AMERICAN MUSEUM OF NATURAL HISTORY
CENTER FOR BIODIVERSITY AND CONSERVATION

# Introduction to Geographic Information Systems

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# What is a Geographic Information System?

- A Geographic Information System (GIS)
  - software, hardware, geographic information, spatially explicit data

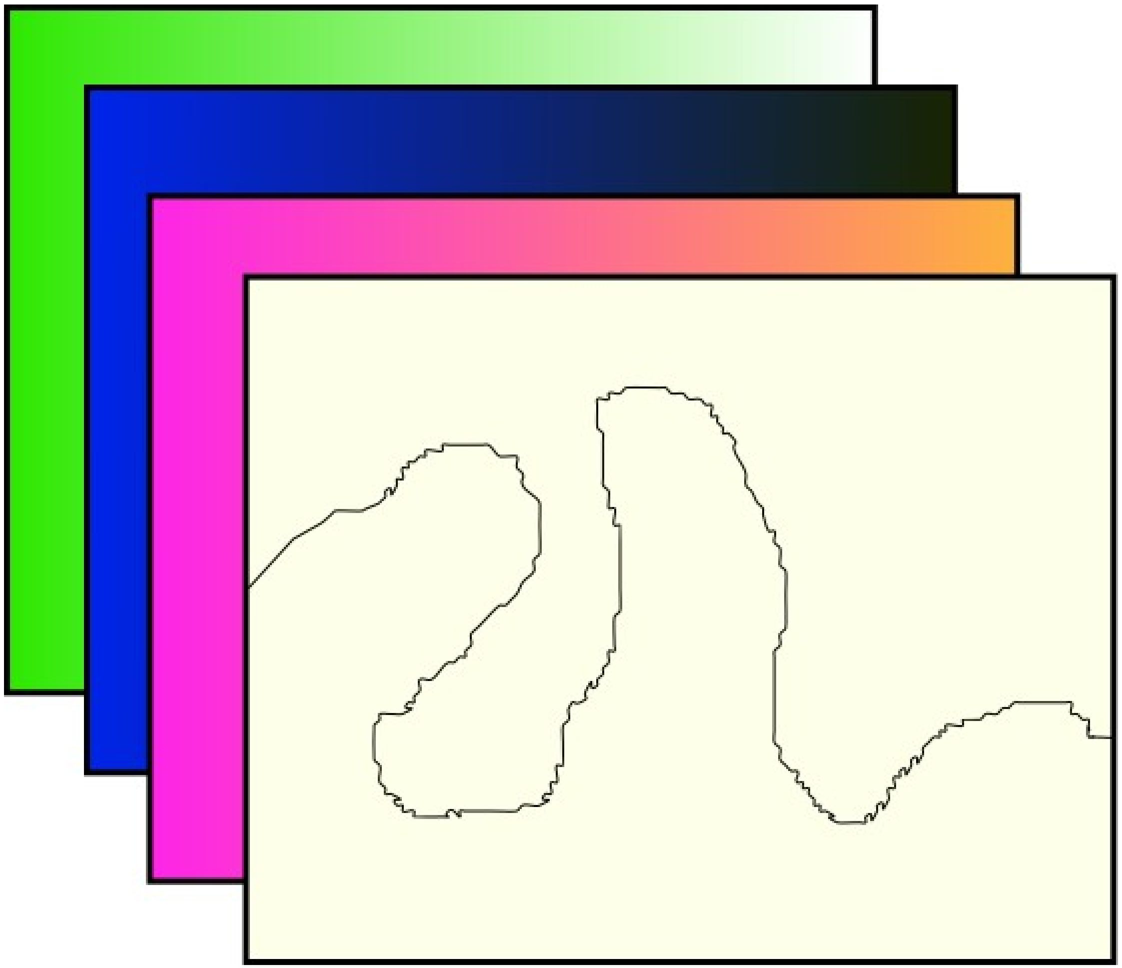
- Software can be used to store, query, manage, analyze and display spatial data.

- A GIS links cartographic, statistical, and data-basing technologies.

# What is a Geographic Information System?

- Data (layers)
  - Spatial – Images, shape data, geographic information
  - Tabular – Spreadsheet data with geographic properties

# Layering



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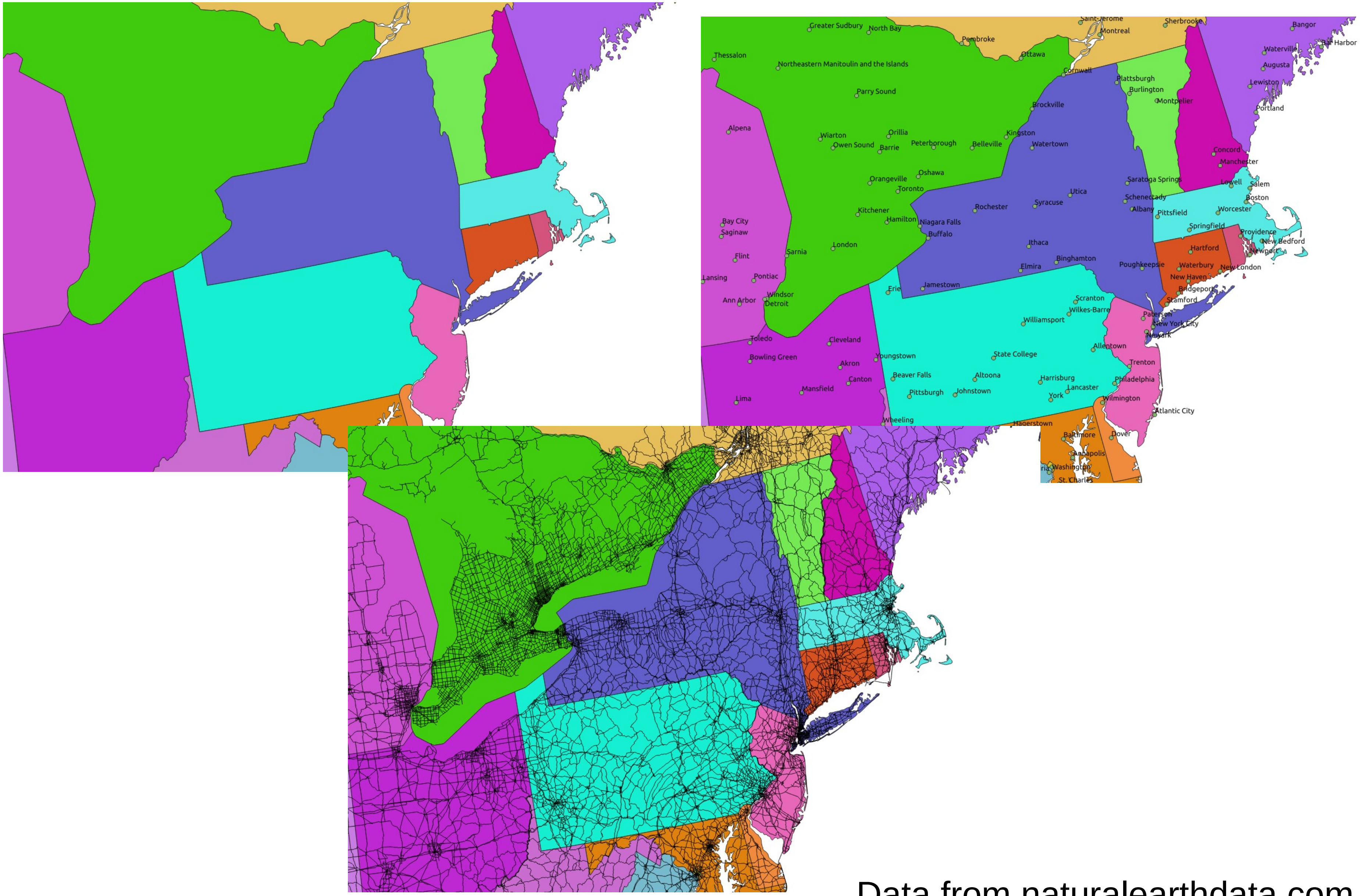
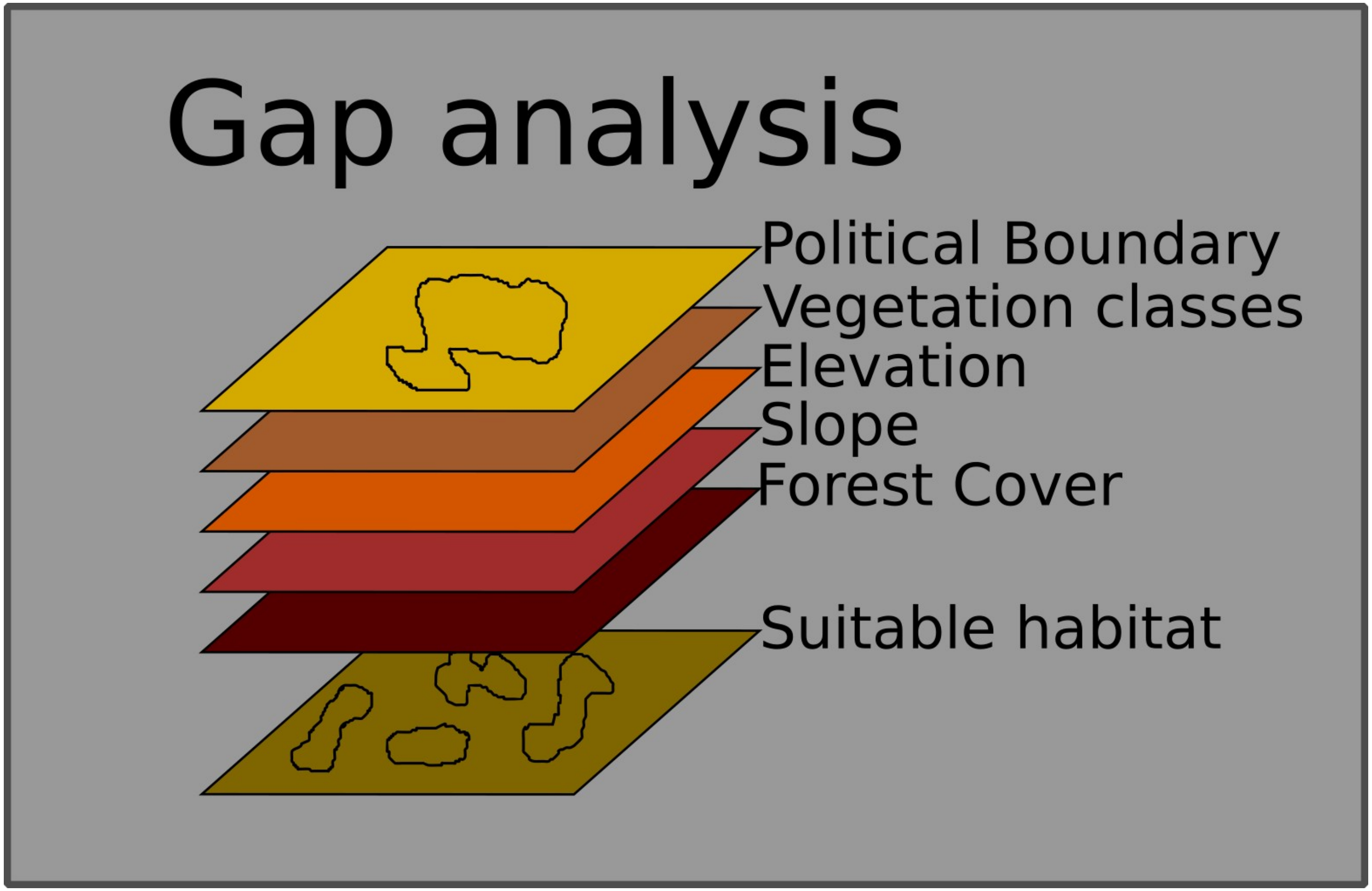



Data from naturalearthdata.com

# Layering


Gap analysis
Political Boundary
Vegetation classes
Elevation
Slope
Forest Cover
Suitable habitat

# Notable GIS software

**Commercial:**

- ArcGIS, including ArcMap (Esri)
- IDRISI (Clark Labs)
- ERDAS IMAGINE (ERDAS Inc.)

**Open source:**

- **Quantum GIS**
- GRASS GIS
- MANIS tool
- GPSvisualizer
- Biogeomancer

**Free (but not open source):**

- DIVA GIS

# Outline

How do we represent real world geographic information with a computer?

- Data models – representations of geographic reality
  - Scale, spatial autocorrelation
- Location information: coordinate systems
- Georeferencing, sampling bias
- Remote Sensing

# Two methods of GIS representation

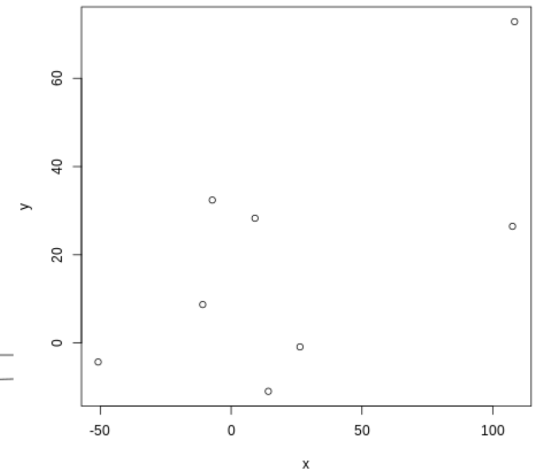
- There are two main ways a GIS can create a logical data model of the world:
  - Vector = discrete features
  - Raster = continuous fields

# Vector - Discrete Objects

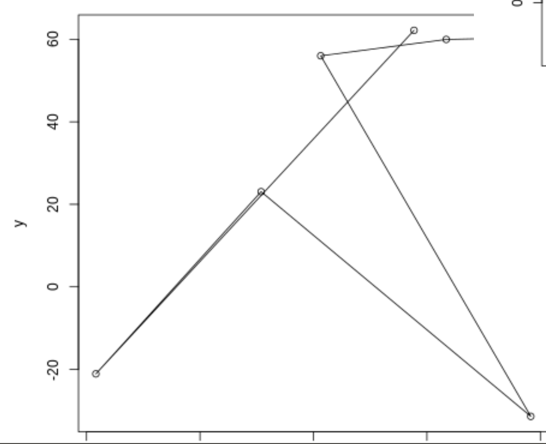
- Discrete objects
  - Represents the geographic world as objects with well-defined boundaries in otherwise empty space

**Bears are easily conceived as discrete objects, maintaining their identity as objects through time and surrounded by empty space.**
(Alaskan Brown Bear diorama at the American Museum of Natural History)

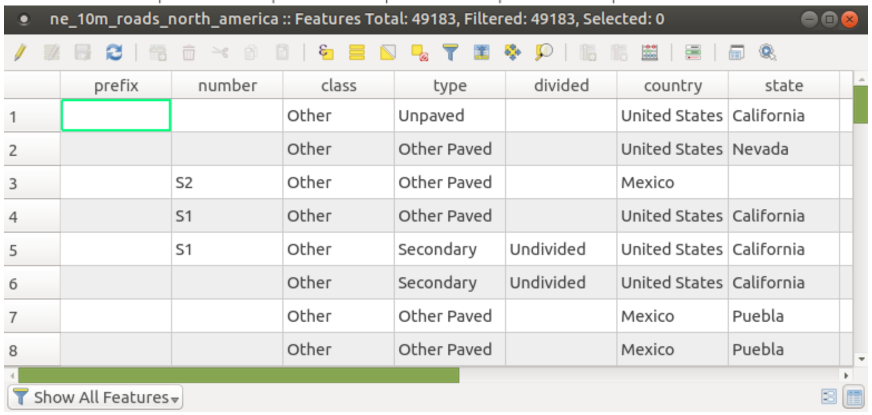
# Vector Data




- Vector data represents features as *points*, *lines*, and *polygons*.
- It is best applied to discrete objects with defined shapes and boundaries.
- It is tied with tabular data



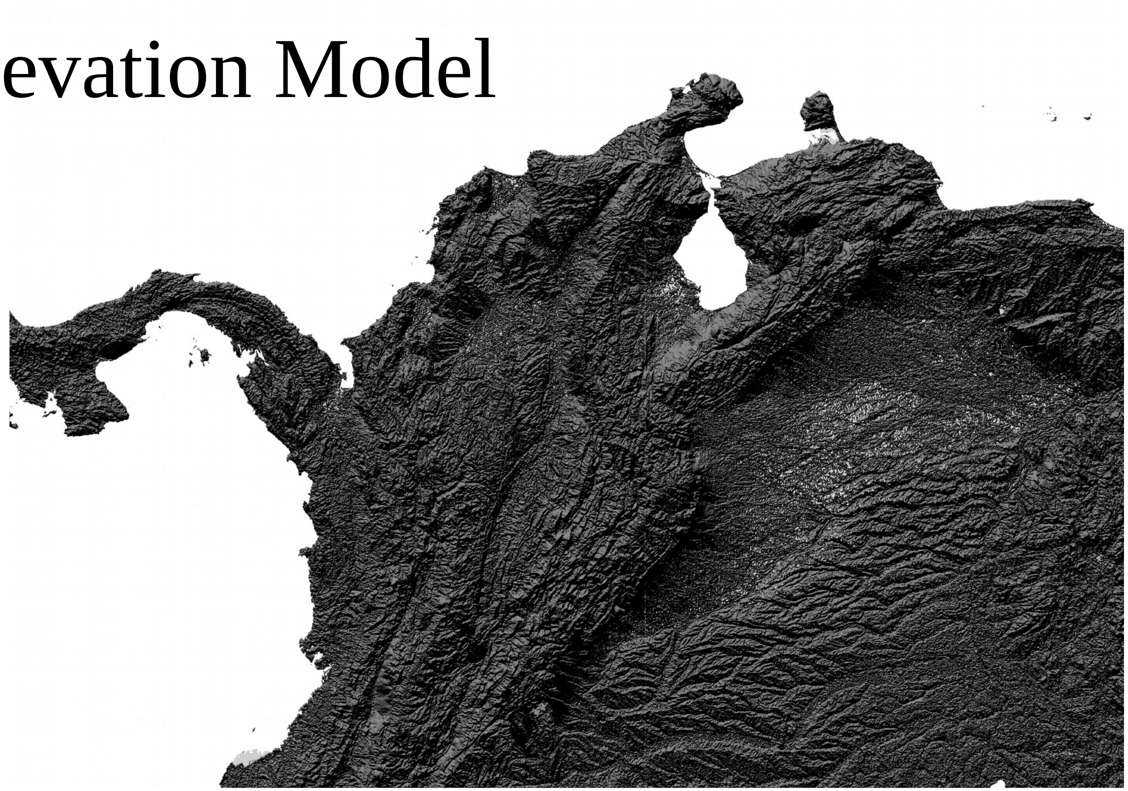

- Examples include:
  - GPS points from radio telemetry
  - Roads
  - Protected areas



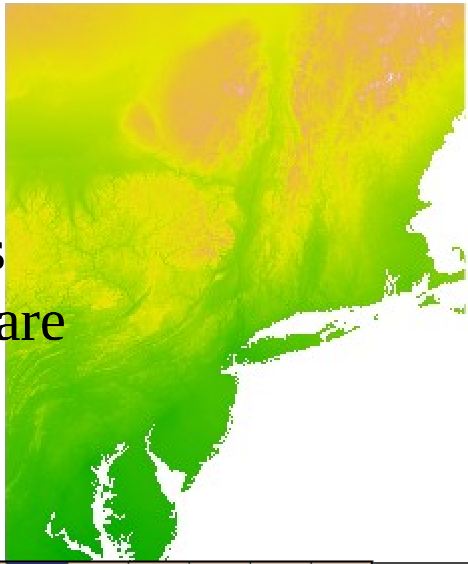

| | prefix | number | class | type | divided | country | state |
|---|---|---|---|---|---|---|---|
| 1 | | | Other | Unpaved | | United States | California |
| 2 | | | Other | Other Paved | | United States | Nevada |
| 3 | | S2 | Other | Other Paved | | Mexico | |
| 4 | | S1 | Other | Other Paved | | United States | California |
| 5 | | S1 | Other | Secondary | Undivided | United States | California |
| 6 | | | Other | Secondary | Undivided | United States | California |
| 7 | | | Other | Other Paved | | Mexico | Puebla |
| 8 | | | Other | Other Paved | | Mexico | Puebla |

# Raster - Continuous Fields

- Continuous fields
  - Represents the real world as a finite number of variables, each one defined at every possible position.
- E.g. a Digital Elevation Model

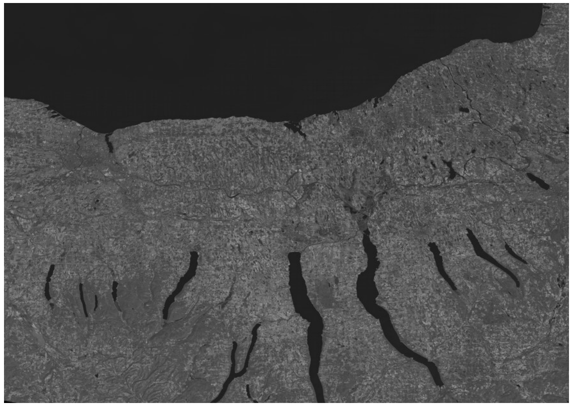


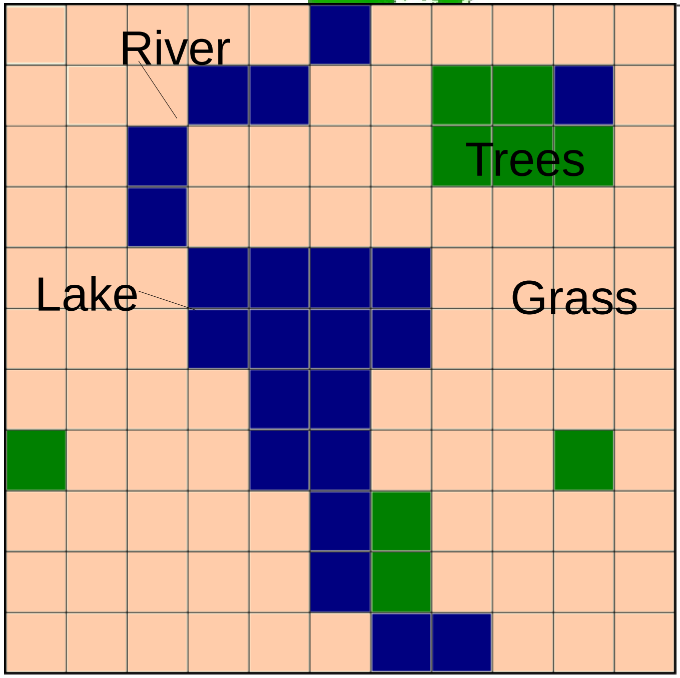
# Raster Data



A raster model represents the world as a surface that is divided into a regular grid of cells, each of which are assigned a value.

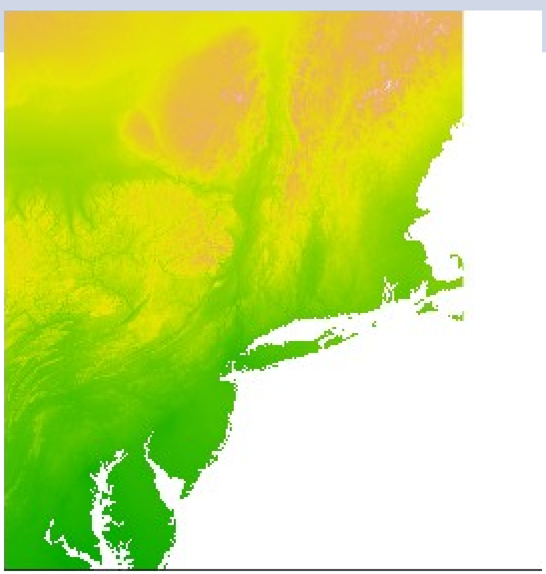
Raster data includes images and grids. aerial photograph, a satellite image, or a scanned map, are often used for generating raster datasets.





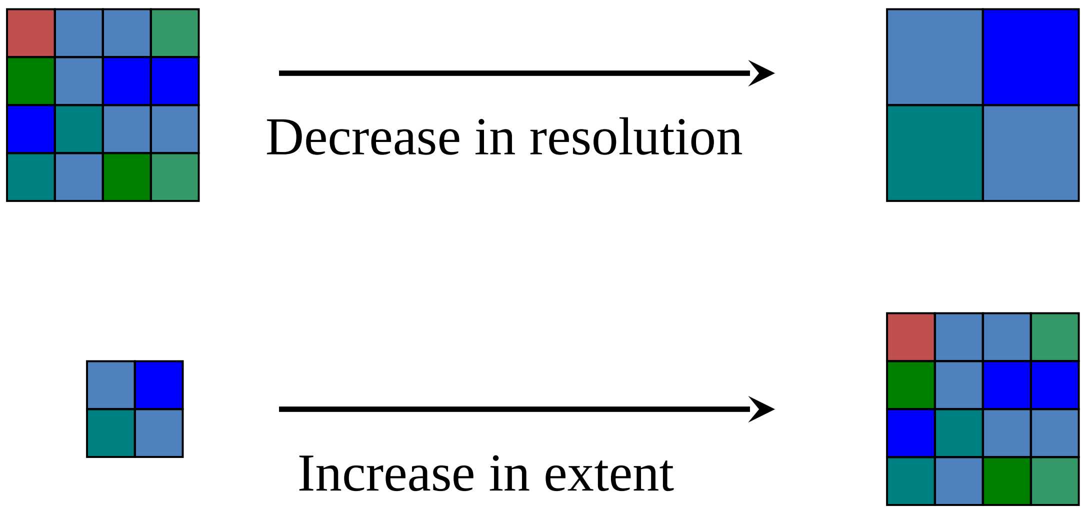
# Resolution

| RASTER | VECTOR |
|---|---|
| Resolution is explicit in the size of the grid cells / pixels | Resolution is difficult to define and therefore typically poorly defined (not rigorous) |

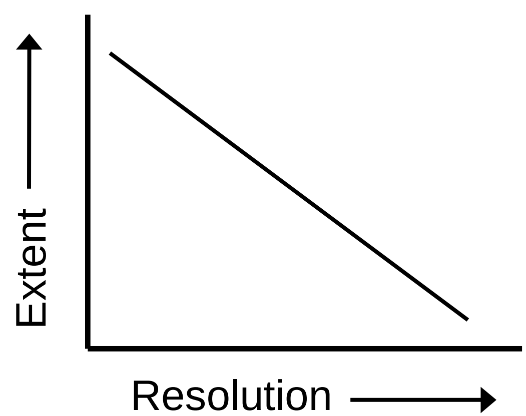


# General data issues: spatial scale

Spatial scale has two elements: **resolution** and **extent**




Resolution and extent tend to be inversely related



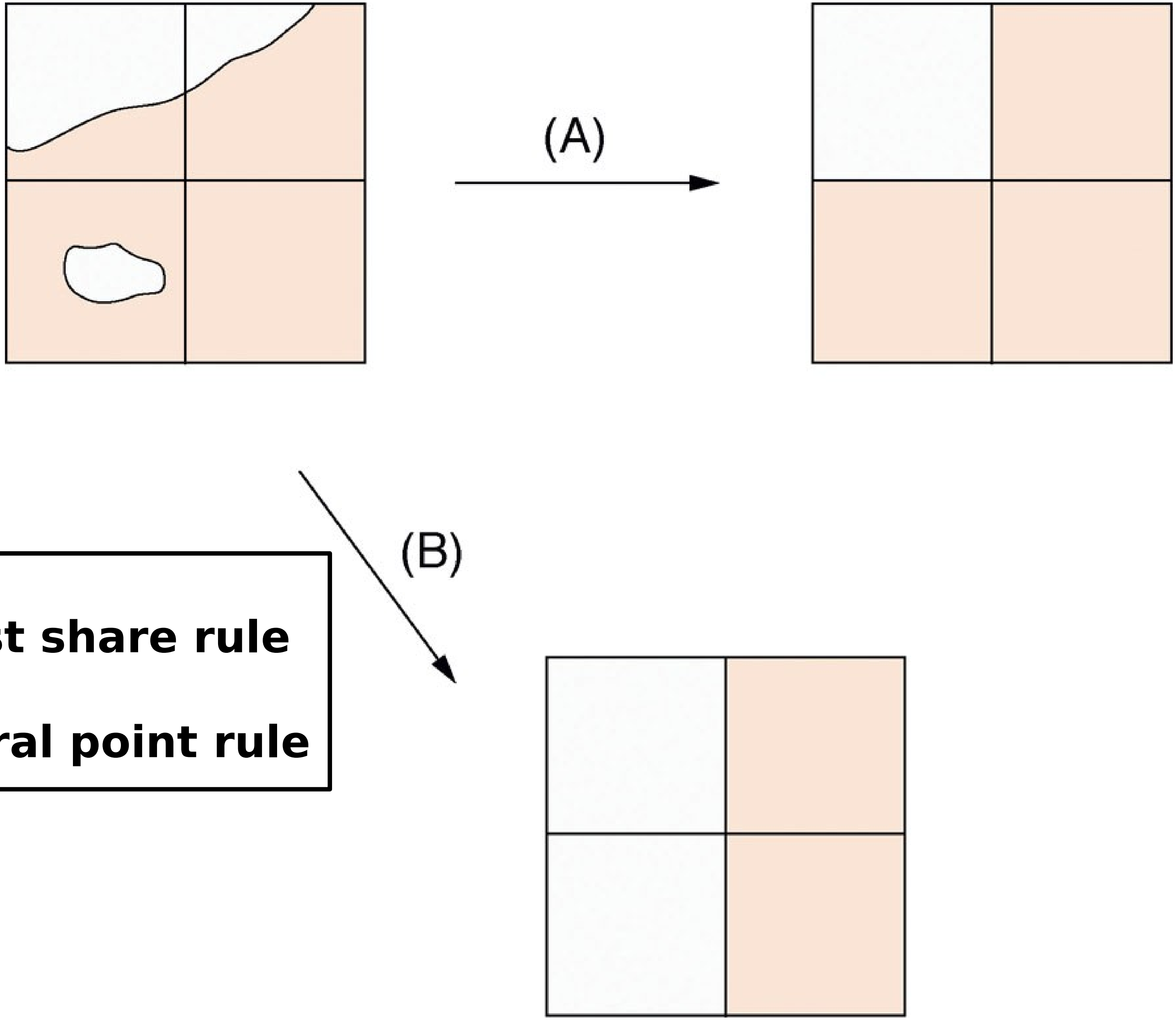
# Vector data

- Advantage
  - precise representation of points, boundaries, and linear features
    - defining spatial relationship (connectivity and adjacency) between coverage features
    - network analysis (for example to find an optimal path between two nodes in a complex transport network)
- Disadvantage
  - boundaries of the resulting map polygons are discrete/enclosed by well-defined boundary lines. In reality the map polygons may represent continuous gradation or gradual change, as in soil maps
  - Resolution is not clear – how many points were used to make up a line?

# Raster data

- Advantage
  - Represent indistinct boundaries
    - thematic information on soil types, soil moisture, vegetation, ground temperatures
  - Reconnaissance satellites and aerial surveys use raster-based scanners
    - scanned images can be directly incorporated into GIS
- Potential disadvantage
  - The higher the grid resolution, the larger the data file is going to be
  - If converting from vector to raster can lose information:

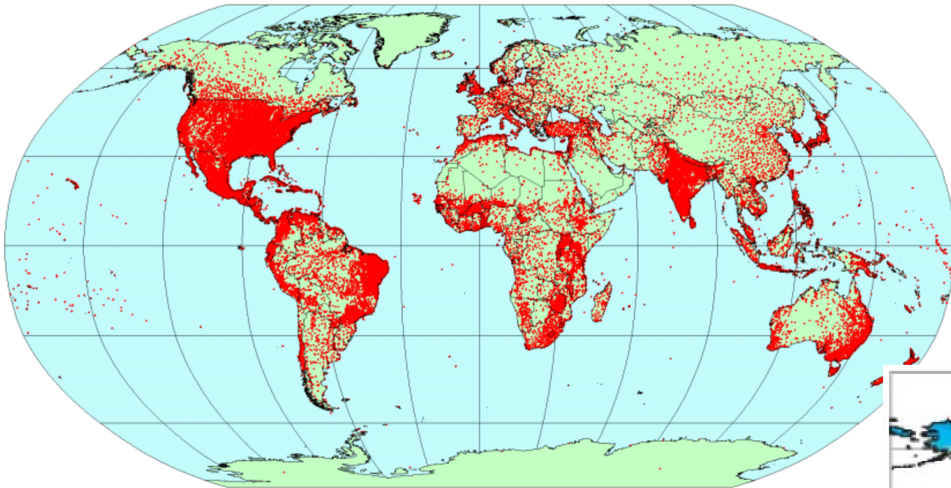
Conversion from vector to raster data



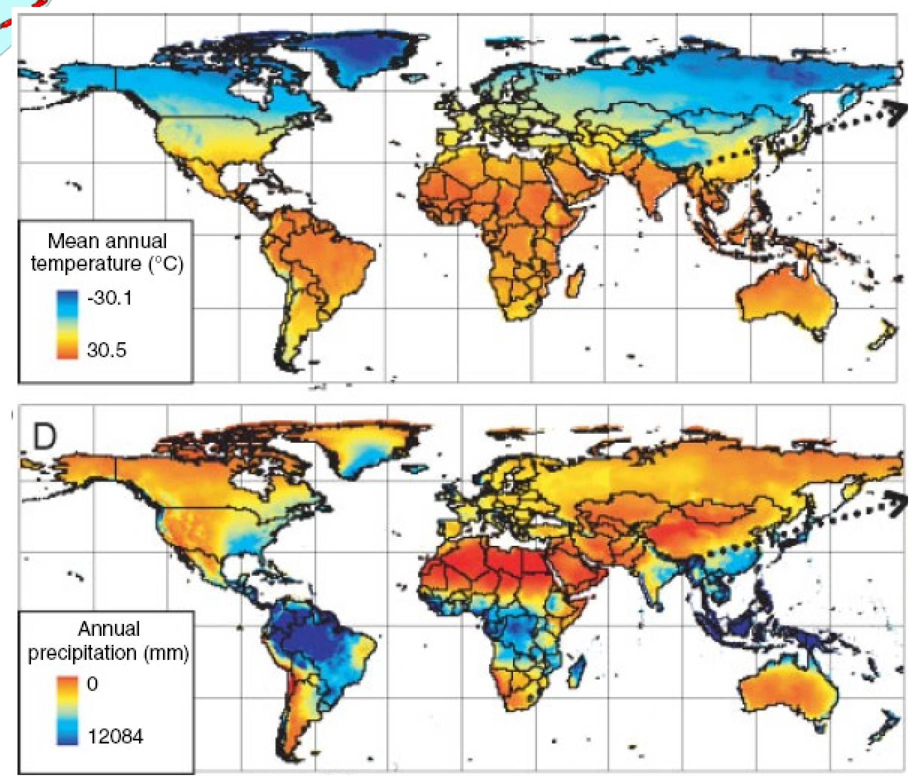

A) the largest share rule

(B) the central point rule

# Conversion from vector to raster data



Weather station records (vector point data; Hijmans et al. 2005)




Interpolated raster climate surfaces (WorldClim)

# Spatial Interpolation – Hijmans et al., 2005



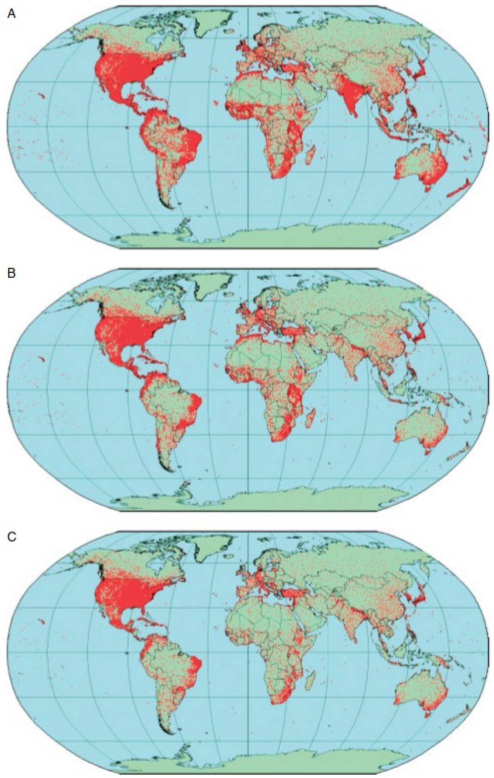
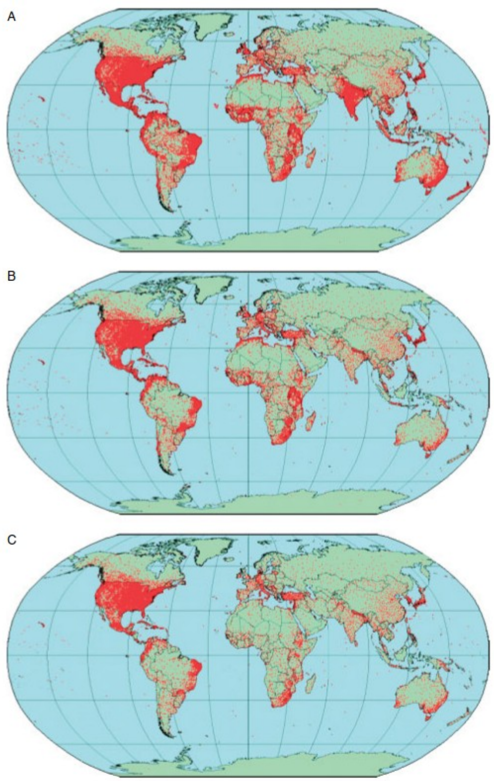



Figure 1. Locations of weather stations from which data was used in the interpolations. (A) precipitation (47 554 stations); (B) mean temperature (24 542 stations); (C) maximum or minimum temperature (14 930 stations). This figure is available in colour online at www.interscience.wiley.com/ijoc

# Spatial Interpolation – Hijmans et al., 2005



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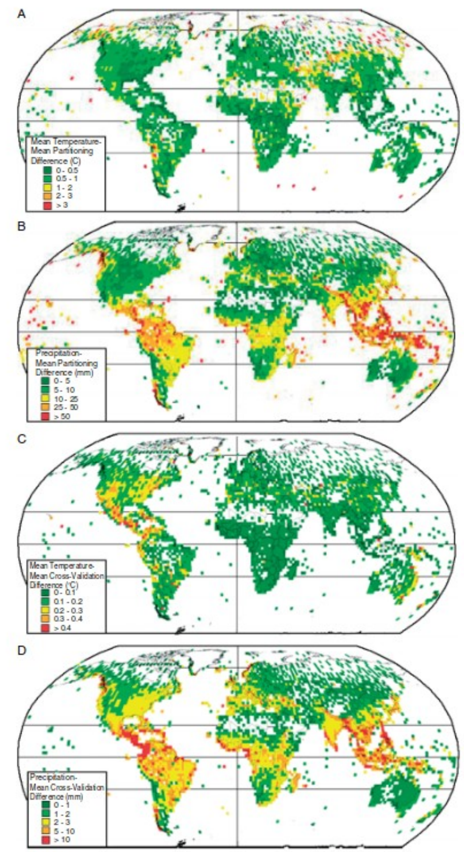



Figure 3. Uncertainty in the climate surfaces. Mean cross-validation deviations for precipitation (A) and mean temperature (C) and deviations when partitioning data in test and training sets for precipitation (B) and mean temperature (D). Values are averaged across 12 months and by 2-degree grid cell. This figure is available in colour online at www.interscience.wiley.com/ijoc

# Spatial Interpolation – Hijmans et al., 2005

1970

GLOBAL CLIMATE SURFACES

1973

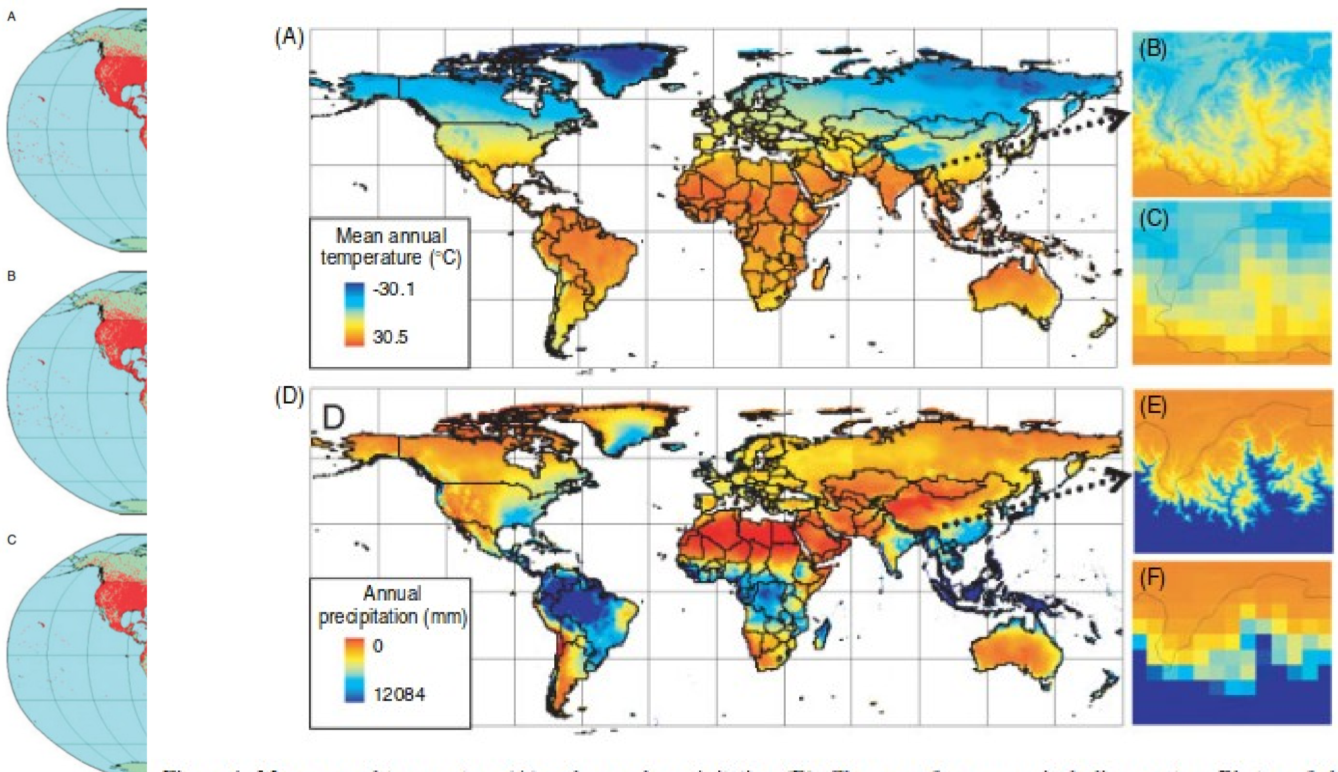



Figure 1. Locations of weather stations from wh
temperature (24 542 stations); (C) maximum or

Figure 4. Mean annual temperature (A) and annual precipitation (D). Close ups for an area including western Bhutan of about 220 by 190 km at the 30 arc s (~1 km) resolution (B and E) and at a 10 arc min (~18 km) resolution (C and F). This figure is available in colour online at www.interscience.wiley.com/ijoc

nean temperature (C) and
alues are averaged across
12 months and by 2-degree grid cell. This figure is available in colour online at www.interscience.wiley.com/ijoc

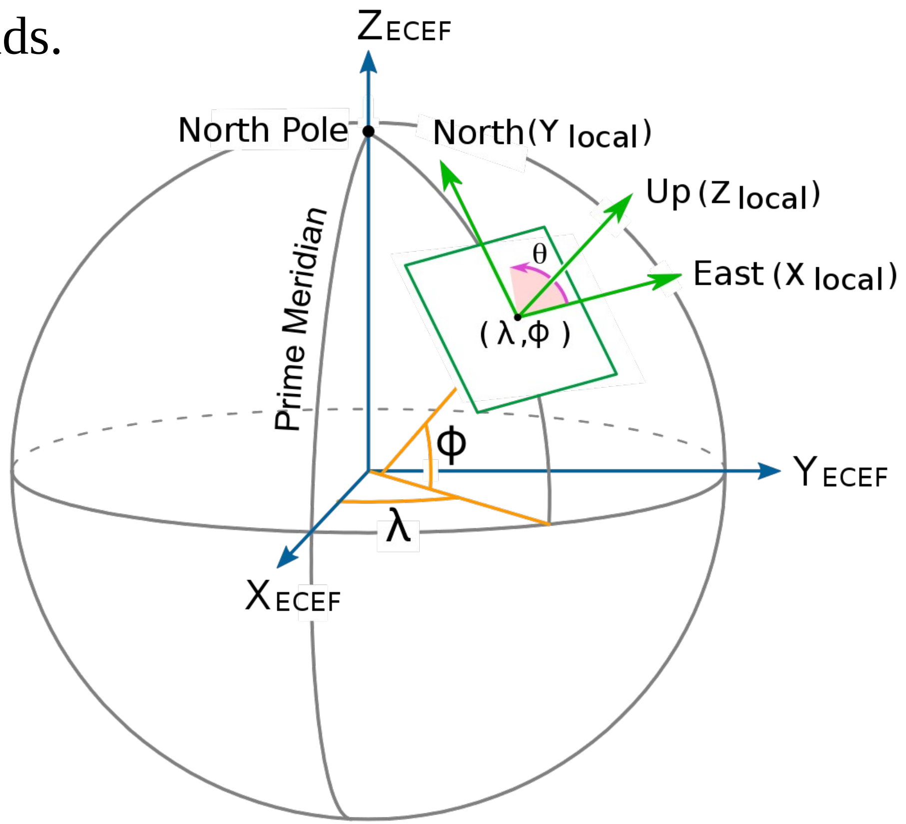
# The nature of spatial data

- Tobler's First Law of Geography:
  - *Everything is related to everything else, but near things are more related than distant things.*

- Most of the things we are interested in are not randomly distributed in space.
  - Con: Need to correct for spatial autocorrelation and bias in analyses
  - Pro: Allows for interpolation

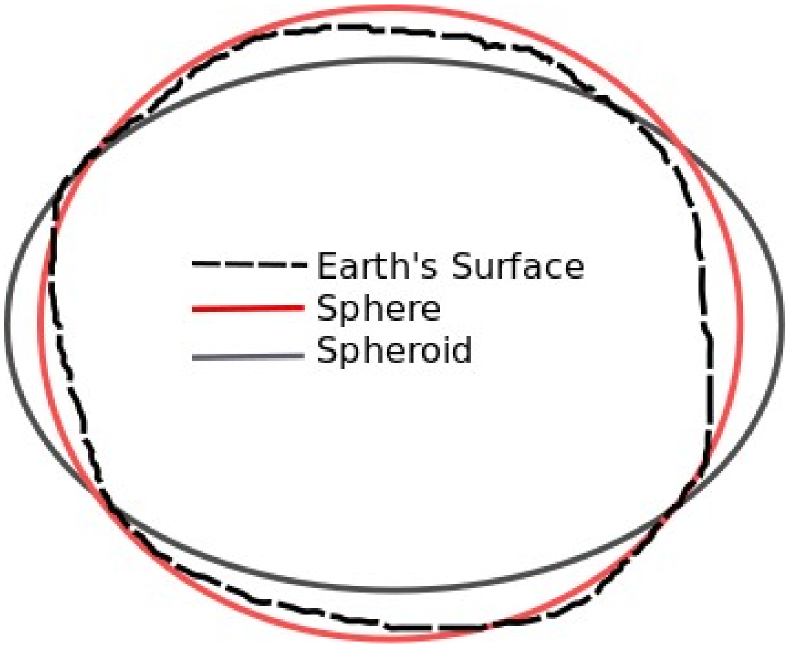
# GIS fundamentals: Geographic coordinate systems (GCS)

- A point is referenced by its *longitude* and *latitude*, which are angles measured from the Earth's center to a point on its surface.
  - Latitude is also the angle from Polaris to horizon (in N. hemisphere)
- Latitude and longitude are measured either in decimal degrees or in degrees, minutes and seconds.



# GIS fundamentals: Geographic coordinate systems (GCS)

- The shape and size of a GCS's surface is defined by a sphere or a spheroid
- In fact, the Earth is neither a perfect sphere nor spheroid (the South Pole is closer to the equator than the North pole!)
- A *datum* defines the origin and orientation of latitude and longitude lines.
- Changing a GCS's spheroid or datum changes all values!
- The standard global system is called World Geodetic System 1984 (WGS1984)

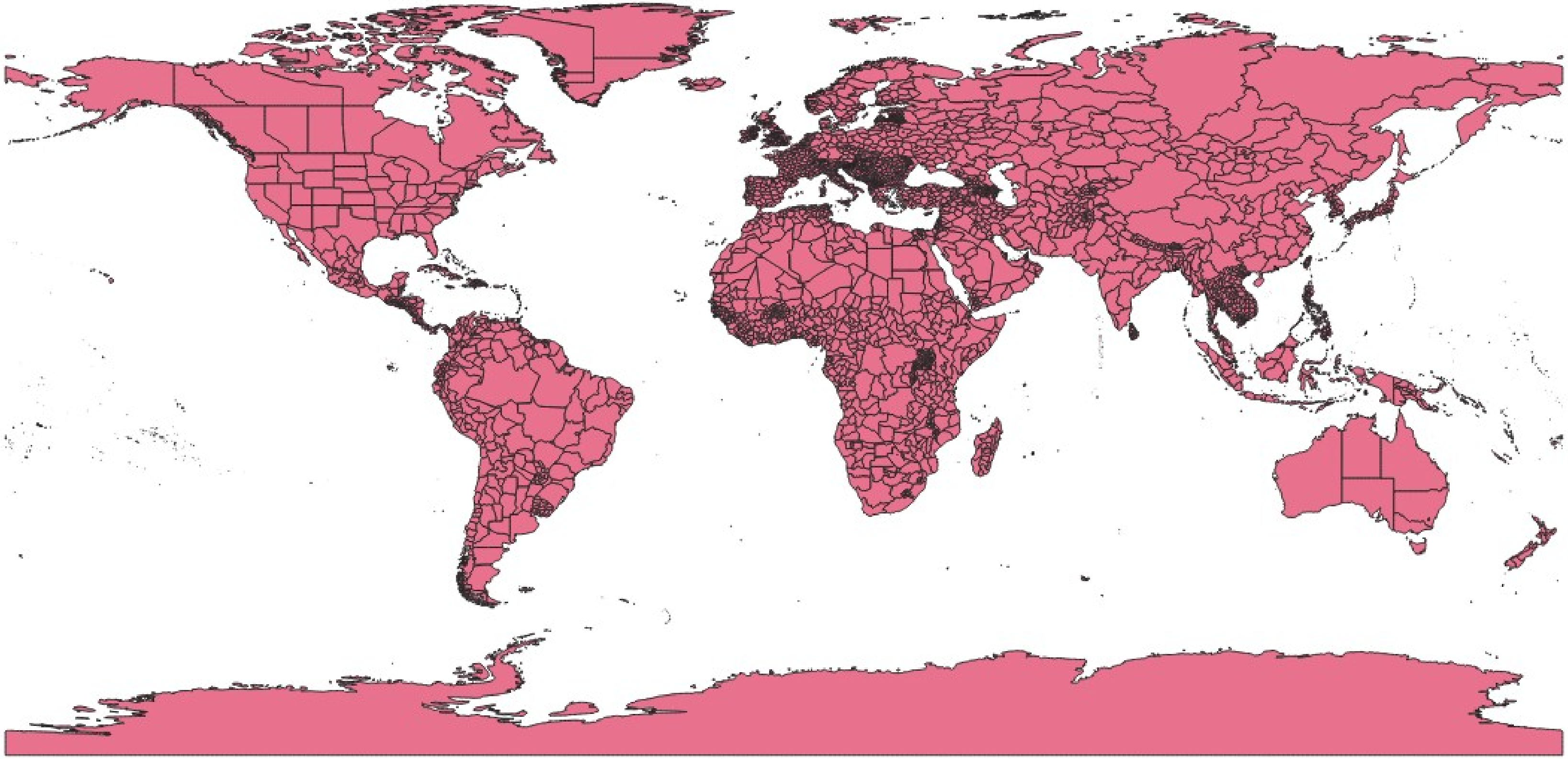


# GIS fundamentals: Geographic coordinate systems (GCS)

- WGS84
  - Default Datum for GPS units
  - Pretty good for global measurements
  - Small changes in landmass movements can be significant at global scale
    - Melting glaciers cause rising elevation
    - Tectonic movements
  - Local datums are better for local maps (e.g., North American Datum; NAD83) and reduce significance of landmass movements.

# GIS fundamentals: Geographic coordinate systems (GCS)

- WGS84 – Unprojected: Distortion near extents of map



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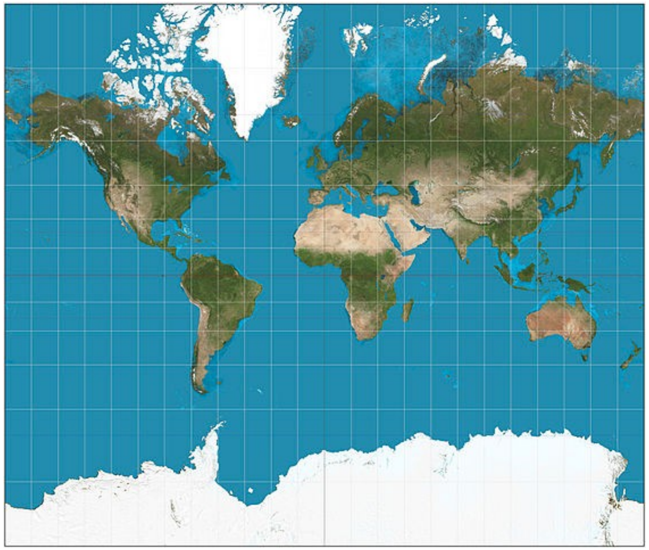
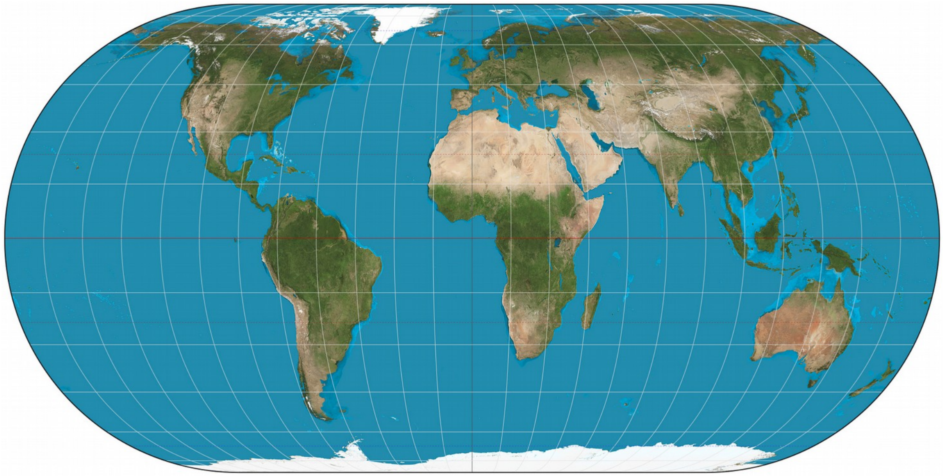
# GIS fundamentals: Projected coordinate systems (PCS)

- Representing the earth's surface in two dimensions causes distortion in the shape, area, distance, or direction of the data.
  - Impossible to show spherical object in 2 dimensions without distortion
- A map projection uses mathematical formulas to relate spherical coordinates on the globe to flat, planar coordinates.
- Different projections are designed to minimize different distortions.

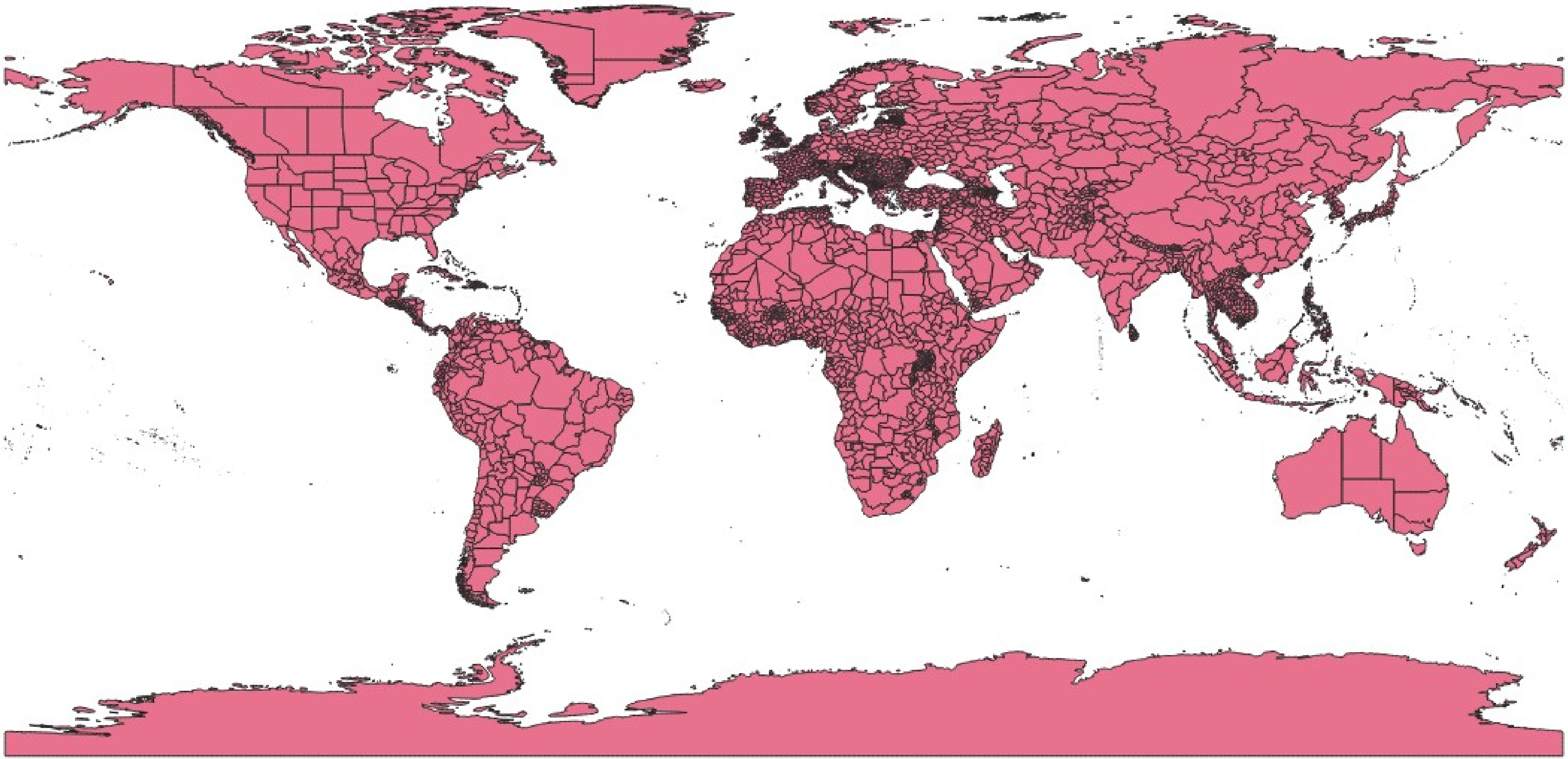


Mercator: maintains direction

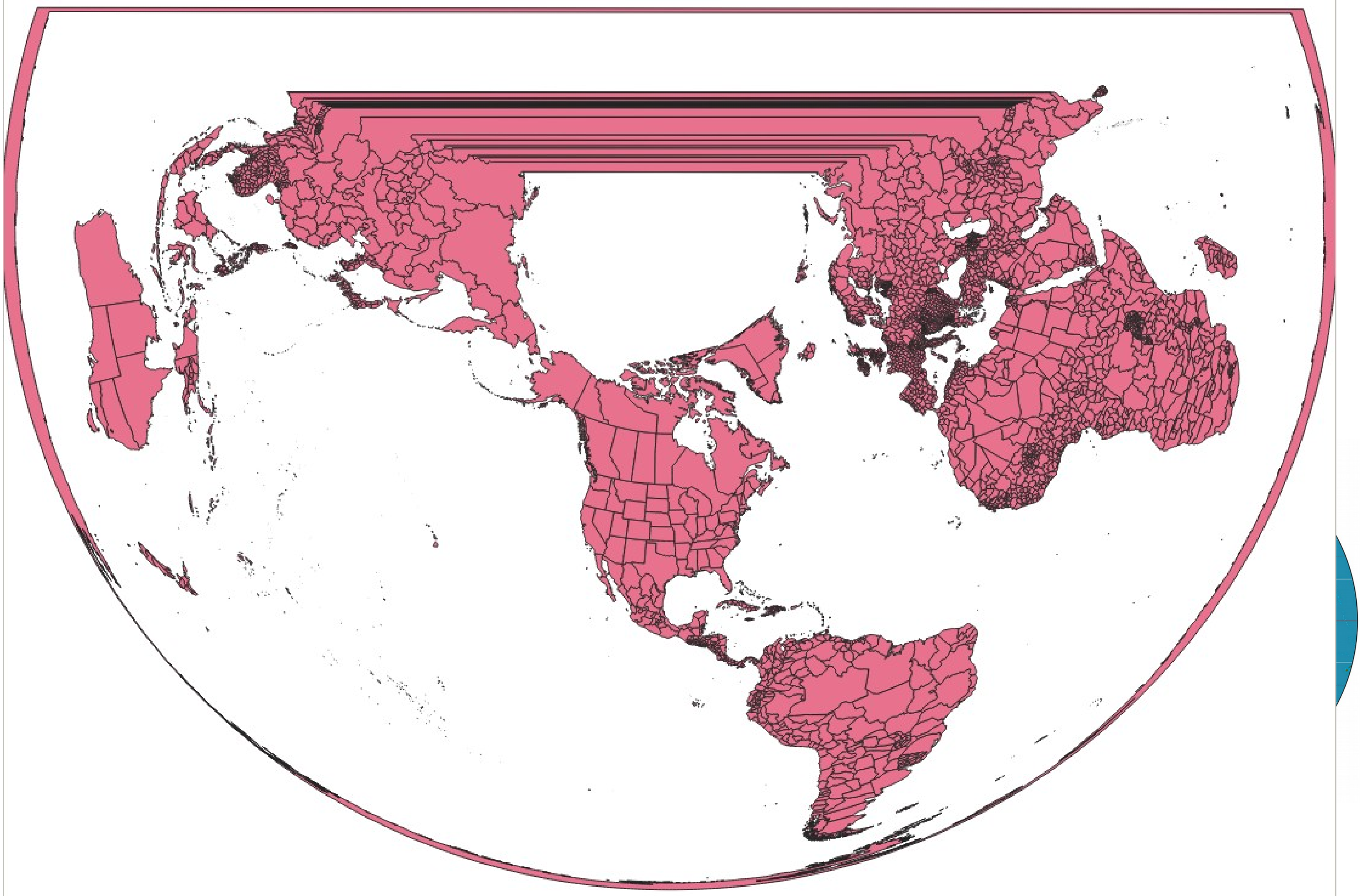


Eckert IV: maintains area

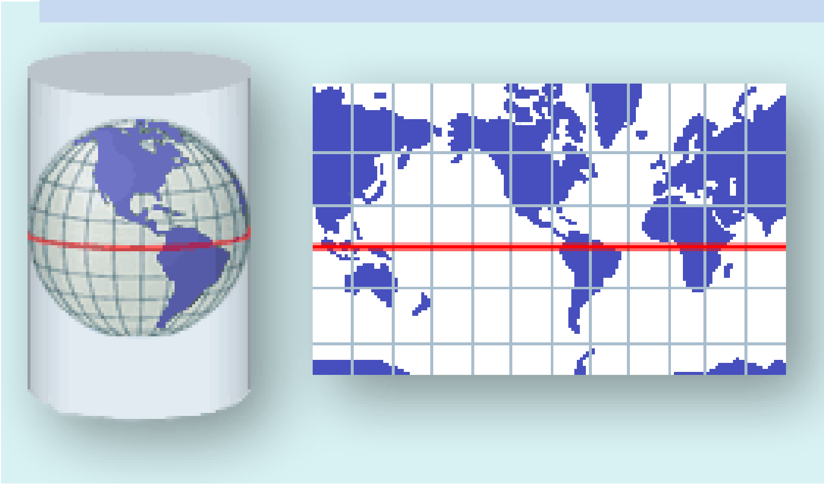
# GIS fundamentals: Projected coordinate systems (PCS)

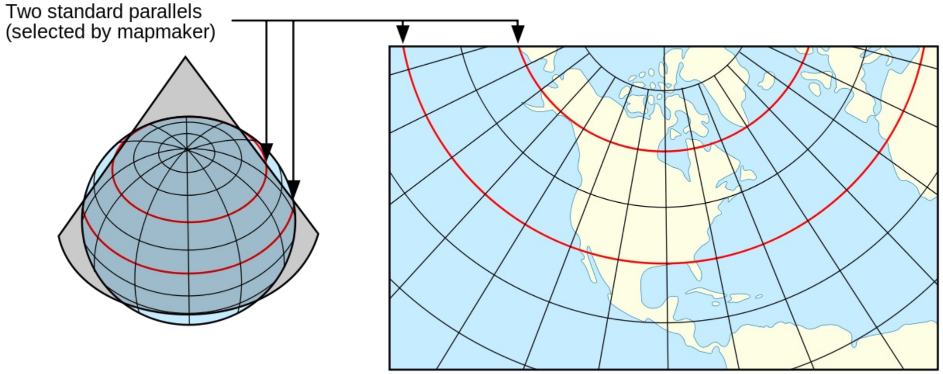


# GIS fundamentals: Projected coordinate systems (PCS)



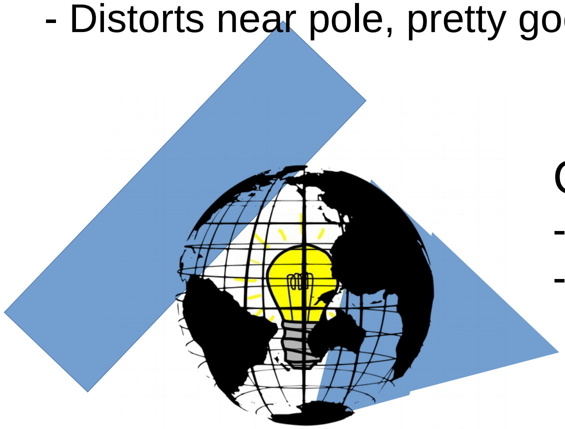
# GIS fundamentals: Projected coordinate systems (PCS)



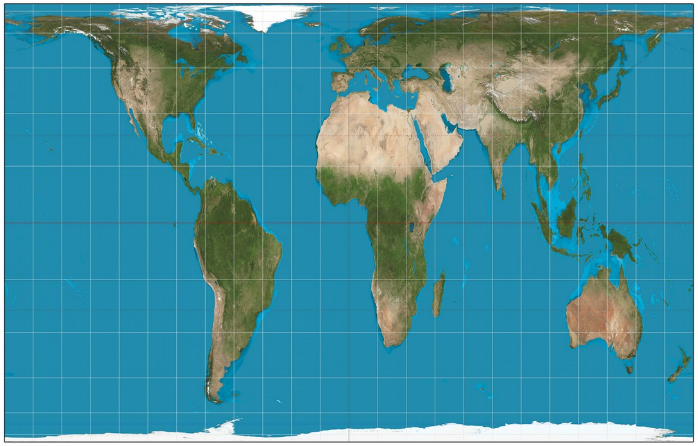



## Conic Projection
- Maintains area near center
- Distortion near edges
- Good for east/west because distortion constant

## Mercator Projection
- Maintains direction
- Good for navigating
- Distorts near pole, pretty good near equator



## Gall-Peters Projection
- Maintains relative areas
- High distortion



https://thetruesize.com/

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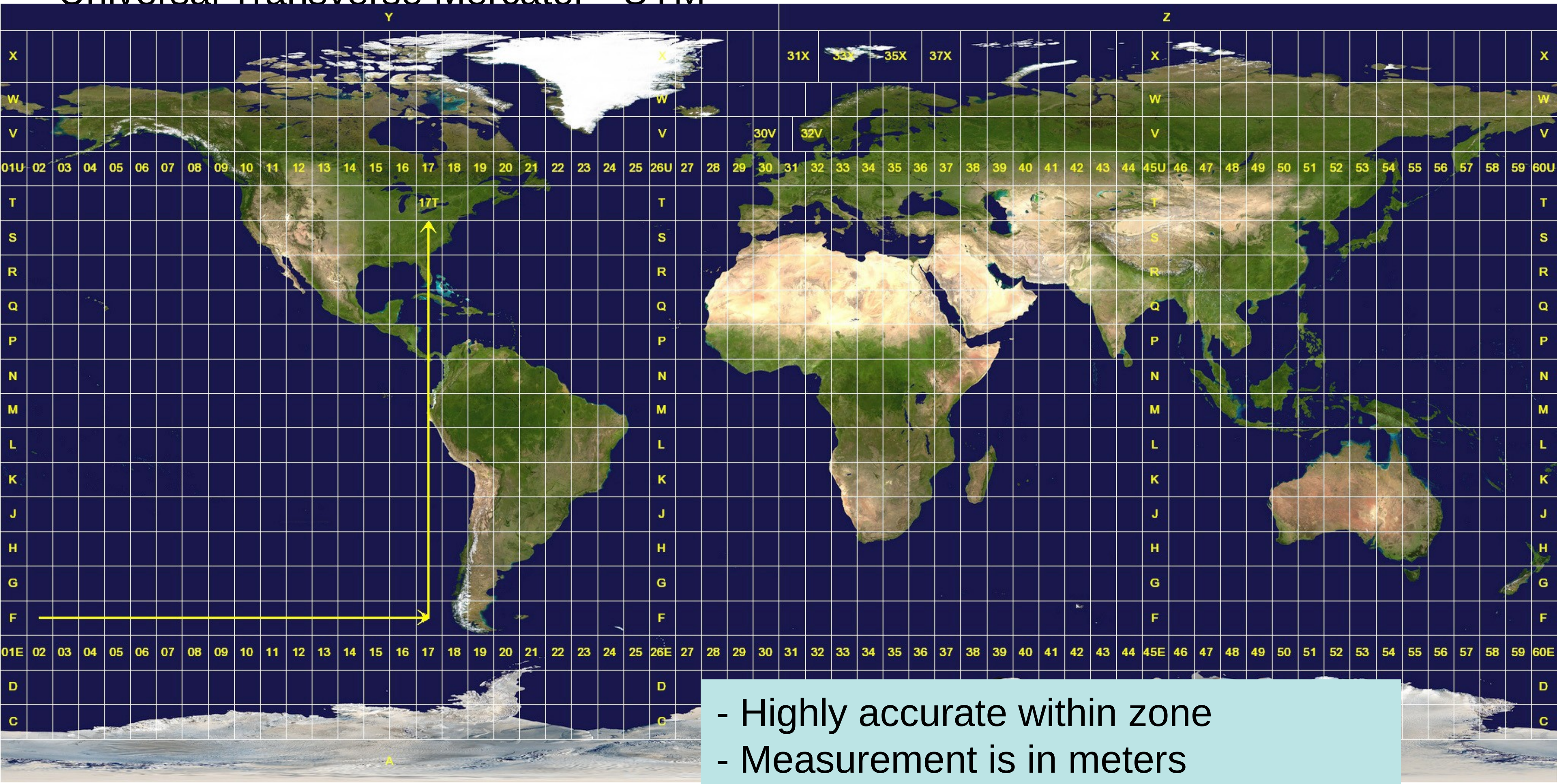
# GIS fundamentals: Projected coordinate systems (PCS)

## Universal Transverse Mercator - UTM

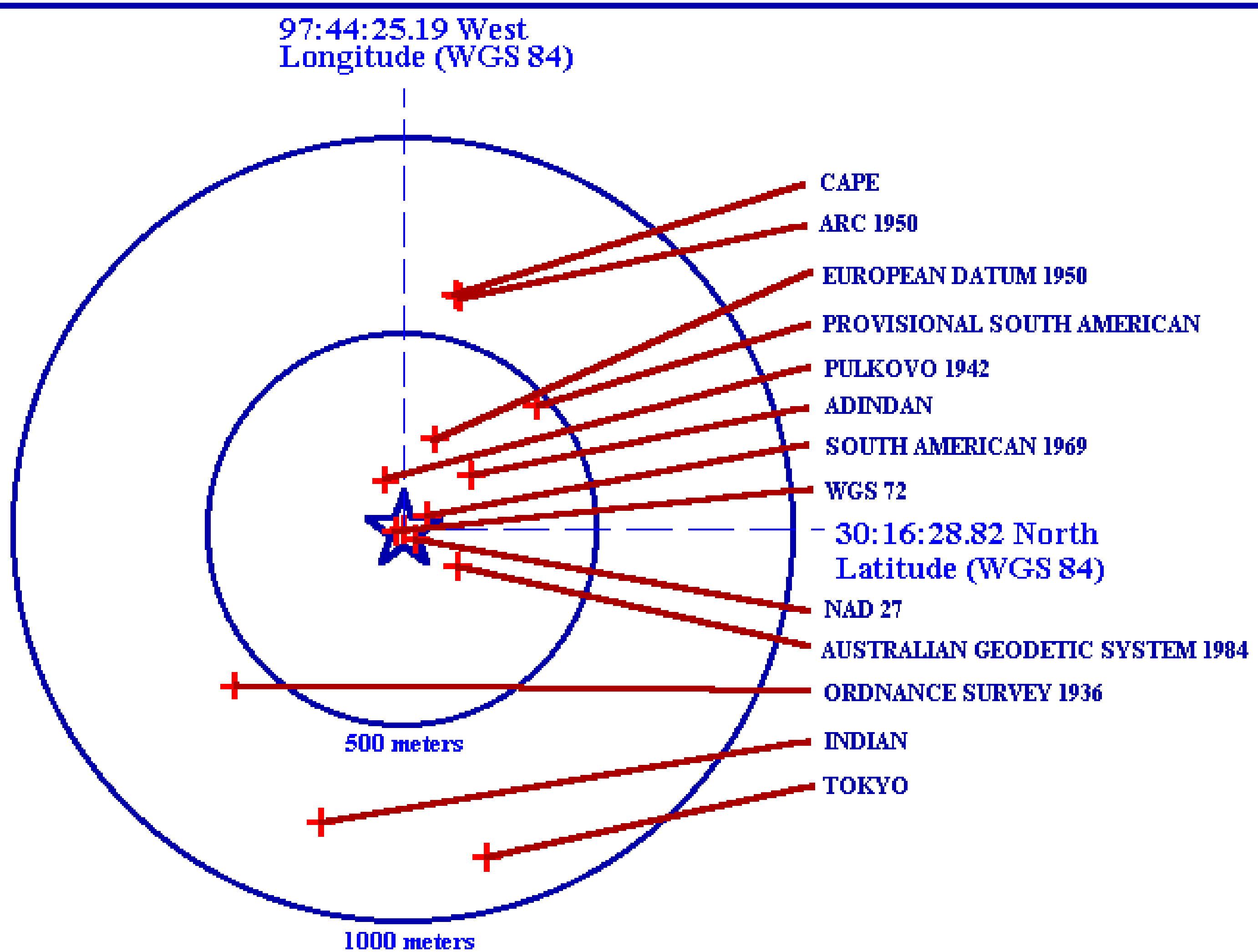



- Highly accurate within zone
- Measurement is in meters
    - intuitive
- Not great for large areas
    (across zones)

# GIS fundamentals: Geographic and Projected coordinate systems

- Modern GIS make dealing with coordinate systems relatively straightforward; however:

IT IS ESSENTIAL TO KNOW THE COORDINATE SYSTEM OF ANY DATA WITH WHICH YOU ARE WORKING!




# Position Shifts from Datum Differences

Texas Capitol Dome Horizontal Benchmark

Peter H. Dana 9/1/94

# Outline

- How do we represent real world geographic information with a computer?
  - Data models – representations of geographic reality
    - Scale, spatial autocorrelation
  - Location information: coordinate systems
  - Georeferencing, sampling bias
  - Remote Sensing

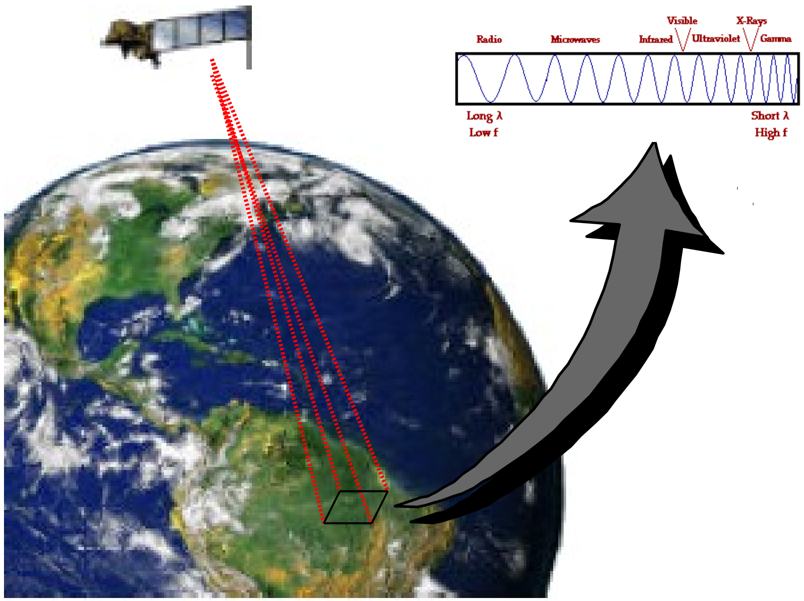
# Species' distribution data: possible sources

- Personal collection during field surveys (e.g., using a GPS receiver or smartphone)
- Extracting data from large surveys (e.g., North American Breeding Bird Survey)
- Digitizing atlases (e.g. *The new atlas of breeding birds in Britain and Ireland: 1988-1991*)
- Collections in natural history museums
- On-line distributed databases (e.g. GBIF, HerpNET, FishNET, ORNIS)

# Georeferencing


- Woodbury, NY
- Near Woodbury
- 5 miles from Woodbury
- 1 mile east of Woodbury
- 10 minutes along the path leading out of Woodbury

# What is Remote Sensing?




*Source: P. Ersts, July 2004*

***General definition:*** *Acquiring information about an object without physical contact.*

***Definition in context of Earth observation:*** *A technology for sampling reflected and emitted electromagnetic (EM) radiation of features on the Earth's land surface, oceans, and atmosphere.*