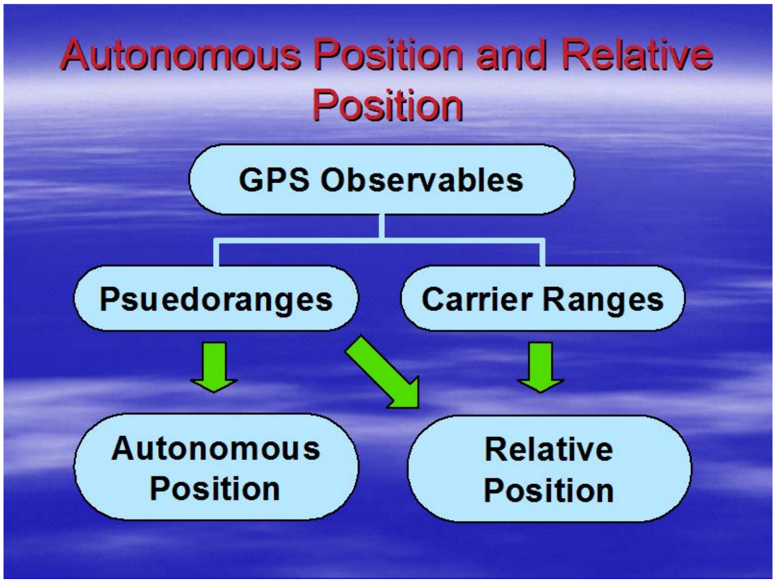
## *GPS Surveying Methods – Differential GPS*

Reading:

As described in the previous lessons, there are two types of positioning techniques: standalone or autonomous positioning and relative positioning. Standalone positioning can achieve an accuracy of 6 – 10 meters while relative positioning can achieve an accuracy to well below a centimeter depending on the equipment, surveying method, and survey specifications.




The autonomous positions are created from the psuedoranges, which are based on the code phases from all of the simultaneous satellites in view. A relative position can be created from the code phases or the carrier phase signals from all of the simultaneous satellites in view.

The Static GPS survey method described in the previous section is a relative positioning technique that utilizes the carrier phase signals to produce baselines and from those baselines a highly accurate result is produced in a network adjustment.

This lesson will describe the Differential GPS (DGPS) relative positioning method. The discussion will cover both the carrier phase DGPS and the code phase DGPS fundamentals and the appropriate applications for both.

### *Differential GPS - Fundamentals*

Some of the error sources that were mitigated by Static GPS surveying techniques are errors in the satellite and receiver clocks, errors in the navigation data (the ephemeris), and errors caused by the signals traveling through the ionosphere and troposphere. These errors are variable and are mitigated by differencing techniques, the application of a precise ephemeris, and the use of a tropospheric model and an ionospheric model.

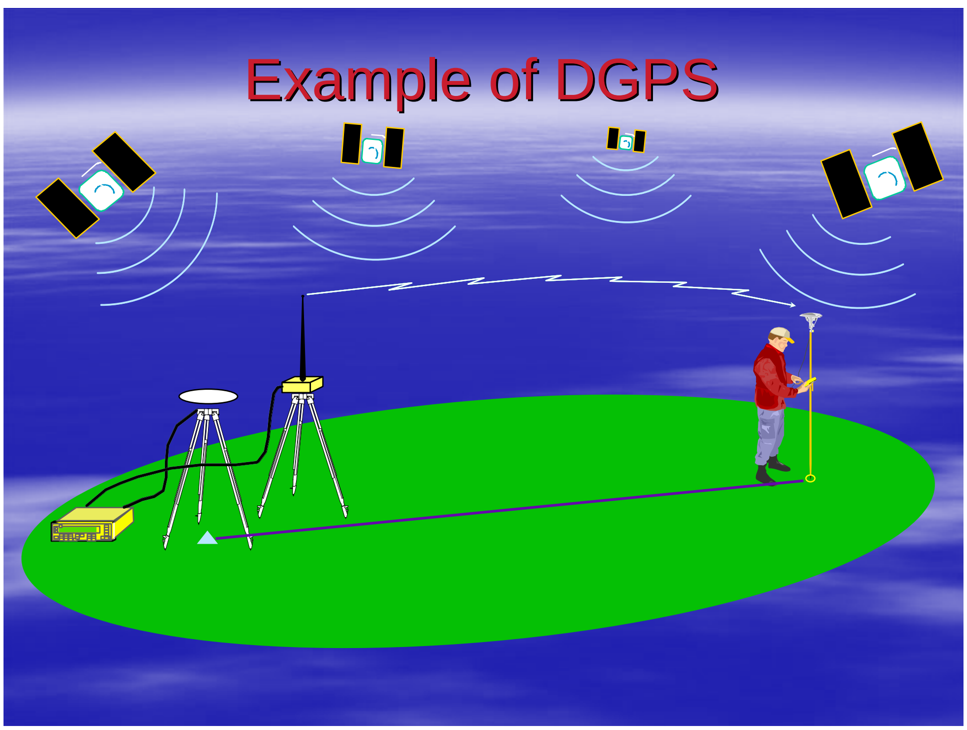
The DGPS survey method is characterized by having a “base station” set up over a station that has known values for the survey project, it collects GPS data, it calculates error corrections, and it sends the error information as well as other information to one or more “rover units” for the rover units to compute their position, typically without postprocessing.

The base station does this by comparing the position it calculate from the GPS data, then comparing the calculated position to the known position, then computing the difference between the two positions. The difference between the two positions allows the base station to derive error correction for the GPS data which are then sent, along with other information, to the rover unit via a data communication link. This allows for positions to be computed in real time. It should be noted that the errors are constantly changing, which means the base station has to monitor the GPS data constantly.

From the data sent to the rover unit from the base station via the data communication link the rover unit is able to calculate a baseline from the base station to the rover unit in real time. This allows the rover unit to compute a relative position from the base to the point being surveyed by the rover unit and achieve highly accurate results on the spot. The rover unit then moves from point to point collecting and computing real time data. Note: in DGPS a network is not created, the relative position is only relative to the base station for that one measurement.

The information that is sent from the base station includes its known position (coordinates and/or heights), the GPS observables, and the delays in the signals from each of the satellites in view. From that information the rover unit calculates a baseline in much the same way as a baseline is created in a Static GPS survey utilizing differencing techniques to resolve the integer ambiguities. From that baseline, the rover unit is able to calculate a coordinate and/or a height for its position in real time.

The following picture is an example of a DGPS survey. Just as in Static GPS surveys the baselines are created from the same satellites that are in view by both GPS units, the same is true for DGPS surveys.




The DGPS surveying method that utilizes carrier phase ranging and the corresponding DGPS correction message is called a **Real Time Kinematic** DGPS survey. The next section will deal with the applications and concepts of Real Time Kinematic surveys.

***Differential GPS – Real Time Kinematic Surveys***

Real Time Kinematic (RTK) DGPS surveys are becoming more and more widespread in their use. The benefits of producing highly accurate coordinates and/or heights in real time by the RTK DGPS surveying technique are manifold. The values produced from the RTK DGPS survey method are used to perform construction staking, collect data to produce topographic maps, survey fixed works, set survey control, control agricultural equipment and earth moving machines (machine guidance systems), control hydrographic surveys, cadastral surveys, and to monitor the deformation of the earth or public works projects to name a few. The acronym RTK is commonly used to denote a RTK DGPS survey.

All of the applications for RTK surveys require the understanding and implementation of the same fundamental concepts. These concepts include establishing the data communication link and initialization. An additional concept that may be used for some of the applications of a RTK survey also needs to be understood and implemented. This concept is called a GPS Site Calibration or a RTK site calibration. The remainder of this lesson will discuss the RTK concepts and ideas specific to surveying. A later lesson in this topic will discuss more completely the RTK concepts specific to machine guidance systems, hydrographic surveys, and RTK networks.

**RTK – Data Communication Link**

The fundamental concept in RTK surveying is that the error sources in the GPS data is the same at the rover unit as it is at the base station. This information, and other information, is sent from the base station to the rover unit via a data communication link.

The data communication link used in RTK allows the base station to transfer the key information to the rover unit for the rover unit to use for computing accurate coordinates and/or heights. The mode of transferring the information can be either a uhf radio signal, a cell phone, or through a wireless internet ip address.

Regardless of the communication mode, the correction information sent by the base station is the same, however, it may be sent in one of two formats. The formats are the Trimble Navigation Inc. created Compact Measurement Record (CMR and $CMR^+$) and The Radio Technical Commission for Maritime Services (RTCM) standard. The RTCM standard is the most pervasive.

Who is RTCM? The RTCM is an international non-profit scientific, professional and educational organization that has over 100 member organizations, including:

- Manufacturers of radionavigation and radiocommunication systems,
- Government agencies concerned with standards for maritime radionavigation and radiocommunication systems,
- Government agencies and commercial entities involved in operation of maritime radionavigation and radiocommunication systems,
- Associations with an interest in maritime radionavigation and radiocommunication systems and related public policy,
- Ship owners and operators,
- Educational institutions, and

- Sales and service providers

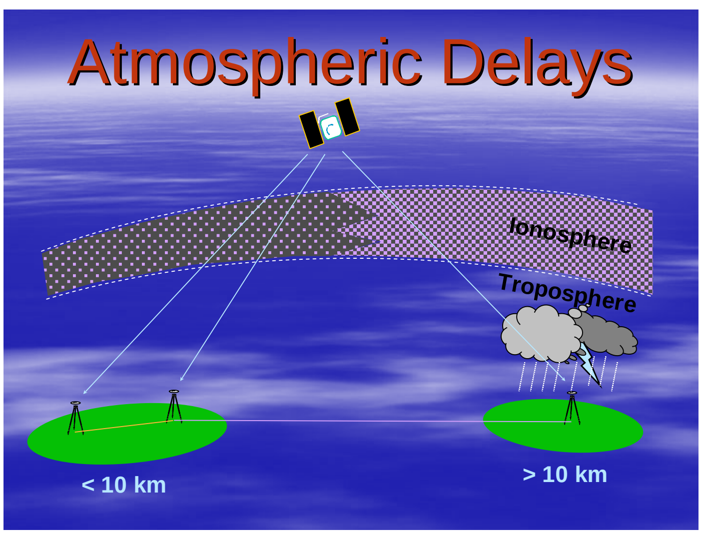
The RTCM charters several special committees that deal with a wide range of issues. RTCM Special Committees are chartered to address in-depth radiocommunication and radionavigation areas of concern to the RTCM membership. The output documents and reports prepared by these Special Committees are usually published as RTCM Recommended Standards. The RTCM recommended standard for DGNSS and, hence, DGPS, is created by RTCM Special Committee 104. RTCM special committee 104's current recommended standard for a message format for DGPS information is RTCM 2.3 and RTCM 3.0.

The RTCM standard contains 59 different "messages" that can be sent out in the same data stream. The messages that are important into an RTK survey are the ones that send out the base stations known coordinate and/or height data, the base station's GPS observables (the GPS data), and the delays in the signals from each satellite.

The delays in the signals are computed from the difference in the base stations known location to that of the calculated GPS position. The base station determines the best solution for the delay in the signals from each satellite that allows the calculated GPS position to be as close as possible to the known position. The delay information sent on the RTCM standard is the delay in each of the satellites signals in nanoseconds.

Note: The delays in the satellites signals is constantly changing. This is why the DGPS systems in general and RTK systems in particular are systems where the base station and the rover units constantly work together where the updated changes in the delays are relayed via the data communication link continually.

The delay in the satellites signals is important to understand because it implements the fundamental assumption in conventional (non network) RTK surveys. The assumption in conventional RTK surveying is that the delay in the satellites signals at the rover unit is the same as the delay in the satellites signals at the base station. In other words, the error sources are the same including the errors caused by atmospheric conditions. Because the effect of the error sources on the satellites signals are effectively modeled (computed) at the base station the rover unit does not have to model or compute them.




At present, a RTK rover unit should not be more than 10 kilometers from the base station because of this assumption. The picture to the left depicts the situation where a base station and a rover unit are within 10 kilometers of each other and shows the satellites signals traveling through virtually the same atmospheric conditions and if they are further than 10 kilometers than the atmospheric conditions are different which would lead to different delays in the satellites signals.

So, the data communication link is one of the most important components of a RTK system. It allows for key information to be sent from the base station to the rover unit so that the rover unit can then compute its accurate location based upon the main RTK assumption that the error sources at the rover unit are the same as the error sources at the base station.

**RTK – Initialization**

The second important concept to understand in RTK surveying is that of the initialization. The reason that initialization is important is that it is one element that ensures the GPS RTK surveyor has confidence in the results of the RTK survey.

Two definition of an **Initialization** are:

- An initialization is where a GPS unit finds the satellite array and orients itself to its current location. After initialization has occurred, the GPS receiver will remember its location and acquire a position more quickly because it knows which satellites to look for.
- Initialization is the process of telling the receiver your approximate location on the surface of the earth. This must be done the first time you use the receiver or if it has moved more than 300 miles from the last location where it was being used. Otherwise, it will take an unreasonable amount of time for the receiver to establish what is called a *Position Fix*.

So, the initialization is the process where the rover unit locates the satellites that are in view and allows it to gain a position fix. The position fix is the uncorrected position (coordinates and/or height) of the rover unit.

Once the rover unit is initialized it knows its relationship to the satellites. The initialization must be maintained throughout the RTK survey. If the rover unit losses *lock* on the satellites by going underneath a tree canopy, a bridge, the GPS antenna is “dumped” or turned sideways or upside down from the GPS constellation, or for any other reason, the rover unit must be reinitialized. If the rover unit is not properly initialized or reinitialized the quality of the results of the RTK survey will be greatly diminished.

The RTK surveyor will know when the rover unit is initialized when the position shown in the RTK software on the screen of the data collector changes from “float” to “fixed”. Once the screen indicates that the initialization is fixed the collection of RTK data can begin.

Manufactures of RTK systems have different initialization methods for their rover units. For the purposes of this discussion the initialization techniques of “on-the-fly” initialization, “new point” initialization, and “known point” initialization will be discussed. For more information on other initialization methods for a particular RTK system, the manufacture should be consulted.

**RTK – On the Fly initialization**

The **On the Fly** initialization technique is characterized by the rover unit first establishing communication with the base station via the data communication link and then roving until an initialization is achieved. Once again, the data collector screen will indicate that the initialization is achieved by showing that the solution is fixed. Note: both the base station and the rover unit must be tracking at least five common satellites simultaneously. The picture to the left shows the On the Fly initialization technique.

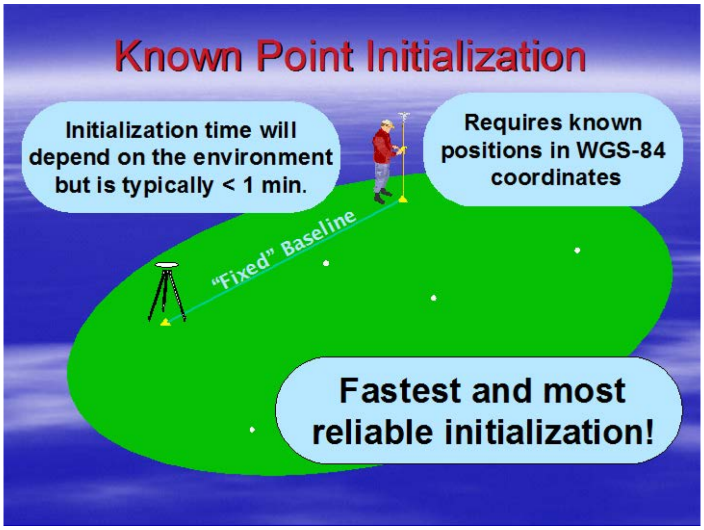

The On the Fly initialization technique is the weakest of all of the initialization techniques. Not only does it take considerably longer to get the rover unit initialized, the errors in the positions produced from a RTK survey performed with an On the Fly initialization are greater than the errors produced from RTK surveys performed with initializations produced from different methods. In general an On the Fly initialization should not be used to produce final values for a RTK survey.

**RTK – New Point Initialization**

The **New Point** initialization is an initialization that is based on surveying a point that had values produced after an On the Fly initialization was achieved. The On the Fly initialization is then dumped and the rover unit then reinitializes on the new point utilizing the WGS84 positions from the values produced from the On the Fly initialization. This allows for the reduction of the errors associated with the On the Fly initialization.

**RTK – Known Point Initialization**

The **Known Point** (also called a fixed point) initialization method is the best initialization method. It is characterized by occupying a station that has a known WGS84 latitude, longitude, and ellipsoid height. Much like the New Point initialization the known values help the rover unit to get a more accurate fixed solution. The Known Point initialization is better than the New Point initialization in that the known values should have a higher accuracy than the values used in the New Point initialization. Additionally, the Known Point initialization method is faster and more reliable than the other initialization methods. The picture to the left illustrates the Known Point initialization technique.

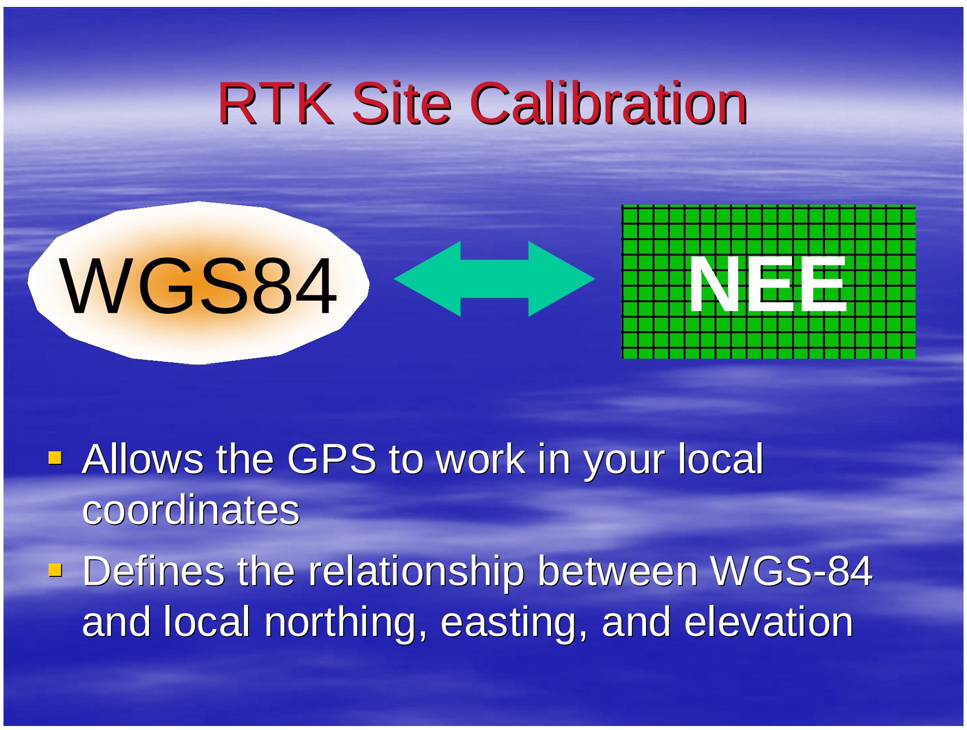


Ok, so when performing a RTK survey the data communication link must be established and the rover unit must be initialized. The other main concept to understand before discussing how to conduct a RTK survey is that of the RTK site calibration.

**RTK – RTK Site Calibration**

The **RTK Site Calibration** is probably the least understood and most misunderstood technique utilized in a RTK survey. The RTK Site Calibration is often times called a local site calibration. The RTK Site Calibration helps to mitigate local variations in the control, both horizontally and vertically, for a particular project or area. Most, if not all, RTK systems on the market today allow for the creation of a RTK Site Calibration.

The RTK Site Calibration is a process that equates observed WGS84 values to your local control point's northings, eastings, and elevations. The RTK Site Calibration is a process where stations with known values are occupied and the GPS positions (WGS84 latitude, longitude, and ellipsoid height) for those stations are produced and saved. The observed values are then evaluated simultaneously with the known positions for all of the stations to produce correction factors to be applied to the rest of the RTK survey.




The information to be included in the RTK Site calibration will come from at least three horizontal control points and/or four vertical control points that should surround your project area. Of course, the more stations included in a RTK Site Calibration the better. Note: If the RTK survey is only for either horizontal or vertical purposes, but not both, then the other control points (vertical if the survey is only a horizontal survey and horizontal if the survey is only a vertical survey) are not necessary.

**RTK – How a RTK Site Calibration Works**

So, what is happening in a RTK Site Calibration when the observed values on known stations are associated with the known values for those stations and evaluated simultaneously? In order to describe what is happening, the horizontal calibration and vertical calibration will be discussed separately.

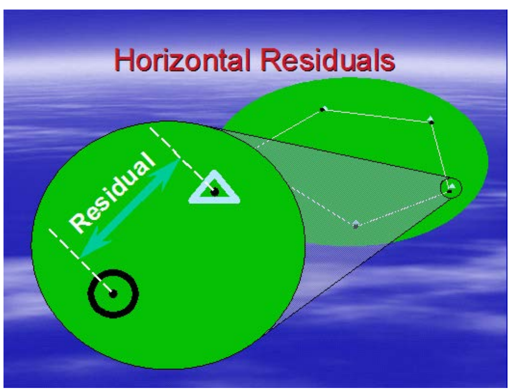
**RTK Site Calibration – Horizontal**

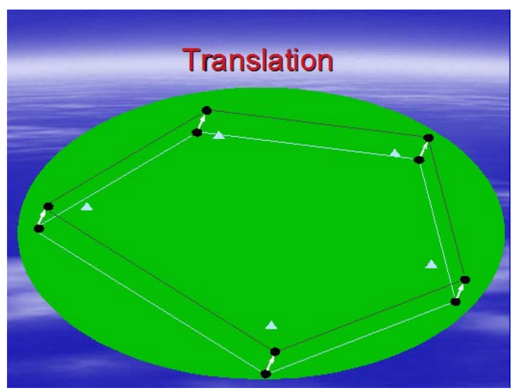
Ok, in the horizontal portion of the RTK Site calibration the control points known grid coordinates, northings and eastings, are associated with the corresponding observed WGS84 latitudes and longitudes for the project control stations.

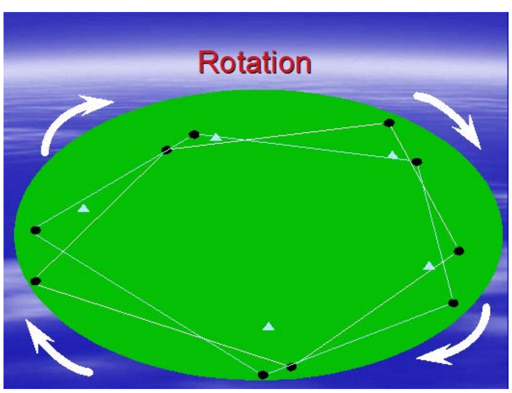
**Step one:** The RTK Site Calibration first derives a transformation from the WGS84 ellipsoid to an ellipsoid that is valid for the RTK project. If the project is on NAD83 the GRS80 ellipsoid is used and one is not created.

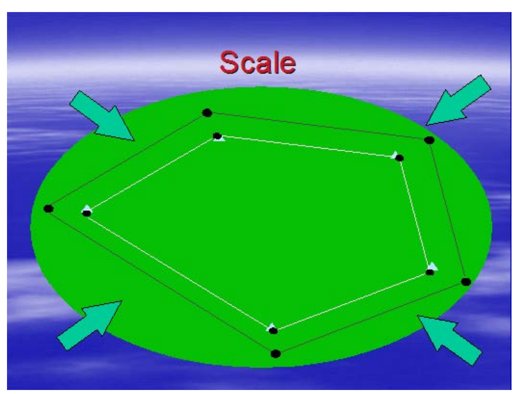
**Step two:** The next step is the creation of a projection from the transformed ellipsoid's spherical coordianates to the local northings and eastings. The projection is typically a seven parameter projection, 3 rotations, 3 translations, and 1 scale. If the project is on NAD83 (CCS83) then the projection is already well defined.

**Step 3:** Then the RTK site calibration computes a rotation, translation, and scale factor for the specific project by producing a least squares adjustment that minimizes the sum of the squares of the residuals produced from the differences in the observation values and the known values. The following pictures illustrate the point.



**Step 4:** The calculated rotation, translation, and scale factor are then applied to the transformed and projected values produced from the rest of the RTK survey.

Note: A RTK Site Calibration can be created from a Static GPS survey that produced final values on the control points to be used in an RTK survey. This RTK Site Calibration method takes the observed WGS84 values from the Static GPS survey and associates them with the final results from that survey. Also, the appropriate values to look for in the calibration results are dependent on the specifications for your project. As stated earlier, specifications will be discussed in a later lesson.

There are some misconceptions about a RTK Site Calibration. Where some of the misconceptions concerning an RTK Site Calibration occur is when the project is on a state plane coordinate system, CCS27 (NAD27) or CCS83 (NAD83). Some feel that there is already a well defined transformation and projection for the state plane coordinate systems and, therefore, a RTK Site Calibration is superfluous. This may be true if the RTK survey project area was in a location that had no crustal motion and the control used for the survey had no error. In California this is an unlikely occurrence. It is recommended that a RTK Site Calibration always by utilized for RTK surveys in California. At a bare minimum it will not hurt anything and will likely improve the results of the survey.

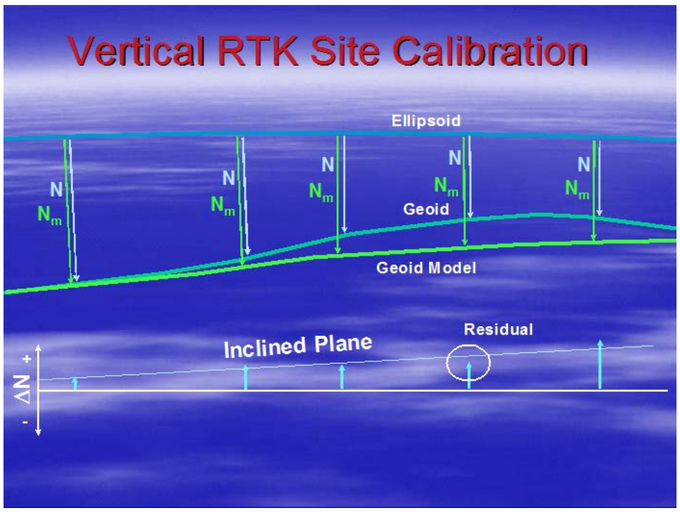
**RTK Site Calibration – Vertical**

The vertical portion of a RTK Site Calibration is characterized by the inclusion of the appropriate geoid model and the creation of an inclined plane from the association of the GPS observed ellipsoid heights with the known elevations.

**Step one:** The RTK Site Calibration first derives geoid heights for the control points.

**Step two.** The RTK Site Calibration then performs a least squares adjustment to minimize the sum of the squares of the residuals of the observations.

**Step three:** Then a best fit "inclined plane" is created that is applied to the rest of the RTK survey. The inclined plane is created from a central point, not a control point or other observed point, and a slope of the plane north and a slope of the plane east. The following picture illustrates the vertical RTK Site Calibration.



**RTK Site Calibration – Evaluation**

The GPS Site Calibration is evaluated by looking at the following information in the results:

- Maximum horizontal residual
- Maximum vertical residual
- Scale factor created
- Rotation
- Translation
- Slope of the inclined plane north
- Slope of the inclined plane east.

The appropriate values for the results are contingent on the requirements of your RTK survey.

The next step will layout the step by step process of performing a RTK survey.

**RTK – Conducting a RTK Survey**

Now that the main concepts of data communication link, initialization, and RTK Site Calibration are understood, they can be put to use in an RTK survey. This section will provide a bulleted list of the steps to follow in conducting a RTK survey.

Here is the list:

- Just as in a Static GPS survey a mission plan should be done to evaluate when there are enough satellites in view and when the PDOP is in the appropriate range.
- The data collector is configured with the appropriate settings for the RTK survey project.
- The base station is set up on a control point for the project that is, or will be, included in the RTK Site Calibration.
- The base station's antenna height is then measured and input into the data collector.
- The rover unit is then set up and the antenna height input into the data collector.
- The data communication link is then established.
- The rover unit is then initialized.
- If an RTK site calibration is not already produced, the rover unit will observe the control points to be included in an RTK Site Calibration.
- The RTK Site Calibration is then created and included in the project.
- The rover unit will then take a "check shot" on a control point to ensure that appropriate values will be produced from the RTK survey.
- The rover unit then collects data.
- Before picking up the equipment another check shot is taken and the antenna heights for both the base station and the rover unit are remeasured.
- The data is then downloaded and included in a project file.

**RTK – Job Folder**

Just as in a Static GPS Survey, the final step in an RTK survey is to produce a job file. The information included in a RTK job file in contingent on the type of survey that was performed. The RTK survey may have been to produce a topographic map, location of fixed works, construction staking, or deformation monitoring to name a few. The following is a list of items to include in the RTK survey job folder depending on the purpose of the survey.

- A narrative describing the purpose of the survey, the points set, the control held, and any problems that were encountered during the RTK survey process.
- A map of the project area.
- "To reach" descriptions and sketches of any points set.
- Descriptions of any monuments set.
- The RTK Site Calibration report.
- A copy of the data collector's survey file.
- The final values produced.
- The topographic map produced.
- A map of the location of the fixed works based on the final RTK survey values.
- The cut sheets for construction surveys.

***Differential GPS – Code Phase***

As stated earlier, a DGPS relative position can be created at the rover unit from either the code phase signals or the carrier phase signals. The achievable accuracy of the resultant DGPS relative position based on the carrier phase signals can be in the centimeter range. However, the achievable accuracy of the resultant DGPS relative position based on the code phase signals is in the .5 meter range at best. The reason for the difference in the accuracy levels is that the code phase signal has a much longer length before it repeats. The .5 meter accuracy is, of course, not suitable for most surveying or scientific applications.

When performing a DGPS survey based on the code phase signal, the base station is typically a National DGPS (NDGPS) site. These are sites that have a permanent GPS unit set up and collecting GPS data continuously. The Department of Transportation's Nationwide Differential GPS expansion initiative to provide DGPS signals for public safety services includes building, operating, and maintaining the NDGPS sites and has seven members. They are the U.S. Coast Guard, U.S. Air Force, Federal Railroad Administration, U.S. Army Corps of Engineers, Federal Highway Administration, National Oceanic and Atmospheric Administration, and the Office of the Secretary of the DOT.

The CGPS NDGPS sites broadcast the code phase DGPS corrections via radio waves to be used by a resource grade GPS unit at the rover unit. The NDGPS corrections are in the RTCM format. Note: a resource grade GPS unit is a unit that can either receive code phase corrections or no corrections at all.

The applications that are suitable for DGPS relative positions created from the code phase signals include: Geographic Information Systems (GIS), applications reliant on navigation information, recovering existing survey monuments, and any other application that only needs the .5 meter level of accuracy.