- Corunsol Education Services -

UNDERSTANDING AND CUSTOMIZING COORDINATE SYSTEM WITH PETREL 2018~2022

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TABLE OF CONTENTS

LIST OF FIGURES

Disclaimer

1. Introduction

Usually, users have a lot of problems georeferencing the data that comes from outside of Kingdom/GeoFrame/Petrel ranges. The main issue is related to the fact that the platforms work with different systems to reference the data. GeoFrame, as Kingdom, uses Coordinate Systems and Petrel uses Conflation Policies (equivalent to Coordinate System). Petrel supports managing data in a spatial context, which means that you can perform transformations into another CRS inside of Petrel.

If you are working with a custom coordinate reference system, your spatial infrastructure should include a custom coordinate catalog of Petrel. You can use Petrel Coordinate System Manager to customize a coordinate catalog or import a custom catalog from a shared location.

Petrel has a Coordinate reference system selection dialog box to select a coordinate reference system (whatever it's built-in or customized) for a Petrel project.

2. Petrel Coordinate System Manager

Sometimes we need to create a new or custom coordinate system due to the type of project, the location, the type of data, etc., that's where Petrel Coordinate System Manager comes into play, enabling the users to create conflation policies that will be added to the Geodetic Catalog and shared with Petrel application (Figure 1), to locate the data inside of Petrel.

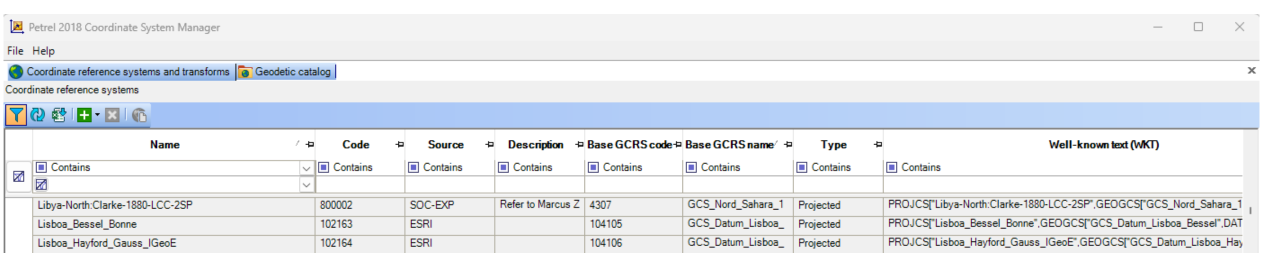

Figure 1 - Geodetic Catalog in Petrel and Coordinate System Manager tool

3. Conflation Policies

A conflation policy, equivalently named as "coordinate system" in most of the industry applications, is a combination of a definition of Coordinate Reference System and a Transformation. The transformation defined the conversion from the coordinate system's datum to the WGS84 datum. The conflation policies are stored in the Geodetic catalog in the Coordinate System Manager tool (Figure 2).

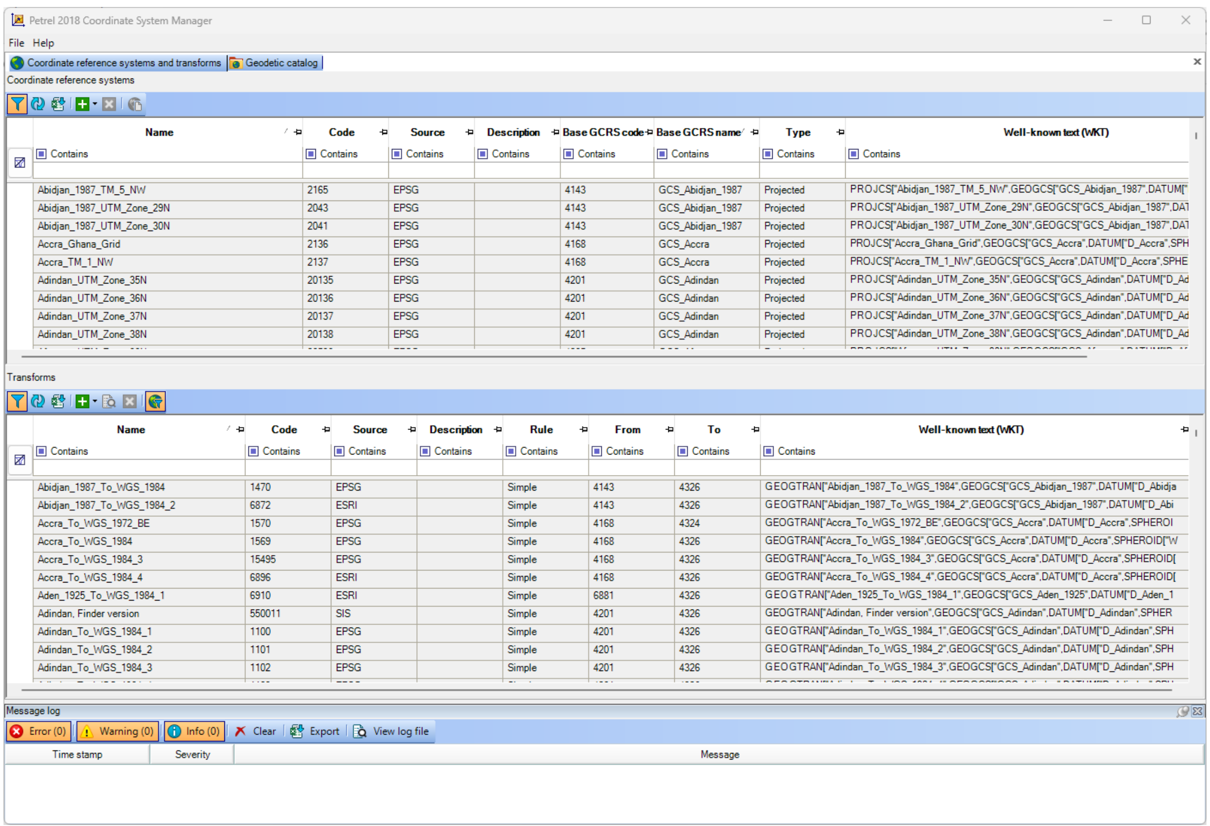

Figure 2 - Coordinate System Manager tool showing the CRS and the Transforms

To create a new conflation policy, you should

(1) define a local Projected/Geographic Coordinate Reference System (CRS) and

(2) create a transformation related to this local Geographic CRS, to "convert" your local GCRS datum into WGS84 datum).

4. Coordinate Configurations in Petrel

4.1 Coordinate Catalog Configuration File

The Coordinate System Manager uses two catalog files, the **enterprise** and the **extension coordinate catalog** file.

Petrel utilizes the CoordinateCatalogConfiguration.xml file (Figure 3) to configure the default location of the Enterprise Coordinate Catalog file and the Extension Coordinate Catalog file. This specific configuration file can be found in the xml folder of the Petrel installation directory, typically:

C:\Program Files\Schlumberger\Petrel 2018\xml\CoordinateCatalogConfiguration.xml

Obviously, this control file defines the location of the Enterprise Catalog file (line #12) and Extension Catalog file (line #15), which will be discussed later at Section 5 and 6.

```
1  <?xml version="1.0" encoding="utf-8"?>
2  <!-- Standard factory configuration for the Coordinate Reference System and     -->
3  <!-- Coordinate Transform catalog file locations. The Coordinate System Manager -->
4  <!-- and Petrel read the content; the Coordinate System Manager also manipulates-->
5  <!-- their content.                                                            -->
6  <!-- The factory catalog must stay as it provides the system with defaults and  -->
7  <!-- mappings for backwards compatibility.                                      -->
8  <!-- Last updated May 22 2014; compatibility: Petrel 2016 and younger; ESRI version PE_10_3_1.-->
9  <CatalogConfiguration>
10   <!--Catalog paths for the current version; the contents is the bases for the CRS selector contents. -->
11   <Catalog name="EnterpriseCatalog">
12     <value>%APPDATA%\Schlumberger\Petrel\CRSCatalogConfiguration\2016.1\CoordinateCatalogEnterprise.ctl</value>
13   </Catalog>
14   <Catalog name="UserdefinedExtensionCatalog">
15     <value>%APPDATA%\Schlumberger\Petrel\CRSCatalogConfiguration\2016.1\CoordinateCatalogExtensions.ctl</value>
16   </Catalog>
17   <!--Look-up path to previous catalogs -->
18   <Catalog name="CopyFromEnterpriseCatalog">
19     <value>%APPDATA%\Schlumberger\Petrel\CRSCatalogConfiguration\2015.1\CoordinateCatalogEnterprise.ctl</value>
20   </Catalog>
21   <Catalog name="CopyFromUserdefinedExtensionCatalog">
22     <value>%APPDATA%\Schlumberger\Petrel\CRSCatalogConfiguration\2015.1\CoordinateCatalogExtensions.ctl</value>
23   </Catalog>
24   <!--Factory catalog containing default CRSs and TRFs-->
25   <Catalog name="FactoryCatalog">
26     <value>.\xml\FactoryCoordinateCatalog.ctl</value>
27   </Catalog>
28   <!--Engine version upgrade instructions to replace ESRI factory codes -->
29   <!--with explicit WKT to preserve identical behaviour.                -->
30   <Catalog name="UpgradeCatalogs">
31     <value>.\EsriCatalog\upgrade\CatalogUpgrade9.3.0.txt</value>
32     <value>.\EsriCatalog\upgrade\CatalogUpgrade10.0.txt</value>
33     <value>.\EsriCatalog\upgrade\CatalogUpgrade10.1.0.txt</value>
34     <value>.\EsriCatalog\upgrade\CatalogUpgrade10.2.1.txt</value>
35   </Catalog>
36   <!--Catalog containing CRSs and TRFs to be added during catalog upgrade-->
37   <Catalog name="AddOnCatalog">
38     <value>.\EsriCatalog\upgrade\MergedAddOnsCatalog.ctl</value>
39   </Catalog>
40   <!--Resources for optional maintenance functionality-->
41   <Catalog name="CRSReplacementTableApproved">
42     <value>%APPDATA%\Schlumberger\Petrel\CRSCatalogConfiguration\2016.1\CRSReplacementTableApproved.txt</value>
43   </Catalog>
44   <Catalog name="CRSReplacementTableProposed">
45     <value>%APPDATA%\Schlumberger\Petrel\CRSCatalogConfiguration\2016.1\CRSReplacementTableProposed.txt</value>
46   </Catalog>
47 </CatalogConfiguration>
```

Figure 3 - Example of an Enterprise Coordinate Catalog .ctl file

4.2 Enterprise Coordinate Catalog File

The enterprise coordinate catalog file includes a list of ESRI and Schlumberger coordinate reference systems, transformations, and conflation policies (Figure 4). You can remove coordinate reference systems, transformations, or conflation policies from the enterprise coordinate catalog, but you cannot add custom ones. The very file is typically located at:

\\%APPDATA%\Roaming\Schlumberger\Petrel\CRSCatalogConfiguration\2016.1\CoordinateCatalogEnterprise.ctl


```
<?xml version="1.0" encoding="utf-8"?><!--WARNING: This file was made by serializing an Slb.Ocen.Coordinates.ICatalog
instance.--><!--WARNING: The only intended usage is rehydration (deserialization).--><!--WARNING: Do not edit his file; do
not expect the format, syntax or content to be identical in future versions.--><!--WARNING: The format and syntax *will*
change in future versions (but deserialization is backwards compatible)--><ICatalog name="SIS Factory Catalog" description=
"Revised version 2017.09.06" creationTime="06/14/2017 13:10:43.0640294 UTC" lastUpdateTime="11/03/2022 20:03:40.7718295
UTC"><IEngine name="ESRI" version="PE_10_3_1"><CartographicTransforms><ISimpleTransform><AuthorityCode>EPSG,1573
</AuthorityCode></ISimpleTransform><ISimpleTransform><AuthorityCode>EPSG,15779
</AuthorityCode></ISimpleTransform><ISimpleTransform><AuthorityCode>EPSG,15743
</AuthorityCode></ISimpleTransform><ISimpleTransform><AuthorityCode>EPSG,1323
</AuthorityCode></ISimpleTransform><ISimpleTransform><AuthorityCode>EPSG,15763
</AuthorityCode></ISimpleTransform><ISimpleTransform><AuthorityCode>EPSG,1321
</AuthorityCode></ISimpleTransform><ISimpleTransform><AuthorityCode>EPSG,15703
</AuthorityCode></ISimpleTransform><ISimpleTransform name="MGI_Ferro_To_MGI_1901_1"><AuthorityCode>ESRI,3913
</AuthorityCode><WKT>
GEOGTRAN["MGI_Ferro_To_MGI_1901_1",GEOGCS["GCS_MGI_Ferro",DATUM["D_MGI",SPHEROID["Bessel_1841",6377397.155,299.1528128]],PRI
MEM["Ferro",-17.6666666666667],UNIT["Degree",0.0174532925199433]],GEOGCS["GCS_MGI_1901",DATUM["D_MGI_1901",SPHEROID["Bessel_
1841",6377397.155,299.1528128]],PRIMEM["Greenwich",0.0],UNIT["Degree",0.0174532925199433]],METHOD["Geographic_2D_Offset"],PA
RAMETER["Longitude_Offset",-63586.02],PARAMETER["Latitude_Offset",0.0],AUTHORITY["EPSG",3913]]
</WKT></ISimpleTransform><ISimpleTransform><AuthorityCode>EPSG,1326
</AuthorityCode></ISimpleTransform><ISimpleTransform><AuthorityCode>EPSG,1325
</AuthorityCode></ISimpleTransform><ISimpleTransform><AuthorityCode>EPSG,1324
</AuthorityCode></ISimpleTransform><ISimpleTransform name="Mhast_To_WGS_1984_1"><AuthorityCode>EPSG,1329
</AuthorityCode><WKT>
GEOGTRAN["Mhast_To_WGS_1984_1",GEOGCS["GCS_Mhast",DATUM["D_Mhast",SPHEROID["International_1924",6378388.0,297.0]],PRIMEM["Gr
eenwich",0.0],UNIT["Degree",0.0174532925199433]],GEOGCS["GCS_WGS_1984",DATUM["D_WGS_1984",SPHEROID["WGS_1984",6378137.0,298.
257223563]],PRIMEM["Greenwich",0.0],UNIT["Degree",0.0174532925199433]],METHOD["Geocentric_Translation"],PARAMETER["X_Axis_Tr
anslation",-252.95],PARAMETER["Y_Axis_Translation",-4.11],PARAMETER["Z_Axis_Translation",-96.38],AUTHORITY["EPSG",1329]]
</WKT></ISimpleTransform><ISimpleTransform name="Malongo_To_Mhast_1"><AuthorityCode>EPSG,1328</AuthorityCode><WKT>
GEOGTRAN["Malongo_To_Mhast_1",GEOGCS["GCS_Malongo_1987",DATUM["D_Malongo_1987",SPHEROID["International_1924",6378388.0,297.0
]],PRIMEM["Greenwich",0.0],UNIT["Degree",0.0174532925199433]],GEOGCS["GCS_Mhast",DATUM["D_Mhast",SPHEROID["International_192
4",6378388.0,297.0]],PRIMEM["Greenwich",0.0],UNIT["Degree",0.0174532925199433]],METHOD["Geocentric_Translation"],PARAMETER["
X_Axis_Translation",0.0],PARAMETER["Y_Axis_Translation",0.0],PARAMETER["Z_Axis_Translation",0.0],AUTHORITY["EPSG",1328]]
```


Figure 4 - Example of the Enterprise Coordinate Catalog Configuration File

4.3 Extension Coordinate Catalog File

This catalog contains all custom coordinate reference systems, transforms, and conflation policies, added by the Petrel users or the company (Figure 5). The default location of the extension coordinate catalog file is:

\\%APPDATA%\Roaming\Schlumberger\Petrel\CRSCatalogConfiguration\2016.1\CoordinateCatalogExtensions.ctl

```xml
<?xml version="1.0" encoding="utf-8"?><!--WARNING: This file was made by serializing an Slb.Ocen.Coordinates.ICatalog
instance.--><!--WARNING: The only intended usage is rehydration (deserialization).--><!--WARNING: Do not edit his file; do
not expect the format, syntax or content to be identical in future versions.--><!--WARNING: The format and syntax *will*
change in future versions (but deserialization is backwards compatible)--><ICatalog name="UserDefinedExtensionCatalog"
description="" creationTime="11/03/2022 18:49:34.9043767 UTC" lastUpdateTime="11/03/2022 20:03:41.4623562 UTC"><IEngine name=
"ESRI" version="PE_10_3_1"><CartographicTransforms /><CoordinateReferenceSystems><ILateBoundCoordinateReferenceSystem name=
"MENTOR:GF:VROL:Voirol"><AuthorityCode>Petrel-SOC,700000</AuthorityCode><WKT>
GEOGCS["MENTOR:GF:VROL:Voirol",DATUM["MENTOR:GF:VROL:Voirol",SPHEROID["Institut Geographique National [France] - Clarke
1880",6378249.145,293.465]],PRIMEM["Greenwich",0.0],UNIT["Degree",0.0174532925199433]]
</WKT></ILateBoundCoordinateReferenceSystem><ILateBoundCoordinateReferenceSystem name="SOC:Libya-North:Lambert Datum, Clarke
80"><Description>Refer to Marcus for technical consulting</Description><AuthorityCode>Petrel-SOC,700001</AuthorityCode><WKT>
PROJCS["SOC:Libya-North:Lambert Datum, Clarke
80",GEOGCS["MENTOR:GF:VROL:Voirol",DATUM["MENTOR:GF:VROL:Voirol",SPHEROID["Institut Geographique National [France] - Clarke
1880",6378249.145,293.4650]],PRIMEM["Greenwich",0.0],UNIT["Degree",0.0174532925199433]],PROJECTION["Lambert_Conformal_Conic"],
PARAMETER["False_Easting",1000000.0],PARAMETER["False_Northing",550000.0],PARAMETER["Central_Meridian",18.0],PARAMETER["Scale_
Factor",0.99938949],PARAMETER["Latitude_Of_Origin",31.0],UNIT["Meter",1.0]]
</WKT></ILateBoundCoordinateReferenceSystem></CoordinateReferenceSystems><Areas /><AreaAssociations /></IEngine></ICatalog>
```


Figure 5 - Example of the Extensions Coordinate Catalog Configuration file

5. How to Share the Coordinate Catalog

If you want Petrel users to share the same Geodetic catalog, you need to store it on a network share drive that all the users can access.

Petrel users can also import the custom catalog. In Petrel, go to “File” > “System” > “System Settings” > “Company Profile” tab, where you can locate the “coordinate systems” section and choose to “Import enterprise/extension coordinate catalog…” (Figure 6).

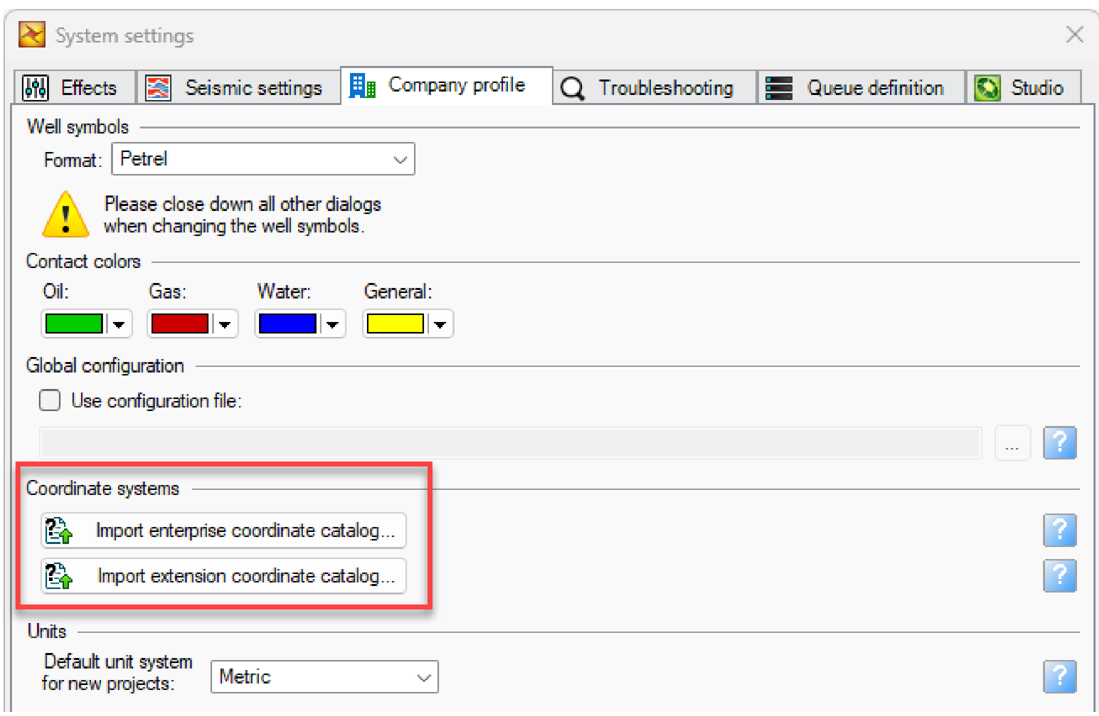

Figure 6 - System Settings window in Petrel

6. Principles to Create Custom Coordinate Reference System

Note: The principles stated in this section can be applied in any applications/platforms, such as, ESRI's ArcGIS, Schlumberger's Petrel, Blue Marble Geographic's Geographic Calculator and Global Mapper.

Basically, you must ensure the following three items to be ready prior to creating a new Coordinate Reference System ("CRS") using any type of applications/platforms:

- a **Geographic CRS** ("GCRS" or "GCS"), normally including an Ellipsoid and a Datum and represented by Latitude and Longitude.
- a **Projected CRS** ("PCRS"), normally including the GCRS just defined and some critical parameters to enable the calculation conducted to convert the Latitudes/Longitudes associated with the local GCRS to an array of X/Y coordinates presenting on a flat display when projected.
- a **Transformation** to transform the representation from a local Geographic CRS to a standard WGS84 based Geographic CRS (which is called "GCS_WGS_1984" in Petrel). Petrel uses the term of "transform" while other applications, such as, ArcGIS, Global Mapper, may call it as "transformation".

If you are working with / creating a new project using a new Coordinate Reference System ("CRS") that is not available in any "conflation policy" in Petrel, you need to create a new / custom CRS. Please be noticed that Petrel deals with Coordinate Systems in a special way, meaning there are 3 steps to follow by:

1) Step 1 - Define a new Projected Coordinate System (PCRS), which is based on a local Geographic Coordinate System (GCRS) and some parameters; if you want to use an existing GCRS, you could borrow from the Geodetic Catalog library.
2) Step 2 - Create a transform to "translate/rotate" the local GCRS (you defined in Step 1) to the standard, WGS84-based GCRS, namely "GCS_WGS_1984".
3) Step 3 - Create a Custom Projected CRS by applying a so-called "Conflation Policy", such that to concatenate the new PCRS in Step 1 with the new Transform in Step 2.

Very important concepts:

(1) The Transform only deal with the transformation between a local Geographic CRS and the standard (or base) WGS84 Geographic CRS; that being said, the transform has nothing to do with X/Y numbers, that's the results of the Projection.
(2) The X/Y coordinates are determined by looking at the calculations/formulas in line with the Projection method ("UTM", or "LCC") and the associated Projection parameters.

Quite often, we use Well-Known Text ("WKT") or WKT2, or Projection Text ("Proj") to define the Custom CRS and Transforms. A WKT format is defined to describe the transformation methods and parameters used to convert coordinates between two different spatial reference systems. Please be noted that (a) the WKT must be OGC-compatible (visit www.epsg.io for more details); (b) the WKT can be downloaded from the EPSG website (https://www.epsg.io), ESRI website (https://www.esri.com) or can be created by the geodesist or any user with relevant expertise.

The WKT shall embrace the following parameters: **datum**, **ellipsoid**, type of **projection**, **false easting**, **central meridian**, **scale factor**, **latitude of origin**, **units**, and **authority**; As for "**authority**", you can specify a name to recognize the custom coordinate system created for the user or company. The parameters used in the WKT for the coordinate reference system are:

- PROJCS: CRS name
  - GEOGCS: coordinate system based on latitude and longitude.
  - DATUM: geodetic datum. The horizontal datum, which corresponds to the procedure used to measure positions on the surface of the Earth.
  - SPHEROID: ellipsoid, which approximates the Earth's surface as a squashed sphere.
  - PRIMEM: prime meridian. The meridian used to take longitude measurements from.
- PROJECTION: projection method from geographic coordinates to projected coordinates, typical values are "Transverse Mercator" and "Lambert Conformal Conic".
- PARAMETER:
  - False Easting, False Northing, Central Meridian, Scale Factor, Latitude of Origin (UTM) or,
  - False Easting, False Northing, Central Meridian, Standard Parallel 1, Standard Parallel 2, Latitude of Origin (LCC)

- UNIT: units used for values elsewhere within the parent WKT clause.
- AUTHORITY: can be “EPSG” or “ESRI” or any 3rd-part organizations.

Bearing the clean principle and steps in mind, let’s get our hands dirty.

7. How to Create a Custom Coordinate Reference System

7.1 Define a New Projected Coordinate System

Launch the application of “**Petrel Coordinate System Manager**”, go to the “Coordinate reference systems and transforms” tab. At the “Coordinate reference systems” section, click on the green “+” symbol to define a new Projected Coordinate Reference System (Figure 7).

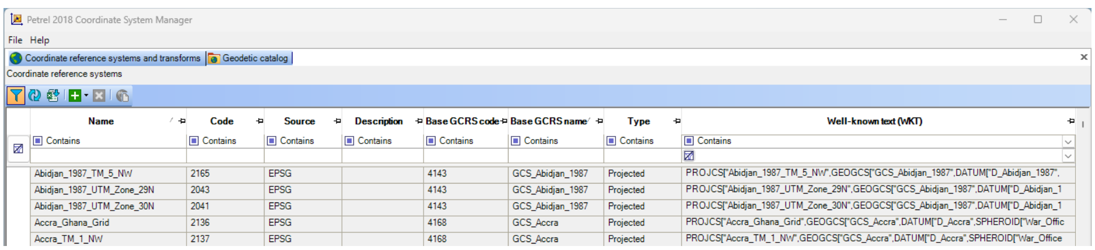

Figure 7 - The Window of Coordinate Reference Systems and Transforms

A window to define the well-known text (WKT) of the new coordinate reference system will open. Once the WKT is copied into the WKT window, click “Ok” button, and the new coordinate reference window will open if no grammar error is detected in the WKT (Figure 8). In this window you should add information to describe the new coordinate reference system, e.g., “Libya-North: Clarke 1880”.

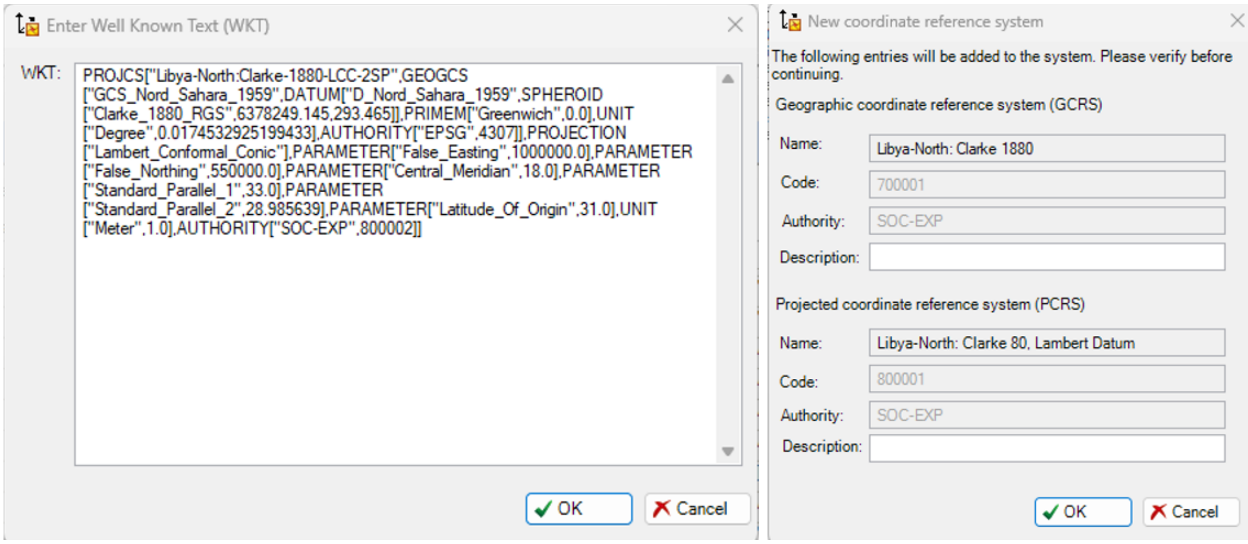

Figure 8 - Well-Known Text for Defining the Custom CRS

Once done, 2 slips of message would pop up in the Message Log window (lower section), stating that 2 coordinate reference systems (one "Geographic2D" CRS and one "Projected" CRS) have been created.

Alternatively, Let's start from scratch, creating a Geographic CRS first (Figure 9):

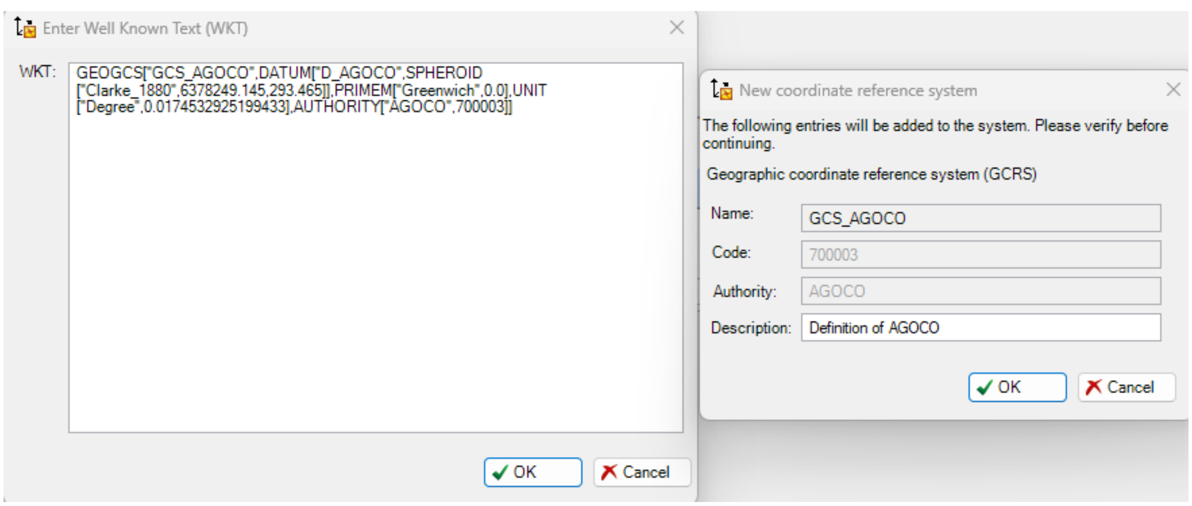

Figure 9 - Creating a Custom Geographic CRS

Then, define a Projected CRS on top of the Geographic CRS we just created (Figure 10).

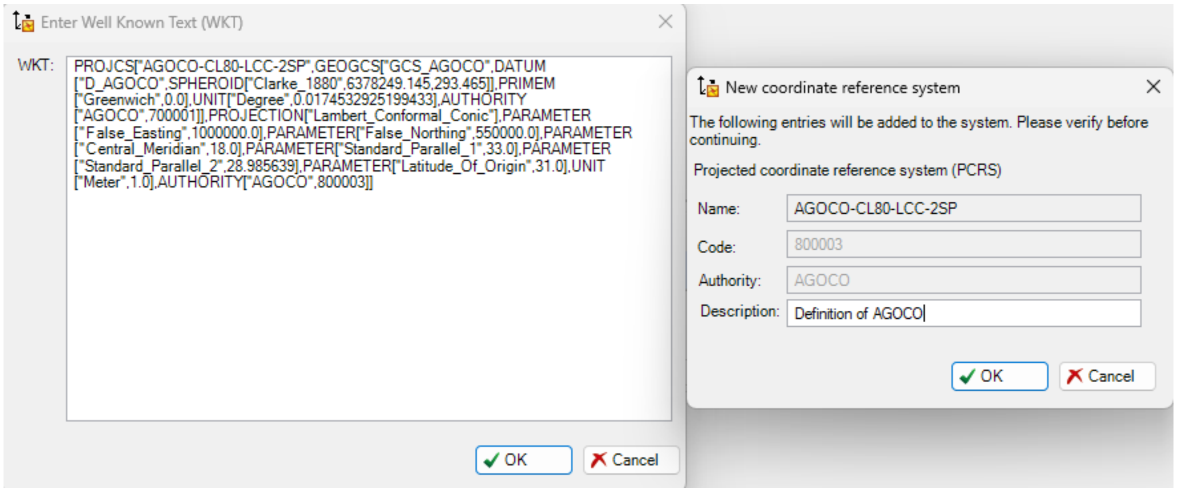

Figure 10 - Defining a Custom Projected CRS

So far, we have 2 new items in the table: one Geographic CRS and one Projected CRS, please check the "type" column below to verify (Figure 11). And we have none of transforms associated with the custom CRS yet by looking at the lower-located section.

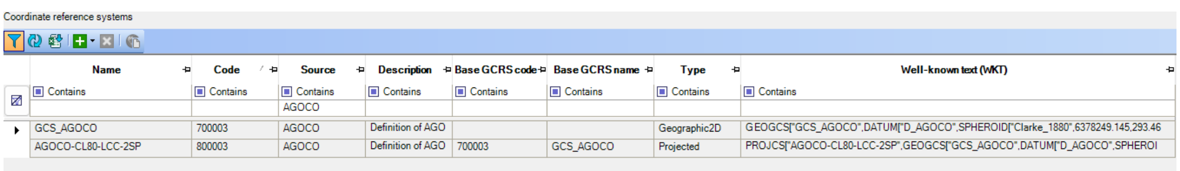

Figure 11 - Two Custom CRS have been defined

7.2 Create a Custom Transform

To be able to use the new Custom Coordinate Reference System (CRS) in Petrel, you need to create a new transform, which will allow you to transform the data from the local GCRS into WGS84 GCRS.

Launch the "**Petrel Coordinate System Manager**", then go to the "Coordinate reference systems and transforms" tab > "Transforms" section > click on "Create new transform" icon "+" (Figure 12).

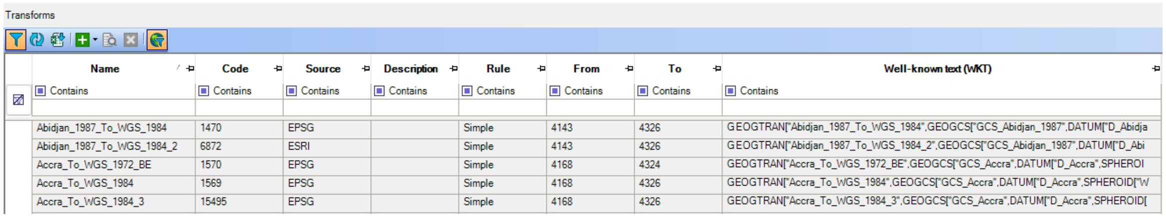

Figure 12 - Creating a Custom Transform

To define the new transformation, the parameters for the well-known text (WKT) must be defined. Depending on the transformation method, the parameters needed could be **spheroid**, **method of transformation**, **X**, **Y**, and **Z translation**, and **X**, **Y**, and **Z rotation** (Figure 13, left). After defining the WKT another window will open to allow you to describe the new transformation (Figure 13, right).

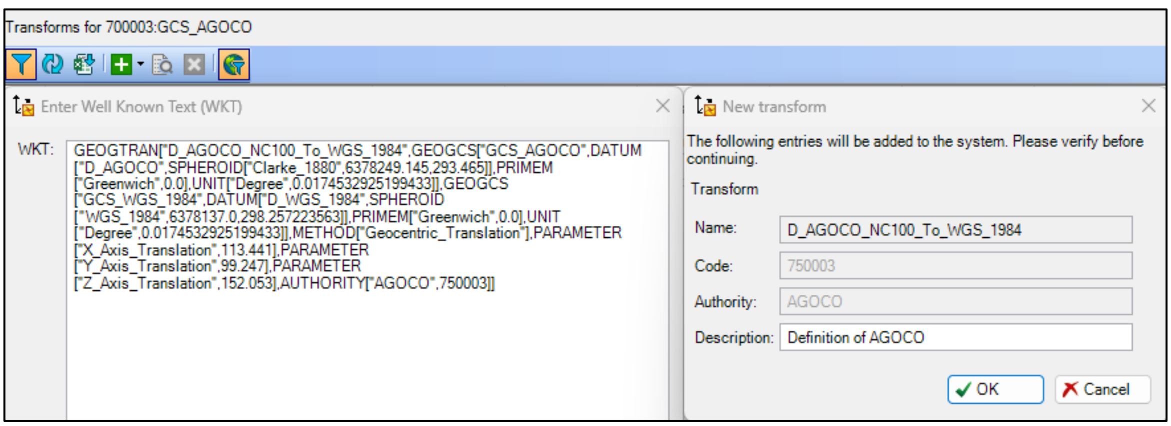

Figure 13 - Definition in WKT for Transforming from Custom GCRS to WGS84

7.3 Create a New Conflation Policy (Custom PCRS)

To create a new conflation policy, a definition of Custom Projected CRS and a related Transform must be coupled and selected. Launch the "**Coordinate System Manager**" > go to "Geodetic catalog" tab > Click on "Create new conflation policy" icon "+" (Figure 14).

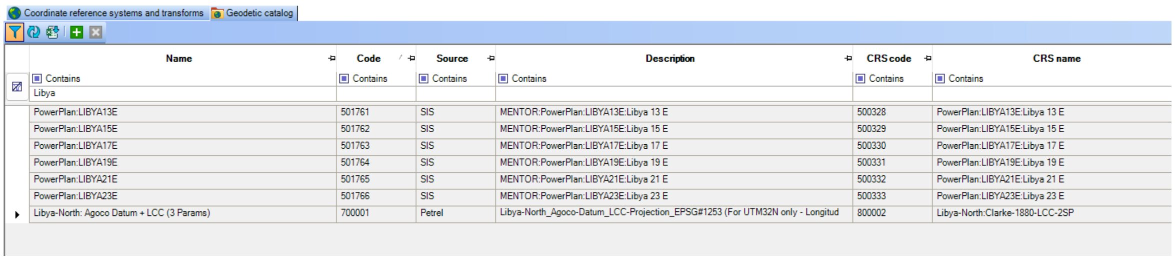

Figure 14 - Creation of a New Conflation Policy in Geodetic Catalog Window

When the "Create conflation policy" window opens, select the newly defined Projected CRS and its related transformation (Figure 15). Then click "Ok" button and wait till the new PCRS pops up in the Geodetic Catalog window (Figure 16).

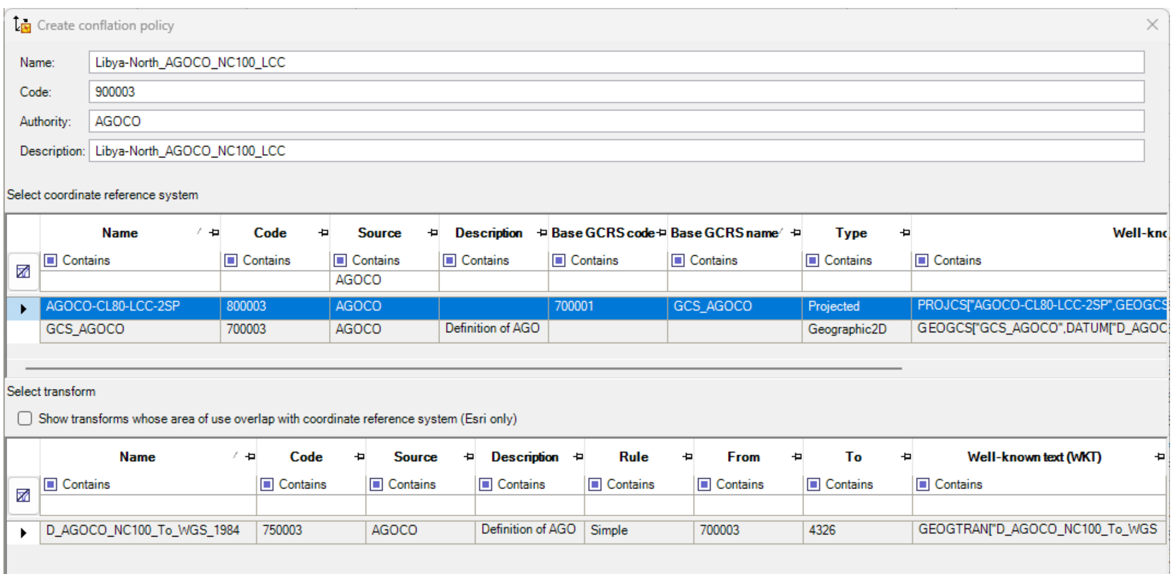

Figure 15 - New Conflation Policy with New CRS and New Transform

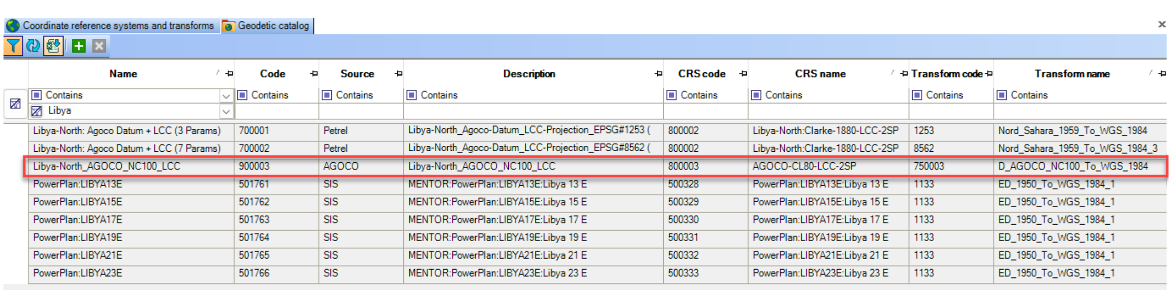

Figure 16 - A Custom Projected CRS Created in Geodetic Catalog Window

After this, the newly created Custom Projected CRS, namely a new Conflation Policy in Geodetic Catalog window, will be able to be picked up in Petrel project.

Launch Petrel and open a new project, then to select the coordinate system, go to "File" → "Project Setup" → "Project settings" → "Coordinates and units" tab → "Select…" button (Figure 17).

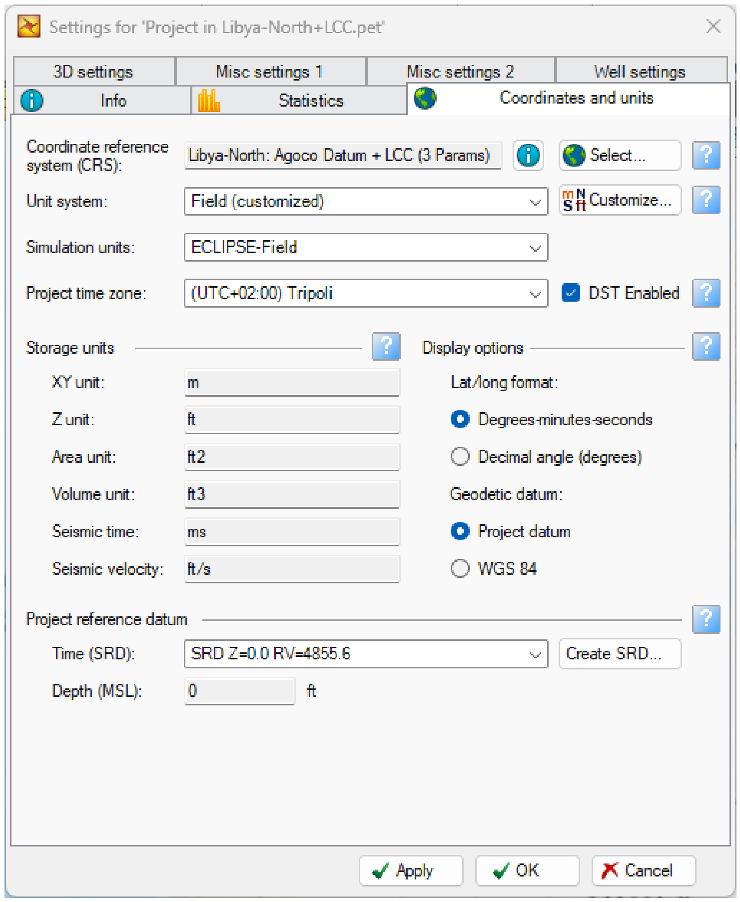

Figure 17 - Setting Coordinate Reference System in Petrel Project

When the Coordinate reference system selection window opens, the new Projected CRS will be available. You can filter the selection with the authority's name (Figure 18).

Note: If you have Petrel open when you created your new conflation policy in the Coordinate System Manager, you will need to re-launch Petrel, to be able to see the new conflation policy.

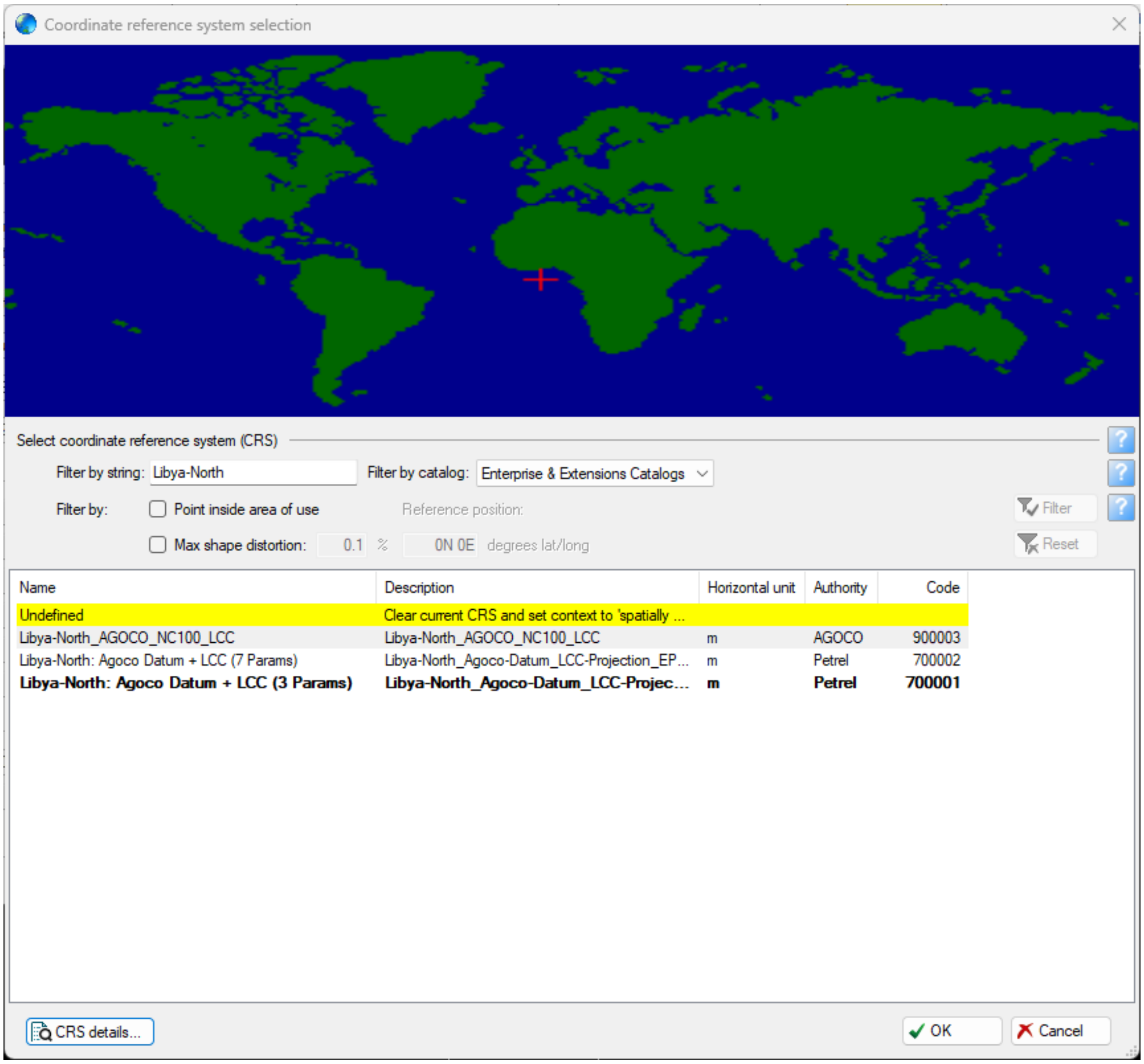

Figure 18 - Projected Coordinate Reference System Selection

The new Conflation Policy (actually, the Custom PCRS) created in the Coordinate System Manager is available in the catalog list. Hop to the one you want to select and click "CRS details" button at lower-left corner to know more details (Figure 19). Eventually select the Projected CRS.

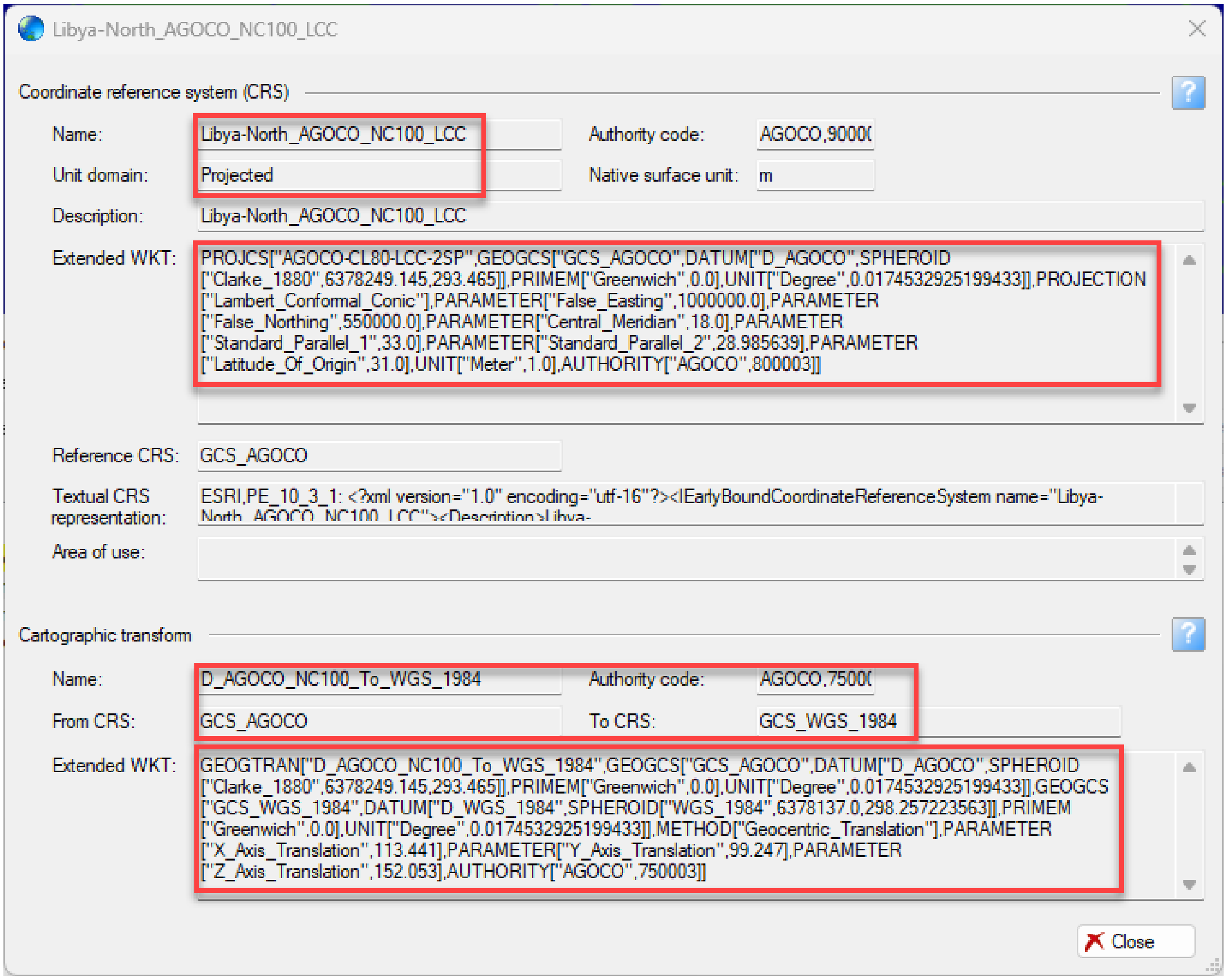

Figure 19 - Details of Newly Created Projected CRS

8. A Primer of Coordinate System

Let's list out some commonly applied concepts to clean the way out.

Ellipsoid (spheroid)

Earth is not a perfect globe, and its surface is irregular. GIS needs to use coordinates values (X/Y, or Longitude/Latitude) to describe an actual position/feature on earth in software system. To mathematically define a coordinate reference system (CRS) we will need to use **a flattened three-dimensional ellipse with smooth surface to approximate the earth, which is called an ellipsoid**.

Different ellipsoids (thus different sizes and shapes) can be defined depending on the needs. In Figure 20, the difference between Ellipsoid WGS 84 (or WGS 1984) and GRS 80 (or GRS 1980) is exaggerated on purpose to highlight the fact that they are different ellipsoids, even though in fact their difference is really small.

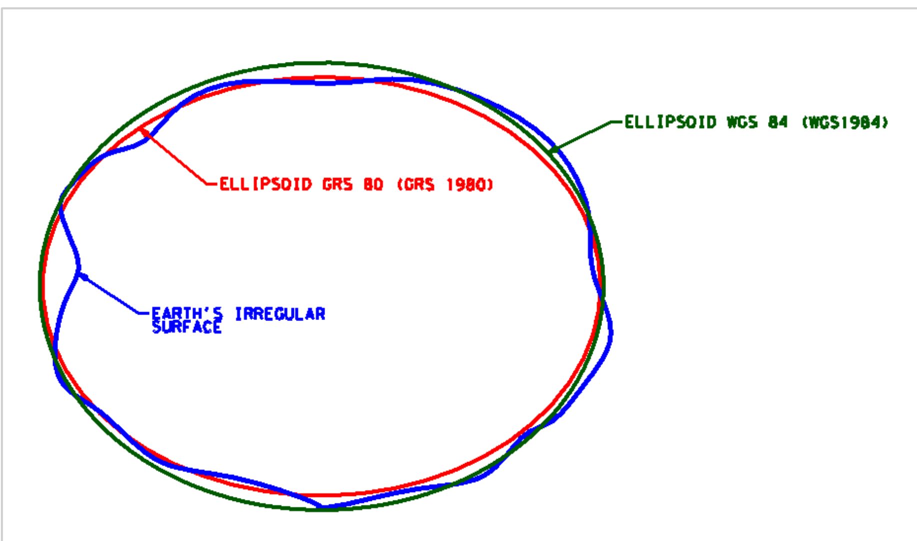

Figure 20 - Pseudo Model demonstrating the difference between Ellipsoids

Typically, an ellipsoid has its own specific parameters, such as, **semi-major axis** (a in meters), **semi-minor axis** (b in meters), and the **inverse flattening** (1/f =a/(a-b)).

Ellipsoid	Semi-Major Axis a (m)	Semi-Minor Axis b (m)	1/f = a/(a-b)
GRS 80	6378137.000	6356752.314140356	298.257222101
WGS 84	6378137.000	6356752.314245179	298.257223563

Datum

An ellipsoid has different **realizations, which are different ways to position itself relative to Earth depending on where its center is located**. **Each realization is called a datum** and therefore an ellipsoid may have different datums (Figure 21). A simple definition of **Datum is a model of the shape of the earth** per se. A common datum for GRS 80 (the ellipsoid) is NAD83 and a common datum for WGS 84 (the ellipsoid) is WGS 84 (the datum has the same name as its ellipsoid in this case). In USA, the difference between two datums of NAD83 and WGS 84 is negligible for most civil infrastructure projects detailed as the table below. Global Positioning System (GPS) uses WGS84 as the datum.

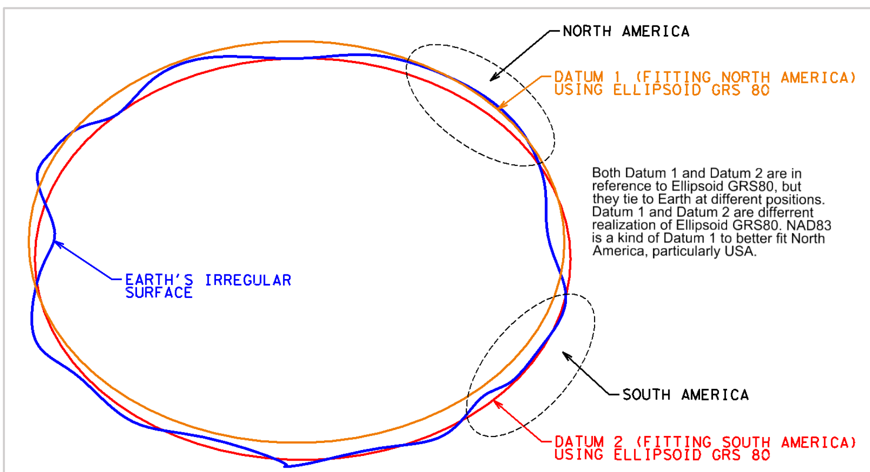

Figure 21 - Different realizations (datums) based on the same Ellipsoid GRS80

Geoid

Ellipsoid is different from geoid. **Geoid, an equipotential surface to which the gravity force is everywhere perpendicular, is usually used to define a vertical datum**. Unlike ellipsoid, which is an idealized representation of the earth, the geoid surface is irregular even though it is still much smoother than earth physical surface.

Since longitude and latitude are in reference to a datum and any location on earth (3D surface) can be defined by longitude and latitude values. This type of CRS is Geographic Coordinate System with coordinate unit of degree.

Another interesting fact is that since longitude and latitude values are tied with datums, **a location's longitude and latitude values in reference to Datum WGS84 are different than in reference to Datum NAD83** as stated by the table below; however, the difference normally is insignificant (because they are referencing to very similar ellipsoids): in US, the difference in terms of horizontal distance between WGS 84 and NAD 83 coordinates is around 1.0 meter or 3~4 feet, which can be neglected for most H&H applications. BTW, the conversions below are performed by using Blue Marble Geographic Calculator 2019 b210219.

City	WGS84		NAD83	
	Latitude	**Longitude**	**Latitude**	**Longitude**
Calgary, AB	51°02′55.0140″	-114°04′15.0456″	51°02′55.0045″	-114°04′15.0608″
St Louis, MO	38°37′37.211″	-90°11′57.847″	38°37′37.185″	-90°11′57.825″
Houston, TX	29°44′59.665″	-95°21′30.316″	29°44′59.646″	-95°21′30.290″
Pasadena, CA	34°09′22.007″	-118°07′54.995″	34°09′22.007″	-118°07′54.951″

But the longitude and latitude values of a physical location could differ a lot, up to hundreds of meters, if referencing to totally different datums, say ED50 and WGS84. As we know, the datum ED50 is based on the ellipsoid of "Hayford/International 1924" while the datum WGS84 is based on the ellipsoid of "WGS84". Here is the table for the parameters of the typical ellipsoids used in North Africa.

Datum	Ellipsoid	Semi-Major Axis a	Semi-Minor Axis b	1/f = a/(a-b)
ED50	International 1924	6378388.000	6356911.946	297.000000000
WGS84	WGS84	6378137.000	6356752.314	298.257223563
Nord Sahara	Clarke 1880 (RGS)	6378249.145	6356514.870	293.465000000

Projection

A projection is **the means by which you display the coordinate system and your data on a flat surface**, such as a piece of paper or a digital screen. Mathematical calculations are used to convert the coordinate system used on the curved surface of earth to one for a flat surface. To represent a point on earth (3D surface) on 2D maps, we use various projection methods to make the conversion (Figure 22). A 3D element will lose at least one of its three characteristics – angle, area, and distance when being projected onto 2D surface, NO MATTER which projection method is used. The coordinate system on 2D surface is called a Projected Coordinate System ("PCS") with coordinate unit of foot (or international foot), US survey foot (or US foot), or meter.

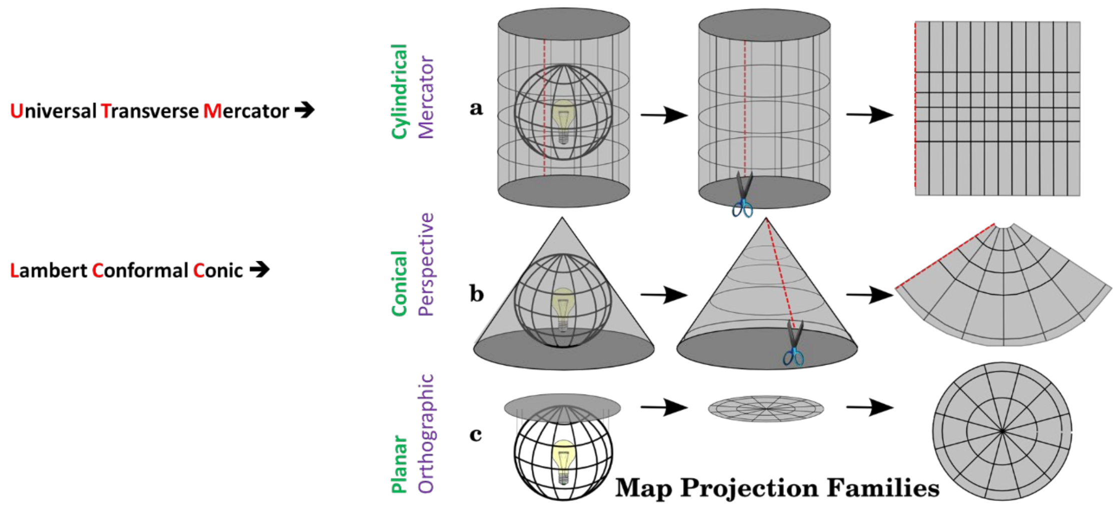

Figure 22 - various Projection methods

It should be noted that the Cylindrical (Mercator) projection in Figure 22 is not the one used for UTM Zones. UTM Zones use Transverse Mercator Projection which is achieved by rotating the cylinder by 90 degree (Figure 23).

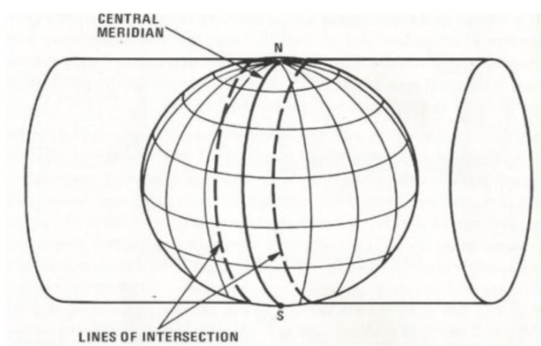

Figure 23 - the Cylinder used in UTM projection

There are two different UTM Zones – UTM Zones (WGS 84) and UTM Zones (NAD83) depending on which datum the UTM zones are based upon. In the United States and North America UTM Zones (NAD83) are popular (for example, EPSG 26915 – UTM Zone 15N), while in the rest of the world you may have a greater chance to work with UTM Zones (WGS 84) (for example, EPSG 32637 – UTM Zone 37N), as shown in Figure 24.

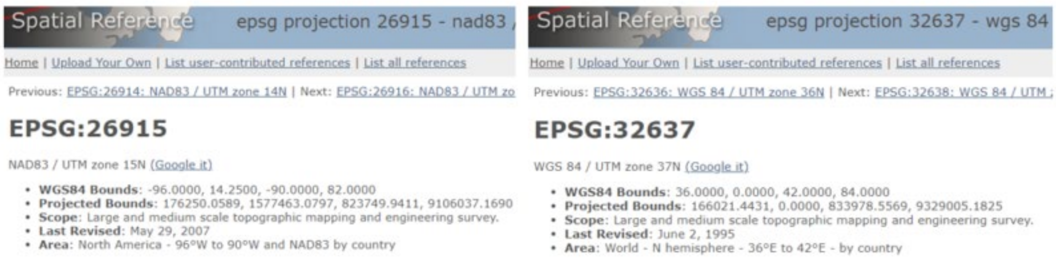

Figure 24 - Different projections: NAD83 vs. WGS84

Let's offtrack to the theory a bit -

Transverse Mercator

The most common method of projection is the Transverse Mercator, also known as: Gauss Conformal or Gauss-Kruger in Europe; the transverse Mercator in the US; or Gauss-Kruger transverse Mercator generally. The projection is conformal with a constant scale on the central meridian.

The transverse Mercator projection is a variant of the Mercator projection. This projection is conformal, so it preserves angles and approximates shape but distorts distance and area. UTM involves non-linear scaling in both Easting and Northing to ensure the projected map of the ellipsoid is conformal.

Universal Transverse Mercator (UTM)

The Universal Transverse Mercator (UTM) geographic coordinate system uses a 2-dimensional Cartesian coordinate system to give locations on the surface of the Earth. It is a horizontal position representation, but differs from the traditional method of latitude and longitude in several respects. The UTM system is not a single map projection. The system instead divides the Earth into sixty zones, each a six-degree band of longitude, and uses a secant transverse Mercator projection in each zone.

Each of the 60 zones uses a transverse Mercator projection that can map a region of large north-south extent with low distortion (Figure 25). By using narrow zones of 6° of longitude (up to 800 km) in width, and reducing the scale factor along the central meridian to 0.9996 (a reduction of 1:2500), the amount of distortion is held below 1 part in 1,000 inside each zone. Distortion of scale increases to 1.0010 at the zone boundaries along the equator. The central meridian is the meridian at the center of each zone. For example, the central meridian of UTM zone 26 would be 27°W (Figure 26).

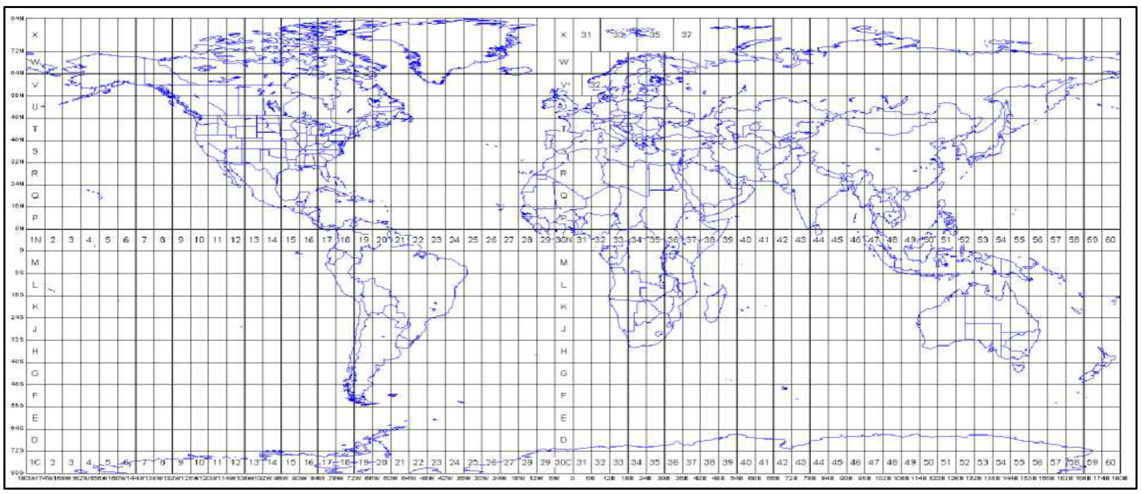

Figure 25 - UTM Grid Zones on a Projected Map of the World

In each zone the scale factor of the central meridian reduces the diameter of the transverse cylinder to produce a secant projection with two standard lines, or lines of true scale, about 180 km on each side of, and about parallel to, the central meridian (Arc cos 0.9996 = 1.62° at the Equator). The scale is less than 1 inside the standard lines and greater than 1 outside them, but the overall distortion is minimized.

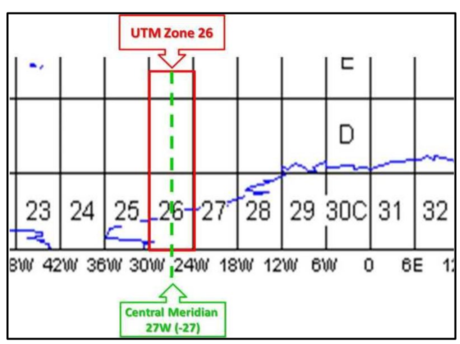

Figure 26 - Correspondence between UTM Zone and Central Meridians

Lambert Conformal Conic

A Lambert conformal conic projection (LCC) is a conic map projection (Figure 22). The projection seats a cone over the sphere of the Earth and projects conformably onto the cone. The cone is unrolled, and the parallel touching the sphere is assigned unitary scale in the simple case. This parallel is called the reference parallel or standard parallel. Free of distortion only exists along the one or two standard parallels. Distortion is constant along any given parallel. Conformal everywhere except at the poles.

This is extensively used in ellipsoidal form for large-scale mapping of regions of predominantly east-west extent, including topographic quadrangles (1:24,000 and 1:62,500 scale) for many of the U.S. State Plane Coordinate system zones, many maps in the International Map of the World (1:1,000,000 scale) series, and topographic mapping in many other nations.

Two common conic projections are **Albers Equal Area Conic Projection** ("AEC") and **Lambert Conformal Conic Projection** ("LCC").

- Albers Equal Area Conic projection is commonly used for large areas which require equal-area representation. USGS uses this projection for maps showing continental 48 US states (EPSG 5070).

- Lambert Conformal Conic is similar to Albers Equal Area Conic Projection, but it's conformal (preserve angles) rather than equal area. This projection is widely used in the United States for a lot of State Plane Coordinate System (SPCS) when zones are east-west oriented, such as Texas State Plane Coordinate System or Louisiana State Plane Coordinate System.

IOGP & EPSG

Regardless, everyone must salute the honorable Oil and Gas industry when speaking of the origination and foundation of Geodesy science and Geodetic Coordinate System.

In 2005, IOGP ("International Oil & Gas Producers", formed in London in 1974) absorbed the European Petroleum Survey Group or EPSG (1986-2005) into its structure as IOGP Geomatics Committee. EPSG was a scientific organization with ties to the European petroleum industry consisting of specialists working in applied geodesy, surveying, and cartography related to oil exploration. The EPSG Geodetic Parameter Dataset is a widely used database of Earth ellipsoids, geodetic datums, geographic and projected coordinate systems, units of measurement, etc., which was originally created by EPSG and still carries the EPSG initials to this day.

EPSG.io

EPSG's official website, EPSG.io (https://epsg.io/) simplifies discovery of coordinate reference systems utilized all over the world for creating maps and geodata and for identifying geo-position. It is a practical tool for anybody interested in cartography and digital map making, who needs to know exact latitude and longitude values for numerical coordinates in different spatial reference systems. Included map application allows to show the precise location anywhere on the planet also visually.

The website comes with a full text search indexing over 6000 coordinate systems. The search starts by typing the name of the system, name of covered country, state, or any of the combinations of these. Searching for EPSG and ESRI codes is supported as well.

Each coordinates system and transformation have a short permanent link and is exportable in various formats (WKT, XML, OGC GML, Proj.4, JavaScript, SQL). The web has also API allowing integration of the search functionality and transformations in third party applications.

MapTiler

Soon this functionality will be used the by the MapTiler (http://www.maptiler.com) to simplify the transformation or existing raster geodata and images into Google Maps and OGC WMTS compatible tiles. MapTiler is the easiest way how to prepare custom maps for mobile devices and web presentation.

GeoReferencer (http://www.klokantech.com/georeferencer/), the online service for turning scanned maps into geodata in a web browser, will soon utilize EPSG.io service as well - allowing a user-friendly selection of any coordinate system and map projection during the georeferencing process.

EPSG Registry

The EPSG.io website is built around the official EPSG database maintained by OGP Geomatics Committee (http://www.epsg.org/). The database comprises of very detailed geodetic parameters from a range of sources and authorities. EPSG.io simplifies access to exact parameters for thousands of spatial reference systems, transformations and conversions, datums, ellipsoids, meridians, units, etc.

EPSG Geodetic Parameter Dataset (also **EPSG registry**) has a coded database of various coordinate systems including Geographic Coordinate Reference System and Projected Coordinate System (**https://www.spatialreference.org/**).

For example, in EPSG dataset, UTM Zone 17N is coded as EPSG 26917 (NAD83 Datum), Texas State Plane Coordinate System South Central Zone is coded as EPSG 2278 (NAD83 Datum), and the Geographic Coordinate Reference System used by Google Earth is coded as **EPSG 4326** (WGS84 Datum).

Common CRS in North America

The following are some common CRS applied extensively in North America:

- **EPSG 4326**: Geographic Coordinate System, WGS84, used by GPS, Google Earth and some US government agencies for example USDA NRCS web soil survey (Note: web soil survey is different from gSSURGO which uses EPSG 5070); Unit: degree
- **EPSG 4269**: Geographic Coordinate System, NAD83, used by USGS, FEMA, and some other US Federal Government Agencies; Unit: degree
- **EPSG 3857**: Projected Coordinate System, WGS84, used by Google Map and some other online map providers including OpenStreetMap; Unit: meter (Some data source gives out Lat/Long degrees for elements projected to EPSG 3857, instead of X/Y coordinates in meters. These Lat/Long are actually converted from X/Y coordinates using WGS 84 datum and only are presented as Lat/Long degree for convenience purpose).
- **EPSG 26910 to 26919**: Projected Coordinate System, UTM Zone 10N to 19N, NAD83, covering Continental US from west coast to east coast; Unit: meter
- **EPSG 2275 to 2279**: Projected Coordinate System, Texas State Plane Coordinate System, North Zone to South Zone (FIPS 4201 to 4205), NAD83, Unit: US survey foot (Note: Texas State Plane Coordinate System has other EPSG coded systems which

use an adjusted NAD83 Datum such as NAD83 2011 which includes EPSG 6582, 6584, 6578, 6588, 6586.

- **EPSG 3451 and 3452**: Projected Coordinate System, Louisiana State Plane Coordinate System, North Zone to South Zone (FIPS 1701 to 1702), NAD83, Unit: US survey foot (ESRI 102681 and 102682 are also for Louisiana State Plane Coordinate System, North Zone to South Zone and they are essentially the same as EPSG 3451 and 3452)
- **EPSG 5070**: Projected Coordinate System, NAD83, used by gSSURGO; Unit: meter. Some agencies refer to EPSG 5070 as ESRI 102039 since they are the same CRS basically (aka USA Contiguous Albers Equal Area Conic USGS version) – Units: Meter; Datum: NAD83; 1st Standard Parallel: 29° 30′ 0″ North; 2nd Standard Parallel: 45° 30′ 0″ North; Central Meridian: 96° 0′ 0″ West; Latitude of Origin: 23° 0′ 0″ North; False Easting: 0.0; False Northing: 0.0.
- **EPSG 6350**: An updated version of EPSG 5070, EPSG 6350 is in reference to NAD83 2011, though. For some reasons, EPSG 6350 has not gained its popularity.
- **ESRI 102003**: So close to EPSG 5070 or ESRI 102039 that some literatures mistakenly suggested they are the same projections; however, ESRI 102003 has its latitude of origin at 37.5° instead of 23.0°.
- **Standard Hydrologic Grid (SHG)** was developed by HEC of USACE and it uses EPSG 5070 or ESRI 102039 as its projected coordinate system and thus SHG is a kind of EPSG 5070. Refer to this post for more information about SHG.
- **MMC Standard Coordinate System**: USACE Modeling, Mapping, and Consequence Production Center (MMC) uses EPSG 5070 Albers Equal Area Conic projection but with unit of survey foot. A sample shapefile in MMC standard projection can be downloaded here. HEC-HMS Tutorials and Guides has an example project which uses MMC standard projection.
- **Albers Conical Equal Area Projection** used by NLCD2016/NLCD2019 (when the entire continental US data is downloaded from https://www.mrlc.gov/data): Projected Coordinate System, similar to EPSG5070 except that it uses WGS84 datum instead of NAD83. It is a type of Albers equal-area conic map projection with the following parameters – Units: Meter; Datum: WGS84; 1st Standard Parallel: 29° 30′ 0″ North; 2nd Standard Parallel: 45° 30′ 0″ North; Central Meridian: 96° 0′ 0″ West; Latitude of Origin: 23° 0′ 0″ North; False Easting: 0.0; False Northing: 0.0. Download its prj file here. However, if you download a NLCD raster file for a project area by drawing a box at https://www.mrlc.gov/viewer/, it seems that raster file is projected as EPSG 5070 – Albers Equal Area Conic Projection in reference to NAD83 Datum.

Most of today's GIS software like QGIS, ArcGIS, and Schlumberger's Petrel can work with geospatial files in different CRS as long as the files are assigned to the correct CRS when being created. When working with files in different CRS, GIS will dynamically convert files to a single CRS which you set up initially (Project CRS) – this is called "projection on the fly". However, "projection on the fly" will consume CPU and memory resources and slow down the computer. Another way is to re-project the geospatial files in other CRS to the Project CRS in advance, and then import them into the GIS project.

In USA, coordinates can be converted between different CRS using NOAA NGS Coordinate Conversion and Transformation Tool (NCAT). Note that latitudes and longitudes are in reference to NAD83 when being used as inputs to NCAT.

9. References

1) EPSG website: www.epsg.io
2) Blue Marble Geographics website: www.bluemarblegeo.com
3) ArcGIS Website: www.arcgis.com
4) Schlumberger Ltd., Petrel Help and Manual, 2018~2021