Purpose:
This technical note describes how to apply coordinate reprojections, datum transformations and geoid adjustments in TerraScan. It covers the following topics:

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Applying reprojections, transformations and geoid models requires the user to have an in-depth understanding of how these tools work and how the various mathematical parameters can impact the resulting accuracy of the reprojected data. In particular, a detailed understanding of different realizations of various datums and how these vary over time is critical to obtaining the most accurate results. These tools should only be set-up by users with a strong background in geodesy who are comfortable working with geodetic coordinate system definitions and reprojections.

It is important to note that the default projection systems in TerraScan have units of meters with no datum shift defined between WGS 84 and NAD 83. This means transformations based on these default projection systems are assumed to be between coordinate systems with units of meters and between equivalent datums. Due to the different realizations (or versions) of particular datums, this assumption about datums is not always correct. These issues are addressed in detail in sections [B], [C] and [D].

Due to these unit conversion and datum shift issues, when performing any reprojections or transformations in TerraScan, it is very important to remember that the default horizontal coordinate reprojections are only valid for:

a. Transformations between WGS 84(Original) and NAD 83(86) datums.

b. Units of ‘meters’.

If you require a more accurate horizontal reprojection between different realizations of WGS 84 and NAD 83 or you need to work in units of ‘feet’, you will need to define a custom reprojection.
[A] Reprojection of Horizontal Coordinates

1. TerraScan allows you to apply a horizontal coordinate reprojection to your data. The simplest way to do this is to apply the reprojection to the points as they are loaded. This method is used to reproject from Geographic Coordinate System (GCS) WGS 84 to a projected, for example UTM or State Plane, coordinate system in the NAD 83 datum, however, other types of coordinate reprojections are supported as well. Reprojections can be applied to loaded points or to an entire project data set as part of a macro.
2. To avoid a lengthy dialog box listing coordinate systems that are not applicable to a project or are not frequently used, the user should enable only desired coordinate systems in the TerraScan settings dialog.
3. TerraScan also supports user-defined transformations that can be applied in the same manner as the default reprojections. These can be user-defined mathematical transforms, for example adding +10 m to all Z values, or user-defined reprojections for conversions other than from GCS(WGS 84); for example to reproject from a UTM zone to a State Plane zone. These user-defined transformations must first be set-up in the TerraScan -> Settings -> Transformations dialog before being available for use.
Note that all custom “reproject” transformations in TerraScan, for example from UTM to State Plane, work through WGS 84; i.e. the reprojection is applied as UTM ▶ WGS 84 ▶ State Plane.

4. In addition to the default projection systems, you can also define additional custom projection systems.
# Coordinate Reprojections, Datum Transformations and Geoid Adjustments in TerraScan

## Projection System

<table>
<thead>
<tr>
<th>Name</th>
<th>My Custom Projection</th>
</tr>
</thead>
</table>

### Ellipsoid
- Semi-major axis: 6378137.00000
- Inverse flattening: 298.25722356300

### Datum Shift from WGS84
- Shift X: 0.00000
- Shift Y: 0.00000
- Shift Z: 0.00000
- Scale correction: 0.000000000 ppm
- Rotation X: 0.000000000 arc sec
- Rotation Y: 0.000000000 arc sec
- Rotation Z: 0.000000000 arc sec

### Projection
- Projection type: Transverse mercator / Gauss-Kruger
- Origin longitude: 0.000000000
- Origin latitude: 0.000000000
- Scale factor: 1.000000000
- False easting: 0.00000
- False northing: 0.00000
- Unit: Meter
[B] Working with Different Units (Meters to Feet)

5. The built-in projection systems in TerraScan all have units of meters. To convert your data to projections in units of feet (US Survey or International), you will need to set-up a custom projection for each system you want to work with in ‘feet’. Note that projection system parameters, such as False Easting or False Northing, are always set in units of meters regardless of the output unit.

### Projection system

- **Name:** NAD83 - Maryland
- **Ellipsoid**
  - Semi-major axis: 6378137.00000
  - Inverse flattening: 298.25722210088
- **Datum shift from WGS84**
  - Shift X: 0.00000
  - Shift Y: 0.00000
  - Shift Z: 0.00000
  - Scale correction: 0.00000000 ppm
- **Rotation X:** 0.00000000 arc sec
- **Rotation Y:** 0.00000000 arc sec
- **Rotation Z:** 0.00000000 arc sec

### Projection

- **Projection type:** Lambert conic conformal
- **Origin longitude:** -77.00000000
- **Origin latitude:** 37.76666667
- **False easting:** 400000.0000
- **False northing:** 0.0000
- **Std parallel 1:** 38.30000000
- **Unit:** Meter

[Diagram of projection system parameters]
6. For example, to set-up a custom reprojection to convert data to a State Plane system in ‘US Survey Feet’ do the following.

   a. First copy the built-in State Plane projection system you need from the list of default projections.

   b. Next paste this into the ‘User Projection Systems’ section.
c. Edit the projection definition, including renaming it, to the appropriate values and change the units.

d. The new projection will now be available any time the user is asked to specify a 'Transformation'.

7. Note that TerraScan (and MicroStation) are limited to working with data with the same units in the horizontal and vertical axis. You cannot configure a TerraScan projection system or a MicroStation design file to have different units on different axis (for example, ‘XY’ in meters and ‘Z’ in feet, or vice versa).
[C] Adding a Datum Shift between WGS84 and NAD83

8. Datums identified only as ‘WGS 84’ or ‘NAD 83’ are not specific enough to clearly define the reference frame of geodetic data. Since datums shift over time, additional information is needed that specifies the realization, or version, of a particular datum. In the case of NAD 83, a “datum tag” must be appended to the name, such as NAD 83(86) or NAD 83(CORS96) or NAD 83(2011); likewise for WGS 84: WGS 84(G1674), WGS 84(G1150), WGS 84(Original), etc. NAD 83(2011) and WGS 84(G1674) are the current realizations of these systems.

While NAD 83(86) and WGS 84(Original) were equivalent datums, this is not the case for the current NAD 83(2011) and WGS 84(G1674) realizations. The magnitude of the shift between them is on the order of two meters, hence, if the highest horizontal accuracy is required, a datum transformation is necessary when reprojecting points between these two datums for any projected or geographic coordinate systems. To apply a datum shift as part of a reproject, for example from source data in WGS 84(G1674) to NAD 83(2011), requires the correct datum shift parameters be entered in the projection system definition in TerraScan.

For a NAD 83(2011) State Plane reprojection that includes the datum shift from WGS 84(G1674), copy the parameters in the projection system definition below to the “Datum shift from WGS84” section of your custom projection system. These particular parameters apply for any State Plane transformation, we just happen to be using Oklahoma Northern Zone for this example.

Note in this example we are also applying a unit conversion from meters to US Survey feet.
9. These datum shift values are the same as those used in GeoCue’s built-in NAD_1983_To_WGS_1984_epoch2010 transformation.

   This is a reverse transformation so the signs are reversed in the GeoCue dialog shown.

   Other sources of these datum shift adjustment parameters are available in the literature.

   [D] Adjusting for Time-Dependent Variations in Datum Shifts

10. It is important to keep in mind that the NAD_1983_To_WGS_1984_epoch2010 values shown above are time dependent. These values were very accurate in January 2010 when NGS defined this transformation, but if you use these values for data collected today then your data will be off in the horizontal. To deal with the time dependent variation between different datums, use a table of more current values (refer to GeoCue Corporation’s CueTip Transforming WGS 84(G1150) Coordinates to NAD 83(CORS96) Coordinates for a detailed mathematical discussion on how these parameters are calculated). Using the most applicable datum shift parameters for the time period of your data should provide for horizontal positioning accuracy after the reprojection within 2 – 3 cm.
[E] Applying an Orthometric Correction/Geoid Adjustment

11. To apply an orthometric correction or geoid adjustment to your data in TerraScan requires an understanding of how TerraScan applies a geoid correction and how to format a geoid correction file for input to the process. In addition, some preliminary set-up is required for the continental United States since US geoid models aren’t supported directly in TerraScan.

12. TerraScan’s Adjust to Geoid tool allows you to apply a generalized height correction model to your data. Since the geoid has no regular mathematical surface, a geoid adjustment cannot be defined mathematically. Therefore the elevation adjustments need to be defined using points for which the vertical difference between the ellipsoid and the geoid is known. Consequently, the input model for TerraScan’s geoid adjustment is a text file containing space-delimited ‘XYdZ’ points listing the correction (dZ) at each horizontal location (XY). When you apply the Adjust to geoid tool, TerraScan will interpolate a correction surface (as a TIN model) from these known correction points and calculate an elevation adjustment for each data point based on its location on the correction surface.

It is important that the correction surface cover the entire project area, so additional interpolated points can be added outside the known correction points if necessary. Adjust to geoid can be run against loaded points or a project definition.

13. To set-up Adjust to geoid for projects in the US, start by downloading the appropriate regional geoid model correction file for your area of interest. These files are available from the U.S. National Geodetic Survey (NGS) web site at www.ngs.noaa.gov. Note there are several recent geoid models available (90, 93 (both obsolete), 96, 99, 03, 06 (Alaska), 09, 12B). Be sure to choose the correct one for your data. The different geoid correction regions for the US are shown in Appendix A.
The NGS geoid corrections are specified in geographic coordinates (Lat/Long) with vertical corrections in units of meters. The latest models (99, 03, 09, 12B) provide heights above the NAD 83 ellipsoid. However, latitudes and longitudes in the WGS 84 and ITRF08 systems are very close to those of the NAD 83 system (with only 1-2 meters of horizontal shift.) So any of these types of latitudes and longitudes (NAD 83, ITRF08, WGS 84) may be used as inputs, without affecting the interpolated geoid values. This does *not* imply that the geoid heights are heights above a different ellipsoid. Using NAD 83 latitudes and longitudes interchangeably with ITRF08 or WGS84 latitudes and longitudes is merely an acceptable horizontal approximation.

However, do *NOT* use NAD 27 latitudes and longitudes as input. The horizontal shifts between NAD 83 and NAD 27 can exceed 100 meters, causing a noticeable difference in the interpolated geoid value. To convert from NAD 27 to NAD 83 latitudes and longitudes you should use a conversion program such as NADCON, available from NGS, or CORPSCON, available from the US Army Corp of Engineers.

14. The NGS geoid correction file is formatted as a file header that lists starting location and grid spacing parameters followed by a list of the dZ values at each grid location. The grid is based on one minute post spacing. To use these corrections in TerraScan, the file has to be converted to a simple list of ‘XYdZ’ triplets at each grid location. Users will either need to create their own tool to make this conversion or use the NGS provided INTG.EXE program available from their website. The output required is a simple list of ‘XYdZ’ points that can be used as an input surface in “Adjust to geoid”.

For reference, the original source NGS files look like the following.
While the converted files properly formatted for use with TerraScan look like this:

15. Once a properly formatted geoid correction file has been created, there are two options you can follow depending on where in the workflow the geoid correction needs to be applied:

   a. The converted correction file of 'XYdZ' values can be used to apply a geoid correction to any data that is already in geographic coordinates with vertical units of meters [Lat/Long (meters)], so if the source data is in such a coordinate system, the orthometric correction can be applied immediately. This would be the typical scenario when the geoid correction is done immediately after the source data is generated.

   b. If the orthometric correction needs to be applied to data that is not in geographic coordinates and/or units of meters, the geoid correction file needs to be reprojected into the appropriate coordinate system and units. This is typically done by limiting the area of the geoid correction to just the project area and creating a project-specific correction file in the correct projection/datum. This would be the typical scenario when the geoid correction is done as the final step in the workflow.

16. **Option A** – Data is in Geographic Coordinates [Lat/Long (heights in meters)]

   a. This is the most straightforward case. After creating the ‘XYdZ’ correction file as explained above, use TerraScan’s *Tools: Adjust to Geoid* to correct loaded point data or apply the same step to an entire project data set.
b. Specify the ‘XYdZ’ correction file in the resulting dialog.

c. After correction, the data will be in Lat/Long coordinates with elevation values adjusted to the geoid with units of meters.

d. You can now apply any additional horizontal reprojections or unit conversions as necessary.

17. **Option B** – Data is not in Geographic Coordinates [(Lat/Long) meters].

   a. Download the software INTG.EXE from the NGS web site. This is a command-line driven utility will allow you to extract sections of the regional geoid model file for the specific area you are interested in. Follow the NGS instructions to extract the geoid corrections in your area of interest. Note these corrections will still be in Lat/Long, meters. The resulting NGS formatted correction file will now be in the desired ‘XYdZ’ file format, as discussed above.
b. Define a custom transformation from geographic coordinates to the desired projection system and correct units that you need to work in; for example State Plane (US Survey Feet). As explained previously, NAD 83, ITRF08, and WGS 84 datums are essentially equal for the purposes of geoid modeling, so you do not need to apply a datum shift as part of your custom transformation, but doing so is acceptable.

c. Read the geoid correction data into TerraScan and apply your custom transformation. This will convert your geoid corrections from Lat/Long, meters to the desired system and units. Ensure that the sign for the geoid adjustment has the correct sense.

d. Save these points as a new geoid correction file.

e. Use this file in the “Adjust to geoid” tool to apply the correction to your data.

18. To verify your correction file once it is converted to ‘XYdZ’ format, you can view the geoid difference model by reading the points into TerraScan. This will allow you to easily check the max/min corrections in your file. The range of values can be compared to the known geoid corrections in your area of interest to verify your correction file is producing results of the correct magnitude. For example, for the eastern part of Alabama our geoid correction file for NAD83 State Plane Alabama Eastern Zone in units of US Survey Feet ranges in height from 85.72 feet to 98.09 feet.
19. It is always advisable to verify your actual results by comparison to an alternate geoid correction tool. Applying the correction to any control or check points and comparing the results is a good test that you are applying the geoid model correctly. There are online tools available on each geoid model's reference page on the NGS web site that will allow you to upload a file of control or check points and compute the correct geoid-adjusted heights. Be sure to verify the coordinate system and units of the points you upload are correct.

[F] Generalized Elevation Adjustment

Note that the *Adjust to geoid* tool is actually a generalized tool that can be used to adjust the elevation values of your data to any correction surface. All that is required is a set of ‘XYdZ’ data points and TerraScan will interpolate the correction surface to be applied to the data. After geoid corrections, the most common use of applying a generalized correction surface is to apply a mission-to-mission dZ adjustment as part of the sensor calibration and geometric correction of the data. This is the equivalent of “warping” your project data to a set of control points. For example if you have several missions in your project and each requires slightly different dZ adjustments (as determined by TerraMatch), you can build a correction surface that will model the error more exactly than simply block adjusting each mission vertically by a fixed amount. Using a custom correction surface via *Adjust to geoid* will smooth the correction across the mission boundaries and minimize the residual vertical error in your data. Note, however, that there now exist tools within GeoCue, Set/Apply LAS Adjustment, and TerraMatch, Find Rubbersheet Correction, which may be better suited for this purpose.
Appendix A – Regional Geoid Models of the United States territory provided by NGS

Figure 1 - CONUS

Figure 2 - Alaska
Coordinate Reprojections, Datum Transformations and Geoid Adjustments in TerraScan
Applies to TerraScan, versions 002.x and above.

Figure 3 - Hawaii

Figure 4 - American Samoa

Figure 5 - Puerto Rico and US Virgin Islands

Figure 6 - Guam and Northern Mariana Islands