An ArcGIS Tutorial Concerning Transformations of Geographic Coordinate Systems, with a Concentration on the Systems Used in Lao PDR.

Written by: Emelie Nilsson & Anna-Karin Svensson
### An ArcGIS Tutorial Concerning Transformations of Geographic Coordinate Systems, with a Concentration on the Systems Used in LaoPDR

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Introduction

A geographic coordinate system (GCS) provides a fundamental spatial framework to support the planning and development of a nation. All spatial data has a coordinate system and a GCS is a system that uses a three dimensional spherical surface to define locations on earth.

In Lao PDR there have been several different geographic coordinate systems or “Datums” used, including Indian 1954, Indian 1960, Vientiane Datum 1982, Lao Datum 1993, WGS84 and the new Lao 1997. A GCS is often incorrectly called a datum, but a datum is only one part of a GCS.

When working with GIS or any other activity involving spatial data it is extremely important to understand these different systems and the relationships between them. Poor understanding of these systems will most likely lead to great difficulties to combine data from different sources, difficulties in sharing maps with other centres or divisions within NAFRI, low map accuracy and overall inefficiency. If possible an organisation should try to use one standard geographic coordinate system or datum.

This document is intended to provide the staff at NAFRI the theoretical background about geographic coordinate systems used in Lao PDR as well as with a technical part describing and guiding people how to use the software ArcGIS as a tool to perform transformations.

PART 1, A Theoretical Background about Coordinate Systems

The information in the first four chapters of this document is mainly taken from the book “Understanding Map Projections” written by ESRI 1994-2000.

1.1 Geographic Coordinate Systems

A geographic coordinate system (GCS) uses a three dimensional spherical surface to define locations on the earth. A GCS is often incorrectly called a datum, but a datum is only one part of a GCS. A GCS includes an angular unit of measure, a prime meridian, and a datum (based on a spheroid).

A point is referenced by it’s longitude and latitude values. Longitude and latitude are angles measured from the earth’s center to a point on the earth’s surface. The angles are often measured in degrees (or in grads) (see figure 1).
Figure 1. A point is referenced by it’s longitude and latitude values. Longitude and latitude are angles measured from the earth’s center to a point on the earth’s surface. The angles are often measured in degrees or in grads (ESRI 1994-2000).

In the spherical system, ‘horizontal lines’, or east–west lines are lines of equal latitude, or parallels. ‘Vertical lines’, or north–south lines, are lines of equal longitude, or meridians.

The line of latitude midway between the poles is called the equator. It defines the line of zero latitude. The line of zero longitude is called the prime meridian. For most geographic coordinate systems, the prime meridian is the longitude that passes through Greenwich, England. Latitude and longitude values are traditionally measured either in decimal degrees or in degrees, minutes, and seconds (DMS). Latitude values are measured relative to the equator and range from -90° at the South Pole to +90° at the North Pole. Longitude values are measured relative to the prime meridian. They range from -180° when traveling west, to +180° when traveling east.

The latitude and longitude reference system assumes that the Earth is a perfect sphere. Unfortunately this is not correct. The earth is actually an oblate spheroid with flatter poles (see figure 2). To complicate matters further the surface of earth is far from smooth and regular.

Figure 2. A representation of earth as a sphere or a spheroid. (ESRI 1994-2000).

Ellipsoid models use the major and minor axes of the earth and mathematically account for flattening at the poles (see figure 3).
Figure 3, Ellipsoid models use the major and minor axes of the earth and mathematically account for flattening at the poles (ESRI 1994-2000).

For historical reasons there are several such ellipsoids in use for mapping different countries of the world. Each of these ellipsoids is generally matched to one or several countries. An ellipsoid appropriate for one region of the earth is not always appropriate to other regions (Lao National Geography Department 1997).

Another property is needed to uniquely specify geographical positions. This is the position and orientation of the ellipsoid relative to the earth. The term used to describe this fitting of an ellipsoid to the earth is the geodetic datum. Many geodetic datums exist throughout the world, each usually associated with the national survey of a particular country or continent. More recently several new geodetic datums have been successively derived, from steadily accumulating satellite and other data, to provide for a best worldwide fit.

A local datum aligns it’s spheroid to closely fit the earth’s surface in a particular area. A point on the surface of the spheroid is matched to a particular position on the surface of the earth. This point is known as the origin point of the datum. The coordinates of the origin point are fixed, and all other points are calculated from it. The coordinate system origin of a local datum is not at the center of the earth. The center of the spheroid of a local datum is offset from the earth’s center (see figure 4). Because a local datum aligns its spheroid so closely to a particular area on the earth’s surface, it is not suitable for use outside the area for which it was designed. The Lao national datum 1997 is an example of a local datum, which has a spheroid with a good approximation to the size, and shape of the sea-level surface in the region of Lao PDR.
Figure 4. A local datum aligns its spheroid to closely fit the earth’s surface in a particular area. A point on the surface of the spheroid is matched to a particular position on the surface of the earth. This point is known as the origin point of the datum. The coordinates of the origin point are fixed, and all other points are calculated from it. The coordinate system origin of a local datum is not at the center of the earth. The center of the spheroid of a local datum is offset from the earth’s center (ESRI 1994-2000).

1.2 Projected Coordinate Systems

A projected coordinate system is any coordinate system designed for a flat surface such as a printed map or a computer screen. Whether you treat the earth as a sphere or a spheroid, you must transform its three-dimensional surface to create a flat map sheet. This mathematical transformation is commonly referred to as a map projection. A map projection uses mathematical formulas to relate spherical coordinates on the globe to flat, planar coordinates.

There are three main ways to project a map:

1.2.1 Azimuthal or Planar Map Projections

Planar projections project map data onto a flat surface touching the globe (see figure 5). This type of projection is usually tangent to the globe at one point but may also be secant. The point of contact may be the North Pole, the South Pole, a point on the equator, or any point in between. This point specifies the aspect and is the focus of the projection. The distortion is the smallest at the point of tangent. Planar projections are used most often to map polar regions.

Figure 5. Planar projections project map data onto a flat surface touching the globe (ESRI 1994-2000).
1.2.2 Conical Map Projections
This way to project a map is based on that you place a cone over the globe (Eklundh et al 1999) (see figure 6). The simplest conic projection is tangent to the globe along one line of latitude. This line is called the standard parallel. In general, the further you get from the standard parallel, the more distortion increases.

![Figure 6](image)
*Figure 6, The conical map projection is based on that you place a cone over the globe. The simplest conic projection is tangent to the globe along a line of latitude. This line is called the standard parallel (ESRI 1994-2000).*

Conic projections are mostly used for mid latitude zones that have an east–west orientation, for example Canada. Conic projections can also have contact with two locations on the globe (see figure 7). These projections are called secant projections and are defined by two standard parallels.

![Figure 7](image)
*Figure 7, Conic projections can also have contact with two locations on the globe. These projections are called secant projections and are defined by two standard parallels (ESRI 1994-2000).*

Generally, a secant projection with two standard parallels has less overall distortion than a tangent projection with one standard parallel. An even more complex conic projection is called oblique where the axis of the cone does not line up with the polar axis of the globe.

1.2.3 Cylindrical Map Projections
Like conic projections, cylindrical projections also have tangent or secant cases. There are three main different cylindrical map projections (see figure 8). A normal cylinder projection has a cylinder in which the equator is the line of tangency. A transverse cylinder projection has its tangency at a meridian and an oblique cylinder is rotated around a great circle line, located anywhere between the equator and the meridians. In all cylindrical projections, the line of tangency or lines of secancy have no distortion and thus are lines of equidistance.
Figure 8. There are three main different cylindrical map projections. A normal cylinder projection has a cylinder in which the equator is the line of tangency. A transverse cylinder projection has its tangency at a meridian and an oblique cylinder is rotated around a great circle line, located anywhere between the equator and the meridians (ESRI 1994-2000).

There are three main properties of a map projection related to distortions. Some projections preserve both distances and directions from a single given point. Such projection is called “equidistant”. There are also projections, which preserve directions at any point on the globe. Such projections are called conformal. Finally, there are projections, which preserve area sizes, and they are called “equal area”. However, no projection can possess more than one of the three qualities: conformality, equidistance, and equal-area.

1.2.4 Conformal Projections
A conformal projection shows perpendicular graticule lines intersecting at 90-degree angles on the map and therefore keeps the shape of objects. For example, the angles between two roads should be the same in the map as in reality (Eklundh et al 1999). There are four conformal projections in common use: The Mercator, the Transverse Mercator, Lamberts Conformal Conic with two standard parallels, and the Stereographic Azimuthal Mercator’s Projection (Robinson et al 1995).

1.2.5 Equal-Area Projections
Equal area projections preserve the area of displayed features. This is an important quality if you want to calculate areas (Eklundh et al 1999). In equal area projections, the meridians and parallels may not intersect at right angles like in the conformal projection. In some cases, especially maps of smaller regions, shapes are not obviously distorted, and distinguishing an equal area projection from a conformal projection is difficult unless documented or measured. Commonly used equal-area projections are Albert’s Equal –Area Conic Projection, and Lambert’s Equal-Area.

1.2.6 Equidistant Projections
An equidistant map keeps the distances between certain points. Scale is not maintained correctly by any projection throughout an entire map; however, there are, in most cases, one or more lines on a map along which scale is maintained correctly. Most equidistant projections have one or more lines, for which the length of the line on a map is the same length (at map scale) as the same line on the globe. Keep in mind that no projection is equidistant to and from all points on a map.
1.2.7 True-Direction Projections

The shortest route between two points on a curved surface such as the earth is along the spherical equivalent of a straight line on a flat surface. That is the great circle on which the two points lie. True-direction, or azimuthal, projections maintain some of the great circle arcs, giving the directions or azimuths of all points on the map correctly with respect to the center. Given a reference point A and two other points B and C on a surface, the azimuth from B to C is the angle formed by the minimum-distance lines AB and AC. In other words, it represents the angle one sitting on A and looking at B must turn in order to look at C. The bearing from A to C is the azimuth considering a pole as reference B (see figure 9).

(http://www.progonos.com/furuti/MapProj/CartIndex/cartIndex.html)

![Figure 9](http://www.progonos.com/furuti/MapProj/CartIndex/cartIndex.html)

*Figure 9, Given reference point A, the azimuth remains unchanged from points B and C on the sphere to corresponding B' and C' on an azimuthal map.*

Some true-direction projections are also conformal, equal area, or equidistant.

GIS maps all have a projection associated with them and to undertake meaningful analysis it is necessary to know something about the projections being used. The result of an analysis will be affected in different ways by different map projections. If an application requires an accurate area calculation, an equal-area projection should be used (Heywood et al 2002).

Today there is a wide range of map projections used in different parts of the world depending on both the areas appearance and the projects application.

1.3 Projection Parameters

A map projection by itself is not enough to define a projected coordinate system. You can state that a dataset is in Transverse Mercator, but that is not enough information. Where is the center of the projection? Was a scale factor used? Without knowing the exact values for the projection parameters, the dataset cannot be reprojected. Each map projection has a set of parameters that you must define. The parameters specify the origin and customize a projection for your area of interest. Linear parameters use the projected coordinate system units, while angular parameters use the geographic coordinate system units.
1.3.1 Linear Parameters

**False easting**: A linear value applied to the origin of the x-coordinates, which is usually applied to ensure that the coordinate is positive.

**False northing**: A linear value applied to the origin of the y-coordinates, which is usually applied to ensure that the coordinate is positive.

**Scale factor**: A unit less value applied to the center point or line of a map projection to minimize the absolute distortion across the zone. The scale factor is usually slightly less than one. The UTM coordinate system, which uses the Transverse Mercator projection, has a scale factor of 0.9996. Rather than 1.0, the scale along the central meridian of the projection is 0.9996. This creates two almost parallel lines approximately 180 kilometers away, where the scale is 1.0. The scale factor reduces the overall distortion of the projection in the area of interest.

1.3.2 Angular Parameters

**Azimuth**: Defines the centerline of a projection.

**Central meridian**: Defines the origin of the x-coordinates.

**Longitude of origin**: Defines the origin of the x-coordinates. The central meridian and longitude of origin parameters are synonymous.

**Central parallel**: Defines the origin of the y-coordinates.

**Latitude of origin**: Defines the origin of the y-coordinates. This parameter may not be located at the center of the projection. In particular, conic projections use this parameter to set the origin of the y-coordinates below the area of the interest. In that instance, you do not need to set a false northing parameter to ensure that all y-coordinates are positive.

**Longitude of center**: Used with the Hotine Oblique Mercator Center (both Two-Point and Azimuth) cases to define the origin of the x-coordinates. Usually synonymous with the longitude of origin and central meridian parameters.

**Latitude of center**: Used with the Hotine Oblique Mercator Center (both Two-Point and Azimuth) cases to define the origin of the y-coordinates. It is almost always the center of the projection.

**Standard parallel 1 and standard parallel 2**: Used with conic projections to define the latitude lines where the scale is 1.0. When defining a Lambert Conformal Conic projection with one standard parallel, the first standard parallel defines the origin of the y-coordinates. For other conic cases, the y-coordinate origin is defined by the latitude of origin parameter.

The four parameters below are used with the Two-Point Equidistant and Hotine Oblique Mercator projections. They specify two geographic points that define the center axis of a projection.
1.4 Geographic Coordinate System Transformations

The geographic coordinates of a point depend on the datum to which they are related. The latitude, longitude and height of a point defined on datum “1” (for example, Lao National Datum 1997) will almost certainly be different to the latitude, longitude and height for the same point defined on datum “2” (for example, WGS84). The difference has to do with that the ellipsoids of the datums are positioned or oriented differently or they may differ in size. Coordinates can be transformed from one datum to another. This requires that the relationship between them is known.

There are several methods of transformations, which have different characteristics, and different levels of accuracy. Some methods first convert the geographic coordinates to geocentric/cartesian (X,Y,Z), then transform the X,Y,Z and finally convert the new values back to geographic coordinates.

Conversion-Geographic to Cartesian

The formulae for converting latitude, longitude and spheroidal height to X, Y, Z are

\[
X = (N+h) \cos \phi \cos \lambda \\
Y = (N+h) \cos \phi \sin \lambda \\
Z = \left(\frac{b^2}{a^2}N+h\right) \sin \phi
\]

Where:
- X, Y and Z are the Cartesian coordinates of the point
- \(\phi, \lambda\) are the latitude, longitude of the point
- h is the height of the point above the spheroid
- a, b are the lengths of the semi-major and semi-minor axes of the spheroid
- N is the radius of curvature in the prime vertical

\[
N = \frac{a^2}{\sqrt{a^2 \cos^2 \phi + b^2 \sin^2 \phi}}
\]
Other methods convert geographic coordinates directly.

The simplest transformation involves applying shifts to three geocentric coordinates (Three-parameter method). The geocentric transformation models the differences between the two datums in the X, Y and Z coordinate system (see figure 10).

A more complex and accurate datum transformation is the Seven-parameter method or Helmert transformation.
This method uses seven geocentric coordinates with three linear shifts ($\Delta X$, $\Delta Y$, $\Delta Z$), three angular rotations around each axis ($r_x$, $r_y$, $r_z$) (see figure 11) and scale factors ($s$).

![Three angular rotations around each axis ($r_x$, $r_y$, $r_z$) (ESRI 1994-2000).](image1)

Another method that converts the geographic coordinates directly is the **Melondensky method**. The Melondensky method requires three shifts ($\Delta X$, $\Delta Y$, $\Delta Z$) and the differences between the semi major axes ($\Delta a$) and the flattening ($\Delta f$) of the two spheroids (see figure 12). Both this method, and the three parameters method above assume that the axes of the source and target systems are parallel to each other. This assumption may not be true and consequently these transformation methods result in only moderate accuracy, especially if applied over larger areas (www.posc.org).

$$
(M + h)\Delta \varphi = -\sin \varphi \cos \lambda \Delta Y - \sin \varphi \sin \lambda \Delta Y \\
+ \cos \varphi \Delta Z + \frac{e^2 \sin \varphi \cos \varphi}{(1 - e^2 \sin^2 \varphi)^{1/2}} \Delta a \\
+ \sin \varphi \cos \varphi \left(\frac{a}{b} + N \frac{b}{a}\right) \Delta f
$$

$$
(N + h) \cos \varphi \Delta \lambda = -\sin \lambda \Delta X + \cos \lambda \Delta Y \\
\Delta h = \cos \varphi \cos \lambda \Delta X + \cos \varphi \sin \lambda \Delta Y \\
+ \sin \varphi \Delta Z - (1 - e^2 \sin^2 \varphi)^{1/2} \Delta a \\
+ \frac{a(1 - f)}{(1 - e^2 \sin^2 \varphi)^{1/2}} \sin^2 \varphi \Delta f
$$

$h$ ellipsoid height  
$\varphi$ latitude  
$\lambda$ longitude  
a semi major axis of the spheroid (meters)  
b semi major axis of the spheroid  
f flattening of the spheroid  
e eccentricity of the spheroid  

$M$ is the meridional radii of curvature at a latitude  
$N$ is the prime vertical radii of curvature at a given latitude
An even more complex transformation method is a Polynomial Transformation also called rubber sheeting. This method uses polynomials of varying orders. The number of parameters needed is rising fast when the level of polynomial increase. The degree of complexity of the polynomial is expressed as the order of the polynomial. First order polynomial results in a linear transformation while a second order or higher results in a non-linear transformation. The higher the order of the polynomial, the better the fit, but the result can contain more curves between the points than the base image (see figure 13).

First order polynomial:
\[ p(x) = b_0 + b_1x \]

Third order:
\[ p(x) = b_0 + b_1x + b_2x^2 + b_3x^3 \]

Forth order:
\[ p(x) = b_0 + b_1x + b_2x^2 + b_3x^3 + b_4x^4 \]

\( p(x) \) is the calculated polynomial and \( b_0, b_1, \ldots, b_k \) is the coefficients that are going to be determined.

1.5 Coordinate Systems “Datums” used in Lao PDR, and there Relationships and Parameters

There have been several different datums used in Laos. To be able to transform from one system to another the parameters of the datums and the relationship between them needs to be known.

The following chapter will therefore present the parameters and relationship of the most commonly used systems in Lao PDR, which is directly taken from the compendium “The Lao National Datum 1997” (National Geography Department of Lao PDR 1997).
1.5.1 The Lao National Datum 1997, Definition and Parameters

Spheroid          Krassovsky (\(a = 6378245.000, \ b = 6356863.018\))
Origin Station    Vientiane (Nongteng) Astro Pillar (36201)
Latitude          \(N 18° 01' 31.3480''\)
Longitude         \(E 102° 30' 57.1367''\)
Spheroidal Height 223.824 meters

Note:
- The latitude and longitude of the origin station are derived from the 1982 Soviet astronomic observation, which defined the Vientiane (1982) datum. The 1982 observations were taken at the original Nongteng ground mark rather than the newer astro pillar.

The original ground mark still exists but is surrounded by the structure of a tower, making it unsuitable for GPS observations. The astro pillar, which is approximately 15 meters from the original mark, has been connected to the original stations. Vientiane datum (1982) coordinates have been calculated for the astro pillar and adopted as the Lao National Datum 1997 origin values.

- The spheroidal height has been defined as being equal to the mean sea height for the station. The geoid-spheroid separation at Vientiane (Nongteng) Astro Pillar is therefore zero.

- The Cartesian coordinate axes of the Lao National Datum (1997) are defined as being parallel to those of WGS84.

1.5.2 Parameters for WGS84, and the Relationship to Lao National Datum 1997

WGS84 coordinates for stations in Laos have been derived using GPS technology and a series of 25 GPS point positions were observed, at network stations distributed throughout the country.

The WGS84 coordinate values for Vientiane (Nongteng) Astro Pillar are as follows.

Spheroid          GRS80 (\(a = 6378137.000, \ b = 6356752.314\))
Latitude          \(N 18° 01' 31.56303''\)
Longitude         \(E 102° 30' 56.62368''\)
Spheroidal Height 188.851 meters

The transformation parameters to be added to Lao national datum 1997 Cartesian coordinates to produce WGS84 Cartesian coordinates are:

\[\Delta X = +44.585 \text{ meters}\]
\[\Delta Y = -131.212 \text{ meters}\]
\[\Delta Z = -39.544 \text{ meters}\]
To transform WGS84 coordinates to Lao National Datum 1997, reverse the signs on the three transformation parameters before applying.

The Global Positioning System GSP generates positions in WGS84 coordinate system. These GPS point coordinates will have a significant difference compared to Lao 1997 coordinates and a transformation is usually needed. There is one exception from this:

GPS baselines, which are output as XYZ vectors, may be directly used in conjunction with Lao National datum 1997 Cartesian coordinate if the vector is in XYZ format. Any vector expressed in terms of latitude, longitude and height must go through a transformation process. The direct use is possible because the axes of the Lao datum are parallel to those of the WGS84 system.

1.5.3 Parameters for Vientiane Datum 1982, and the Relationship to Lao National Datum 1997

The Vientiane Datum 1982 was established to support survey work undertaken in cooperation with the Soviet Union. It is defined by the following parameters:

<table>
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<th>Parameter</th>
<th>Value</th>
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<tr>
<td>Spheroid</td>
<td>Krassovský ( a = 6378245.000, b = 6356863.018 )</td>
</tr>
<tr>
<td>Origin Station</td>
<td>Vientiane (Nongteng)</td>
</tr>
<tr>
<td>Latitude</td>
<td>( N 18° 01' 31.6301'' )</td>
</tr>
<tr>
<td>Longitude</td>
<td>( E 102° 30' 56.6999'' )</td>
</tr>
<tr>
<td>Spheroidal Height</td>
<td>223.56 meters</td>
</tr>
</tbody>
</table>

Note:
- The latitude and longitude of the origin station are derived from the 1982 Soviet astronomic observation. The spheroidal height has been defined as being equal to the mean sea height for the origin station. The geoid-spheroid separation at Vientiane (Nongteng) Astro Pillar is therefore zero.
- The transformation parameters to be added to Lao National Datum 1997 Cartesian coordinates to produce Vientiane datum 1982 Cartesian coordinates are:

\[
\Delta X = +2.227 \text{ meters (Standard Error } = 0.79 \text{ meter)} \\
\Delta Y = -6.524 \text{ meters (Standard Error } = 1.46 \text{ meter)} \\
\Delta Z = -2.178 \text{ meters (Standard Error } = 0.79 \text{ meter)}
\]

To transform Vientiane Datum 1982 coordinates to Lao National Datum 1997, reverse the signs on the three transformation parameters before applying.

Note:
- The horizontal displacement between the two coordinate systems is approximately 3 meters. This is insignificant at map scales of 1:5000 or smaller. The existing 1:100 000 and 1:250 000 topographic mapping provided under technical assistance from the Soviet Union are therefore unaffected.
• The parameter generation assumed that Vientiane Datum 1982 spheroidal heights were the same as mean sea level height in all parts of Laos. As this assumption is incorrect, extreme caution should be exercised when interpreting transformed height information.

1.5.4 Parameters for Lao Datum 1993, and the Relationship to Lao National Datum 1997
This system was created in 1993 following completion of a national GPS survey in cooperation with Socialist Republic of Vietnam. It is defined as follows.

Spheroid       Krassovsky (a = 6378245.000, b = 6356863.018)
Origin Station Pakxan (35203)
Latitude       N 18° 23’ 57.00560”
Longitude      E 103° 38’ 41.80200”
Spheroidal Height 177.600

Note.
• The latitude and longitude of the origin station are derived from the 1982 Soviet astronomic observation.

• The spheroidal height has been defined as being equal to the mean sea height for the station. The geoid-spheroid separation at Pakxan is therefore zero.

The transformation parameters to be added to Lao national Datum 1997 Cartesian coordinates to produce Lao Datum 1993 Cartesian coordinates are.

\[\Delta X = +0.652 \text{ meters (Standard Error = 0.15 meter)}\]
\[\Delta Y = -1.619 \text{ meters (Standard Error = 0.15 meter)}\]
\[\Delta Z = -0.213 \text{ meters (Standard Error = 0.15 meter)}\]

To transform the Lao Datum 1993 coordinates to Lao National Datum 1997, reverse the signs on the three transformation parameters before applying.

• The horizontal displacement between the two coordinate systems is approximately 0.8 meters. This is insignificant at map scales of 1:2 000 or smaller.

1.5.5 Parameters for Indian Datum 1954, and the Relationship to Lao National Datum 1997
The Indian datum was introduced to Lao PDR in 1967/68. Its purpose was to support survey for a hydropower project on the Mekong River. The datum is believed to have been an extension of the Thai datum at that time. It appears only to have been used in the vicinity of Vientiane.

There is no specific origin station for the datum but it’s spheroid is:

\text{Everest 1830 (a = 6377276.345, b = 6356075.413)}
In the vicinity of Vientiane, the transformation parameters to be added to Lao National datum 1997 Cartesian coordinates to produce Indian Datum 1954 Cartesian coordinates are:

\[
\begin{align*}
\Delta X &= -168.711 \text{ meters (Standard Error} = 0.034 \text{ meter)} \\
\Delta Y &= -951.115 \text{ meters (Standard Error} = 0.034 \text{ meter)} \\
\Delta Z &= -336.164 \text{ meters (Standard Error} = 0.034 \text{ meter)}
\end{align*}
\]

To transform Indian datum 1954 coordinates to Lao National Datum 1997, reverse the signs on the three transformation parameters before applying.

**Note:**
- The effect of the transformation is very large on all mapping scales up to 1:1 000 000 (approximately 400 meters in horizontal position). Map users in the Vientiane area should exercise caution.
- The transformation parameters are not valid outside the Vientiane area.

**1.5.6 Parameters for Indian Datum 1960, and the Relationship to Lao National Datum 1997**

This datum is understood to have been extensively used to support U.S. sponsored 1:50 000 mapping between 1963 and 1975. France established the mapping utilised control in 1902. However it is not clear whether France originated the Indian Datum 1960 or whether the control values were recomputed by other agencies.

It is considered unlikely that any French control marks still exist. Consequently, it has not been possible to compute new transformation parameters as part of the Lao National Datum Project. Parameters relating Indian Datum 1960 to WGS84 have been obtained from the U.S. National Imagery & Mapping Agency (NIMA).

They have been combined with the parameters relating Lao National datum 1997 to WGS84 to provide the following estimates:

The spheroid used is:

**Everest 1830 (a = 6377276.345, b = 6356075.413)**

The transformation parameters to be added to Lao National datum 1997 Cartesian coordinates to produce Indian Datum 1960 Cartesian coordinates are:

\[
\begin{align*}
\Delta X &= -153 \text{ meters} \\
\Delta Y &= -1012 \text{ meters} \\
\Delta Z &= -357 \text{ meters}
\end{align*}
\]

The accuracy of these parameters is unknown. To transform Indian Datum 1960 coordinates to Lao National Datum 1997, reverse the signs on the three transformation parameters before applying.
Note:
- The effect of the transformation is very large on all mapping scales up to 1:100 000 (approximately 400 meters in horizontal position). Map users should exercise caution.

PART 2, ArcGIS as a Tool to Transform Between Different Coordinate Systems

Before you start to transform any data to a chosen coordinate system, each data layer needs to have a defined coordinate system. The reality while working with Geographical Information Systems (GIS) is often that the layers are not defined at all and that no metadata exist. Most of the time, this has nothing to do with that the layer is missing a coordinate system, but rather that the producer of the data either forgot to define the system or did not have the knowledge to do so.

2.1 Determining if the Data Layers Have a Defined Coordinate System

To determine if the data layers have been defined already, can be done in different ways and we will present two of them.

1. Start by opening ArcCatalog, which you find as an icon under ArcGIS.
2. Click your way until you find the data layers of interest. Mark one data layer at the time and click the metadata button.

3. In the metadata window click the Spatial tab. Now the spatial information is shown, and in this case, the layer is already defined to Lao97_UTM_Zone_48N. If there is no information written about the coordinate systems it means that you have to define it before transforming the layer.
There is also another way to distinguish if the layer has a defined coordinate system.

1. Open ArcMap which you find as an icon under ArcGIS.

Choose to open a new empty map and click OK.

2. Add your data of interest by marking the plus sign or choose add data under the file menu.

3. Right click on the data frame icon and choose properties > coordinate systems. Look in the bottom window and mark layers. Now you will see all the layers and by clicking on each of them you can distinguish if they have a defined coordinate system or not. In this example the layer “river2” does not have one, and therefore is defined as unknown.
2.2 How to Define a Coordinate System

2.2.1 Defining a Shapefile's Coordinate System

1. Open ArcToolbox, which you find as an icon under ArcGIS.

2. Click Data Management Tool > Projection > Define Projection Wizard (shapefiles, geodatabase).

3. Click the shapefile whose coordinate system you want to define. If there are many layers that you want to define to the same system you can add more than one.
4. Click Next > Select Coordinate System and this window will appear. Here you have a choice of selecting a, by ArcGIS already defined coordinate system, importing a system from an existing shapefile or geodataset, or create a new coordinate system.

5. We will start by selecting a predefined coordinate system. This time we know that the layer is in Indian 1960, with Everest ellipsoid and in UTM zone 48. Therefore we click on Projected coordinate system > UTM > Other GCS and choose Indian 1960 UTM zone 48. Sometimes it is difficult to find the coordinate system you are looking for, which means that you have to go through each folder. Click the add button or simply double click on the system. The same window as before will appear, but now with the chosen coordinate system.

6. Click Apply > OK > Next and finally Finish.
Now we will create a new coordinate system.

1. Do like before open ArcToolbox, click on Data Management Tool > Projection > Define Projection Wizard (shapefiles, geodatabas). Choose the shapefile whose coordinate system you want to define. If there are many layers that you want to define to the same system you can add more then one.

2. Click on the tab New. This time we know that the layer of interest is in Lao National Datum 1997 but the layer is not defined, and this system does not exist within ArcGIS. This means that we have to create a new projected coordinate system by ourselves. This is simply done by using the information given in PART 1 of this document.

3. Start by giving the system a name, for example Lao97_UTM_Zone_48N. Choose the Transverse Mercator as the projection and fill in the parameters. Universal Transverse Mercator UTM is a global implementation of the Transverse Mercator Projection and is divided into 60 zones. Lao PDR lies in UTM zone 47N and 48N and for this layer zone 48 is the correct one (see figure 14).

Figure 14, Universal Transverse Mercator UTM is a global implementation of the Transverse Mercator Projection and is divided into 60 zones. Lao PDR lies in UTM zone 47N and 48N. Each UTM zone is 6° wide and the meridian at its center is referred to as the Central Meridian (http://www.Colorado.edu/geography/gcraft/notes/coordsys/gif/utmzones.gif).
Each UTM zone is 6° wide and the meridian at its center is referred to as the Central Meridian. The point of intersection between the Equator and the Central Meridian is assigned the coordinates:

**East:**  500 000.000 meters  
**North:**  0.000 meters  
**Central meridian:** 105.0°

A scale factor of 0.9996 is applied to all grid distances to minimize the absolute distortion across the zone.

Choose linear unit meter. Click on Select > Geographic Coordinate System. Choose spheroid based and "Krassovsky 1940". Click Apply > OK > Next and finally Finish.

Now you have defined your data layer to Lao National Datum 1997. If you are unsure about the spheroid numbers given by ArcGIS look at chapter, 1.5 Coordinate systems “Datums” used in Lao PDR, there relationships and parameters.
If you have already existing layers with a given coordinate system you can use that layer to define other layers. In that case click the button Import.

### 2.2.2 Defining a Coverage, Grid or TIN's Coordinate System

1. Open ArcToolbox, which you find as an icon under ArcGIS.

2. Click Data Management Tool > Projection > Define Projection Wizard (coverage, grid or TIN).

3. Choose either to define the coordinate system interactively or to match an already existing file. Click Next.

4. Choose a projection and enter the proper parameter values for the coordinate system; each one has a different set of parameters.

5. Choose the datum or spheroid that applies to your dataset. Click Next and Finish.

**Note:**
ArcGIS does not have a tool to define your own coordinate system for a coverage, grid or TIN. This means that you have to choose from the given list of system or use an already defined coverage, grid or TIN to match your data.
2.3 Transformations

There are different ways within ArcGIS to make transformations between coordinate systems.

2.3.1 On the Fly Transformations

One way to transform data is to make what is called an “On The Fly Transformation”. An On the Fly Transformation is done in ArcMap.

1. Open ArcMap and click on Data Frame > Coordinate Systems. Here you can define the data frame to a specific coordinate system.

2. Click for example, Projected Coordinate System > UTM > WGS84 Zone 48N. Click Apply > OK. Now the dataframe will be defined as WGS84 Zone 48N and all the layers that you add, or that already are open, will automatically be transformed to this chosen system.

The transformation is not permanent, and if you look at each individual data layer’s properties, the original coordinate system is still there, even though a transformation was done.
On the Fly Transformations are also automatically done as follows.

1. Close the dataframe you just defined and open a new one Insert > Dataframe. Add any data that is defined. We will add a layer in Lao 1997. This layer will automatically define the whole data frame to be Lao 1997 and the next data layer we open will automatically be transformed to this system. This transformation is not permanent either, and if you look at each individual data layers properties the original coordinate system is still there, even though a transformation was done.

Note:
Personally we think that this “On the Fly Transformation Function” within ArcGIS has many downsides. First of all the transformation is most often done without the users knowledge. Secondly, it is difficult to evaluate the accuracy of the transformation since the methods used are undefined in the program. Thirdly, the “On the Fly Transformations” we did were less accurate in comparison with the real transformations within “ArcToolbox Project Wizard”. Fourthly, if one of the layers has an undefined reference system in ArcGIS, for example Lao 1997, which has to be defined by the user, a transformation still occurs but this transformation is not correct since the transformation parameters are unknown within the system. To summarize we think that “On the Fly Transformations” should be used with cautions.

2.3.2 Transformation using ArcToolbox Project Wizard

1. Open ArcToolbox.

2. Click on Data Management Tool > Projections.

3. Here you can choose between transforming a coverage/grid or shapefile/geo database depending on if you have a vector or raster file. In our case we mostly had shape files, therefore we will show you an example of that so click on projection wizard shape files.
4. Click on the shapefile that you want to transform. If there are many layers that you want to transform to the same system you can add more than one. We choose the layer laoroad with the system Indian 1960, which we are going to transform to Lao 1997.

![Project Wizard (shapefiles, geodatabase)](image1.png)

5. Create a new name for the layer and choose a destination and click Next.
6. Click on the select coordinate system button. At the Spatial Reference Properties you have a choice of selecting a by ArcGIS already defined coordinate system, importing a system from an existing shapefile or geodataset, or create a new coordinate system.

7. Because we already have a layer, which we defined as Lao 1997, we can use the parameters from that layer. Click on Import. If an already defined layer is not existent you can choose to create a new coordinate system or in some cases select a by ArcGIS predefined coordinate system. Click Apply and OK.
8. Click next. At the step “Select the geographic transformation” a sad smiley face appeared. Click set transformation.

9. Now the Geographic Coordinate System Transformations window appear which shows that a transformation will be done from Indian 1960 to Lao97. However, because the Lao 1997 is not a predefined coordinate system within ArcGIS we have to specify the transformation parameters. Click the button New.
10. At this step you have to choose the transformation method as well as specifying the X, Y and Z parameters. We will choose the Geocentric Three Parameters Transformation since we only have three parameters. The parameters needed to be used to transform from Indian 1960 to Lao 1997 is defined earlier in his document under 1.5.6 Parameters for Indian Datum 1960, and the Relationship to Lao National Datum 1997.

Insert the parameters and press OK.

\[ \Delta X = 153 \text{ meters} \]
\[ \Delta Y = 1012 \text{ meters} \]
\[ \Delta Z = 357 \text{ meters} \]

11. A happy face appears click Next > Next and Finish. The transformation is finished and your resulting file is in Lao 1997.
2.3.3 Using Georeferencing as a way to Geocorrect Data

Nearly all data comes from an already defined data source, for example a layer can have been created through digitizing over an already existing map. When doing so, the new digitized layer should be given the same coordinate system as the map used for digitizing. Example of data with no coordinate systems is “raw” satellite imagery or scanned data layers, which have to be geo-corrected. Geo-correction is a procedure when you fit points in your satellite imagery or scanned map to known points or points in an already defined data layer. You can also use geo-correction as a kind of transformation method, if it is totally impossible to know what coordinate system your layer has. However, this requires that you can identify the exact points within two layers.

The basic procedure for georeferencing is to move the raster into the same space as the target data by identifying a series of ground control points of known x,y coordinates that link locations on the raster with locations in the target data in map coordinates. A combination of one control point on the raster and the corresponding control point on the target data is called a link. Ideally the ground control points should be as small as a single pixel. Examples of places to find control points are road intersections, water bodies, rivers, edges of land cover parcels, and similar features.

The number of links you need to create, depends on the method you plan to use to transform the raster to map coordinates. However, adding more links will not necessarily yield a better registration. If possible, you should spread the links out over the entire raster rather than concentrating them in one area. Typically, having at least one link near each corner of the raster and a few throughout the interior, produces the best results.

When you have created enough links, you can transform or warp the raster to map coordinates. Warping uses a mathematical transformation to determine the correct map coordinate location for each cell in the raster.

The degree to which the transformation can accurately map all control points can be measured mathematically by comparing the actual location of the map coordinate to the transformed position in the raster. The distance between these two points is known as the residual error. The total error is computed by taking the root mean square (RMS) sum of all the residuals to compute the RMS error. This value describes how consistent the transformation is between the different control points.

While the RMS error is a good assessment of the accuracy of the transformation, do not confuse a low RMS error with an accurate registration. The transformation may still contain significant errors, for example, due to a poorly entered links. Bernstein et al (1983) recommend that 16 links may be a reasonable number if each can be located with an accuracy of 1/3 of a pixel. This number may not be sufficient if the links are poorly distributed, or if the nature of the landscape prevent accurate placement.
Georeferencing a Raster

1. Open ArcMap.
2. Add the raster you want to georeference as well as the layer containing the coordinates you want to use to create the link.
3. Click on view > Toolbar and add georeferencing. Now the georeferencing toolbar appears.
4. From the Georeferencing toolbar, click the layer dropdown arrow and click the raster layer you want to georeference.
5. Click the Control Points button to add control points.
6. To add a link, click the mouse pointer over a known location on the raster, then over a known location on the target data. You may find it useful to use a magnification window to add your links in.
7. Add enough links for the transformation order. You need a minimum of three links for a first-order transformation, six links for a second order, and 10 links for a third order.
8. Click View Link Table to evaluate the transformation. You can examine the residual error for each link and the RMS error. If you're satisfied with the registration, you can stop entering links.
9. Click Georeferencing and click Update Georeferencing to save the transformation information with the raster. This creates a new file with the same name as the raster but with an .aux file extension.

While you might think each cell in a raster is transformed to its new map coordinate location, in reality the process works in reverse. During georeferencing, a matrix of "empty" cells is computed in map coordinates. Then, each cell is given a value based on a process called resampling. The three most common resampling techniques are nearest neighbor assignment (see figure 15), bilinear interpolation (see figure 16), and cubic convolution (see figure 17). These methods assign a value to each empty cell by examining the cells in the untransformed raster. Nearest neighbor assignment takes the value from the cell closest to the transformed cell as the new value. It is the fastest resampling method and is appropriate for categorical, or thematic data, for example a land use map.

Bilinear interpolation and cubic convolution techniques combine a greater number of nearby cells (4 and 16, respectively) to compute the value for the transformed cell. These two techniques use a weighted averaging method to compute the output transformed cell value and thus are only appropriate for continuous data such as elevation, slope, and other continuous surfaces.
Figure 16 and 17, Bilinear interpolation and cubic convolution techniques combine a greater number of nearby cells (4 and 16, respectively) to compute the value for the transformed cell (Campbell 1996).

Resampling

1. Click on georeferencing on the georeferencing toolbar and on rectify. Choose location and name and the resample type to be used. Click OK.

3. Conclusions and Advice Concerning Work with Geographical Data and Transformations

Something very important while working with any type of digital data is to always have a backup copy of the data you are using. The backup is a copy of the original data before any manipulations were made. This copy can be very useful since all transformations or manipulations lower the accuracy of the data. Therefore it is not recommended to, for example transform already transformed data but to use the original. If further manipulations are required for the analysis it is a good idea to make backup copies, every so often, in case anything happens to the computer and the data. This way less work will be lost.

Metadata it data about data and is used as support information for geographical data. It is a documentation that describes the contents of the data and is essential for future users (Eklundh et al 1999). Metadata for any type of geographical data should contain:

- Thematic contents including for example land use classes.
- The name of the data set.
- If each layer only contains one type of geometrical elements this can be included.
- Geographical region.
- Map of origin.
- Covered area in longitude and latitude.
- Reference system and coordinate system.
- Name of the projection.
- Parameters, ellipsoid.
- A complete description of the thematic contents.
- The origin of the data e.g. field data, origin map.
- Originator.
- Organisation.
- Availability
- Production date.
- Name and address to a contact person.
- Accuracy.
- A list of what has happened to the data from when it was created to the last manipulation done to it, all transformations, interpolations and so on.

Raster data should also contain information about.

- Number of columns.
- Number of rows.
- Cell size.

To avoid problems when working with digital data it is vital to always directly update the metadata simultaneously.

The accuracy of a data set is very important. A map is not an exact description of the real world. It involves assumptions and estimations. In a village layer for example, the villages might have a different geographic coordinates in the reality compared to the coordinates on the map. Accuracy is usually a number represented in percentile and is a measure of the closeness or nearness of the true location. To be able to prove anything statistically when doing an analysis or at all to be able to say how correct something is you have to know the accuracy of it.

When transforming data the most basic thing is to know which reference system the data is in and which system you want to transform the data into. If you do not know this there is a number of ways to try to find out.

1. If you have both data in a known reference system and data in an unknown system, you can easily compare this data. However it depends on what type of data the layer contains. If both layers show for example rivers over the same area it is rather easy to see if they match. On the other hand if one layer contains a district boundary and the other contains rivers over a much larger area it is impossible to compare the two.

If you have a match after the comparison you can assume that your unknown layer is in the same system as your known.

2. Trial and error. If you have some data in a known reference system and some in an unknown system, you can transform the unknown data to the known system and see if it matches. To do this you first need to define a system for the unknown data. There is a large number of reference systems in the world so to make this task easier, find out which systems are the most commonly
used within your region. In Lao PDR for example, Gauss Krüger is a commonly used system with a false easting of 18 000 000 meters. It is the only system with such a large false easting and therefore it is possible to assume that all layers with this false easting are in Gauss Krüger. Based on that assumption you can define your layer and transform it to your known system. If you have a match, your assumption was probably right. If not, try defining it as another system.

3. If you have no data in a known system an alternative is to visit the National Geographic Department and ask them for some data to compare with. They have data in a number of known reference systems.

If transformation parameters for transformation between different reference systems do not exist predefined in ArcGIS, it is possible to find them in other places. The National Geographic Department (NDG) has transformation parameters for the most common transformations in Laos. Other transformation parameters can be found on the world wide web for example at http://www.epsg.org/.

4. References


