

# **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:

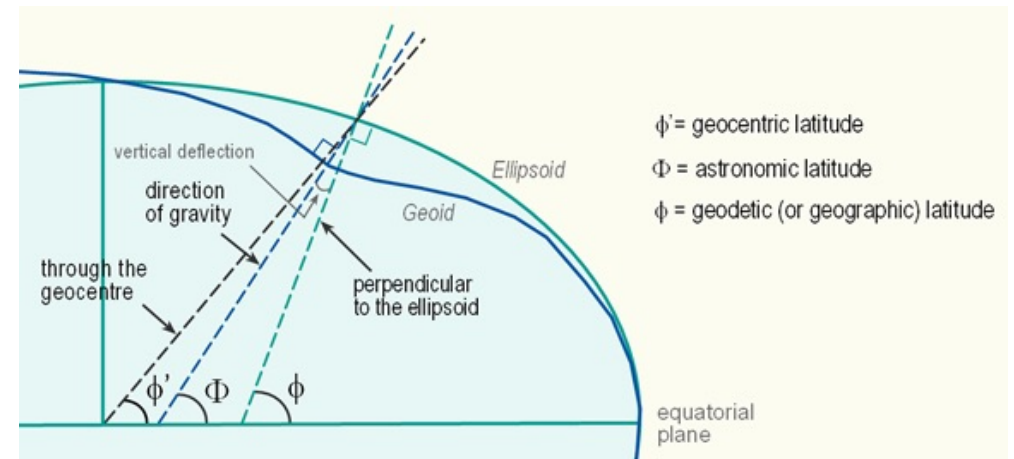
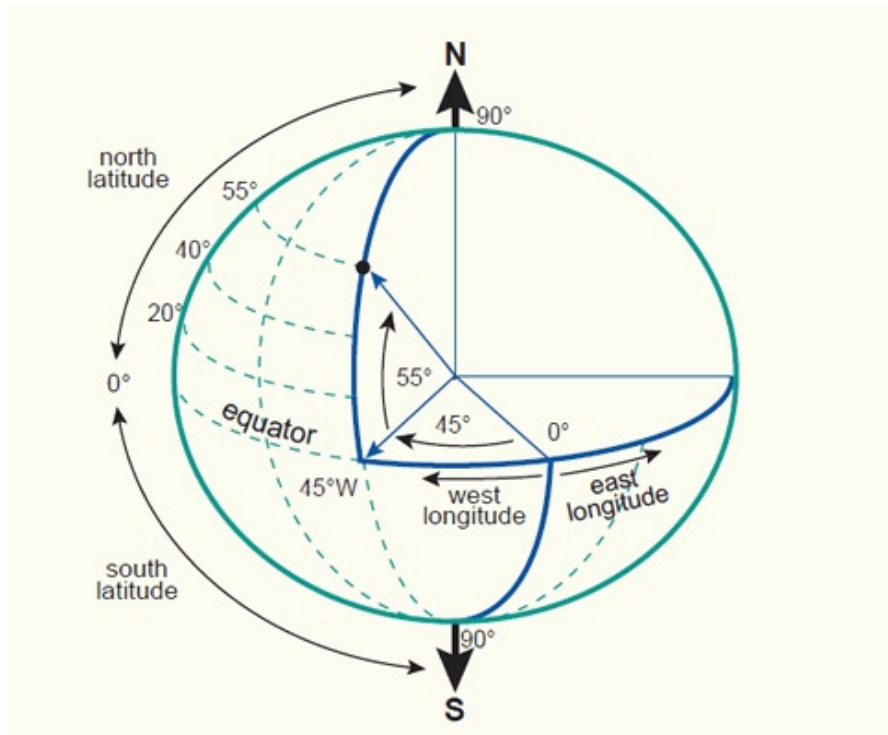
- a **projections**: how points on the Earth's surface are mapped to a 2D piece of paper (or computer screen).

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 ( $\phi$ ), longitude ( $\lambda$ ), 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**

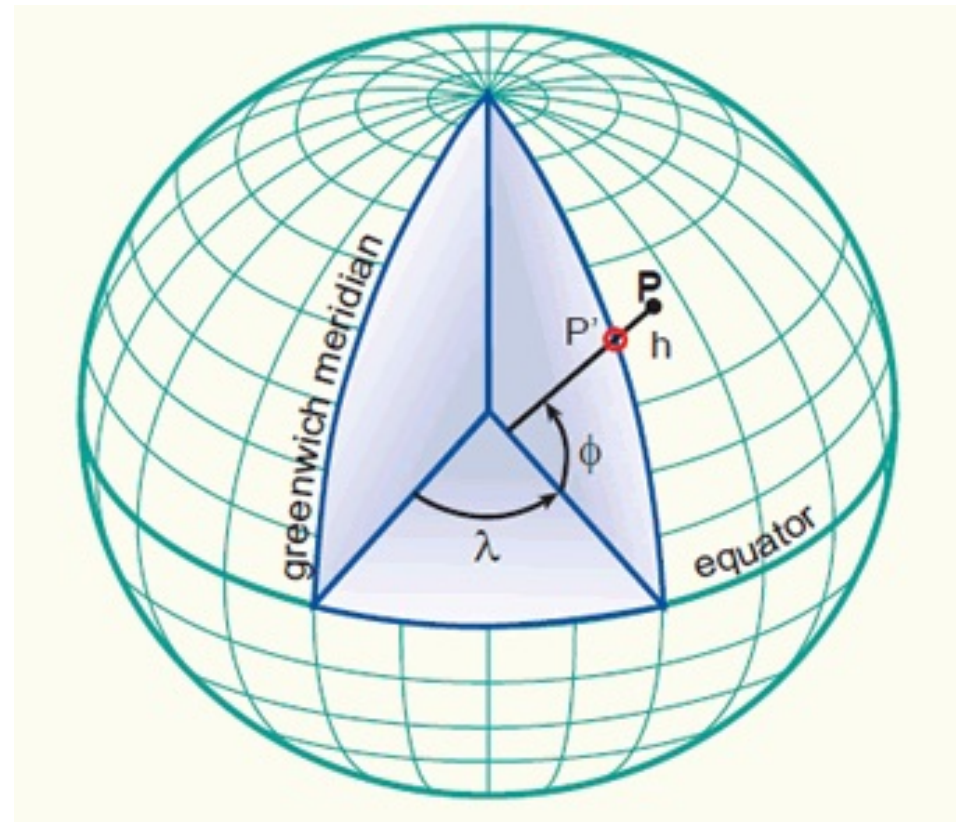
# Geographic coördinates



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

Note that geodetic latitude  $\phi$  (used in mapping) depends on the ellipsoid shape.

# Specifying position with geographic coördinates and height above elipsoid



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

$P'$  is Longitude  $\lambda$  and Latitude  $\phi$  on the elipsoid  
 $P$  includes height relative to elipsoid

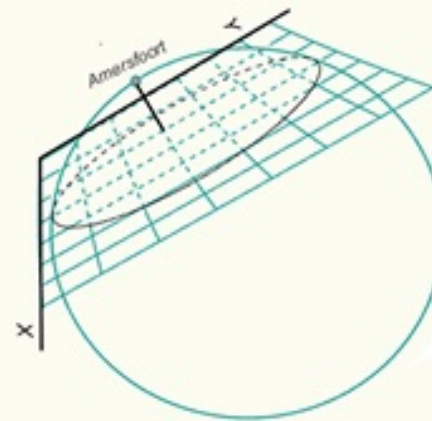
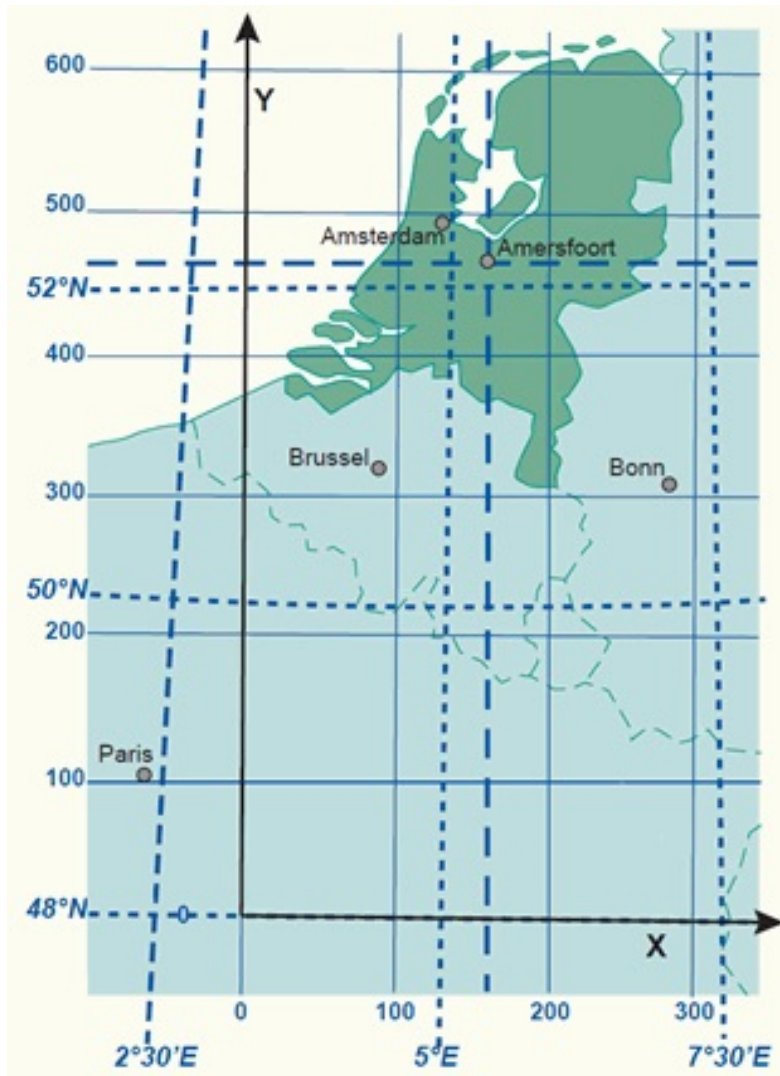
## Projection

- 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](http://kartoweb.itc.nl/geometrics)

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



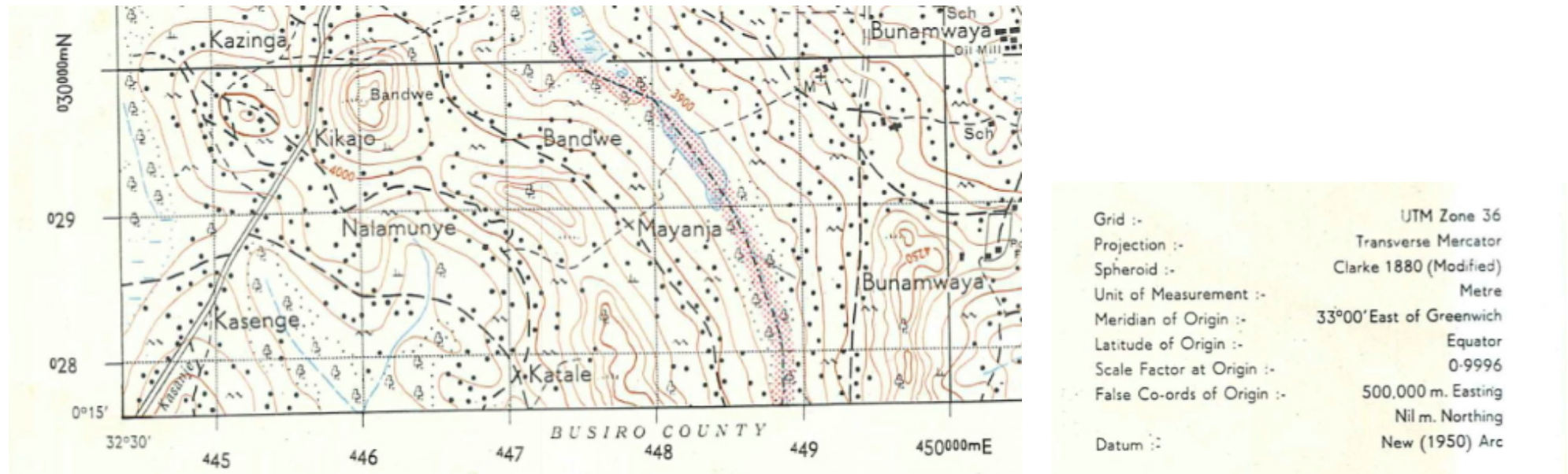
## Coordinate Reference Systems (CRS)

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



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!

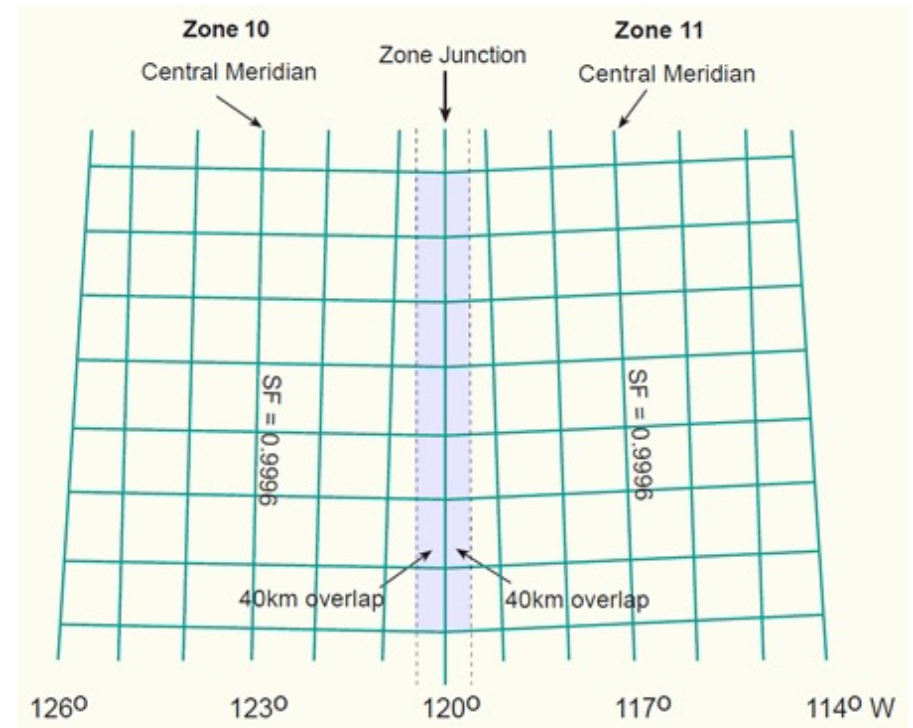
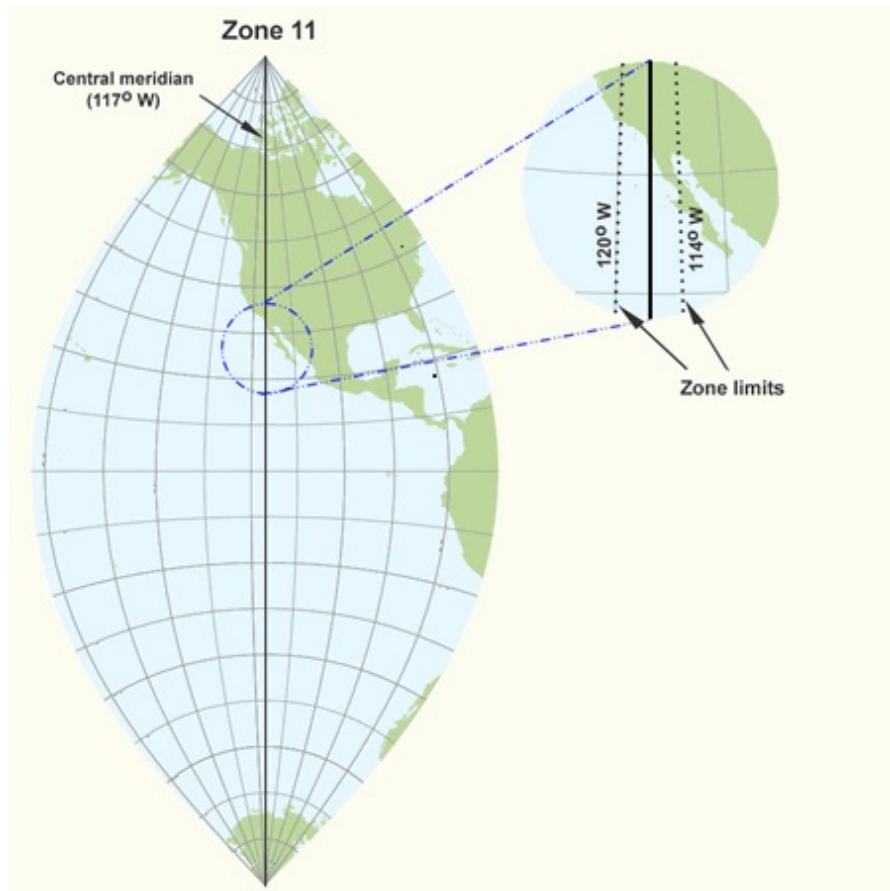
## Why so many coördinate system?

- 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  $\pm 180^\circ$  to -174°; central meridian -177°;  $\approx 800$  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 ( $\approx$  distance from S pole)

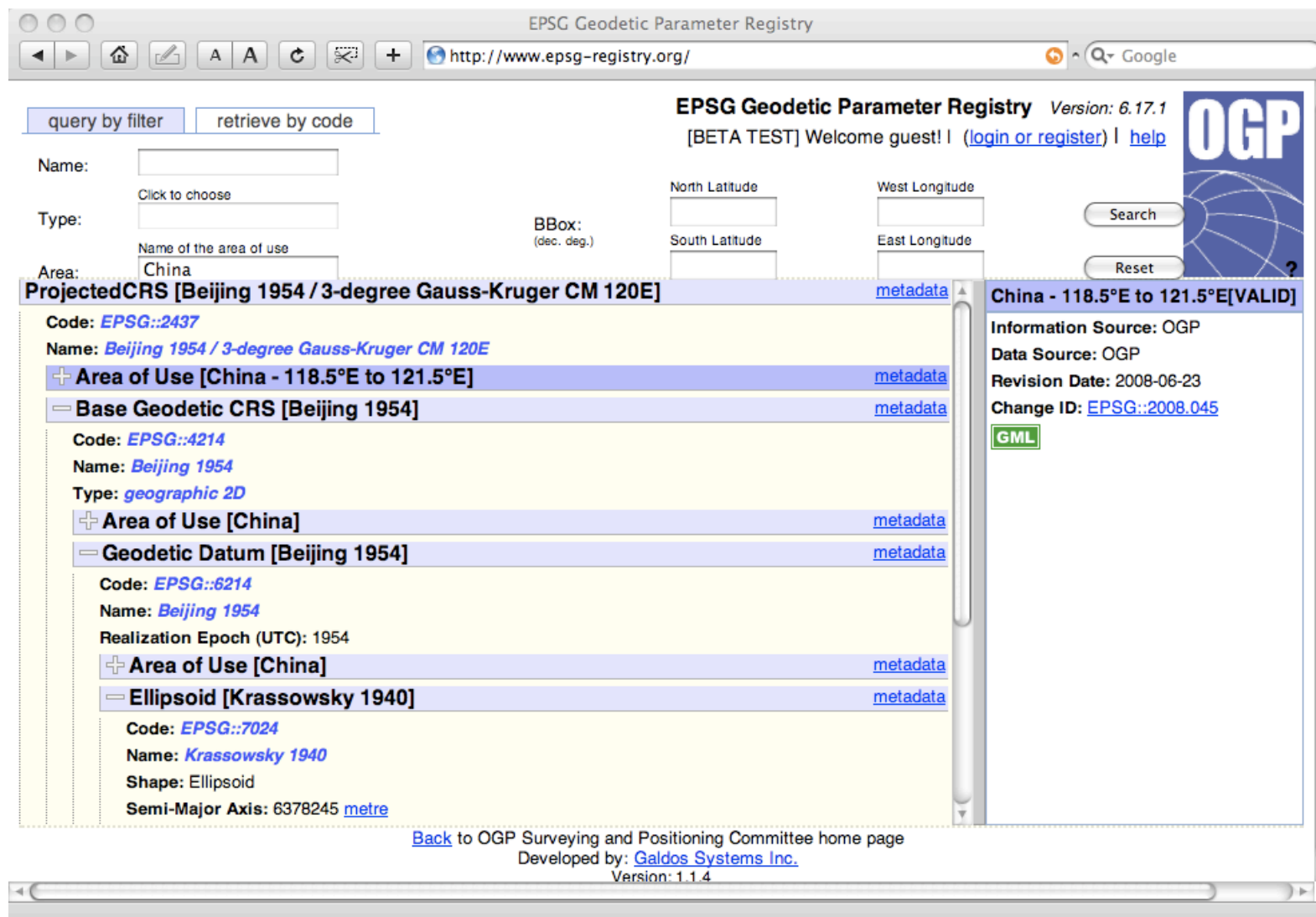
# UTM grids



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

## CRS database

Most CRS are included in the European Petroleum Survey Group (**EPSG**) database<sup>1</sup>



The screenshot shows the EPSG Geodetic Parameter Registry website. The browser address bar displays <http://www.epsg-registry.org/>. The page title is "EPSG Geodetic Parameter Registry Version: 6.17.1". A navigation bar includes "query by filter" and "retrieve by code" buttons. A search form is present with fields for Name, Type, BBox, North Latitude, West Longitude, South Latitude, and East Longitude, along with "Search" and "Reset" buttons. The main content area displays the details for the CRS "ProjectedCRS [Beijing 1954 / 3-degree Gauss-Kruger CM 120E]" (Code: EPSG::2437). The details are organized into a tree structure with expandable sections: "Area of Use [China - 118.5°E to 121.5°E]", "Base Geodetic CRS [Beijing 1954]", "Area of Use [China]", "Geodetic Datum [Beijing 1954]", "Area of Use [China]", and "Ellipsoid [Krassowsky 1940]". Each section provides specific information such as Code, Name, Type, and Shape. A right-hand sidebar shows "China - 118.5°E to 121.5°E[VALID]" with information source, data source, revision date, and change ID. The footer includes a "Back" link to the OGP Surveying and Positioning Committee home page, the developer "Galdos Systems Inc.", and the version "1.1.4".

EPSG Geodetic Parameter Registry Version: 6.17.1  
[BETA TEST] Welcome guest! | ([login or register](#)) | [help](#)

query by filter retrieve by code

Name:

Type:

BBox: (dec. deg.)

North Latitude

West Longitude

South Latitude

East Longitude

Search

Reset

ProjectedCRS [Beijing 1954 / 3-degree Gauss-Kruger CM 120E] [metadata](#)

Code: [EPSG::2437](#)

Name: [Beijing 1954 / 3-degree Gauss-Kruger CM 120E](#)

+ Area of Use [China - 118.5°E to 121.5°E] [metadata](#)

- Base Geodetic CRS [Beijing 1954] [metadata](#)

Code: [EPSG::4214](#)

Name: [Beijing 1954](#)

Type: [geographic 2D](#)

+ Area of Use [China] [metadata](#)

- Geodetic Datum [Beijing 1954] [metadata](#)

Code: [EPSG::6214](#)

Name: [Beijing 1954](#)

Realization Epoch (UTC): 1954

+ Area of Use [China] [metadata](#)

- Ellipsoid [Krassowsky 1940] [metadata](#)

Code: [EPSG::7024](#)

Name: [Krassowsky 1940](#)

Shape: Ellipsoid

Semi-Major Axis: 6378245 [metre](#)

China - 118.5°E to 121.5°E[VALID]

Information Source: OGP

Data Source: OGP

Revision Date: 2008-06-23

Change ID: [EPSG::2008.045](#)

[GML](#)

[Back](#) to OGP Surveying and Positioning Committee home page  
Developed by: [Galdos Systems Inc.](#)  
Version: 1.1.4

<sup>1</sup><http://www.epsg.org/>

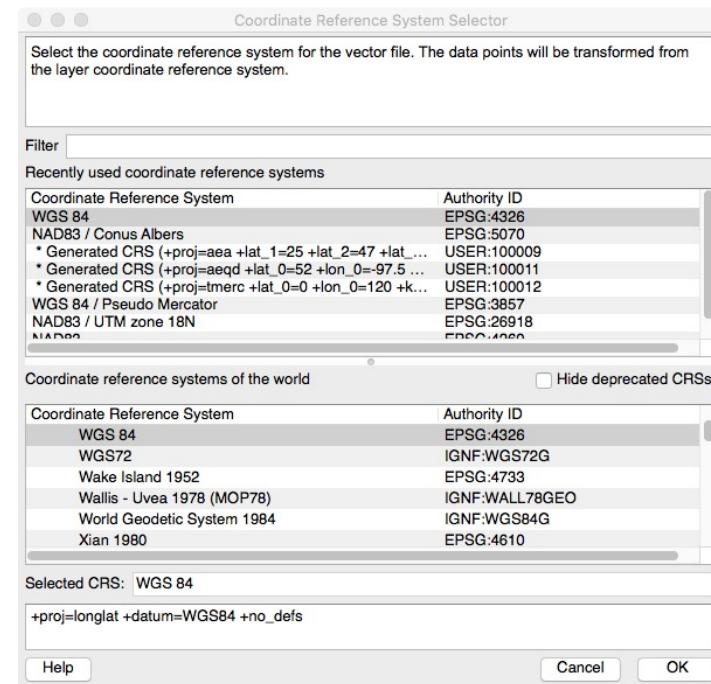
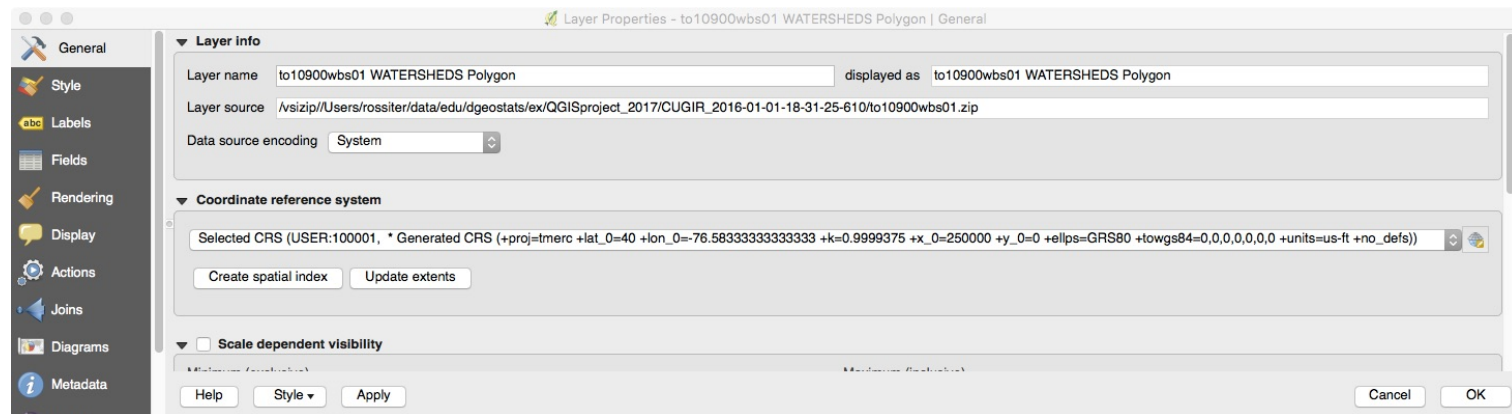
## CRS within an ESRI Shapefile .prj file

```
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)<sup>2</sup>: 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"
```

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<sup>2</sup><http://www.gdal.org/>

# PROJ.4 parameters

The screenshot shows the PROJ.4 4.9.3 documentation page for Parameters. The left sidebar contains a navigation menu with links to Download, FAQ, Applications, Projections, Parameters, and Geodesic Calculations. The main content area is titled 'Parameters' and includes a date of 01/28/2016. A 'Contents' section lists the following topics: Parameter list, Units, Vertical Units, False Easting/Northing, lon\_wrap, over - Longitude Wrapping, pm - Prime Meridian, towgs84 - Datum transformation to WGS84, nadgrids - Grid Based Datum Adjustments (with sub-items: Skipping Missing Grids, The null Grid, Downloading and Installing Grids, and Caveats), and Axis orientation.

proj.4  
4.9.3

Search docs

Download  
FAQ  
Applications  
Projections

Parameters

- Parameter list
- Units
- Vertical Units
- False Easting/Northing
- lon\_wrap, over - Longitude Wrapping
- pm - Prime Meridian
- towgs84 - Datum transformation to WGS84
- nadgrids - Grid Based Datum Adjustments
  - Skipping Missing Grids
  - The null Grid
  - Downloading and Installing Grids
  - Caveats
- Axis orientation

Geodesic Calculations

Docs » Parameters

## Parameters

Date: 01/28/2016

### Contents

- Parameters
  - Parameter list
  - Units
  - Vertical Units
  - False Easting/Northing
  - lon\_wrap, over - Longitude Wrapping
  - pm - Prime Meridian
  - towgs84 - Datum transformation to WGS84
  - nadgrids - Grid Based Datum Adjustments
    - Skipping Missing Grids
    - The null Grid
    - Downloading and Installing Grids
    - Caveats
  - Axis orientation

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[grepl("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$code[1]))
> proj4string(ds)
[1] "+init=epsg:4326 +proj=longlat +datum=WGS84 +no_defs +ellps=WGS84 +towgs84=0,0,0"
> # find the code for UTM 15S on WGS 84, we want to transform to this one
(epsg.utm15s <- epsg[grepl("WGS 84 / UTM zone 15S", epsg$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=0,0,0"
```

## References: Datums, ellipsoids, projections – Web sites

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

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<sup>3</sup><http://www.gdal.org/>

<sup>4</sup><http://www.epsg-registry.org>

<sup>5</sup><https://proj4.org/usage/index.html>

<sup>6</sup>[http://geotiff.maptools.org/proj\\_list/](http://geotiff.maptools.org/proj_list/)

<sup>7</sup><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>