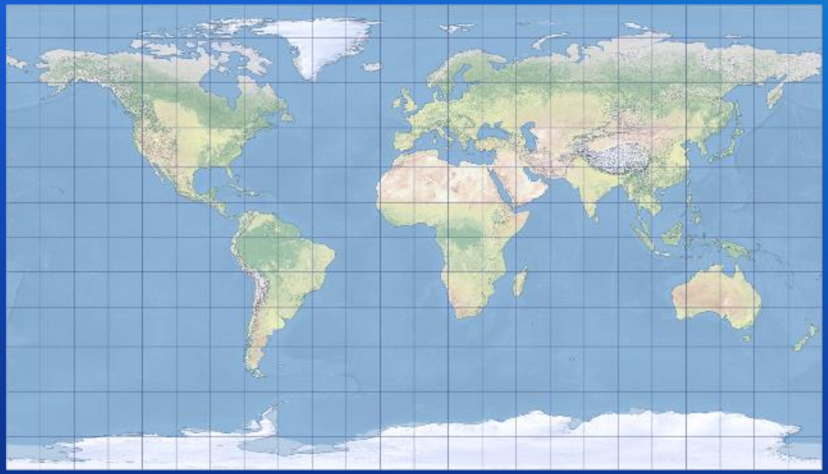
Robinson

Winkel Tripel

Appropriate for World Maps

- Cylindrical projections
  - Compromise

Only for rare phenomena based on longitude (time zones) or very good aesthetic reasons!



Patterson

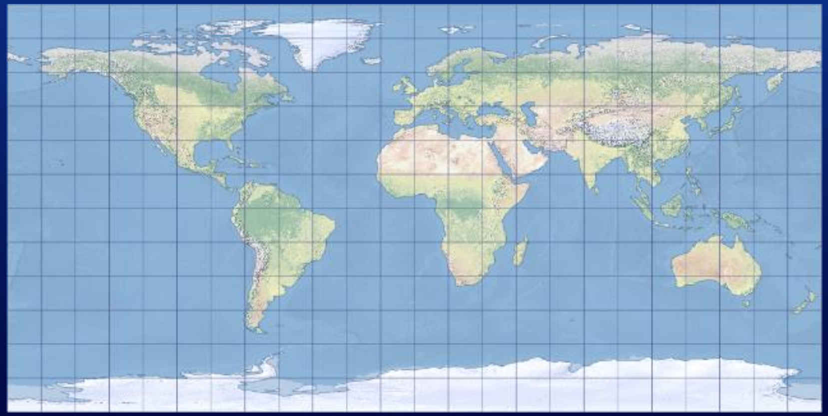
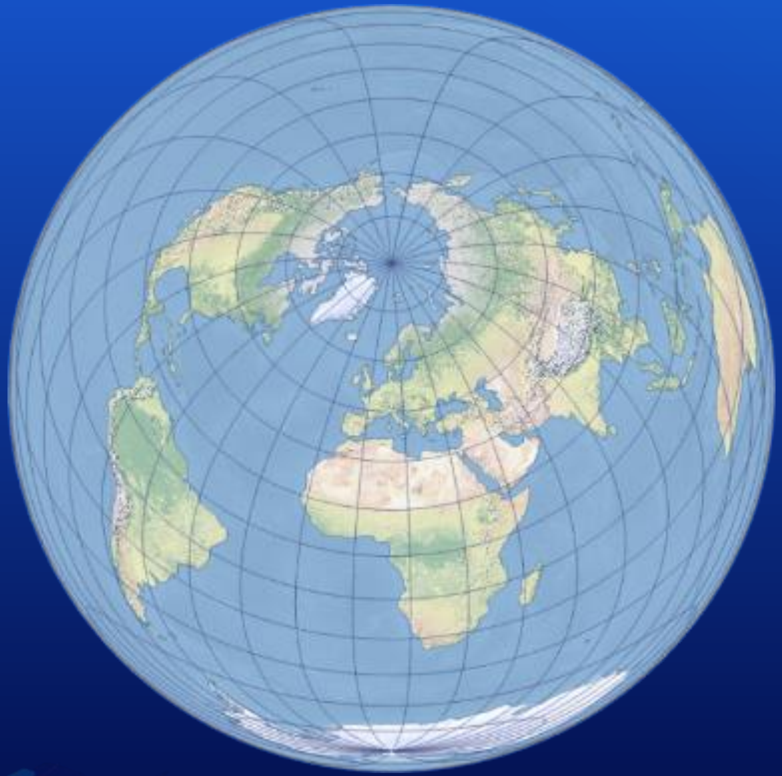


Plate Carrée

Appropriate for Hemisphere Maps

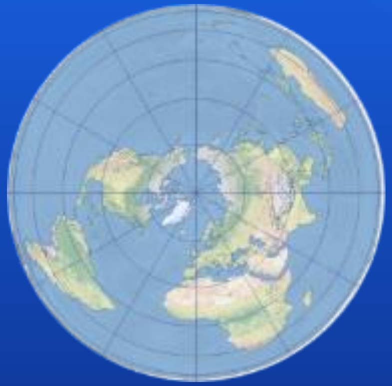
- Only azimuthal projections
  - Azimuthal equidistant
  - Lambert equal area
  - Orthographic


Lambert azimuthal equal area


Orthographic

Appropriate for Continents and Smaller Areas

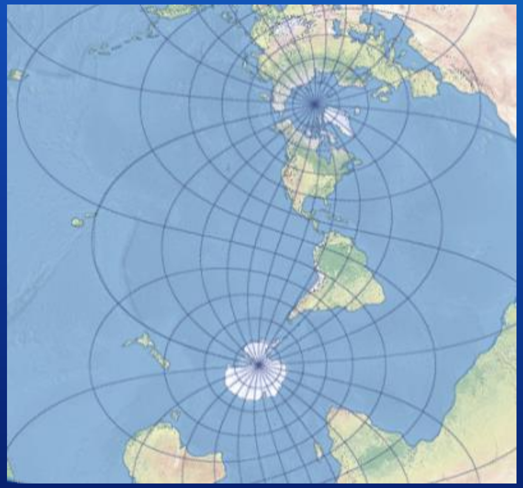
- Azimuthal
  - Polar areas
  - Equal extent



- Conic
  - Mid-latitudes
  - East to west extent

- Cylindrical
  - Equatorial areas
  - East to west extent

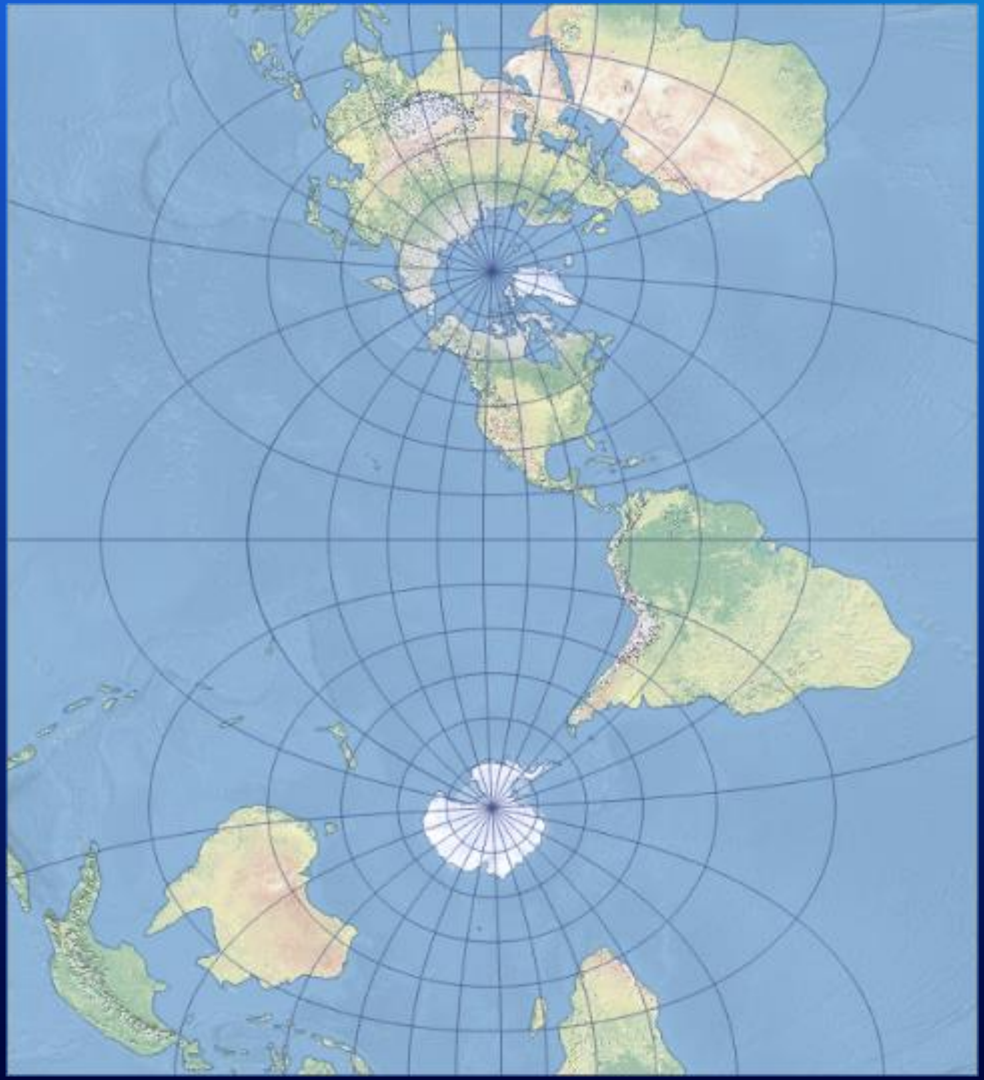
- Oblique cylindrical
  - Oblique extent



- Transverse cylindrical
  - North to south extent

Appropriate for Topographic Maps

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



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

Selecting Projection Properties

- Use equal area for thematic maps, especially when areas are compared, or when densities of objects are compared.
- Use equidistant projections only if distances are measured along certain (equidistant) lines.
- Regional maps (continents or smaller areas): Use either equal area or conformal.
- Only for regional maps: use conformal projection when measuring angles (surveying, military, naval navigation, etc.)
- World maps should use compromise or equal area projections.

Map Projections in Esri Software

Adams square II
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
Perspective cylindrical
Plate Carrée
Polyconic
Quartic authalic
Rectified skew orthomorphic
Robinson
Sinusoidal
Stereographic
Times
Tobler cylindrical I
Tobler cylindrical II
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

Map Projections in Esri Software

Adams square II
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

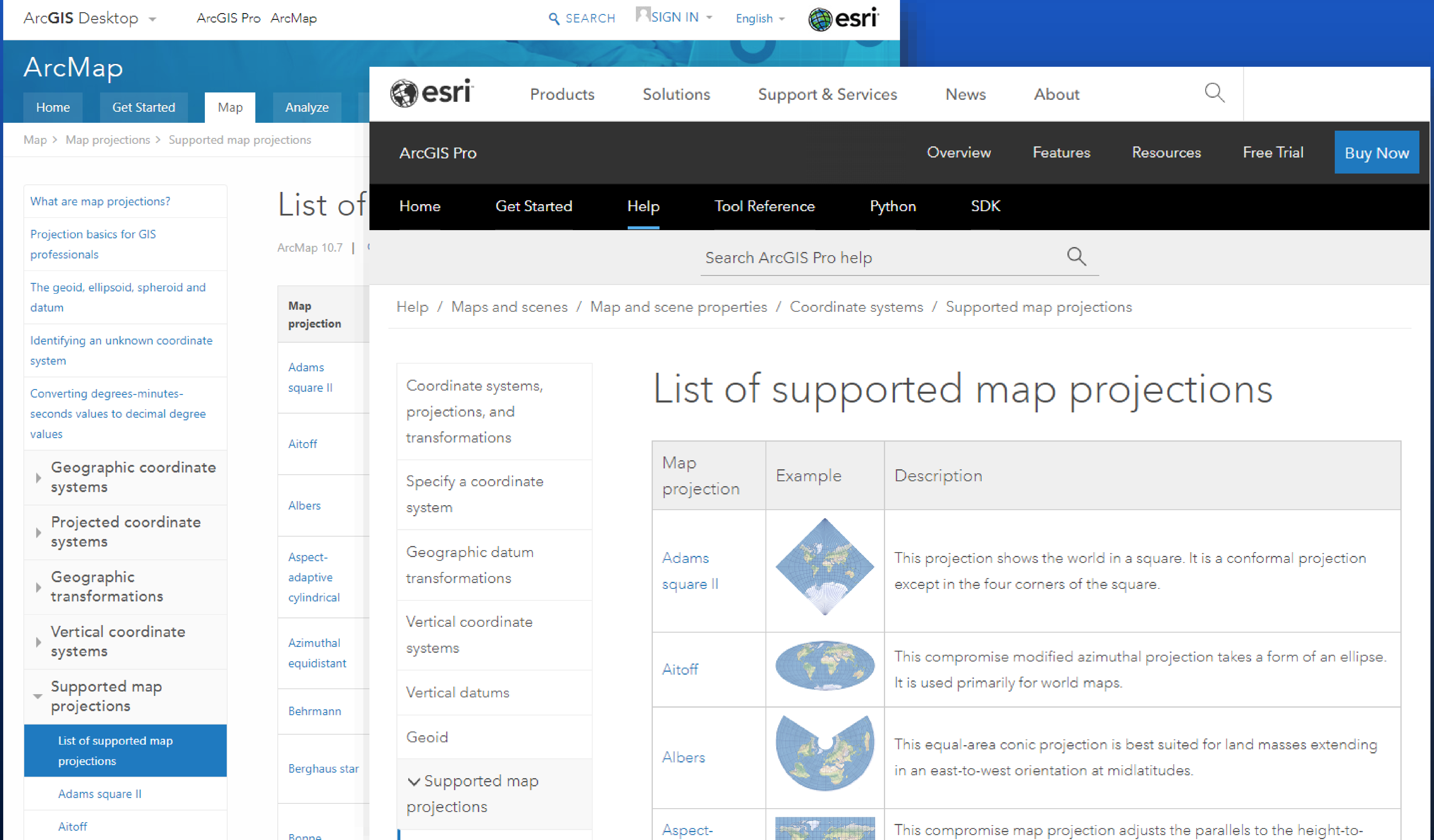
Eckert V
Eckert VI
Eckert-Greifendorff
Equal Earth
Equidistant conic
Equidistant cylindrical
Fuller
IGAC Plano Cartesiano
Krovak
Laborde oblique Mercator
Lambert azimuthal equal-area

Lambert conformal conic
Local
Loximuthal
McBryde-Thomas flat-polar quartic
Mercator
Miller cylindrical
Mollweide
Perspective cylindrical
Plate Carrée
Polyconic
Quartic authalic

Rectified skew orthomorphic
Robinson
Sinusoidal
Stereographic
Times
Tobler cylindrical I
Tobler cylindrical II
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

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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Projection basics for GIS professionals
The geoid, ellipsoid, spheroid and datum
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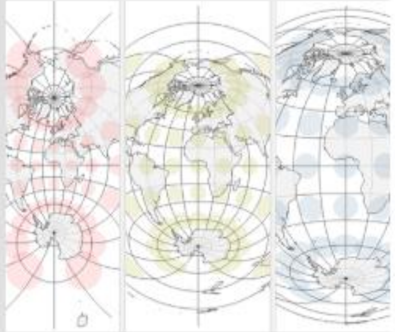
Map projection
Example
Description
Adams square II
This projection shows the world in a square. It is a conformal projection except in the four corners of the square.
Aitoff
This compromise modified azimuthal projection takes a form of an ellipse. It is used primarily for world maps.
Albers
This equal-area conic projection is best suited for land masses extending in an east-to-west orientation at midlatitudes.
Aspect-
This compromise map projection adjusts the parallels to the height-to-

Gallery / Paths

Map projections

Explore different ways to project the round earth onto a flat map.



Choose the right projection

Learn some tips for choosing an appropriate projected coordinate system for your map.

1

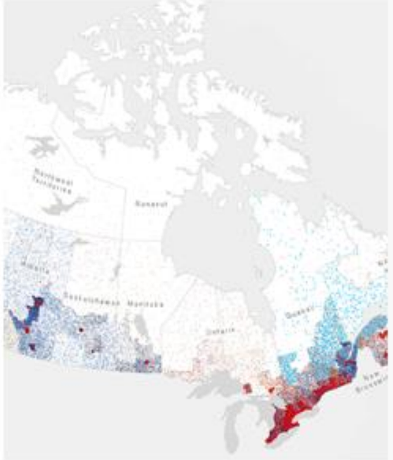
1 hr
Lesson

Mercator, it's not hip to be square

The purpose and problems of the Mercator projection and some methods for replacing it in web maps.

2

30 min
Article
English Only



Earth peel

Illustrate map projections by peeling a digital orange in ArcGIS Pro.

3

10 min
Article
English Only

Make a web map without Web Mercator

Make web maps with projections other than Web Mercator. Build and publish vector tiles from ArcGIS Pro to make a basemap in a chosen projected coordinate system.

Duration

50mins

Mapping Education

As a GIS consultant in Bogotá, Colombia, you make web maps for clients, all with different needs. You have two upcoming projects that require you to make web maps with specific projections—not the default of Web Mercator.

In this lesson, you'll learn how to change the projection of a web map by changing the basemap. You'll also learn how to make your own basemap in ArcGIS Pro with a coordinate system of your choice, which you can then use to build projected web maps.

View final result

Requirements

- Publisher or Administrator role in an ArcGIS organization (get a free trial)
- ArcGIS Pro (get a free trial)

Lesson Plan

Make an equal-area web map	10 minutes

“ Publish your authoritative data in authoritative coordinate systems!

Coordinate Systems in Esri Software

5619	projected coordinate systems
978	geographic coordinate systems
398	vertical coordinate systems
1767	geographic transformations
181	vertical transformations

Useful Links

- Snyder’s selection guidelines
  https://doi.org/10.3133/pp1395, p. 33–35
- Projection Wizard
  https://projectionwizard.org
- ArcGIS Python Add-In Map Projection Selection Toolbar
  https://github.com/pcgosling/ArcGIS-ProjectionSelection
- List of Supported Map Projections in ArcGIS Pro
  https://pro.arcgis.com/en/pro-app/help/mapping/properties/list-of-supported-map-projections.htm
- Quick Notes on Map Projections in ArcGIS
  https://github.com/Esri/projection-engine-db-doc/tree/master/other
- ArcGIS Online: Use your own basemap
  https://doc.arcgis.com/en/arcgis-online/create-maps/choose-basemap.htm

Useful Links

- Map Projections Learning Path
  https://learn.arcgis.com/en/paths/map-projections
- Make a Web Map without Web Mercator Lesson
  https://learn.arcgis.com/en/projects/make-a-web-map-without-web-mercator
- Blog: Mercator, It’s not Hip to be Square
  https://www.esri.com/arcgis-blog/products/arcgis-pro/mapping/mercator-its-not-hip-to-be-square
- Here Are Some Equal Area Projected Maps for ArcGIS Online (and how to make them)
  https://www.esri.com/arcgis-blog/products/arcgis-online/mapping/here-are-some-equal-area-projected-maps-for-arcgis-online-and-how-to-make-them
- DevSummit 2018: Client-side Processing in Web Applications
  https://www.youtube.com/watch?v=vCw5ASyAGSU&t=2m50s

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