



LECTURE 2

GEOSPATIAL DATA: SOURCES, MODALITIES, AND APPLICATIONS

Geospatial Representation Learning

PRESS – OR SPACE. →

Learning Outcomes

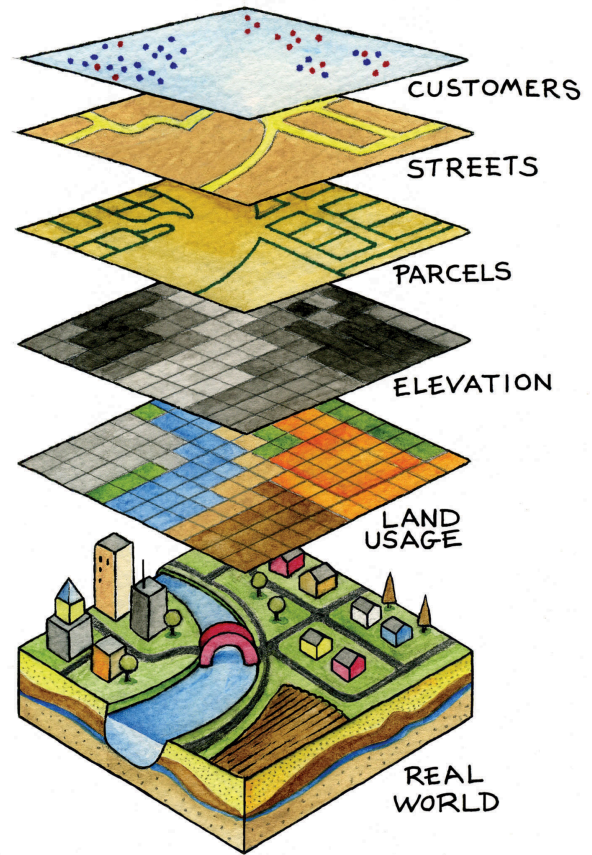
Lecture

- Understand and compare major geospatial data sources from GIS, remote sensing, meteorology, geophysics, and environmental monitoring.
- Distinguish common geospatial data modalities, including raster images, vector layers, point data, point clouds, time series, trajectories, and gridded fields.
- Explain key properties of geospatial data, including spatial resolution, temporal resolution, spectral resolution, coverage, uncertainty, and coordinate reference systems.
- Describe common geospatial data formats and access patterns used in Python-based workflows.
- Match geospatial data sources and modalities to suitable environmental and socio-ecological applications.
- Identify practical challenges such as scale mismatch, missing data, sampling bias, spatial autocorrelation, and heterogeneous data quality.

Lab

- Access and preprocess raster, vector, and time-series geospatial data using Python-based tools.
- Combine multiple geospatial data layers into a common spatial reference and resolution.
- Extract training samples or analysis regions from geospatial datasets.
- Evaluate practical limitations of data quality, coverage, scale, and interoperability.

Coordinates



[Campbell & Shin \(2011\), Figure 1.8.](#)

Coordinates and Location

How many coordinates do we need to uniquely define a spatio-temporal location?

3 spatial dimensions

*Cartesian (x, y, z) or
Spherical/Ellipsoidal (λ , φ , r) or or UTM
Projections (Easting, Northing, Height)*

Where is it in space?

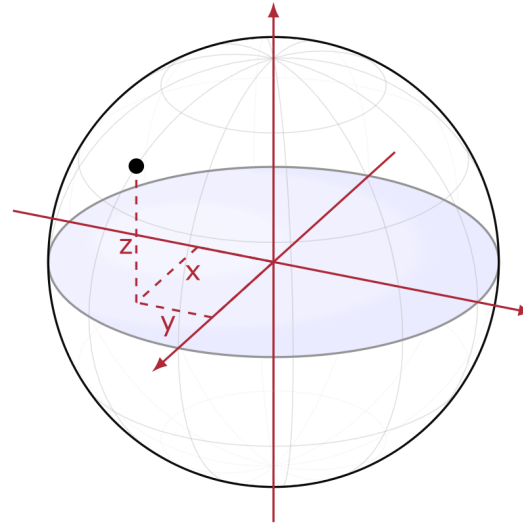
1 temporal dimension

t

When does it occur?

Cartesian Coordinates x,y,z

A location can be represented by three orthogonal coordinates $\mathbf{p} = (x, y, z)$ in an Earth-Centered, Earth-Fixed (ECEF) coordinate system



Spherical Coordinates

Expressing location on the surface of Earth is often more practical than working directly in 3D Cartesian coordinates
 $x, y, z \mapsto \lambda, \varphi, r$ of longitude λ , latitude φ , and constant radius r

Spherical to Cartesian

$$x = r \cos \varphi \cos \lambda$$

$$y = r \cos \varphi \sin \lambda$$

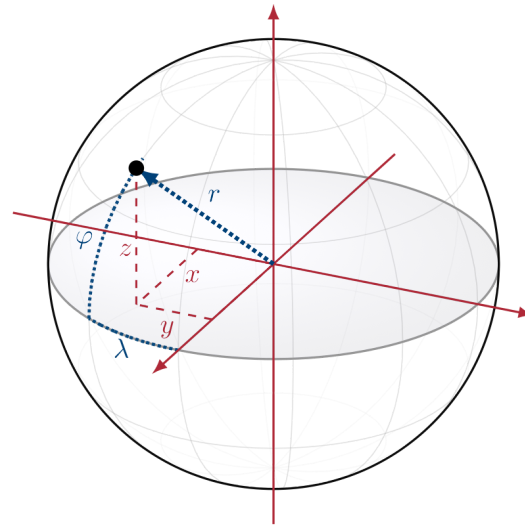
$$z = r \sin \varphi$$

Cartesian to spherical

$$r = \sqrt{x^2 + y^2 + z^2}$$

$$\lambda = \text{atan2}(y, x)$$

$$\varphi = \arcsin\left(\frac{z}{r}\right)$$



Ellipsoidal Coordinates

But the Earth is not a sphere: It is an ellipsoid.

Geodetic to Cartesian

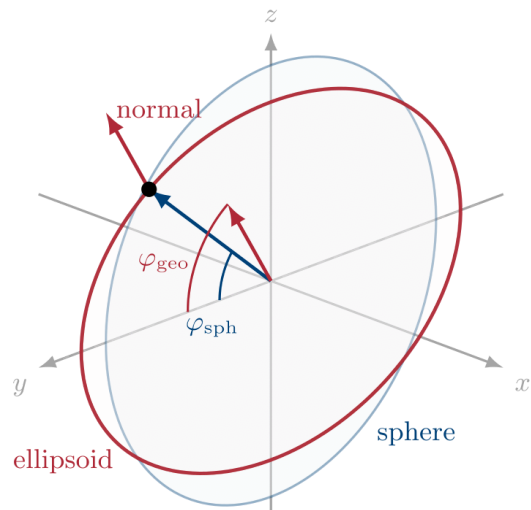
$$\begin{aligned}x &= (N(\varphi) + h) \cos \varphi \cos \lambda \\y &= (N(\varphi) + h) \cos \varphi \sin \lambda \\z &= ((1 - e^2)N(\varphi) + h) \sin \varphi\end{aligned}$$

$$N(\varphi) = \frac{a}{\sqrt{1 - e^2 \sin^2 \varphi}}$$
$$e^2 = \frac{a^2 - b^2}{a^2}$$

Cartesian to Geodetic

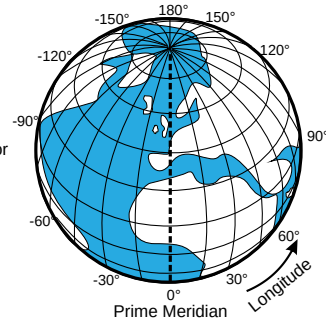
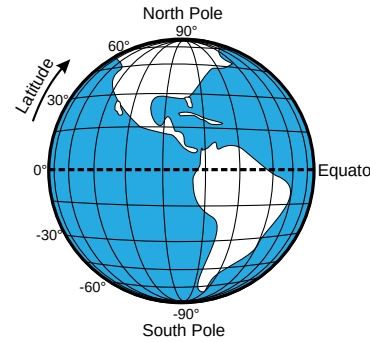
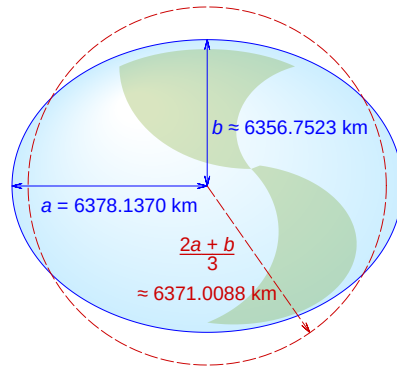
The inverse is usually computed iteratively.

See [Wikipedia](#) .



World Geodetic System 1984 (WGS 84)

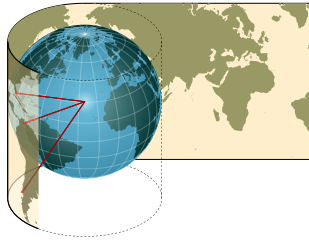
WGS 84 is the global reference system used by GPS and most web mapping workflows.



Cylindrical Map Projections and Web Mercator

Cylindrical projections - Mercator

A cylinder touches or cuts the globe along a line or lines. The classic case is a cylinder around the equator.



Cylindrical projections minimize distortion along their standard line(s).

Web Mercator

Web Mercator is the projection used by many web maps. It is a cylindrical, conformal projection: local shapes are preserved, but areas grow strongly toward the poles.



Web maps trade area accuracy for visually stable local shapes and simple tiled rendering.

Cylindrical Map Projections and UTM

Cylindrical projections - UTM

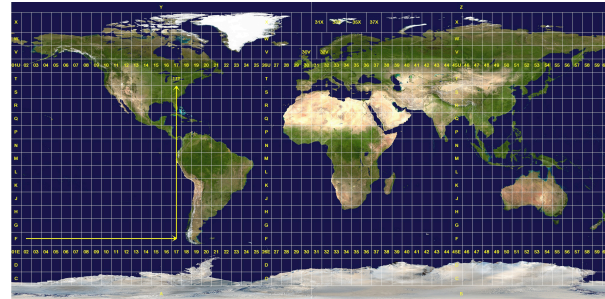
The Universal Transverse Mercator system rotates the cylinder: each zone uses a transverse cylinder around a local central meridian.



UTM turns longitude/latitude into local metric coordinates: easting and northing.

Universal Transverse Mercator (UTM)

Pre-defined UTM zones give geodata local coordinate systems with comparatively low distortion inside each zone.



UTM uses different cylinders to avoid local distortions.

Radius: Atmosphere and Ocean

Geospatial fields are not only horizontal.

They also vary vertically:

- wind fields change across atmospheric columns
- ocean currents differ at the surface and at depth
- temperature, humidity, pressure, and salinity depend on height or depth
- many Earth-system processes require a vertical coordinate

Location often means latitude, longitude, and height or depth.

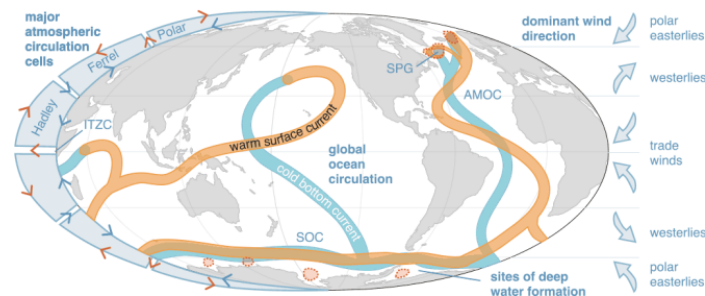


Figure: University of Exeter, [Atmospheric circulation cells, dominant wind directions, key ocean basins, surface currents and deep water formation sites](#), Licensed under CC-BY-SA: Creative Commons Attribution-Share Alike 4.0 International. The rest of this slide deck remains CC-BY-NC.

Time: The Earth is Dynamic

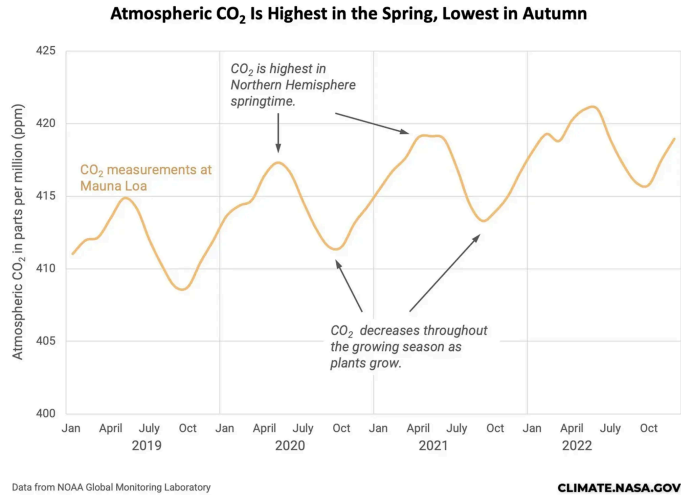


Figure: NASA Science, [Carbon Dioxide](#)



Figure: Google Earth Engine, [MODIS NDVI time series animation](#). Licensed under CC-BY.

Time: Common Frequencies

Earth observations contain processes at many characteristic temporal frequencies.

| Time scale | Frequency | Examples |
|-----------------------------|-----------------|---|
| Seconds to minutes | High frequency | Wind gusts, turbulence, lightning, traffic, waves, sensor noise |
| Minutes to hours | Sub-daily | Cloud motion, precipitation cells, tides, urban mobility, river discharge |
| ~12 hours | Semi-diurnal | Ocean tides, coastal water levels |
| 24 hours | Daily / diurnal | Temperature cycle, solar radiation, human activity, vegetation |
| Several days | Weather | Storms, pressure systems, cloud regimes, heatwaves, cold fronts |
| Weekly | Anthropogenic | Commuting, energy use, shipping patterns, some air pollution signals |
| Monthly / ~29.5 days | Lunar | Spring-neap tide cycle, moon-related illumination effects |
| Seasonal / annual | Yearly | Phenology, crop cycles, snow cover, monsoon, sea ice, temperature |
| Interannual | 2-7 years | ENSO / El Nino, drought cycles, vegetation anomalies |
| Decadal | 10+ years | Climate variability, land-use change, glacier retreat, urban expansion |
| Multi-decadal to centennial | Long-term trend | Climate change, sea-level rise, ecosystem shifts |



PRACTICAL 2

WORKING WITH GEOSPATIAL DATA SOURCES

Geospatial Representation Learning

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