# C1: Collection of Sentinel-2 and Landsat-8 Images

January 16, 2020

**Abstract**

The objective of this lesson is to create a video of your house seen from space using satellite images freely available online. For that we are going to learn how to access and manipulate optical images from the Sentinel-2 and Landsat-8, and radar images from Sentinel-1. We will cover the following topics:

- coordinate reference systems, WGS84 (longitude/latitude), and projections (Mercator, UTM, and EPSG codes)
- search and download images available at a given position
- image metadata, GeoTIFFs, and GDAL (gdalinfo)
- spectral bands and file formats

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## 1 Coordinate systems

Coordinate reference systems (CRS) provide a standardized way of describing locations. Many different CRS are used to describe geographic data, the choice depends on the geographic extent of the data, the purpose of the data, etc.

Determining the shape of the earth is the first step in developing a CRS. An ellipse is a simple model for describing the basic shape of the Earth. The modern trend is to use a global **ellipsoid** for compatibility, such as WGS. The **datum** defines an origin point of the coordinate axes and defines the direction of the axes.

A natural choice for describing points in 3d relative to the ellipsoid, is using latitude, longitude, and altitude. These are unprojected (or geographic) reference systems. Projected systems, on the other hand, are used for referencing locations on 2d representations of the Earth (maps).

Most geographic information systems and libraries use EPSG codes for identifying the coordinate systems. EPSG Geodetic Parameter Dataset (also EPSG registry) is a public registry of spatial reference systems, Earth ellipsoids, coordinate transformations and related units of measurement. Each entity is assigned an EPSG code between 1024-32767.

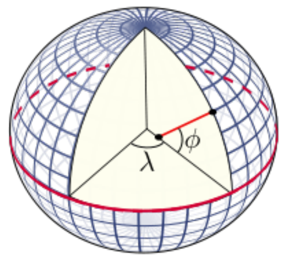


Figure 1: Latitude and longitude graticule on an ellipsoid.

**Geodetic Longitude, Latitude, and WGS84** The World Geodetic System (WGS84) is a standard for use in cartography, geodesy, and navigation including GPS. It comprises a standard coordinate system for the Earth, a standard spheroidal reference surface (reference ellipsoid) for raw altitude data, and a gravitational equipotential surface (the geoid) that defines the nominal sea level.

Note that the difference between the semi-major and semi-minor axes of the reference ellipsoid is about 21 km and as fraction of the semi-major axis it equals the flattening; on a computer screen the ellipsoid could be sized as 300 by 299 pixels. So, illustrations usually exaggerate this flattening.

The geodetic latitude (usually denoted as $\varphi$) is the **angle between the equatorial plane** and a line that is **normal to the reference ellipsoid**. This is the definition assumed when the word latitude is used without qualification. Note that the normal to the ellipsoid does not pass through the center (as illustrated in Figure 1), except at the equator and at the poles.

The longitude of a point on Earth's surface is the angle east or west of a reference Greenwich meridian to another meridian that passes through that point. All meridians are halves of great ellipses (often called great circles), which converge at the north and south poles. The antipodal meridian of Greenwich is both 180°W and 180°E.

**Projections and UTM** Projections are needed to transform the elliptical earth into a flat surface. It is impossible to flatten a round object without distortion, and this results in trade-offs between area, direction, shape, and distance.

For instance, the Mercator projection (used in Google maps, shown in Figure 2) is a cylindrical map projection that is conformal so it preserves angles (which is usefull for navigation). The Mercator projection does not preserve areas, but **it is most accurate around the equator, where it is tangent to the globe**.

The **Universal Transverse Mercator (UTM)** system is not a single map projection. The system instead divides the Earth into sixty **zones, each being a six-degree band of longitude**, and uses a secant transverse Mercator projection in each zone (shown in Figure 3). The WGS84 ellipsoid is generally used to model the Earth in the UTM coordinate system.

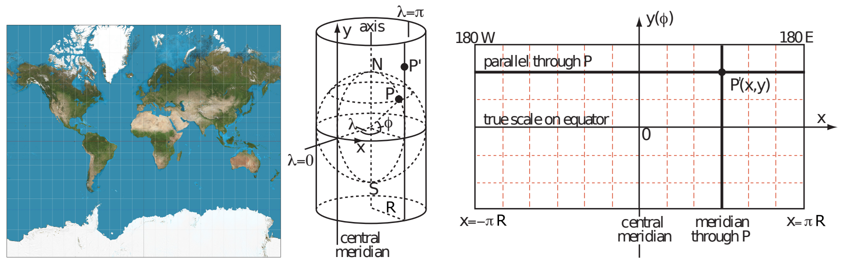


Figure 2: Mercator is a cylindrical map projection that is conformal so it preserves angles. The Mercator projection does not preserve areas, but it is most accurate around the equator, where it is tangent to the globe.

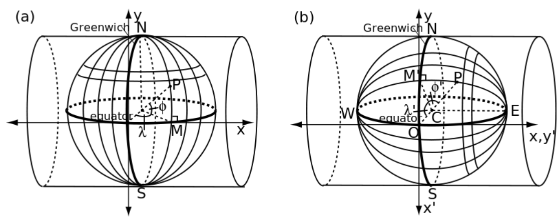


Figure 3: Universal Transverse Mercator.

Since a Transverse Mercator projection results in extreme distortion in polar areas, the UTM zones are limited to 80°S and 84°N latitudes. Polar regions (below 80°S and above 84°N) use the UPS - Universal Polar Stereographic coordinate system based on the Polar Stereographic projection.

Each UTM zone is further divided into horizontal bands 8° of latitude wide. The 20 bands are labeled with letters. Letters A, B, Y and Z label polar regions in the UPS coordinate system. For instance, Paris is in the UTM (WGS84) Zone 31U.

Within an UTM zone the coordinates are expressed as easting and northing. The **easting** coordinate of a point refers to the eastward-measured distance (measured in meters) from the central meridian of the UTM zone, which is assigned a value of 500000m. While the **northing** coordinate refers (in northern hemisphere) to the number of meters a point is located north of the equator. The northing of a point south of the equator is equal to 10000000m minus its distance from the equator (this way there are no negative coordinates).

It should be noted that in practice the UTM bands are only useful to determine the hemisphere. Hence, in practice many applications only require knowledge of the UTM zone and the hemisphere, or just use to the corresponding EPSG code, which is computed as:

```
if northern_hemisphere:      EPSG = 32600 + zone_number
else:                        EPSG = 32700 + zone_number
```

In summary, an UTM point (i.e. UTM (WGS84) Zone 31U E: 450504.27 N: 5408937.43) is specified by:

- The UTM zone number (from 1 to 60) and letter, i.e. Zone 31U or the corresponding EPSG 32631
- For latitudes between 80°S and 84°N the letter can be omitted if the hemisphere is indicated. In the case of EPSG no letter is needed.
- Easting: the x coordinate
- Northing: the y coordinate

There are many coordinate system conventions and projections, the reason we talk about UTM is that satellite image providers frequently use it to georeference its products. The conversion between different projections is handled by libraries such as **GDAL**, so understanding one projection should suffice to rule them all. For instance, the following GDAL shell command

```
gdalwarp -t_srs "+proj=longlat +datum=WGS84" in.tif  out_longlat.tif
```

converts any georeferenced TIF to the CRS used by Google Maps and the U.S. Department of Defense for all their mapping and tends to be used for global reference systems.

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## 2 Query & download images

Given the coordinates of an area of interest (AOI), we will query and download our first Sentinel-2 or Landsat-8 images. This task is simplified by the **tsd module**, which allows to connect to on-line services for searching the Sentinel-2 and Landsat-8 image indices. One of these services is provided by developmentseed.org), which indexes all the Sentinel-2 and Landsat-8 images that are hosted by Amazon AWS Public Datasets and Google Cloud.

The query produces a catalog (a list) of images that contain the area of interest. The catalog contains the URL of each full image, thumbnail, and other information useful to filter the results before downloading the images.

Since the images are usually quite large (40k x 40k pixels, about 1Gb) instead of downloading the entire images we shall download just a crop containing the desired AOI. With the GDAL library it is possible to crop the AOI from an image on the web without downloading the full image. The **tsd module** wraps this functionality allowing to download just the AOI.

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# 3 Image metadata

We rarely just see the data acquired by the satellite. The images we download are the **product** of a complex processing pipeline. The same data might be offered as various products.

A typical serviced satellite image (bought or downloaded) includes several processing steps. From the raw image (Level 0), data are calibrated into units of physical reflectance (called Level 1 processing), and the image is geolocated and orthorectified following an elevation model of the terrain or Ground Control Points (GCP) of a certain accuracy, under a geodetic reference frame (E.g. UTM).

Satellite images can contain more than three channels as in multi-spectral imaging, or be complex-valued as in radar, and we must understand what these channels represent. For the moment we will focus on multi-spectral optical image products that are orthorectified. This means that the raw data has been:

- radiometric corrected and resampled to a single reference sensor
- geometrically corrected using a digital elevation model (DEM) to correct for relief displacement
- and spatially registered with respect to a global reference

Satellite images are also accompanied with valuable metadata, which can include the acquisition date&time, georeferencing information, cloud masks, resolution on the ground (or Ground Sample Distance, GSD). Other metadata is known from the satellite or the product type: number bands, pointing capability, and others.

Finally, we must deal with the file formats. We'll mostly rely on GeoTIFF and use the GDAL library to convert between formats. The relevance of the GeoTIFF format is that it encapsulates the georeferencing information.

Summarizing, raster satellite images are a cartesian product of:

- diverse types of pixel data
- georeferencing conventions and metadata
- and image formats

But don't worry, GDAL is the "go for" tool for remote sensing images and metadata. The `gdalinfo` shell command, for instance, will read all the metadata from a file and print a summary.

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# 4 Reprojection

To determine the longitude latitude (wrt the WGS84 reference ellipsoid) corresponding to positions in the GeoTIFF image (at pixel coordinates x, y) we also use GDAL. The command below determines CRS of the input GeoTIFF form the metadata and computes the longitude and latitude corresponding to the pixel (x y)

```
echo x y | gdaltransform -t\_srs "+proj=longlat'' input.tif
```

The long/lat CRS is used by Google Earth and the U.S. Department of Defense for all their mapping, which tends to be used for global reference systems. To reproject a GeoTIFF image into the long/lat CRS use

```
gdalwarp -t_srs "+proj=longlat +datum=WGS84" input.tif out.tif
```

In the `ipytools` module we provide wrapper functions `gdal_get_longlat_of_pixel` and `gdal_project_image_to_longlat` to perform these operatios.

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## 5 Multi-spectral images

The interest of multi-spectral images is to measure things that are otherwise non-visible. Combining information from multiple spectral bands allows to compute indices with different properties. For instance, using the NIR (near infrared) and Red channels, the normalized difference vegetation index (NDVI) can be computed. The NDVI index assess whether the target being observed contains live green vegetation or not

$$NDVI = \frac{NIR - RED}{NIR + RED}. \tag{1}$$

NDVI values range from +1.0 to -1.0. Areas of barren rock, sand, or snow usually show very low NDVI values (for example, 0.1 or less). Sparse vegetation such as shrubs and grasslands or senescing crops may result in moderate NDVI values (approximately 0.2 to 0.5). High NDVI values (approximately 0.6 to 0.9) correspond to dense vegetation such as that found in temperate and tropical forests or crops at their peak growth stage.

Other indices can be found here:

- http://www.sentinel-hub.com/apps/wms/wms-parameters/EOproducts
- https://www.indexdatabase.de/db/ias.php

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Table 1: Sentinel-2 has 13 spectral bands from Wikipedia Sentinel-2

| Sentinel-2 Bands | Central Wavelength | Resolution | Bandwidth |
|---|---|---|---|
| Band 1 – Coastal aerosol | 0.443 $\mu$m | 60 m | 20 nm |
| Band 2 – Blue | 0.490 $\mu$m | 10 m | 65 nm |
| Band 3 – Green | 0.560 $\mu$m | 10 m | 35 nm |
| Band 4 – Red | 0.665 $\mu$m | 10 m | 30 nm |
| Band 5 – Vegetation Red Edge | 0.705 $\mu$m | 20 m | 15 nm |
| Band 6 – Vegetation Red Edge | 0.740 $\mu$m | 20 m | 15 nm |
| Band 7 – Vegetation Red Edge | 0.783 $\mu$m | 20 m | 20 nm |
| Band 8 – NIR | 0.842 $\mu$m | 10 m | 115 nm |
| Band 8A – Narrow NIR | 0.865 $\mu$m | 20 m | 20 nm |
| Band 9 – Water vapour | 0.945 $\mu$m | 60 m | 20 nm |
| Band 10 – SWIR – Cirrus | 1.375 $\mu$m | 60 m | 20 nm |
| Band 11 – SWIR | 1.610 $\mu$m | 20 m | 90 nm |
| Band 12 – SWIR | 2.190 $\mu$m | 20 m | 180 nm |

Table 2: Landsat-8 has 11 spectral bands from Wikipedia Landsat_8

| Spectral Band | Wavelength | Resolution | Solar Irradiance |
|---|---|---|---|
| Band 1 - Coastal / Aerosol | 0.433 – 0.453 $\mu$m | 30 m | 2031 W/(m$^2\mu$m) |
| Band 2 - Blue | 0.450 – 0.515 $\mu$m | 30 m | 1925 W/(m$^2\mu$m) |
| Band 3 - Green | 0.525 – 0.600 $\mu$m | 30 m | 1826 W/(m$^2\mu$m) |
| Band 4 - Red | 0.630 – 0.680 $\mu$m | 30 m | 1574 W/(m$^2\mu$m) |
| Band 5 - Near Infrared | 0.845 – 0.885 $\mu$m | 30 m | 955 W/(m$^2\mu$m) |
| Band 6 - Short Wavelength Infrared | 1.560 – 1.660 $\mu$m | 30 m | 242 W/(m$^2\mu$m) |
| Band 7 - Short Wavelength Infrared | 2.100 – 2.300 $\mu$m | 30 m | 82.5 W/(m$^2\mu$m) |
| Band 8 - Panchromatic | 0.500 – 0.680 $\mu$m | 15 m | 1739 W/(m$^2\mu$m) |
| Band 9 - Cirrus | 1.360 – 1.390 $\mu$m | 30 m | 361 W/(m$^2\mu$m) |
| Band 10 - Long Wavelength Infrared | 10.30 – 11.30 $\mu$m | 100 m | 361 W/(m$^2\mu$m) |
| Band 11 - Long Wavelength Infrared | 11.50 – 12.50 $\mu$m | 100 m | 361 W/(m$^2\mu$m) |

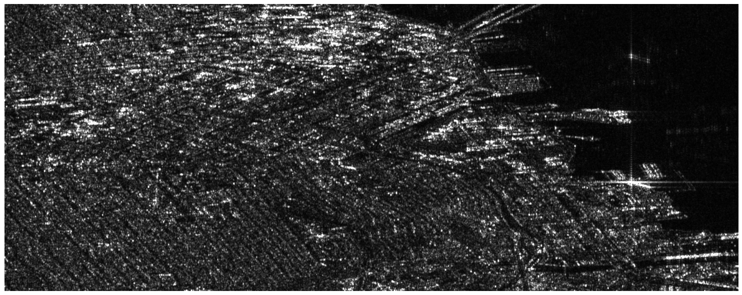

Figure 4: Crop of a Sentinel-1 SAR (synthetic aperture radar) image of San Francisco downtown. This image is a crop represents the amplitude of the SLC (single look complex) product. Note that SLC images appear stretched in the azimuth direction (flight direction).

## 6 Synthetic Aperture Radar (SAR) time series

Sentinel-1 is a two satellite Synthetic Aperture Radar (SAR) constellation. Images from the Sentinel-1 mission are also are freely available on-line, but they cannot be cropped online. For this reason we will work on a time series of pre-computed crops of SLC (single look complex) products shown in Figure 4. Note that SLC images appear stretched in the azimuth direction (flight direction). In addition, for this lesson, we will only observe the amplitude (scaled to the 0-255 range) of the complex-valued pixels, which is proportional to the strenght of the reflected signal.

The radar images are georeferenced (GeoTIFF) but the image axis are not aligned with a CRS, yet geographic coordinates corresponding to its pixels can be computed using GDAL.

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## 7 Cheat sheet

- `display`: IPython display objects
- `vistools.display_image`: display an image in a file, url, or np.array
- `vistools.display_imshow`: display an image (similar to matlab)
- `vistools.display_gallery`: display an image gallery (several images)
- `vistools.clickablemap`: interactive map
- `utils.readGTIFF` & `ipytools.writeGTIFF`: read and write TIF, PNG, JPG
- `utils.lonlat_to_utm` & `utils.utm_to_lonlat`: convert long/lat to UTM and back
- `tsd.get_sentinel2.search`: search online index of sentinel2 images
- `tsd.get_landsat.search`: search online index of landsat images

- `tsd.get_sentinel2.get_time_series`: search and download Sentinel-2 time series
- `tsd.get_landsat8.get_time_series`: same for Landsat-8
- `tsd.utils.get_crop_from_aoi`: download a crop form
- `tsd.utils.crop_with_gdal_translate`: gdal_translate wrapper for cropping an image
- `utils.gdal_get_longlat_of_pixel`: returns image coordinates reprojected in long/lat CRS
- `utils.gdal_resample_image_to_longlat`: reproject GeoTIFF image in the long/lat CRS

**GDAL (shell) cheat sheet**

- prints all the metadata of image.tiff

```
gdalinfo
```

- crop the image.tif image from the upper-left (ul) to lower-right (lr) UTM coordinates

```
gdal_translate image.tif out.tif -of GTiff \
    -projwin ulx uly lrx lry  +proj=utm +zone=31 [+south]
```

- reproject any image in the lon/lat image CRS used by Google Earth and the U.S. Department of Defense for all their mapping, which tends to be used for global reference systems.

```
gdalwarp -t_srs "+proj=longlat +datum=WGS84" in.tif out.tif
```

- compute the longitude latitude and altitude (wrt the WGS84 reference ellipsoid) for the points at pixel coordinates (x, y) of the image input.tif. The CRS of the input GeoTIFF is determined from the metadata in the file. The pixel coordinates must be provided interactively

```
echo x y | gdaltransform -t_srs "+proj=longlat" input.tif
```

# A Online resources and sources

- The ipython notebook is inspired on Katerine Scott's Python From Space Lectures
- Wikipedia articles about geodesy
- About UTM
- All the sentinel and Landsat images are stored in Amazon AWS Public Datasets
- A curated list of awesome tools related to data from the Copernicus Sentinel Satellites.
- `http://eduscol.education.fr/localisation/pedago/geologie/coordonnees.htm`
- `http://landscape.satsummit.io/capture/`
- Overview of Coordinate Reference Systems (CRS) in R
- `http://rspatial.org/spatial/rst/6-crs.html`
- EPSG codes `https://spatialreference.org/ref/epsg/`

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