Aligning Local Transverse Mercator (LTM) Grids with UTM Grids such as the Papua New Guinea Map Grid (PNGMG)

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Introduction

One of the main limitations of Universal Transverse Mercator (UTM) grid projections such as the Papua New Guinea Map Grid (PNGMG), Australian Map Grid (AMG) and Map Grid Australia (MGA) is the large scale factor (*k*) at the edges and centre of each grid zone. These large scale factors arise from distortion due to the curvature of the Earth (Figure 1).

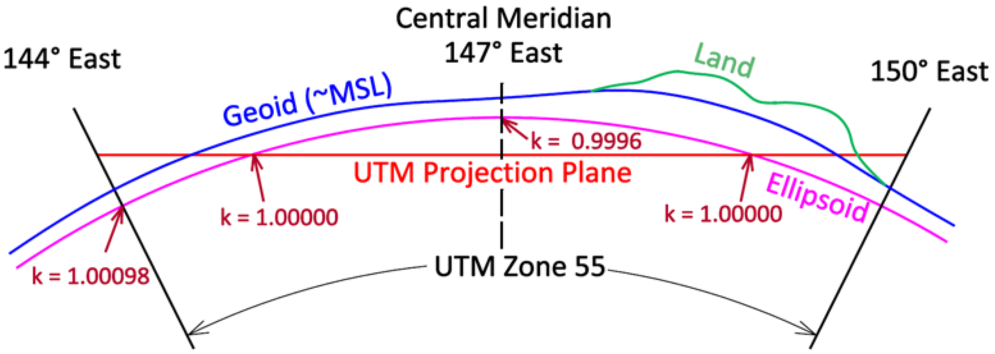

Figure 1. Schematic cross-section of a UTM grid zone showing scale factor (*k*) variation (e.g. Zone 55)

Scale factor variations depend upon the location within the grid zone, the elevation of the survey above sea level (approximated by the geoid) and to a lesser extent, the geoid-ellipsoid separation (n value). In the example below (Figure 2), a horizontal distance of 1000.463 metres is measured in the PNG Highlands to provide control for an LNG processing facility. Dimensional tolerances of 1:20,000 are described in tender specifications (so on a line of 1000.463 metres, a precision of better than 50 mm is required). Because of the high elevation, the equivalent distance at sea level (MSL) is actually 1000.212 metres after the sea-level (height) scale factor applied. Sea level (approximated by the geoid) sits up 80 metres above the reference ellipsoid in PNG, so the equivalent ellipsoidal distance is 1000.200 metres. At the location in question, the average grid scale factor is 0.9998, so the actual grid distance is 1000.000 metres. If the plant designers are using UTM, the effect of the scale factor exceeds the dimensional tolerances by almost a factor of ten if a local site grid is not used. Users beware!!

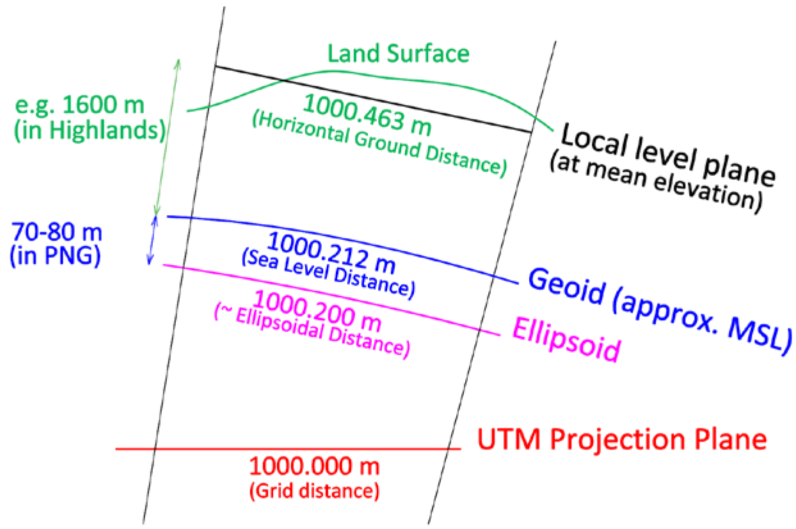

Figure 2. Effect of scale factors on distances

UTM aligned Local Transverse Mercator (LTM) Grids

With the exception of geodetic control and mapping surveys, scale factors of grid systems should be close to unity (*k* = 1.0000000) so that ground distances in the local horizontal plane are identical to those in the grid system within the required tolerances for surveys using the grid. This is particularly the case for cadastral and precision engineering surveys, where dimensional tolerances may be very high (e.g. better than 1:20,000). Strictly speaking, it is practically impossible to parameterise a plane grid free of distortion unless the projection surface is continuously coincident with the ground, however, careful design of a local grid system can minimise scale differences.

The optimal projection systems for different shaped localised areas are as follows:

Square or circular:	Stereographic (flat plane)
Long (East-West):	Lambert Conformal Conic (with two standard parallels)
Long (North-South):	Transverse Mercator

The most widely used projection system is Universal Transverse Mercator (UTM) which divides non-polar regions of the world into sixty 6° wide zones. In Papua New Guinea, UTM projections have been adopted for use with the older AGD66 datum (projection is called AMG66) and the current datum, PNG94, where the map projection is referred to as PNGMG94.

Bearings in projections other than UTM, however, will not be coincident with UTM/PNGMG grid bearings because the UTM projection surface is usually not parallel with the projection plane. A UTM/PNGMG aligned LTM Grid can be realised by scaling the UTM/PNMG projection plane so that it is coincident with the mean elevation an LTM within defined limits (Figure 3).

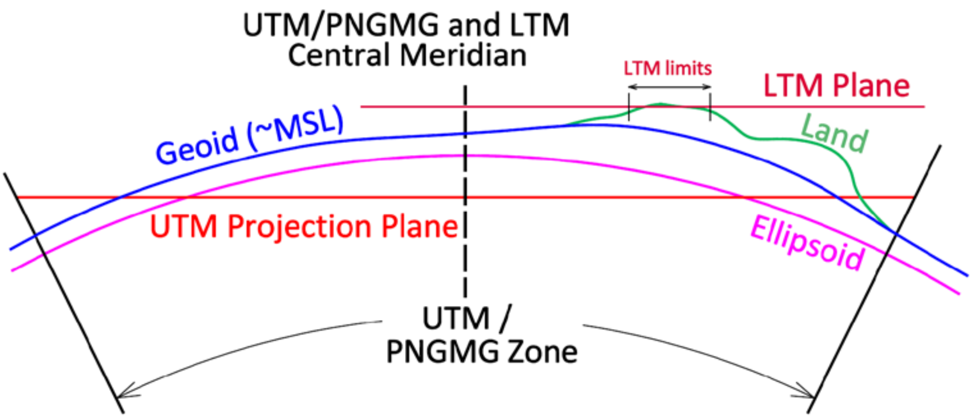

Figure 3. A UTM aligned LTM grid plane

The local origin is typically close to the mean Easting of the area of coverage. The local datum plane origin is typically the mean elevation of the coverage area (and not necessarily at ground level at the origin). If the LTM grid and parent UTM/PNGMG zone share the same longitude origin (longitude of the central meridian) then grid bearings in the two systems will be identical.

This paper shows how an LTM projection, aligned with a UTM projection such as PNGMG94 and AMG66 can be computed and setup in a GNSS system such as RTK to enable GNSS methods to be used for positioning within a local grid system.

Limitations of GNSS site calibrations used to define a local grid

At present, the most common way for a local plane grid to be defined is by means of a site calibration (also called localisation or site transformation). Local site calibration involves surveying a number of existing survey control stations within a local project area using GNSS RTK equipment. Algorithms within the GNSS controller software compute a projection system that best fits the surveyed locations and these algorithms are then used subsequently to transform directly from the GNSS native system (ITRF or WGS84) back to the local system.

Benefits of using site calibration method:

- Easy to setup in a GNSS system
- Accurate if geometry of calibration is good and existing control is of high quality (Figure 4a)

Disadvantages of the site calibration method:

- Cannot be used on new sites where there is no existing control
- Propagates significant errors if the calibration geometry is poor (Figure 4b)
- Errors in coordinates or GPS fixing of the site control propagate into the transformation (Figure 4c)
- Site calibration not easily documented
- Site calibration not usually interchangeable with other GNSS manufacturers
- Site calibration not usable in conjunction with GIS software

For these reasons, a rigorous definition of a local plane grid (e.g. an LTM) should be defined.

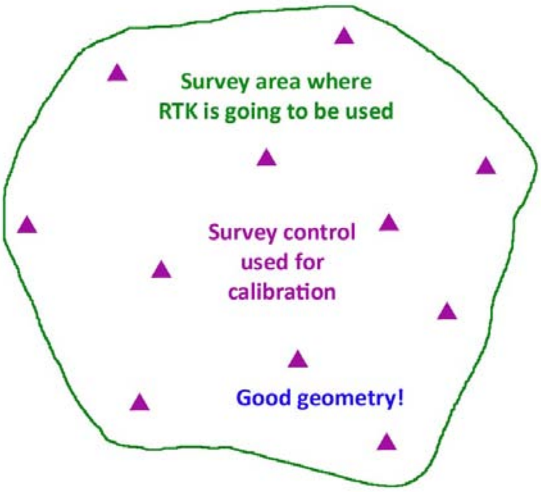

Figure 4a. Good site calibration geometry

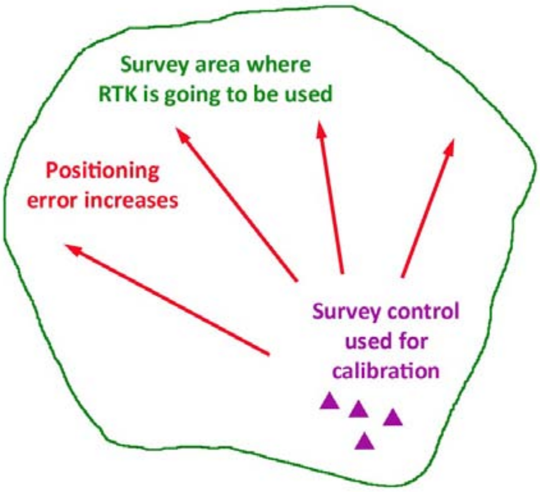

Figure 4b. Bad site calibration geometry

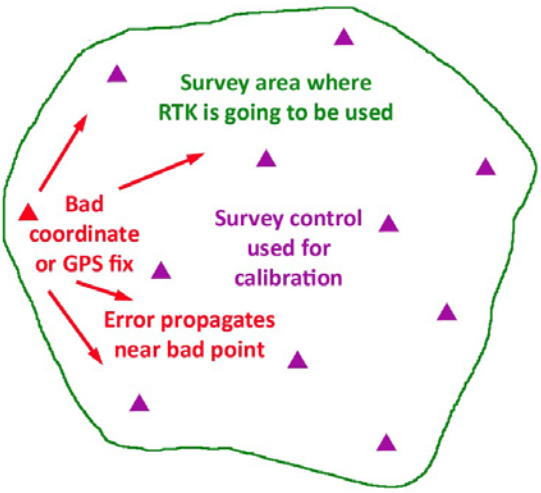

Figure 4c. The effect of a bad coordinate on site calibration

Computing UTM aligned LTM projection parameters

The first step is to choose a local coordinate origin **(E_{LO}, N_{LO}, H_{LO})** that is close to the median of the survey area. The origin does not necessarily have to be a physical station and the height origin should be close to the median elevation in the survey area. The local origin can be derived from the equivalent PNGMG coordinate, or can be completely arbitrary. For example an origin at UTM E 4*26000* N 76*67900* could have local coordinates E *26000* and N *67900*.

The choice of coordinates of the local origin should consider the following:

a. The maximum Easting in the project area should be less than the minimum Northing
(in case the coordinate order is inadvertently reversed)

b. Coordinates should have the same number of significant figures in the project area (e.g. 5 in the example above)
(for ease of use and also to prevent confusion of LTM coordinates with full UTM coordinates)

c. Potential for negative coordinates should be be avoided.

The following expressions can be used to define a LTM projection that can be implemented in RTK-GNSS and GIS systems:

$$\lambda_{PO} = \lambda_M \tag{1}$$

$$\phi_{PO} = \phi_M = 0 \tag{2}$$

$$E_{PO} = \left(E_{LO} + \frac{500000 - E_{MO}}{F_M} \right) \tag{3}$$

$$N_{PO} = \left(N_{LO} + \frac{10000000 - N_{MO}}{F_M} \right) \tag{4}$$

$$k_{PO} = \frac{0.9996}{F_M} \tag{5}$$

where,

λ_{PO}	is the Longitude of the LTM central meridian
λ_M	is the Longitude of the UTM/PNGMG Zone central meridian
ϕ_{PO}	is the Latitude of the LTM latitude origin (usually 0°)
ϕ_M	is the Latitude of the UTM/PNGMG latitude origin (0°)
E_{PO}	is the LTM Easting of the UTM/PNGMG Central meridian
E_{LO}	is the LTM Easting of the local origin
E_{MO}	is the UTM/PNGMG Easting of the local origin
F_M	is the Combined Scale Factor (UTM/PNGMG and Sea level) at the height of the local origin*
N_{PO}	is the LTM Northing of the UTM/PNGMG Latitude origin (0°)
N_{LO}	is the LTM Northing of the local origin
N_{MO}	is the UTM/PNGMG Northing of the local origin
k_{PO}	is the LTM scale factor at the UTM/PNGMG central meridian

* MSL elevations should be converted to PNG94 ellipsoidal heights using a geoid model such as EGM96 or EGM2008.

Limitations of a UTM/PNGMG aligned LTM system

The scale factor is exactly 1 at the local origin Easting (at the elevation of the datum plane), however as one moves East or West from the local origin, the scale factor will diverge from 1. The scale factor will also diverge (more significantly) as one goes above or below the datum plane. A UTM/PNGMG aligned LTM grid at the UTM/PNGMG Zone boundary will be subject to the largest variations in scale factor change, whereas the change will be minimal near the UTM/PNGMG central meridian. Assuming that a precision of 1:20,000 is required for most cadastral and engineering surveys, an LTM grid at a UTM/PNGMG Zone boundary can only extend up to 6,000 metres East or West of the LTM origin before this tolerance is exceeded. An LTM Grid near the UTM/PNGMG Central Meridian, however, can be extended 60,000 metres East or West before the tolerance is exceeded.

Of greater significance is the effect of elevation differences over the extent of the LTM grid coverage. If the elevation difference between any point in the coverage and the datum plane exceeds 300 metres, then the tolerance will be exceeded if the sea level / ellipsoidal height correction is ignored.

Conclusions

Development of an LTM aligned with a parent UTM projection such as PNGMG94 and AMG66 can provide several important benefits when using GNSS RTK methods for high precision engineering and cadastral surveys:

- The scale factor (combined height and grid factor) is close to 1
- LTM bearings will be identical to those in the parent UTM projection grid (no swing)
- Coordinate magnitudes should be kept small to prevent confusion with UTM coordinates
- LTM parameters can be easily setup in GNSS RTK software (no calibration required)
- LTM parameters can be exchanged consistently between different manufacturers
- LTM parameters can also be setup easily in GIS software projection configurations

Some disadvantages of the LTM system need to be considered though:

- A UTM aligned LTM cannot be used beyond 6 kilometres close to the UTM Zone boundary
- An LTM is not particularly suited to regions that have large extents in an East/West orientation

Nevertheless, this paper describes how an LTM can be designed and implemented in practice and should provide some useful guidance for surveyors wishing to use GNSS RTK methods on cadastral and engineering projects.

APPENDIX 1. Example: Madang LTM Grid *(example only – not actually used)*

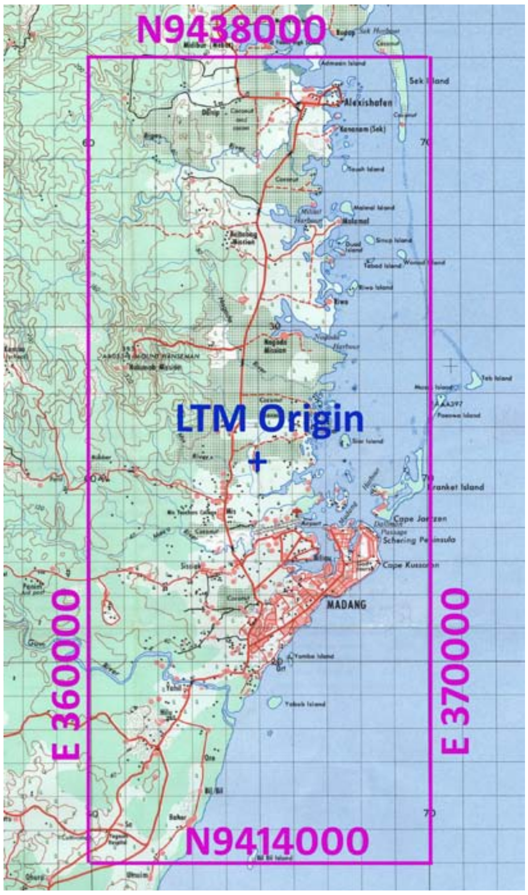

Figure 5. Madang LTM area

A new Madang LTM Grid aligned with PNGMG94 Zone 55 is required to be established for use within the bounds of Madang which are approximately (Figure 5):

PNGMG94 Zone 55 Easting 360000 to 370000
(10000 metres E-W)

PNGMG94 Zone 55 Northing 9414000 to 9438000
(24000 metres N-S)

MSL predominantly 0-20 metres
(PNG94 ~ ellipsoid height 70-90 metres)

PNGMG Zone 55 has the following defined parameters:

λ_M = 147° (Longitude of central meridian)

ϕ_M = 0° (Latitude of origin)

The median coordinates of the Madang area are adopted as the LTM (Madang Grid) origin:

PNGMG Zone 55 E 365000 N 9426000
(Ellipsoid Ht 80 metres adopted as median height for area)

E_{MO} = 365000

N_{MO} = 9426000

F_M = 0.9998130
(using the GDA94 technical manual & Height scale factor)

LTM Grid coordinates are assigned to the origin (arbitrary but using the guidelines above):
Madang LTM Grid E 30000 N 80000

E_{LO} = 30000

N_{LO} = 80000

Using equations 1-5, the projection parameters for Madang LTM Grid are computed as follows:

λ_{PO} = 147°

ϕ_{PO} = 0°

E_{PO} = 165025.250

N_{PO} = 654107.358

k_{PO} = 0.99978696

These parameters can be entered using the GRS80 ellipsoid parameters (a = 6378137m, 1/f= 298.257222101) into a GNSS RTK controller, post-processing or GIS software as a user-defined Local Transverse Mercator Grid.