Why postprocess GPS data?

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Introduction

This paper is intended for those who would like to improve the accuracy of their GPS data but are not sure how postprocessed differential correction works.

Real-time differential correction for GPS (real-time DGPS) has had a very positive effect on navigation and the verification of spatial data. But there are places in the world that don't have reliable real-time DGPS services, and many applications need better accuracy than is achievable from current real-time correction methods.

Depending on the technique used, postprocessed differential correction (postprocessing) can deliver GPS data accurate to a few meters in moving applications and to a few centimeters in stationary situations, and these levels of accuracy are now easier than ever to achieve.

The paper is in two main sections. The first section provides an overview of differential GPS and how it works. The second section discusses the benefits of differential correction by postprocessing.

The material on reference frames in the first section is important. It is not well understood that to add GPS data to a GIS, the reference frames must be matched, typically by transforming the GPS data into the reference frame used by the GIS. Ignoring this aspect of GPS data management can leave you with puzzling offsets in your GIS, no matter how much care has been taken with differential correction.

Section 1: How differential GPS works

What is differential correction?

Differential correction is a method of removing the errors, both man-made and natural, that affect GPS measurements.

Corrections of GPS coordinates can be accomplished at a later time (postprocessing) or while the ‘roving’ GPS receiver is in use (real time DGPS). This section of the paper will explain in some detail how differential correction works.

In saying that we correct GPS positions, we actually correct GPS measurements and calculate positions from the corrected measurements. Additionally, we derive coordinates from the resultant GPS position, relative to some reference frame.

The Global Positioning System

To understand how differential correction works, it is useful to review the Global Positioning System (GPS).

The Global Positioning System was developed by the US Department of Defense as a worldwide navigation resource for military and civilian use. It is based on a system of 24 satellites orbiting the earth, acting as reference points from which receivers on the ground compute their position.

By listening to a series of specially coded messages transmitted by each satellite, a receiver on the ground can calculate how long it took the timing signal to get from the satellite to its own antenna. To calculate its distance to the satellite, the receiver multiplies that travel time by the speed of light. This is important to an understanding of differential correction because it is errors in the travel time measurement that differential GPS (DGPS) corrects.

Types of errors in GPS

Satellite errors

Timing is critical to GPS, and the GPS satellites are equipped with very accurate atomic clocks, but they are not perfect and slight inaccuracies can lead to errors in position measurements. As well, the satellite's position in space is important and errors occur when a satellite drifts from its predicted orbit.

The atmosphere

GPS satellites transmit their timing information by radio, and since radio signals in the earth's atmosphere don't always behave predictably, this is another source of error. The assumption is that radio signals travel at the speed of light, and that the speed of light is a constant, but this is only true of light if it is in a vacuum.

In the real world, light slows down, depending on what it is traveling through. As a GPS signal comes down, it gets delayed a little, and because a calculation of distance assumes a constant speed, this delay leads to a miscalculation of the satellite's distance, which in turn creates an error in position.

Good receivers add in a correction factor for the signal's trip through the atmosphere, but given the number of variables, no correction factor or atmospheric model can compensate exactly for the delays that actually occur.

Multipath error

When the signal arrives at the surface of the earth, it can reflect off obstructions such as buildings and trees, before making it to the receiver's antenna. The signal arrives at the antenna by 'multiple paths' which is why this type of error is called multipath error. The antenna receives the direct signal first because the direct route is always fastest, and then the reflected signals arrive later, interfering with the direct signal and giving 'noisy' results. Well designed antennas can reduce multipath interference but not eliminate it.

Receiver error

Receivers can introduce errors of their own, usually from their clocks or internal noise, however Trimble has a long history of designing handhelds with integrated antennas and its receivers are built with the most sophisticated anti-jamming technology available.

Selective availability (SA)

This is a man-made error introduced by the US Department of Defense. Selective Availability was turned off on May 1, 2000 by an executive order from President Clinton. The U.S. has stated it is not their intent to ever use SA again, since the military is instead developing regional denial capabilities to ensure that potential adversaries do not use GPS. For further information about SA, see: http://www.ngs.noaa.gov/FGCS/info/sans_SA/

How differential correction works

GPS receivers use timing signals from at least four satellites to establish their position, and each of those signals has its own set of errors. The satellite clocks might be inaccurate, or the satellites might not be in their predicted orbits. If Selective Availability is switched on, this adds further clock and orbit (ephemeris) error. As the signals travel down through the atmosphere, they are deflected and delayed because the earth's atmosphere is not a vacuum. The signals are bounced around when they meet local obstructions (creating multipath error) before finally reaching the receiver.

Fortunately, satellites are so far out in space that distances on earth are small by comparison. As long as GPS receivers are within a few hundred kilometers of each other, the signals that reach them will have traveled through virtually the same piece of atmosphere, and will have virtually the same delays. The receivers will have the same errors, excluding multipath and receiver errors, so one receiver can measure the errors and provide correction data to the other.

Provided that the exact location of a reference receiver (on a point that has been very accurately surveyed), and the location of satellites in space are known, it is possible to compute a distance between the receiver and each satellite. The reference receiver then divides that distance by the speed of light and gets a time for how long the signals should have taken to reach it. This theoretical time is compared with the time the signals actually took to reach it, and the difference is the error in the satellite's signal.

Differential correction counteracts nearly all of the errors that can be introduced into GPS signals, but it does not help with multipath and receiver errors because those are local effects. A reference station must be carefully positioned, so that the measurements it makes contain no multipath effects. DGPS only counteracts errors that are common to both the reference and the roving receivers.

Data can be differentially corrected in the field in real time, using various correction sources (radio beacon, WAAS, OmniSTAR), or it can be corrected afterwards, by postprocessing, using correction data from the hundreds of private and government-run terrestrial reference stations around the world.

Note that the source of the correction is always a reference station, whereas the medium used to transmit the correction varies. Radios, beacons, satellites and internet are all mediums from which users can access corrections in real time.

In real-time DGPS, the error value is computed as the GPS signal is received, and transmitted to one or more roving receivers over a radio or other link. The roving receiver is sent a complete list of errors for all satellites visible at the reference receiver and it then applies the corrections for the particular satellites it is using.

In postprocessed DGPS, the postprocessing software calculates the error in each GPS (pseudorange) measurement logged by the reference station receiver, and applies the error corrections to the measurements in the rover data file.

The principal difference is that the real time corrections have latency in them, so that the corrections used to correct a measurement are predictions based on the broadcast corrections from a few seconds beforehand.

Postprocessing can use multiple base observations from before and after the measurement to achieve better accuracy, as well as using more sophisticated algorithms.

Reference frames

GPS positions are defined in terms of earth centered, earth fixed Cartesian coordinates, X, Y and Z. Typically, they are converted into the latitude, longitude and height system, sometimes referred to as a geographic coordinate system.

Coordinate systems are based on mathematical models of the earth called datums that can be defined globally or for specific regions. Over time the models are updated as continents shift and the earth's surface changes, and hence many revisions of a single datum can exist.

Differential corrections are generated against a known coordinate, referred to as the reference position. It is important to understand that for the exact same physical location, many reference positions can exist, depending on how the coordinate system was defined. For example, the National Geodetic Society in the US, under the Continually Operating Reference Stations (CORS) program, publishes reference positions for each reference station in terms of both the ITRF 2000 datum and the NAD 83 (CORS 96) datum.

When using differential correction, an important issue to bear in mind is that GPS positions generated from differential correction will be in terms of the datum used for the reference position.

If GPS positions are to be used in the context of GIS data referenced in a **different** frame, the positions must be transformed to that new reference frame. If this is not done, an offset (often referred to as a datum shift or bias) is observed between the GPS position and the background GIS data. This can be a difference of meters.

Mixing Reference Frames

Differential correction sources use a variety of reference frames. Autonomous GPS positions use the WGS-84 (World Geodetic System) datum as the reference frame. WAAS corrections use ITRF 2000 (International Terrestrial Reference Frame), US Coast Guard beacons use the NAD 83 (North American Datum), and OmniSTAR uses NAD 83 in North America and WGS-84 in all other world areas. Postprocessed GPS positions are in terms of the base provider's reference position.

This variety of reference frames means mixing autonomous, real-time, and postprocessed positions can lead to inconsistency in your data. Merging data from different reference frames requires vigilance, otherwise you may be unknowingly comparing data from one coordinate system with data from another.

The best safeguard against introducing datum shift errors into your data is to postprocess all data—including real-time corrected data—against a base provider with a reference position in a known datum. All postprocessed positions will be in this known datum. After postprocessing, carefully apply the appropriate datum transformation between your GPS data and your GIS.

Trimble maintains a list of base providers; however because system operators make their own choice as to the reference frame for their data output, this list does not use a common reference frame for all reference positions. Even base stations from the same provider (for example National Geodetic Survey CORS stations) may use different reference frames. Trimble can provide no guarantee as to the accuracy or reference frame of any reference position. Best practice requires that users check base station details themselves.

NAD 83 and WGS-84

An added complication for North American users of GPS data is the historical assumption that NAD 83 and WGS-84 are the same, and that no transformation between these two datums is required. This assumption is no longer true.

The NAD 83 datum was developed to best represent the US continental region, and the WGS-84 was developed to best represent the globe. Previously, the NAD 83 and WGS-84 datum definitions were very similar. Over time, the global WGS-84 datum has shifted away from the local NAD 83 datum. The WGS-84 and ITRF 2000 definitions are both global and derived from satellite based measurements; hence they are now very similar.

So while the WGS-84 and ITRF 2000 reference systems differ by only a centimeter worldwide, NAD 83 now differs from WGS-84 (and thus ITRF) by up to a meter. For many applications, a difference of this magnitude is unacceptable.

Software that performs datum transformations, such as the Trimble® GPS Analyst™ extension for ESRI ArcGIS or the GPS Pathfinder® Office software, may perform a "zero" transformation between NAD 83 and WGS-84, under the assumption that the two are the same. This is not a problem if data has been differentially corrected against a NAD 83 correction source, and the GIS uses NAD 83. But if the reference frames of the GPS data and target GIS do not match, a zero transformation can introduce up to a meter of error.

The Support Note titled *Resolving the NAD 83 datum transformation issue in GPS Pathfinder Office and GPS Analyst* describes NAD 83 datum issues in Trimble postprocessing software, and provides solutions for these issues. The support note may be found at:

http://trl.trimble.com/docushare/dsweb/Get/Document-170369/SprtNote_PFO_NAD 83Datum.pdf

Real-time differential GPS

Real-time correction sources include the following:

Beacon

The US Coast Guard has an existing network of radio beacons which broadcast data for marine users. (Many other countries have a similar system.) Piggybacking on existing hardware, GPS corrections are broadcast for free from the beacons. To use the corrections, you need a beacon differential GPS receiver (either integrated into the GPS receiver or connected to it. Accuracy is submeter, depending on the receiver; coverage is very good in US coastal areas but not inland.

OmniSTAR

This is a subscription-based service which transmits corrections from a network of reference stations to the service's satellites, which then broadcast corrections to subscribers. To use the corrections, you need a satellite differential receiver (either integrated into the GPS receiver or connected to it). Accuracy is submeter and coverage is worldwide. For more information see: http://www.omnistar.com/home.html

Satellite-based augmentation systems (SBAS)

This is similar to the OmniSTAR satellite service but corrections are broadcast on the L1 GPS frequency. Examples of this are the US-based Wide Area Augmentation System (WAAS), available in most parts of the US and southern Canada; EGNOS in Europe; MSAS planned for Japan. To receive WAAS corrections you need an SBAS-capable GPS receiver. The correction service is free and delivers submeter accuracy, but coverage is geographically limited to the reference station area.

Other

It is also possible to set up your own reference station and broadcast corrections, or subscribe to a commercial/community network.

Setting up your own reference station

If there are no base data providers in your area, you can set up your own GPS reference station, using a GPS receiver connected to GPS reference station software. The reference station software may simply be GPS data collection software that is configured to record GPS measurement data in base mode. At the other end of the scale, you can use dedicated reference station software that logs GPS base data in a variety of file formats (for example, RINEX format and Trimble's SSF format) and even automatically uploads base files to an Internet server.

The main requirement for a reference station is that it be situated over a very accurately surveyed reference position. Any error in the reported reference position will contribute to errors in the corrected rover data. There are many methods for transmitting and receiving corrections for example:

- A reference receiver connected to a radio modem or data radio, transmits corrections by radio to a rover receiver connected to a radio modem that receives the corrections.
- A reference receiver connected to the Internet can broadcast corrections so that a rover receiver can connect to and use these corrections via an Internet link from the field.

The most common method is radio modem. Several protocols have been developed for transferring differential corrections. The reference receiver and rover receiver must be configured with identical protocols to ensure successful reception of the correction messages.

Postprocessed DGPS

Postprocessing techniques require raw GPS base data to be stored in digital files that are later processed (by postprocessing software such as GPS Pathfinder Office or GPS Analyst) against raw GPS rover files.

Base correction data is collected by numerous government, commercial, and private providers around the world. Coverage is very good in most well-populated areas, especially in the US. Most providers make data available on the Internet, and many provide it for free.

Accuracy can be submeter and better, but this depends on the capabilities of the rover receiver and the type of postprocessing software used. To postprocess data, the roving receiver and base receiver must be collecting GPS data at the same time, and must have at least four satellites in common.

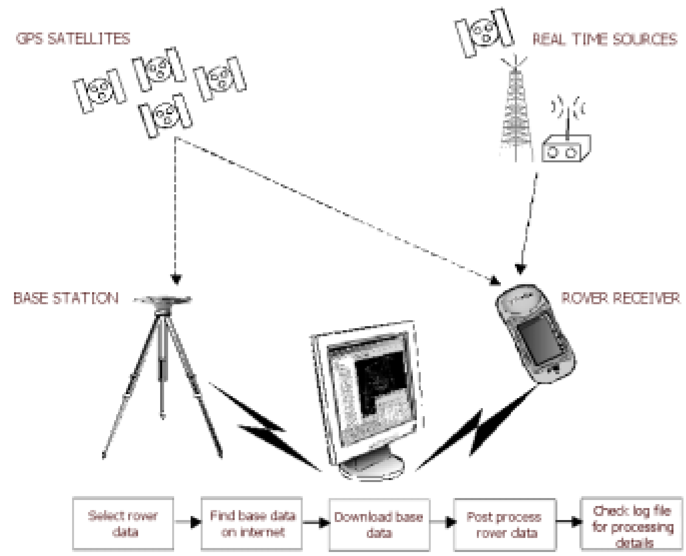


Figure 1: *Diagram showing differential correction*

Comparison of real-time and postprocessed DGPS

	Real-time	Postprocessed
Pros	Immediacy Better accuracy in the field	Accuracy Reliability Free base stations around the world More control over reference frame of corrected positions
Cons	Can be unreliable Sources not available in all areas Some sources expensive Inconsistent reference frames	After the fact Requires postprocessing software
Applications	Navigation Feature verification When accurate data required in real time	Where accuracy and reliability are the main consideration When real time accuracy is not so important When real-time correction sources are not available

Table 1: *Comparison of real-time and postprocessed DGPS*

Accuracy

Measuring accuracy

A GPS receiver calculates its position once every second but because each measurement is subject to introduced errors, each position is slightly different from the previous one, even if the receiver is static at one location.

Over time a 'scatterplot' of GPS positions is built, from which a measure of the receiver's absolute accuracy can be derived, using a Root Mean Square (RMS) calculation. RMS is the standard statistical measure for specifying GPS accuracy. The HRMS value represents the horizontal distance from truth (a fixed location where coordinates have been accurately measured using survey techniques) within which at least 63% of the recorded positions fall.

Figure 2, illustrates the difference in accuracy between autonomous, real-time DGPS and postprocessed GPS data. The smaller the HRMS value, the more accurate the data.

Why is postprocessed data more accurate than real-time DGPS?

In this example, two GPS Pathfinder Pro XRS receivers were set up side by side for 50 hours, one with WAAS corrections applied and the other logging autonomous data. The WAAS-corrected and autonomous files can be seen in Figure 2.

The WAAS-corrected file was then postprocessed (using a local Trimble base station about 30km away), to show the degree of improvement possible with postprocessing.

The top scatterplot in Figure 2. shows the postprocessed data, demonstrating how postprocessing reduces the HRMS value considerably, in this case so that at least 63% of GPS positions recorded are within 0.33 meters of truth. The corresponding value for WAAS corrected data is 0.51 meters and for uncorrected data, 2.08 meters.

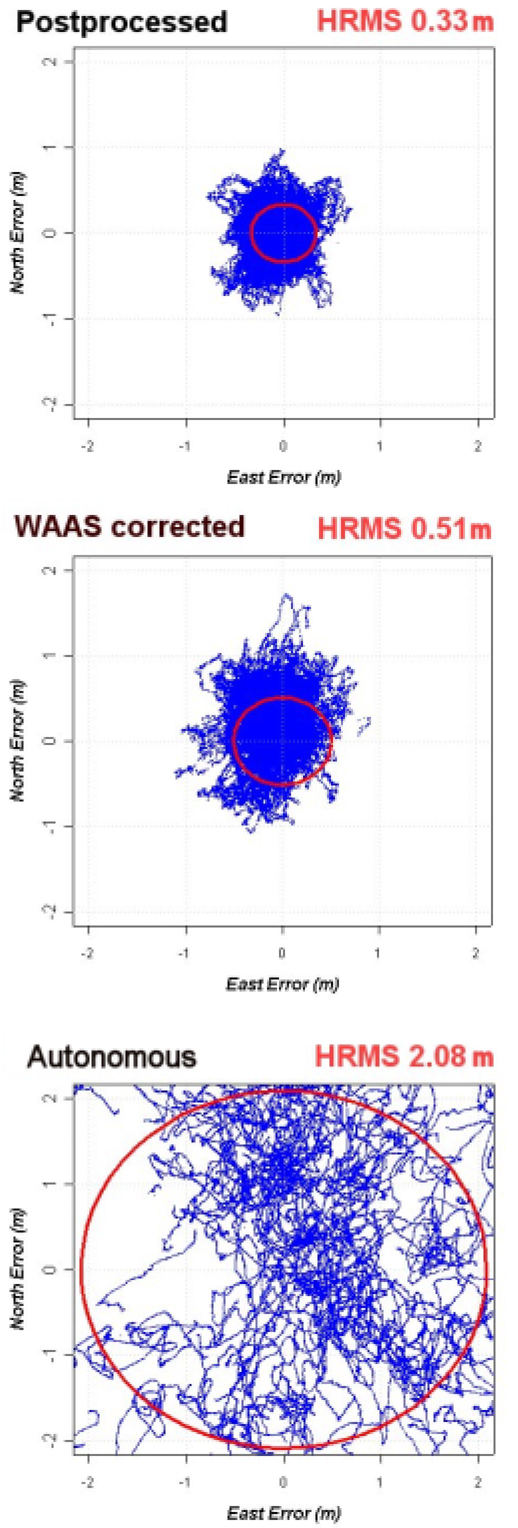


Figure 2:.*Comparison of HRMS values for autonomous, WAAS and postprocessed data*

Postprocessing achieves better accuracy because of the ability to use data collected both before and after the position time. With real-time differential correction, the corrections are predictions based on broadcast corrections from a few seconds earlier, whereas postprocessing uses multiple base observations from before and after the position time. The software is also more powerful and uses more sophisticated algorithms in calculating errors and corrections.

Postprocessing eliminates the problem of dealing with files in different datums, as can occur when a combination of real-time correction sources (eg from WAAS and beacon) are used. When you postprocess, all postprocessed positions will be in the same reference frame as the base station correction source, regardless of what real-time correction sources were used. This simplifies matters. Not only are your positions more accurate, they are also in one known reference frame which can then be matched with the GIS.

Section 2:Benefits of Postprocessed GPS

Accuracy

Not all applications require data to be verified or collected using real-time DGPS. To determine the most appropriate technique, the time frame needs to be considered. If GPS is being used for high-accuracy navigation purposes, real-time DGPS is the only option as the need for accurate positions is immediate.

But for most GPS data collection work, where time is not of the essence, postprocessing back at the office produces much more accurate GPS data. Postprocessing techniques are often essential to ensure that a feature's position can be defined to the required accuracy level.

For example, a land parcel mapping project may require all data to be submeter in order to accurately define the area of the land parcels. However, there is no requirement to have this information in real time. By employing postprocessing techniques in the office, field crews can focus on efficiently mapping as many land parcels as possible, without concerning themselves with real-time DGPS reliability or accuracy results. Postprocessing will provide the required high levels of position accuracy without hampering workflow or imposing extra field mapping requirements.

Availability

Trimble monitors more than 2000 terrestrial reference stations all over the world, and more are being added to the list all the time. Coverage is excellent in the US and very good in many other parts of the world. The list is available in the GPS Pathfinder Office and GPS Analyst software.

To postprocess data, it is necessary to have postprocessing software but the corrections are generally available free of charge.

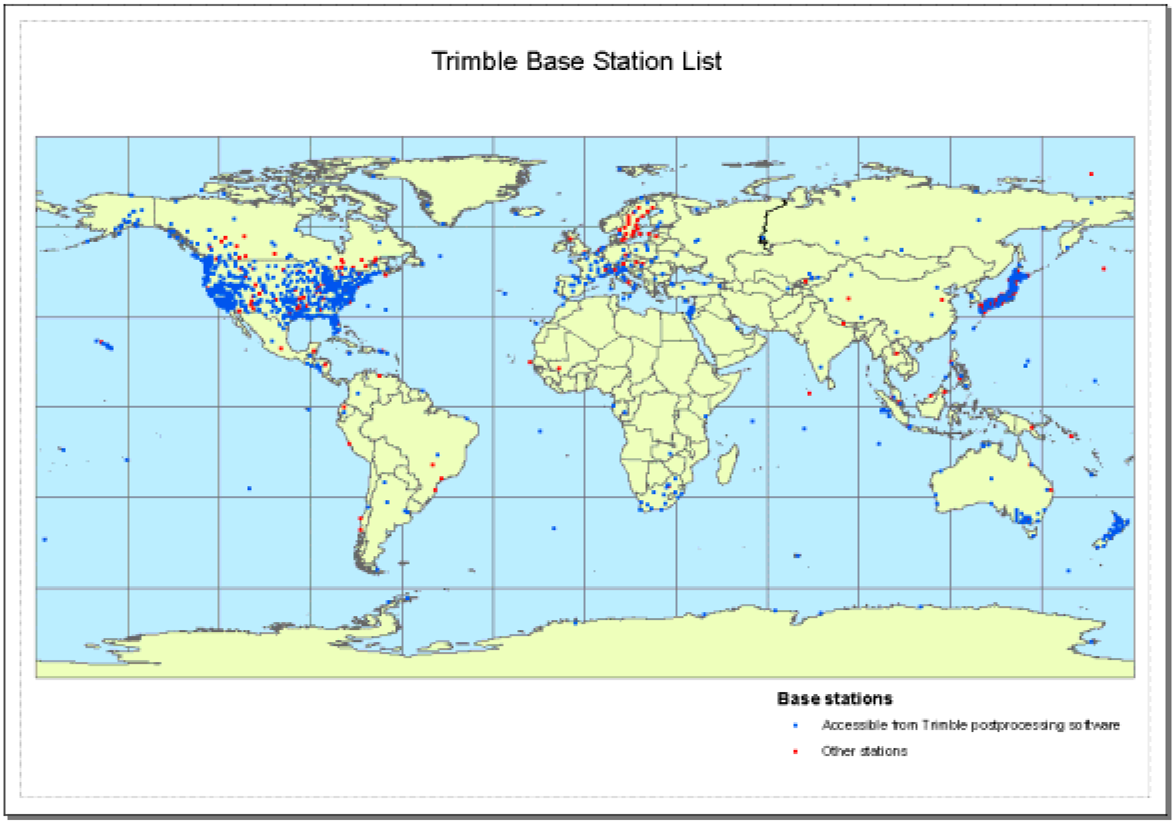
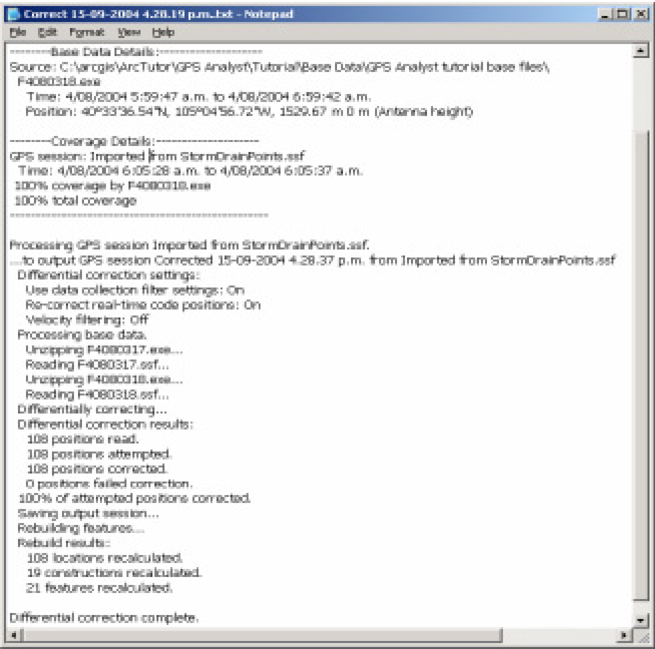


***Figure 3:** Worldwide distribution of base stations*

Quality control (QA/QC)

An important advantage of postprocessing over real-time differential correction is the opportunity to view and record quality assurance and quality control (QA/QC) information. Postprocessing allows you to re-process your data multiple times, and automatically records the settings used each time. If correction fails or does not provide the accuracy results you expect, you can check error logs to analyze the problem, and re-process until you reach the required accuracy.



Correct 15-09-2004 4.28.19 p.m..txt - Notepad

File Edit Format View Help

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--------Base Data Details:--------------------
Source: C:\arcgis\ArcTutor\GPS Analyst\Tutorial\Base Data\GPS Analyst tutorial base files\
 F4080318.exe
  Time: 4/08/2004 5:59:47 a.m. to 4/08/2004 6:59:42 a.m.
  Position: 40°33'36.54"N, 105°04'56.72"W, 1529.67 m 0 m (Antenna height)

--------Coverage Details:--------------------
GPS session: Imported from StormDrainPoints.ssf
 Time: 4/08/2004 6:05:28 a.m. to 4/08/2004 6:05:37 a.m.
 100% coverage by F4080318.exe
 100% total coverage
-----------------------------------------------

Processing GPS session Imported from StormDrainPoints.ssf.
...to output GPS session Corrected 15-09-2004 4.28.37 p.m. from Imported from StormDrainPoints.ssf
 Differential correction settings:
  Use data collection filter settings: On
  Re-correct real-time code positions: On
  Velocity filtering: Off
 Processing base data.
  Unzipping F4080317.exe...
  Reading F4080317.ssf...
  Unzipping F4080318.exe...
  Reading F4080318.ssf...
 Differentially correcting...
 Differential correction results:
  108 positions read.
  108 positions attempted.
  108 positions corrected.
  0 positions failed correction.
 100% of attempted positions corrected.
 Saving output session...
 Rebuilding features...
 Rebuild results:
  108 locations recalculated.
  19 constructions recalculated.
  21 features recalculated.

Differential correction complete.
```

Figure 4: *Postprocessing log*

Using real-time *and* postprocessed GPS

Applications that provide the ability to record location data shouldn't rely on real-time DGPS alone, unless the applications are solely for navigation purposes. Real-time DGPS is useful, but it is not yet 100% reliable. With WAAS for example, the angle of sight has been shown to be too low for users working in heavily forested areas in some parts of the US and Canada.

GPS integrators need to consider how to ensure that the data maintain positional accuracy when real-time DGPS isn't available. The only option is to enable the application to record raw GPS data and allow post-processing techniques to be used—either solely, or even better, in conjunction with real-time DGPS. GPS integrators must be sure their application makes the best use of real-time DGPS, which means that backup techniques should be used to ensure that positional accuracy is maintained when real-time DGPS signals aren't available.

When evaluating GPS field products, it is important to pay close attention to how the GPS software handles DGPS techniques. If you intend to use the GPS application to collect feature positions, then it is important to consider the system's reliability in achieving the needed level of accuracy.

Sometimes real-time DGPS is desirable for the initial verification of features, but post-processing is more appropriate to attain a higher level of accuracy or to fill in gaps where real-time signals were not received.

The ability to reprocess GPS positions in the office allows the data to be verified for confidence, and positions differentially corrected to the highest level of accuracy. There are situations, therefore, when it's desirable to get the best from both real-time DGPS and post-processing techniques.

Re-correcting real-time corrected data requires Trimble field software[1] that can collect SuperCorrect™ data, and Trimble postprocessing software. SuperCorrect data is pseudorange data from the GPS satellites.

With SuperCorrect data, the postprocessing engines in the Trimble software can postprocess any data that was corrected in real time in the field.

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[1] Trimble field software that can log SuperCorrect data includes the following:
Version 2.10 or later of the TerraSync™ software; the Trimble GPScorrect™ extension for ESRI ArcPad software; the GPSAnalyst extension for ESRI ArcGIS software; any applications created using version 1.60 or later of the GPS Pathfinder Tools software development kit (SDK).

As well as increasing the number of corrected positions (by correcting autonomous data where the real-time corrections dropped out), postprocessing gives better results by re-correcting real-time corrected data.

Postprocessing also provides a good quality assurance check (QA) as you will get the results of what happened during postprocessing in a log file. This will tell you how many positions were corrected in real time and how many were corrected in postprocessing.

As explained above, postprocessing eliminates the confusion that can result when a number of different correction sources are used, since all positions end up in the same, known reference frame as the base station correction source.

Trimble-specific features

Base station list

Using the base station list available in Trimble's postprocessing software (GPS Pathfinder Office and GPS Analyst), the software will automatically find and download the required files to cover the rover time span.

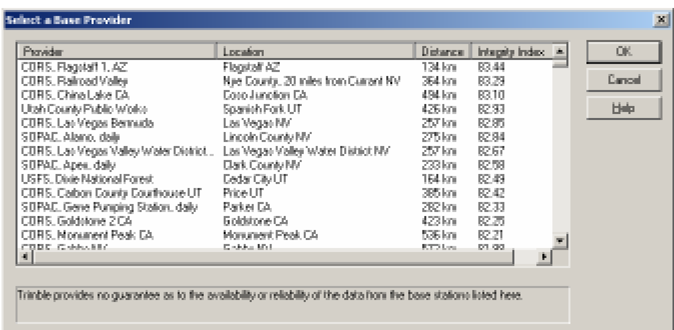

***Figure 5**: Base station list*

Trimble monitors key provider networks (including SOPAC and CORS) for new stations and adds these to its list. These provider websites can be viewed at:

sopac.ucsd.edu/

www.ngs.noaa.gov/CORS/

Other providers can add their base station to Trimble's list by filling in a form at:

www.trimble.com/trs/trsform.asp.

Base station integrity index

Trimble does not guarantee any base data. However, it does perform integrity monitoring to provide an indication of the quality of each station's data.

Trimble's 'integrity index' grading system monitors base station providers from around the world. It rates each station on its reliability, precision, and accuracy, and assigns each station an integrity index value.

When you postprocess rover data in Trimble software[2], you can view and sort stations by distance from the rover data or by integrity index value. The integrity index value displayed is adjusted with proximity to rover data as generally the shorter the baseline the better the results.

Postprocessed accuracy

The accuracy (or real deviation-from-truth number) of a postprocessed GPS position depends in part on the rover receiver characteristics and environmental factors at the time of collection. However, postprocessed accuracy begins and ends with the accuracy and reliability of the GPS base station that the rover data is corrected against.

When considering which base station to use for post-processing, there are several factors that will affect the results:

1. Reference position bias

Base station reference position bias can introduce error. For example, if the reference position for Base Station A is 45 cm from truth, a corresponding error of 45 cm is introduced into the postprocessed solution right from the start. Consequently, those base stations whose reference positions were carefully obtained and are demonstrably accurate are to be preferred.

Since the reference position may have been derived by simply averaging GPS positions over a period of time or even by assuming a coordinate, rather than by conventional or GPS survey operations, trusting a base station's reference position usually takes some research into the method used to obtain it.

[2] Requires GPS Pathfinder Office version 3.00 or later or the GPS Analyst extension version 1.00 or later.

Also, the location of a base station antenna may change due to various factors (such as extreme weather conditions or building renovations); when that occurs, base station operators must be sure to update the reference position using sound practices.

2. Receiver precision

Precision is a measure of the relative spread of a sampling of positions collected over a period of time, or 'repeatability.' A receiver whose reference position is extremely accurate but whose precision is lower (for example, a GPS Pathfinder Pro XL base station as compared to a GPS Pathfinder Pro XR or perhaps a dual-frequency receiver) will contribute to 'wander' in the postprocessed rover data.

3. Baseline length

The farther away you are from the base station, the more error is introduced. This is the ppm (parts per million) component of the accuracy specification for a receiver. For example, 20 cm + 1 ppm means that in addition to the 20 cm of error that will always be present (in a code solution), an additional 10cm per 100 km of baseline distance will also be introduced.

4. Base station reliability

If base station data is not consistently available, then some field data may have to be corrected using another base station with different characteristics. This can result in relative accuracy shifts within a project.

Monitoring base stations

In view of these various factors, Trimble began the Base Station Integrity Monitoring Project (BSIM) in 2002.

This is an ongoing project designed to characterize the integrity of a base station, so that users are able to choose the stations that will give the best postprocessed results. Two servers monitor the reliability of every base station with freely available data and process the data in order to derive a bias measurement and precision value for each base station.

This project continues to monitor base stations on its list and detect changes in bias, precision or reliability. The results of this monitoring project are made available through the base station integrity index in Trimble's postprocessing software.

Base Station Integrity Index

The Base Station integrity index is scaled from 0 to 100, with the best base stations scoring the highest. The station with the highest integrity may not necessarily be the closest. This index is calculated using the integrity characterizations above (bias, precision and reliability) combined with baseline distance between rover and base.

Bias, precision and reliability are subject to change due to various factors, such as station or Web server malfunction, receiver hardware changes, damage to or movement of a base station antenna, etc. These changes are picked up by the BSIM server and passed on to users whenever they download the latest base station list from Trimble's website.

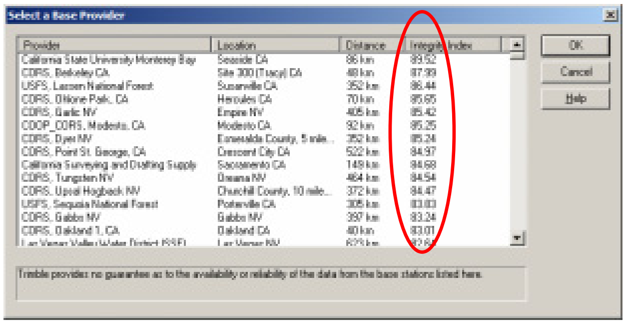

Figure 6: *Integrity index*

Recommendations

- Use base stations with the highest integrity index for code corrections, regardless of distance, data format, or other factors.
- Download the latest base station list from Trimble's website on a monthly basis so that the integrity index shown during differential correction reflects the most recent results of the BSIM. This can be done when selecting a new internet base station provider in the Differential Correction utility.

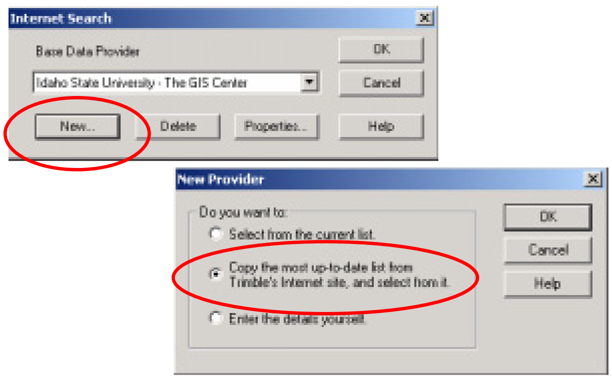

Figure 7: *Downloading the base station list*

- Users of older versions of GPS Pathfinder Office are encouraged to upgrade to the latest version or to the GPS Analyst extension. This ensures that field data is consistently corrected using those base stations that have the highest integrity index.

Conclusion

Postprocessing is an effective differential correction method when:

- There is a need for greater accuracy and greater reliability than can be achieved with real-time DGPS
- Quality Assurance and Quality Control (QA/QC) are important
- Real-time DGPS isn't available or there are gaps when signals were not received
- More than one real-time correction source is used and it is difficult to ensure a match with data in the GIS
- The immediacy of real-time correction isn't needed

In many parts of the world, real-time correction sources are not available, either because the infrastructure does not exist or because users are out of range geographically. Where subscription services are available, the cost of subscription may still be too high.

Base data for postprocessing is often freely available and easily accessible, particularly if using Trimble software. This solves the problem of matching data corrected from different sources with data in the GIS.

There are times when real-time DGPS is useful for the initial verification of features but postprocessing is needed to achieve the required level of accuracy or to fill in the gaps where real-time signals were not received.

Most importantly, postprocessing allows positions to be differentially corrected to the highest level of accuracy, and for many applications, anything less won't do. Postprocessing data provides the most accurate and consistent GPS data of all and is essential for any application requiring reliable submeter accuracy.