WAAS performance with Trimble GPS receivers

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Introduction

WAAS (Wide Area Augmentation System) is a free, real time GPS differential correction service available in the U.S. and southern Canada.

WAAS hasn't been publicized as aggressively as a commercial GPS correction service — it is a United States government Federal Aviation Administration (FAA) program — but recent field tests indicate that properly equipped GPS users can expect submeter correction accuracy across the whole of the U.S. and southern Canada.

By presenting these test results, it is hoped to dispel some popular misconceptions about WAAS and to demonstrate that it is a differential correction source worth considering for U.S. and Canadian users, especially because it is available at no charge.

The paper contains background material about how WAAS works, so that users will have a better understanding of geographical and equipment issues that affect WAAS performance.

Field tests were conducted in 2003 to assess any regional variation in WAAS performance across the Continental U.S. Results showed remarkably consistent WAAS performance.

In a separate series of tests in 2004, Trimble® GPS Pathfinder® Pro XRS receivers were used in a comparative study of WAAS, U.S. Coast Guard radio beacon, and OmniSTAR corrected data, with the aim of ranking WAAS performance. Results showed all correction sources to be submeter, and only a few centimeters apart.

What is WAAS?

WAAS was developed by the FAA primarily for aircraft navigation, but it is available to all GPS users in the U.S. and much of southern Canada. The system has been operating for more than three years and as field tests have shown, properly equipped users within the base station network area are getting consistent sub-meter GPS accuracy.

The system consists of a network of precisely surveyed WAAS Reference Stations (WRS) situated throughout the U.S. The WRS sites continuously receive signals from orbiting GPS satellites and relay their observations to Wide Area Master Stations. The master stations prepare the correction message and transmit it to WAAS satellites via a Ground Uplink Station (GUS). There are currently two WAAS satellites located in geostationary positions above the equator (Figure 1). These broadcast the correction message on the GPS L1 frequency, free to any GPS receiver which is capable of decoding the signal.

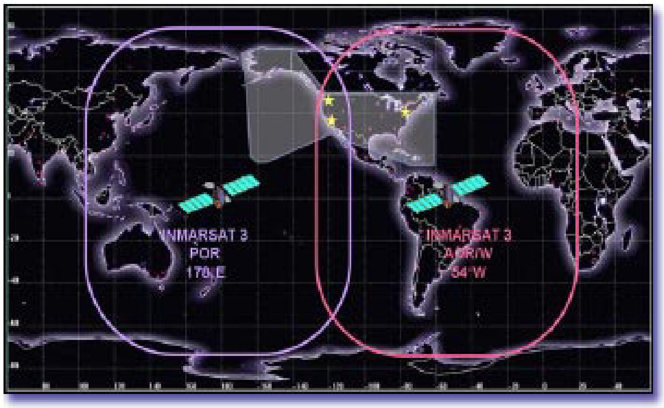

Figure 1: *WAAS satellite locations, broadcast coverage and service volume*

Source: *SatNews, November 2003, gps.faa.gov*

Where can WAAS be used?

As the name suggests WAAS corrections are broadcast over a wide area. Figure 1 shows the broadcast area as the purple and magenta lines, covering almost half the earth's surface. This is in contrast to terrestrial, single base differential correction services such as the U.S. Coast Guard's DGPS beacon service, for which users must be directly within the broadcast radius of a specific beacon station to receive the corrections. While beacon coverage is continually improving towards a goal of U.S. wide coverage, it is possible for users to 'fall between the cracks' and have no corrections available in some locations in the U.S.

It is important to note that WAAS will only provide accuracy improvements when used within the WAAS service volume. The WAAS service volume is the area defined by the WRS network, and is shown in Figure 1 as the opaque area spanning Hawaii, Alaska, the mainland U.S. and Puerto Rico. Even though many users outside the service volume are able to receive a WAAS signal, it will not improve the accuracy of their GPS data.

There are plans to extend the WRS network into Canada and Mexico. Additionally in Europe, the European Geostationary Navigation Overlay System (EGNOS) and in Japan, the MTSAT Satellite Augmentation System (MSAS), are comparable Satellite Based Augmentation Systems (SBAS) currently under development that will provide a free correction service for those regions in the same manner as WAAS.

Does the WAAS satellite need to be in view?

For WAAS corrections to be received there must be line of sight between the GPS receiver and the satellite. The positions of the two WAAS satellites over the equator means that they are low on the horizon for users in some parts of North America, including the northwest United States. Correction signals can be blocked by high terrain, dense vegetation and buildings. This has meant that users in forested environments in the northwest U.S., for example, have had difficulty receiving WAAS corrections because their line of sight to the satellite is blocked by trees. To determine the elevation of the satellite from where you are, go to the following website:

Users in western U.S. go to
http://www.lyngsat.com/tracker/inmar3f3.shtml

Users in eastern and central U.S. go to
http://www.lyngsat.com/tracker/inmar3f4.shtml

The FAA is aware of the problem and plans to launch two additional WAAS satellites within the next two years. This should substantially improve coverage, signal strengths, and system redundancy, particularly in the Western U.S.

A U.S. Coast Guard beacon DGPS broadcast does not require line of sight to exist between the beacon reference station and the roving beacon receiver. This makes the beacon a better differential correction option for working in forested areas, but it should be remembered that beacon signals can be subject to localized terrain shadowing effects, in a similar way to AM radio or TV reception.

What field equipment is required to use WAAS?

A real advantage of WAAS is that not only are WAAS corrections completely free to use, but no additional equipment beyond a GPS receiver is required to receive the signal. Since the WAAS signal is broadcast on the L1 frequency, which is the same frequency as the GPS signal, a WAAS enabled GPS receiver has all the hardware it needs to use WAAS.

There is no need to buy additional hardware, such as the beacon receiver needed by those using U.S. Coast Guard beacon corrections. However you should be careful to ensure that the embedded firmware capabilities of your GPS receiver include WAAS support, as data processing of the WAAS signal differs considerably from the processing of GPS signals.

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.

Measures of accuracy are made relative to a known or 'truth' position (see "Measuring Accuracy"). Similarly, 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 U.S., 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.

GPS positions use the WGS 1984 (World Geodetic System) datum as the reference frame. WAAS corrections use the ITRF 2000 (International Terrestrial Reference Frame) datum as the reference frame, while U.S. Coast Guard beacon and OmniSTAR corrections use the NAD 83 (North American Datum) as the reference frame.

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. Thus WAAS corrected GPS positions are accurate in terms of the ITRF 2000 reference frame and beacon and OmniSTAR corrected GPS positions are accurate in terms of the NAD 1983 reference frame. To compare WAAS positions to beacon positions, a datum transformation between ITRF 2000 and NAD 1983 must be applied to the WAAS positions.

Similarly, 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.

What accuracy can be achieved with WAAS?

Normally, when a GPS base station is used for real-time differential correction, the accuracy of the corrected GPS position deteriorates as the GPS rover moves away from the base station. The WAAS system compensates for this by using data from multiple WAAS reference station sites to model ionospheric corrections that are applicable to all user positions in the WAAS service volume.

In the WAAS system, rather than making the corrections more accurate than single base sources such as beacon, this method maintains the accuracy over wider areas. This in turn has allowed a greater spacing between reference station sites without degrading correction performance. This aspect of the system was tested in the WAAS regional performance tests detailed below.

If the WAAS correction signal is suddenly lost, such as when a user passes behind a structure blocking the line of sight, a WAAS-enabled GPS unit may automatically continue to apply the last good correction. This is an attractive feature, but users should be aware that the older the true correction is, the less accurate the predicted GPS position will be.

Overall, it is important to remember that even with differential correction, it is the quality of the GPS receiver together with your working environment that dictates GPS accuracy. The strongest, most-accurate differential signal available cannot make the average recreational GPS unit perform at a submeter level.

WAAS performance tests

Scope of study

The study of WAAS performance took two separate approaches to gain an overall understanding of how WAAS performs with Trimble receivers. Firstly, Trimble mapping receivers were used to record WAAS corrected GPS positions from multiple locations spanning the U.S. and Southern Canada, in order to determine if any significant regional variations in WAAS-corrected GPS position accuracy existed.

Secondly, in one central location of Westminster, Colorado, WAAS-corrected positions were compared to U.S. Coast Guard radio-beacon, and satellite L-Band OmniSTAR corrected positions in order to determine if any significant differences between these correction sources could be identified.

Testing

GPS positions from both a GPS Pathfinder Pro XRS receiver and a GeoXT™ handheld were collected with Trimble's TerraSync™ software. WAAS was turned ON with a 1 second output interval in both receivers, but otherwise the TerraSync software was used at default quality settings to give an accurate picture of out-of-the-box performance.

In the regional test, the two receivers were logging side by side at each location for four days, to produce four eight-hour data sets. Test sites were selected in California, Wyoming, Montana, Missouri, Texas, South Carolina, Ontario and British Colombia.

Data was not recorded concurrently at each test site due to logistical limitations, however only test sites that had a completely open view of the sky and assessed as interference and multipath-free were used. The purpose of this was to ensure that localized environmental factors did not bias results, but as a result the figures for WAAS-corrected GPS performance should be considered as the optimal results that could be obtained with these receivers.

To compare the performance of WAAS corrections with Beacon and OmniSTAR correction sources, DGPS data from all three correction sources was logged concurrently on three adjacent GPS Pathfinder Pro XRS receivers for over 70 hours. In each instance the integrated real-time option in the GPS Pathfinder Pro XRS receiver was used to track and apply the corrections.

All data was transformed to the North American Datum (NAD) 1983 reference frame (used by beacon and OmniSTAR) before being analyzed for accuracy, to ensure that an 'apples with apples' comparison was achieved. In every instance, the GPS antennas were set up over centimeter accurate truth locations, surveyed in with RTK GPS or conventional survey instruments. It is by comparison to these known coordinates that accuracy statistics were generated.

Measuring accuracy

GPS receivers calculate their position once every second, and 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 a standard statistical measure for specifying GPS accuracy.

As many Geographical Information Systems are primarily focused on horizontal accuracy, horizontal RMS (HRMS) has been used. The HRMS values represent 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.

The smaller the HRMS value, the more accurate the GPS positions. It should be noted that although derived from large data sets, the HRMS value represents the accuracy you could expect at least 63% of the time even if you only logged a single position.

Regional variation in WAAS accuracy

Results from the WAAS regional variation testing are displayed in Figure 2.

The data showed that both the GeoXT handheld and the GPS Pathfinder Pro XRS receiver delivered submeter accuracy with WAAS across all tested locations.

In each instance, the GPS Pathfinder Pro XRS showed greater accuracy than the GeoXT handheld, which is to be expected due to the additional receiver noise of the integrated (GeoXT) handheld and the larger antenna area of the Pro XRS.

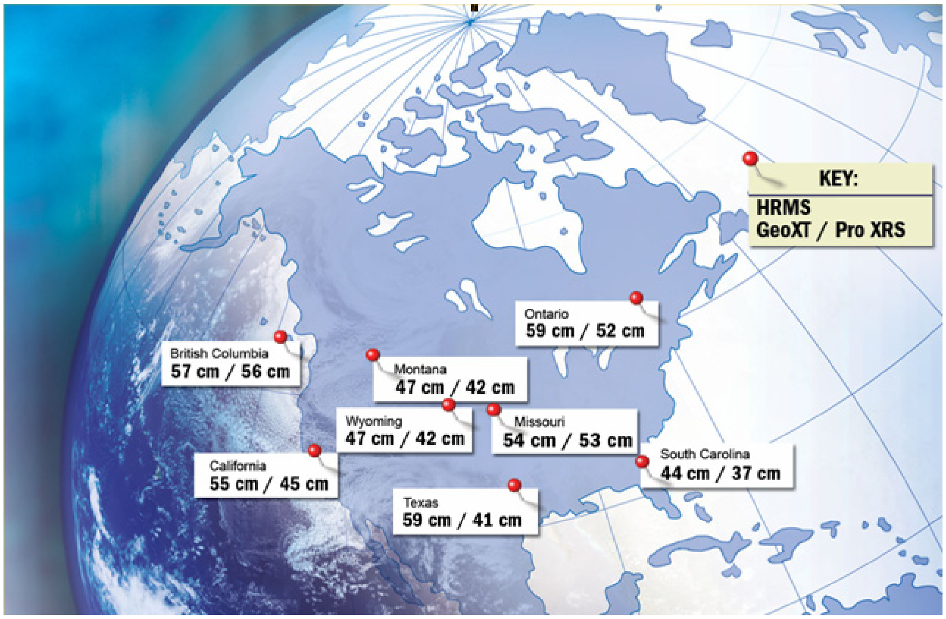

Figure 2: *HRMS values for WAAS corrected GPS accuracy with Trimble GeoXT handhelds and GPS Pathfinder Pro XRS receivers*

Between the test sites themselves, differences of around 20cm were observed in the HRMS values. As previously discussed, there is regional variation in the azimuth and elevation of the WAAS satellites, however because our test sites were set up in open sky environments, this factor has not introduced any regional variance in performance. Likewise the sites were free from local interference sources that may have biased results.

Studies of extreme ionospheric events, such as solar flare activity, have shown that short term ionospheric variations may cause geographically localized errors in WAAS correction data and warning systems are being developed to avoid use of this data in safety critical operations such as aircraft precision approach systems.

Given the test set-up and an understanding of the WAAS correction system, these small observed variances are most likely to have been introduced due to recording datasets on different days, rather than geography.

Comparing WAAS with other realtime correction sources

WAAS corrections are made up of:

- Satellite-specific corrections for clock drift and orbital errors, which are applied regardless of the receiver's location and
- Ionospheric corrections which are applied to each pseudorange by the receiver, depending on its location. As noted earlier, the ionospheric model is produced from data derived from multiple WRS sites located across the U.S.

Beacon corrections use the RTCM (Radio Technical Commission for Maritime Services) correction format to provide pseudorange corrections on a per satellite basis. These are generated based on the single reference location of the beacon station whose broadcast is being received. So although there is almost nationwide DGPS coverage via the U.S. Coast Guard's beacon sites, at any given time the corrections are only derived from one location. This means that the beacon corrections are prone to baseline degradation, while the WAAS corrections are not.

For mapping receivers, a typical single baseline degradation is up to 1 part per million (maximum), or 1cm for every 10km distance between the beacon reference station and the roving GPS receiver. This is a general guideline to the amount of error users can expect from baseline degradation as distance from the reference station increases.

OmniSTAR is a subscription-based service which works in a similar way to WAAS – corrections are transmitted from a network of reference stations to the service's satellites, which then broadcast corrections to subscribers. To use the corrections, you need a receiver capable of decoding the messages. In Trimble's Pro XRS receiver, the decoder is built in. Coverage is worldwide (but not free) and the service is subject to the same line of sight limitations as WAAS.

The following table shows the accuracy of the data recorded in tests run at the Trimble Rockies facility located in Westminster, Colorado. All correction sources performed well in these tests, with 50cm or better accuracy being achieved in real-time.

	Beacon	OmniSTAR	WAAS
HRMS	40cm	48cm	50cm

Table 1: *GPS Pathfinder Pro XRS HRMS values by correction source, Westminster, Colorado.*

The test results produced scatterplots that are typically tightly distributed around the truth location, as displayed in Figure 3. The red circle on each scatterplot represents the HRMS value from Table 1.

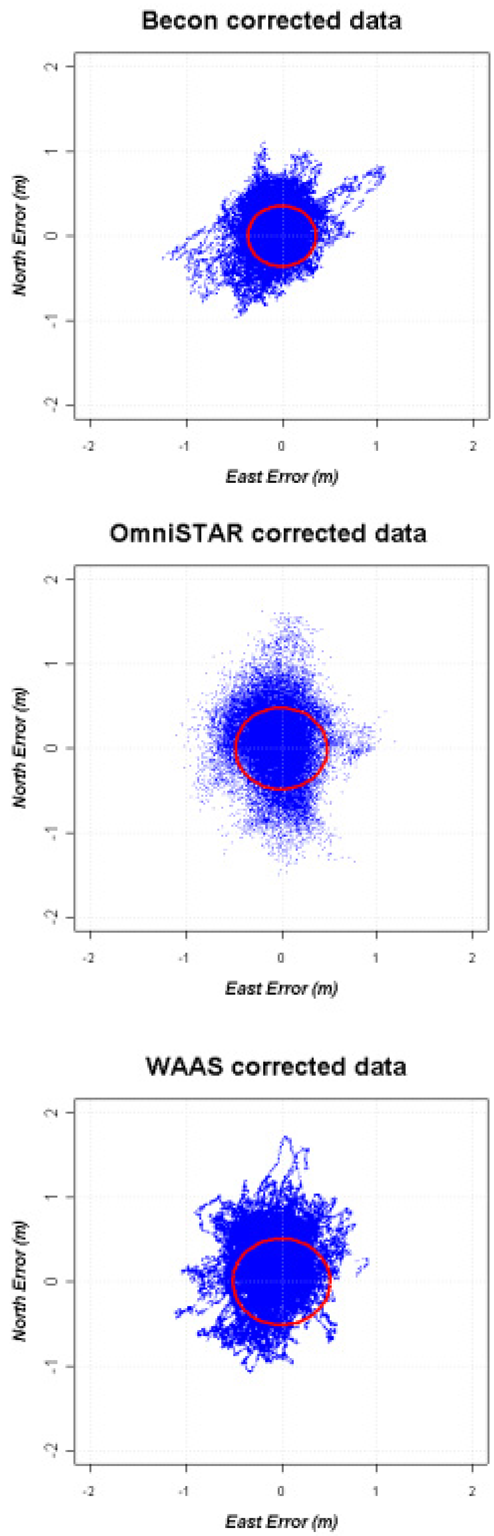

***Figure 3:**: Scatterplots by correction source*

In this test, the beacon corrections from the Pueblo beacon station, 188km distant, gave the best results of the three correction sources. That said, it is important to note that the accuracy of these different correction sources is likely to vary with proximity to the different base station networks, and also with prevailing ionospheric conditions. So that if the test had been performed at a different location or at a different time, the accuracy ranking of the different correction sources may have varied.

Due to being a single base solution, the accuracy of beacon corrections are most likely to vary over a given region, as opposed to the WAAS and OmniSTAR corrections, which due to their networked base and ionospheric modeling are more likely to give consistent results, day to day and location to location.

Summary

- Test results show that WAAS-corrected data is consistent and reliable across the U.S., with little variation geographically.
- Compared with beacon and OmniSTAR corrected data, WAAS also delivers submeter accuracy. All three correction sources were within centimeters of each other in terms of accuracy in tests conducted at Westminster, Colorado.
- On any given day, depending on ionospheric conditions and proximity to their respective base station networks, any of the correction sources could be slightly more or less accurate than the others.
- Since all correction sources tested provide submeter accuracy, users should select the one that best suits their working environment.
- WAAS has the advantage of requiring no additional equipment, and is thus highly convenient. Line of sight issues may preclude its use in forested environments, where beacon may be a better choice.
- Over 500 hours of testing across the U.S. have shown that WAAS is a correction source which consistently provides submeter accuracy. And best of all, the corrections are free.