PSCS/NTRES 6200
Spatial Modelling and Analysis

Coördinate Reference Systems

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Topic: Coördinate Reference Systems

Coördinate Reference Systems (CRS): a way to specify position on the Earth's surface. It must include:

- A **datum**: an origin;
- an **ellipsoid** : a mathematical description of the Earth's shape;

It may include:

- a **projections**: how points on the Earth's surface are mapped to a 2D piece of paper (or computer screen).

These are explained more fully next.

Datums and ellipsoids

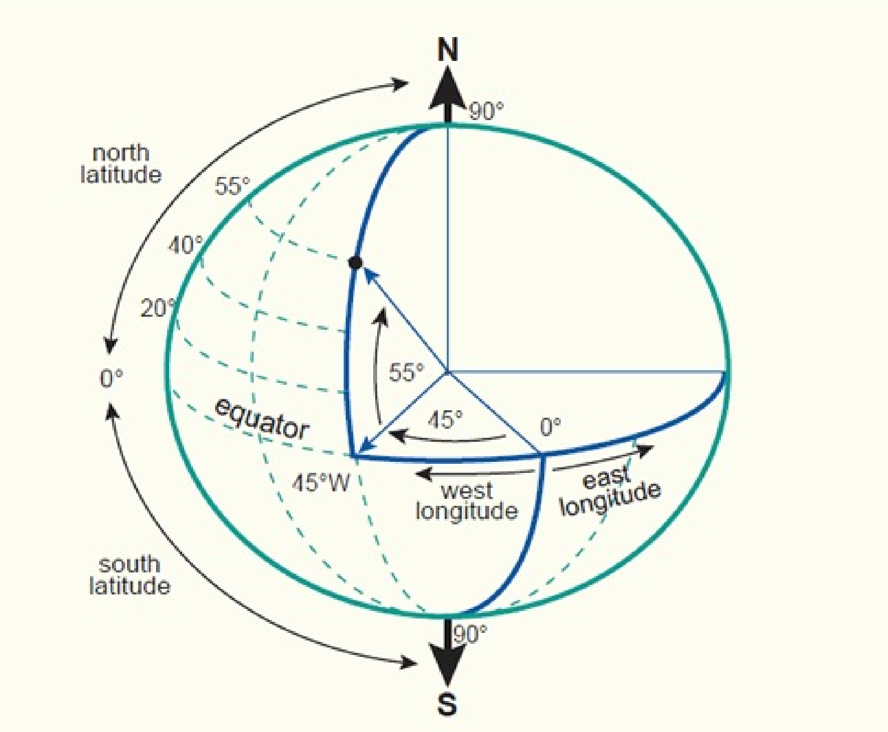
- A **datum** is a **reference point** from which measurements are made, either **vertical** (e.g., mean sea level at a known point) or **horizontal** (e.g., a position on the Earth's surface).

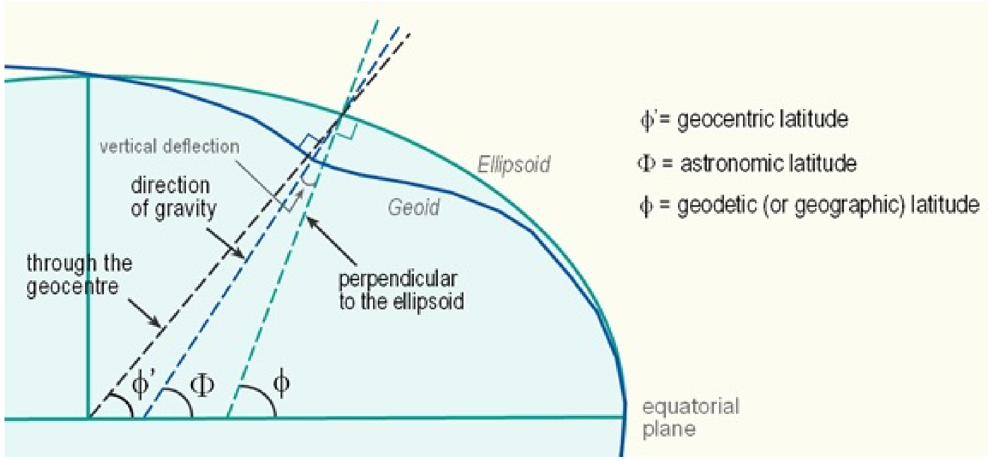
- It is usually associated with an **ellipsoid**, i.e., an assumed shape of the Earth – these two together are often called a **geodetic system**.

- Unprojected, a point is defined by the latitude (ϕ), longitude (λ), and height relative to ellipsoid (h).

- **All coverages with the same datum and ellipsoid are compatible** in their **unprojected** form.
  - If not, must do a **datum transformation**

Geographic coördinates

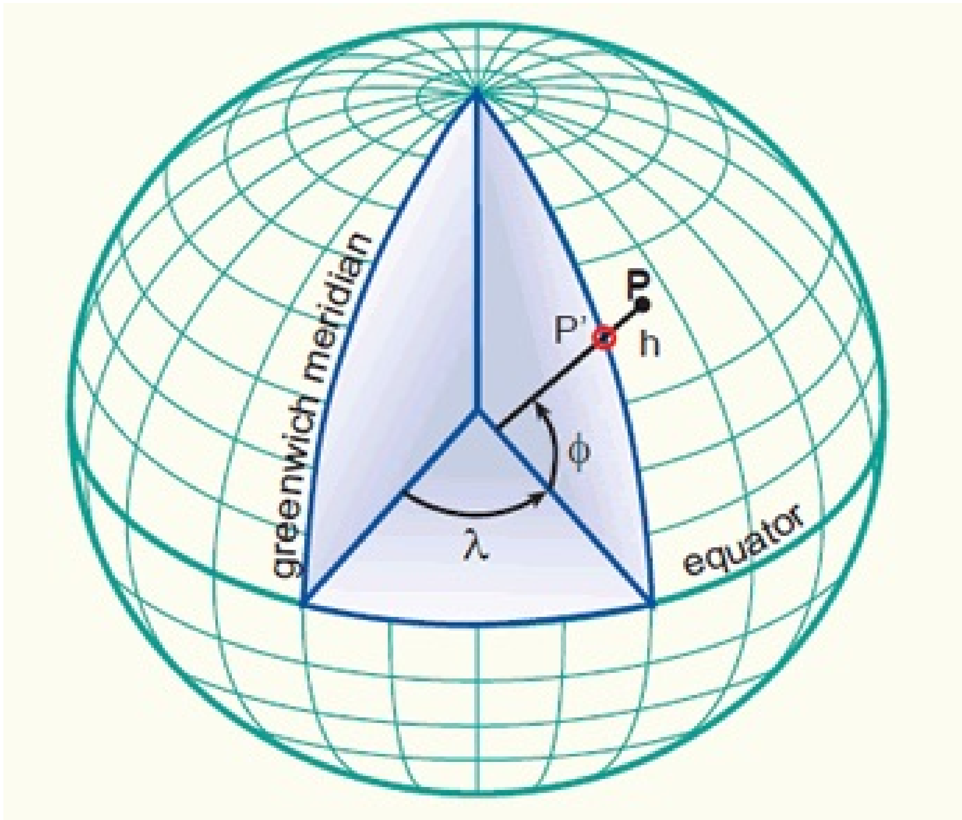




source: `http://kartoweb.itc.nl/geometrics`

Note that geodetic latitude ϕ (used in mapping) depends on the elipsoid shape.

Specifying position with geographic coördinates and height above elipsoid



source: `http://kartoweb.itc.nl/geometrics`

P' is Longitude λ and Latitude ϕ on the elipsoid
P includes height relative to elipsoid

Projection

- A **projection** converts points on the **geodetic system** (ellipsoid and datum) to a position on a 2D representation ("map"), with defined 2D **metric coördinates**, with a defined **unit of measure**, and defined **coördinate axes**.

- Then **distances**, **azimuths**, **angles** and **areas** can be computed in 2D – although all projections compromise between true distances, angles, and areas.

- If the geodetic system is the **same** for two projections, the two coverages can be made compatible with a **re-projection**
  - In practice this is often a back-projection to the geodetic system, then a forward projection to the second projection

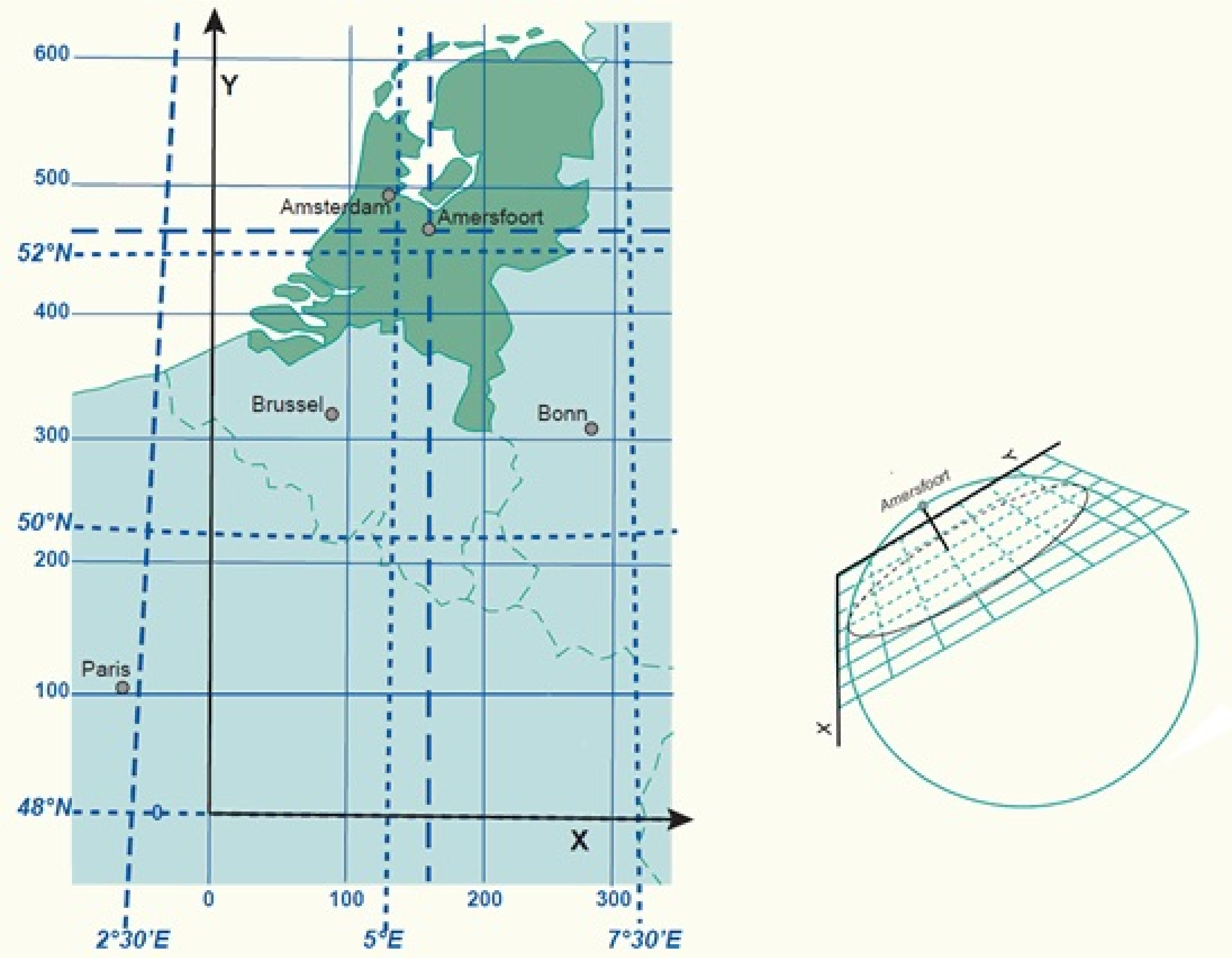
- If If the geodetic system is **different** for two projections, one must first be re-projected on a different geodetic system
  - In practice this is often a back-projection to the first geodetic system, then a datum transformation, then a forward projection to the second projection

Why so many projections?

- No distortion-free way to convert 3D on an ellipsoid to 2D on a map

- Projections can preserve some properties but not others – which is most important?
  - **areas** if measuring areas is the main purpose of the map
  - **distances** if measuring areas is the main purpose of the map (e.g., geostatistics)
  - **angles** if finding directions is the main purpose of the map

Example projection and metric grid



RDH (*Rijksdriehoek*) Dutch projection and grid

source: `http://kartoweb.itc.nl/geometrics`

Centre of projection: Onze Lieve Vrouwetoren, Amersfoort
False origin (150 000, 463 000) m.

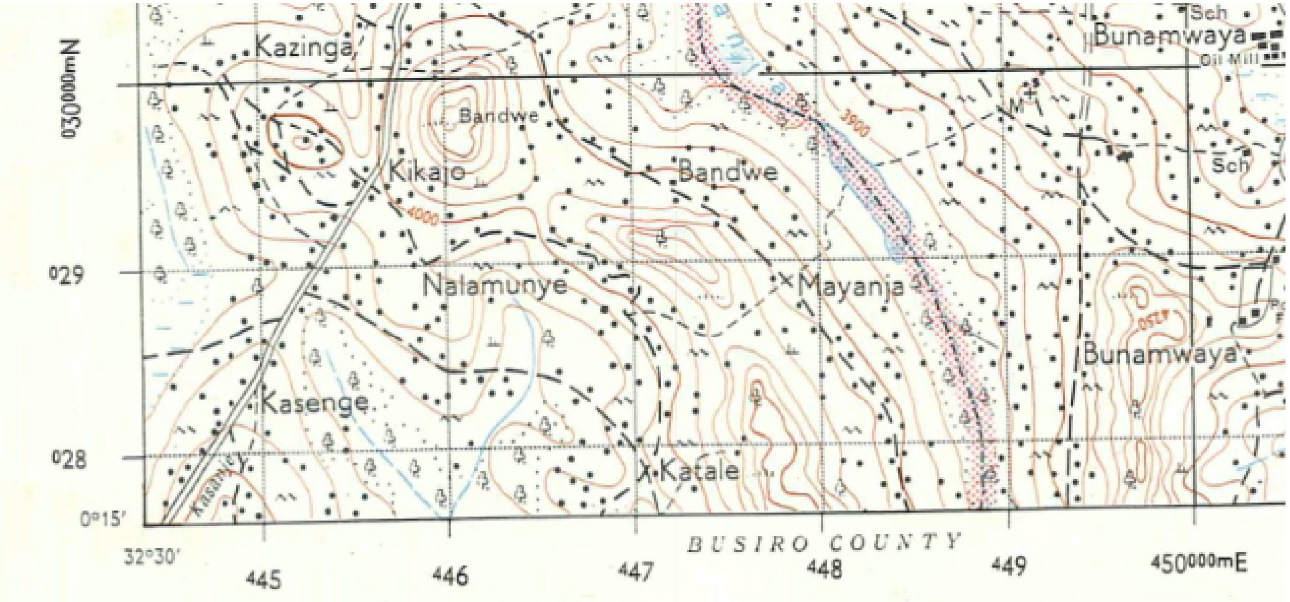
Coordinate Reference Systems (CRS)

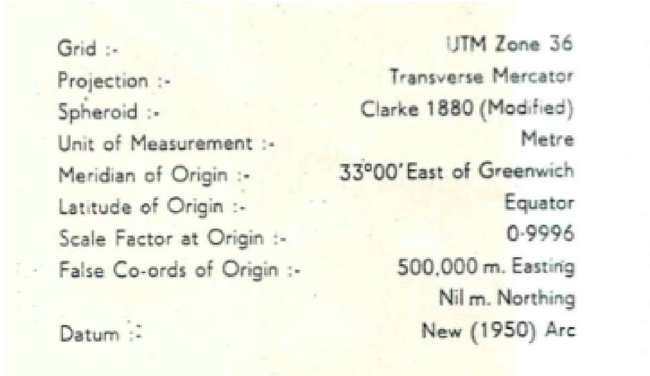
These combine (1) a **datum**, (2) an **ellipsoid**, (3) a **projection**, (4) an **origin**, (5) **distance units** to give coördinates for any point in a defined area of the Earth's surface.

- A coördinate system must be referenced to its own origin and a datum defined on an elipsoid.
- The origin can be assigned any coördinates; if not $(0, 0)$ it is called a **false origin**.
- Example: Universal Transmercator (UTM): points in a 6° zone N or S of the equator are mapped to (UTM E, UTM N) on the WGS84 datum;
- note there are two origins here:
  1. centre of the Earth (therefore 0° latitude) and 0° longitude (Greenwich, England)
  2. origin of UTM zone at equator and central meridian (E relative to Greenwich)

Example

Uganda map series Y732, sheet 71/1, 1:50 000; Lands & Surveys Department, Uganda 1958





Grid :-	UTM Zone 36
Projection :-	Transverse Mercator
Spheroid :-	Clarke 1880 (Modified)
Unit of Measurement :-	Metre
Meridian of Origin :-	33°00′ East of Greenwich
Latitude of Origin :-	Equator
Scale Factor at Origin :-	0·9996
False Co-ords of Origin :-	500,000 m. Easting Nil m. Northing
Datum :-	New (1950) Arc

Note exact geographic coördinates are used to define the map corners.

UTM 36N origin is (33° E , 0° N); note scale factor, false Easting.

Not on WGS84 ellipsoid! “New (1950) Arc” was superseded in 1960 with a “newer” Arc!

Why so many coördinate system?

- Different projections have different distortions (can preserve areas, distances, angles but not all), different applications require different properties

- Historical: diverse mapping projects

- Different ellipsoids fit best to the geoid in different regions

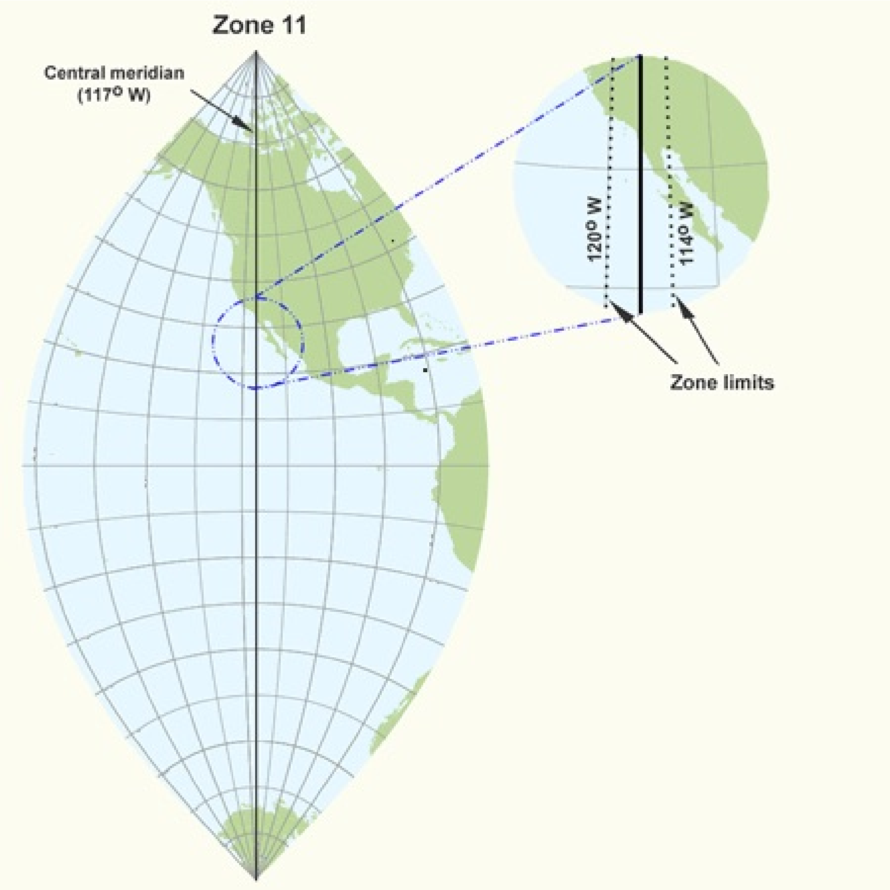
- Different units of distance measure are used in different applications

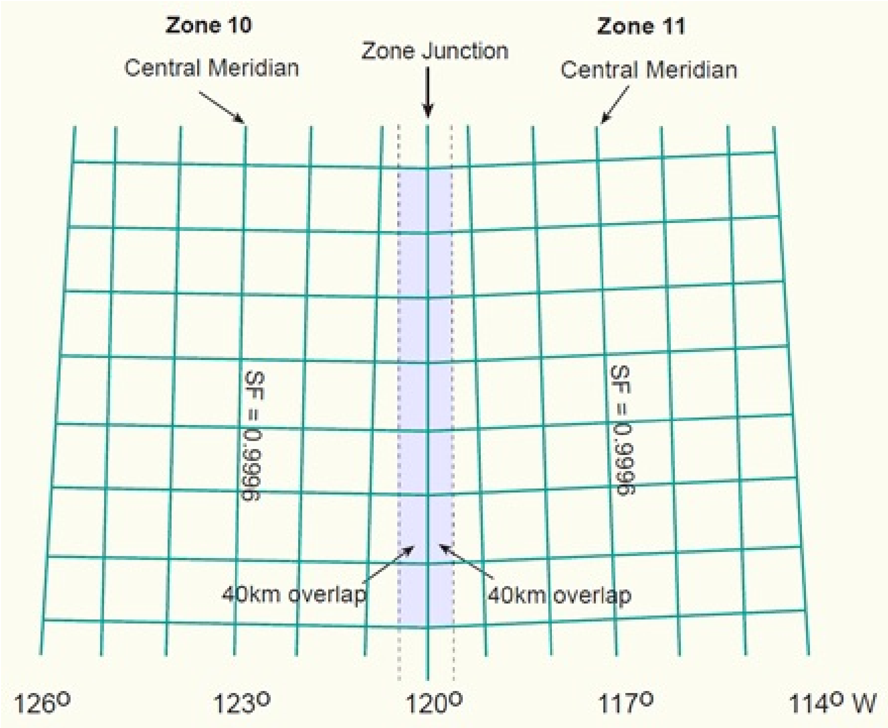
- For convenience of calculation
  - Once a datum, ellipsoid and projection are defined, the origin of a CRS can be anywhere
  - often prefer only positive coördinates, small numbers
  - to avoid confusion; e.g., in NL all coördinates $< 300\ 000$ are Eastings, $> 300\ 000$ Northings

Example CRS: UTM = Universal Transmercator

- developed for US military applications in small areas
- preserves angles (conformal) but distorts distance; this is limited by zone size
- world divided into 60 6° wide zones
- Central and Eastern NY State in zone 18N; -78° to -72°; central meridian -75°
- zone 1 from ±180° to -174°; central meridian -177°; ≈ 800 km wide at equator
- scale factor (ground distance / projected distance) at meridian 0.9995; maximum scale factor 1.0010 at edges
- 40 km buffer zone on each side
- false Easting 500000 m at central meridian
- equator is 0 m for UTM N, 10'000 000 m for UTM S (≈ distance from S pole)

UTM grids

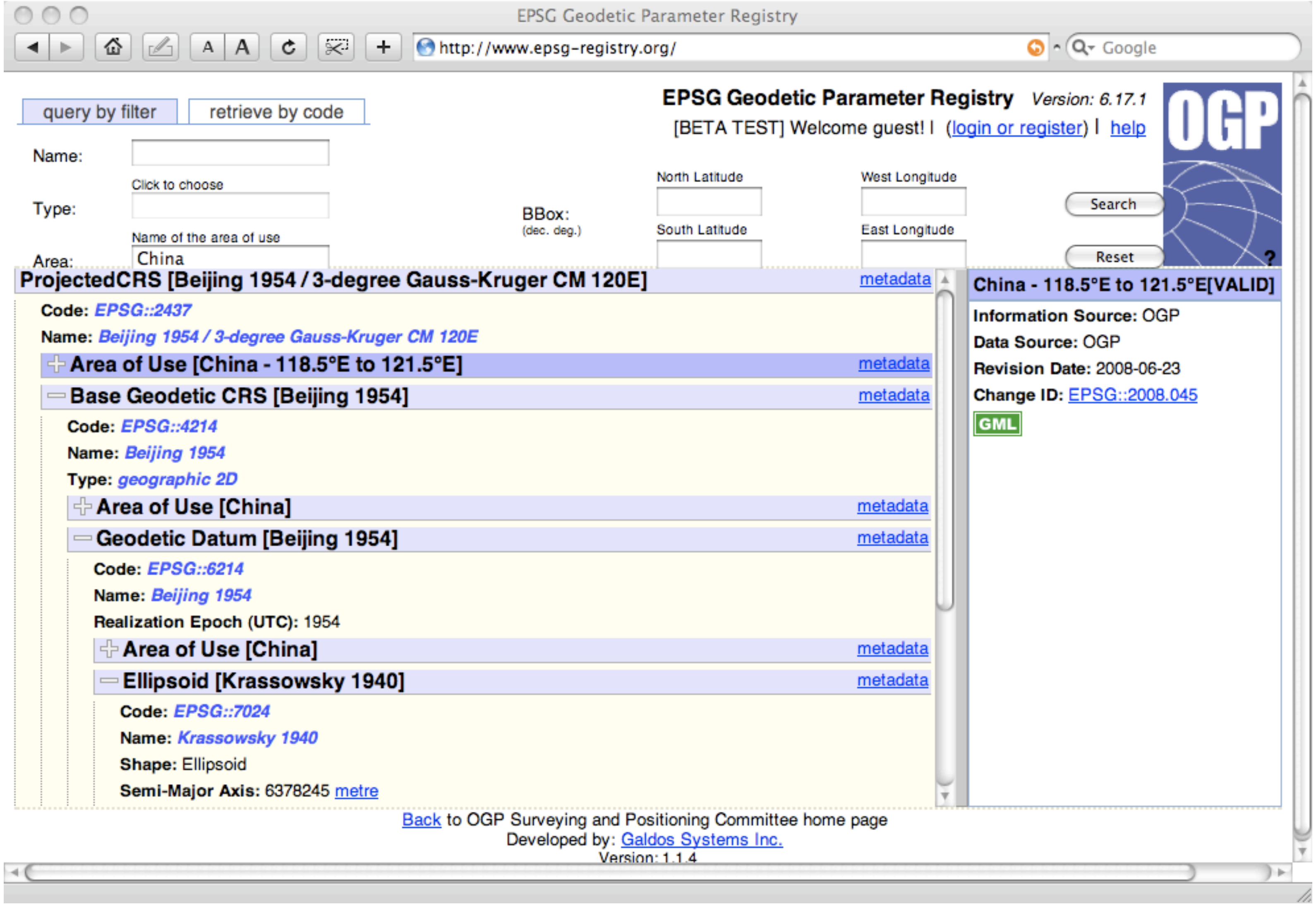




source: http://kartoweb.itc.nl/geometrics

CRS database

Most CRS are included in the European Petroleum Survey Group (**EPSG**) database[1]



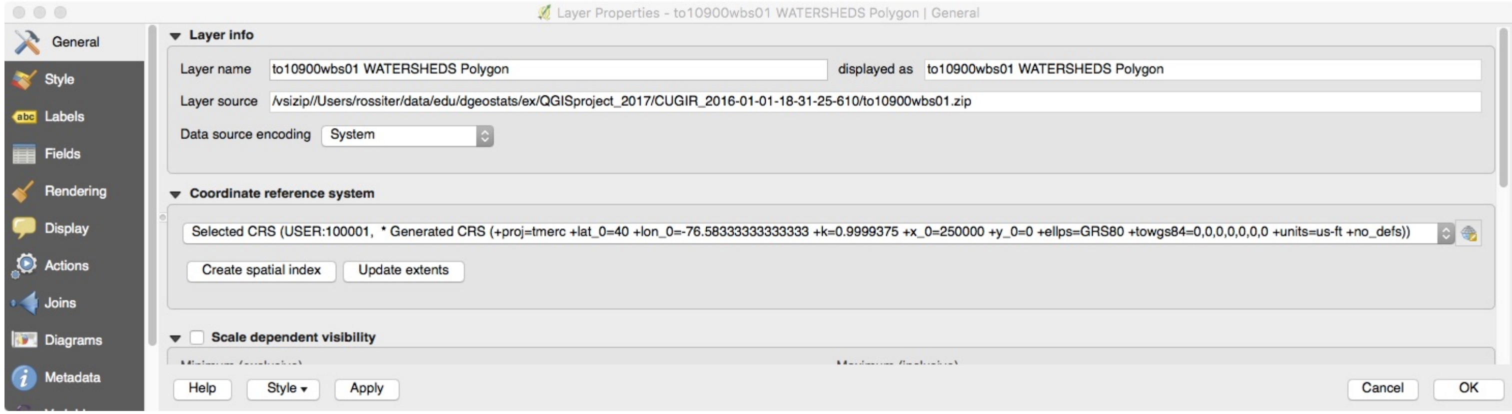
[1] http://www.epsg.org/

CRS within an ESRI Shapefile .prj file

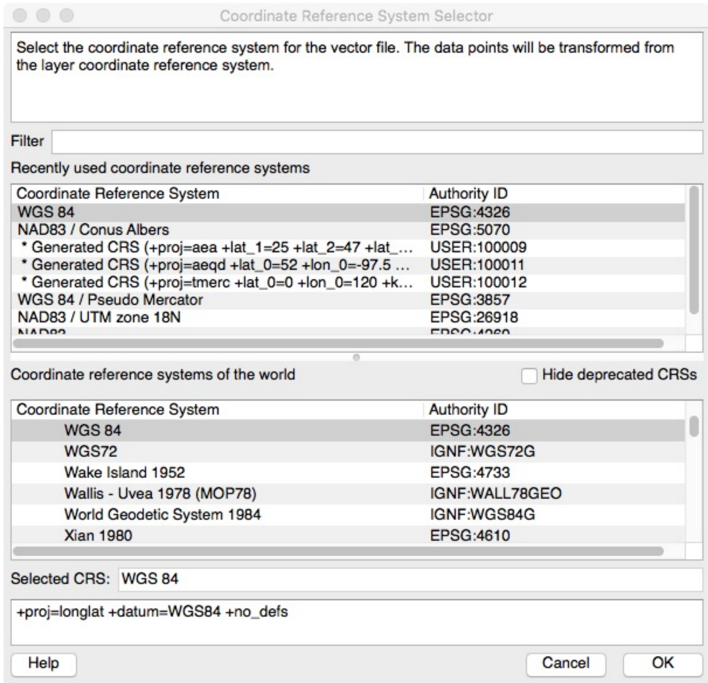
```
PROJCS["NAD_1983_StatePlane_New_York_Central_FIPS_3102_Feet",
GEOGCS["GCS_North_American_1983",DATUM["D_North_American_1983",
SPHEROID["GRS_1980",6378137.0,298.257222101]],
PRIMEM["Greenwich",0.0],UNIT["Degree",0.0174532925199433]],
PROJECTION["Transverse_Mercator"],
PARAMETER["False_Easting",820208.3333333333],
PARAMETER["False_Northing",0.0],
PARAMETER["Central_Meridian",-76.58333333333333],
PARAMETER["Scale_Factor",0.9999375],
PARAMETER["Latitude_Of_Origin",40.0],
UNIT["Foot_US",0.3048006096012192]]
```

CRS specified within QGIS

Properties:



Transforming a CRS "Save As . . . "

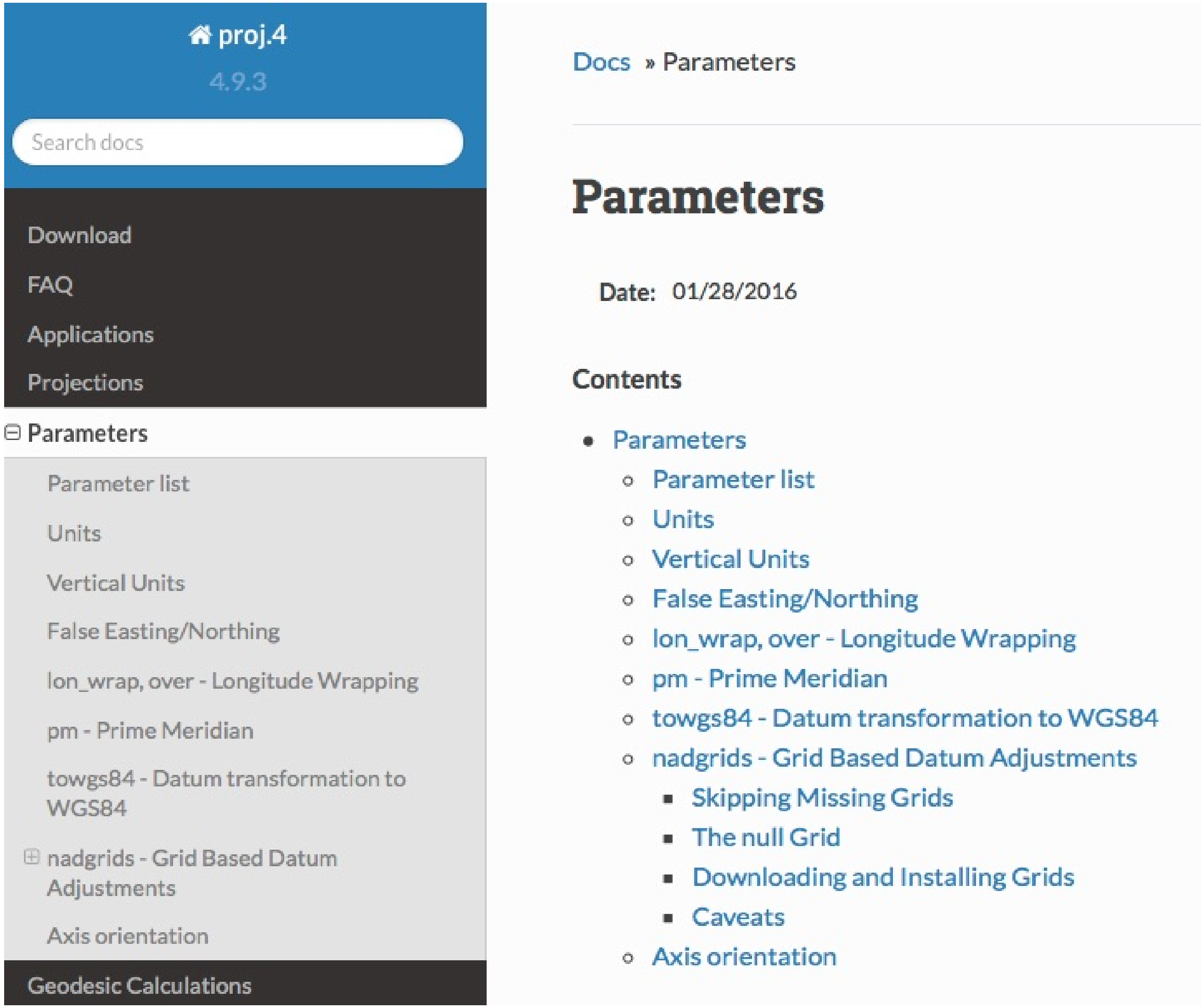


GDAL

- Geospatial Data Abstraction Library)[2]: a set of functions to set and transform CRS
  - Includes the `proj.4` C library: converts geographic coördinates into metric coördinates & vice versa
  - Implemented in QGIS “behind the scenes” for all CRS operations
  - Implemented in R via the `rgdal` package
    * Setting a CRS from an EPSG entry:
      ```
      > proj4string(state.ne) <- CRS("+init=epsg:4269")
      ```
    * Setting a CRS directly:
      ```
      > proj4string(state.ne) <- CRS("+proj=aea +lat_0=38
      +lat_1=40 +lat_2=44 +lon_0=-76 +ellps=WGS84 +units="m")
      ```
    * CRS without projection:
      ```
      > proj4string(dem.1km)
      [1] "+proj=longlat +ellps=WGS84 +towgs84=0,0,0,0,0,0,0
      +no_defs"
      ```

[2] `http://www.gdal.org/`

PROJ.4 parameters



source: `http://proj4.org/parameters.html`

Finding an EPSG code in R

```
> library(rgdal); epsg <- make_EPSG(); str(epsg) # get the EPSG database
'data.frame': 5513 obs. of  3 variables:
 $ code:Class 'AsIs'  int [1:5513] 3819 3821 3824 3889 3906 4001 4002 4003 4004 4005 ...
 $ note:Class 'AsIs'  chr [1:5513] "# HD1909" "# TWD67" "# TWD97" "# IGRS" ...
 $ prj4:Class 'AsIs'  chr [1:5513] "+proj=longlat +ellps=bessel ...
> # part of the name of the desired system in the grep() function
> # find the code for WGS84 at end of the string
> (epsg.wgs84 <- epsg[grep("WGS 84$", epsg$note), ])
     code     note                                          prj4
249  4326 # WGS 84          +proj=longlat +datum=WGS84 +no_defs
5311 4978 # WGS 84 +proj=geocent +datum=WGS84 +units=m +no_defs
> # we want the first one, this is our source in this case
> proj4string(ds)
[1] NA
> proj4string(ds) <- CRS(paste0("+init=epsg:",epsg.wgs84$code[1]))
> proj4string(ds)
[1] "+init=epsg:4326 +proj=longlat +datum=WGS84 +no_defs +ellps=WGS84 +towgs84=0,0,0"
> # find the code for UTM 15S on WGS 84, we want to transform to this one
(epsg.utm15s <- epsg[grep("WGS 84 / UTM zone 15S", epsg$note), 1:2])
      code                    note
5164 32715 # WGS 84 / UTM zone 15S
> ds.utm <- spTransform(ds,CRS(paste0("+init=epsg:",epsg.utm15s$code)))
> proj4string(ds.utm)
[1] "+init=epsg:32715 +proj=utm +zone=15 +south +datum=WGS84 +units=m +no_defs +ellps=WGS84 +towgs84
```

References: Datums, ellipsoids, projections – Web sites

- GDAL (Geospatial Data Abstraction Library)[3]
- EPSG registery of CRS, with codes and details[4]
- PROJ.4 parameter names and meanings[5]
- List of projections, with required parameters and their meaning[6]
- "Grids & Datums" articles in *Photogrammetric Engineering & Remote Sensing* about many countries[7]

[3] http://www.gdal.org/
[4] http://www.epsg-registry.org
[5] https://proj4.org/usage/index.html
[6] http://geotiff.maptools.org/proj_list/
[7] https://www.asprs.org/asprs-publications/grids-and-datums

References: Datums, ellipsoids, projections – Manuals and texts

- Bugayevskiy, L. M., & Snyder, J. P. (1995). Map projections: a reference manual. Taylor & Francis. ISBN: 0-7484-0303-5

- Snyder, J. P. (1987). Map projections: a working manual. USGS Professional Paper 1395 `https://pubs.er.usgs.gov/publication/pp1395`

- Snyder, J. P., & Voxland, P. M. (1989). An album of map projections. USGS Professional Paper 1453 `https://pubs.er.usgs.gov/publication/pp1453`

- Iliffe, J., & R. Lott (2008) Datums and map projections for remote sensing, GIS, and surveying. Whittles Pub.; CRC Press

- “Geometric aspects of mapping” from ITC `http://kartoweb.itc.nl/geometrics`