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Tailoring GPS for the Forest Service: MTDC's Testing and Evaluation Program

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Introduction

Many employees in the Forest Service, U.S. Department of Agriculture, rely on the global positioning system (GPS) for accurate information on their location and for help with navigation. Just a decade ago, GPS was an expensive technology used by a few individuals in the Forest Service. Although inventory and mapping (figure 1) are now the most common uses of GPS in the Forest Service:

- Firefighting employees use GPS to record fire boundaries.
- District employees use GPS to record the locations of invasive species.

Figure 1—GPS is used throughout the Forest Service for a variety of purposes. MTDC has been evaluating GPS technology to help Forest Service employees understand its capabilities. (Photo by Paul Bolstad, University of Minnesota, Bugwood.org).

Highlights...

- MTDC began evaluating GPS technology in 1983.
- In the early days, MTDC helped manufacturers modify their products to meet the Forest Service's needs.
- MTDC has managed a program that allowed Forest Service employees to use GPS receivers with military-grade accuracy.
- Test courses established on national forests in different parts of the country provide realistic tests of GPS receivers' accuracy.
- As GPS systems improve in coming years, MTDC will continue testing and evaluating the technology for the Forest Service.

- Researchers use GPS to record the locations of nesting trees or other important features of wildlife habitat.
- Recreation specialists use GPS to record the location of trails.
- Crews use GPS when surveying roads, boundaries, and other areas that require high accuracy.

In the early days, the accuracy of GPS receivers was poor, especially under tree canopies. Now, recreation-grade receivers cost just a few hundred dollars and provide reasonable accuracy (within 15 meters). Receivers with accuracies within a few meters (even under tree canopies) can be purchased for several thousand dollars.

Since the early 1980s, the Missoula Technology and Development Center (MTDC) has been helping the Forest Service with issues regarding GPS equipment. This report summarizes the history of the GPS program at MTDC, discusses the current state of the program, and describes the work that will be required for the Forest Service to adapt to new GPS technologies.

History of MTDC's GPS Program

MTDC has been working with GPS technology since 1983 when the Washington Office engineering and timber staffs asked the center to investigate potential uses of GPS in resource management. Since then, MTDC has worked closely with GPS equipment manufacturers to evaluate and test receivers for use by Forest Service employees (figure 2). The GPS program at MTDC was officially chartered in 1989.

Figure 2—In 1988, GPS receivers were bulky, heavy, and expensive. It sometimes took hours to determine a position. Now hand-held GPS receivers that cost just a few hundred dollars can do an even better job.

History of GPS

The U.S. Department of Defense (DOD) launched the first GPS satellite in 1978. Seventeen years after the launch of the first test satellite, the satellite constellation was fully operational. It included 24 NAVSTAR satellites: 21 operational satellites, and 3 spares.

The satellites are arranged in six orbital planes inclined 55 degrees relative to the earth's equator and separated by 60 degrees from one another. Four satellites are in each plane. The satellites orbit at an altitude of 12,550 miles (20,200 kilometers), completing each orbit in about 12 hours. This arrangement ensures that at least four satellites will always be in view above the horizon at any time from any point on earth.

The broadcast signal identifies each satellite, its status, its location, and the time. This precise time is used by the ground-based GPS receiver to calculate the distance to the satellite. The receiver determines the time of broadcast and the position of the satellite at the time of broadcast using the satellite's identification and an almanac stored on the GPS receiver. The difference between the broadcast time and reception time is used to determine the distance to a given satellite. If distances can be calculated to a minimum of four satellites, the receiver's location can be determined in three dimensions. If more satellite signals are available, accuracy can be increased.

The signal is broadcast from each satellite on two different codes: the precise P(Y) code for military users and the course/acquisition (C/A) code for civilian users. Until a few years ago, the C/A code was purposely degraded to reduce its accuracy. This degradation, called selective availability (SA), could be turned on and off by the military.

When SA is turned off, civilian GPS receivers are typically 10 times more accurate than when SA is turned on. SA was permanently turned off in 2000. In September 2007, President Bush mandated that future GPS satellites would not have the SA capability.

In 1995, the DOD began allowing some civilian government agencies, such as the Forest Service, to use P code receivers. When the P code is encrypted, as it is under DOD policy, it is referred to as the P(Y) code. The P(Y) code, which is inherently more accurate than the C/A code used by civilians, can only be decrypted by GPS receivers with a valid decryption key.

Differential GPS

Several systems have been developed to improve the real-time accuracy of civilian GPS receivers. These systems are called differential GPS or DGPS. DGPS uses the fixed location of a reference station to determine just how far off the location based on the satellite signal is from the station's surveyed location at any moment. The difference, or inaccuracy, can be transmitted to DGPS receivers, which use the inaccuracy to correct the location determined by the satellite signal. The DGPS systems in the United States include:

NDGPS—This land-based nationwide DGPS system has 86 operational sites, each with a precisely surveyed GPS antenna. When a site is brought online, its GPS receiver calculates the pseudorange (estimated distance) from the antenna to each of the satellites in view. The pseudorange is compared to the actual distance from the receiver's antenna based on the survey. The difference between these values is the correction factor or differential correction. This differential correction is broadcast for users in the coverage area of the NDGPS facility. To use NDGPS, your GPS receiver must be able to receive broadcasts from NDGPS sites. Such receivers are called beacon receivers. The NDGPS system can provide 1- to 3-meter accuracy. The closer you are to the NDGPS site, the better the accuracy.

WAAS—WAAS (Wide Area Augmentation Service) consists of about 25 ground reference stations across the United States that monitor GPS satellite data. Two master stations, located on either coast, collect data from the reference stations and create a GPS correction message. This correction accounts for drifts in the satellites' orbits and their

clocks as well as signal delays caused by the atmosphere and ionosphere. The corrected differential message is broadcast through one of two geostationary satellites (satellites with a fixed position over the equator). The information is compatible with the basic GPS signal structure, which means any WAAS-enabled GPS receiver can read the signal. WAAS can improve GPS accuracy to within 3 meters.

CORS—Some GPS manufacturers have developed software packages that allow users to improve the accuracy of information that has already been collected. For instance, a recreation specialist can collect GPS points on a trail and process the information later to improve the accuracy. The National Geodetic Survey, an agency of the National Oceanic and Atmospheric Administration, coordinates the Continuously Operating Reference Station (CORS) network. These reference stations (sometimes called base stations) collect correction information from each satellite and store the data in files. Software packages use the information from the CORS files to correct the user's data.

The Forest Service operates several base stations around the country to provide correction information for users in those areas. MTDC maintains and archives the correction information on the Forest Service's GPS Web site (figure 3, *http://www.fs.fed.us/database/gps*).

Figure 3—MTDC maintains the national GPS Web site for the Forest Service.

GPS in the Forest Service

The Forest Service began to use GPS receivers for surveying in the mid-1980s. At the time, each receiver cost $75,000. A company provided the receivers, processing software, and support for the Forest Service.

These survey-grade GPS receivers were large, heavy, and power hungry. A 12-volt automotive battery would operate the unit for just 3 to 4 hours. Preparing to use the GPS units required quite a bit of planning because the satellite constellation included only four to five satellites in the early days, the minimum required. The satellites were available simultaneously only for 3½ to 4½ hours a day. It took 45 to 90 minutes to get an accurate position at each station.

As the technology matured, the Forest Service separated GPS activities into two functions: surveying and resource management. The two functions had different requirements. Survey-grade receivers have to track both the C/A code and the carrier phase code (an additional code broadcast from GPS satellites that enables higher accuracy). Doing so requires a clear view of the sky 10 to 15 degrees above the horizon to prevent losing the lock on the satellite signal. This type of receiver is not suited for resource management activities where much of the work is under the forest canopy. Resource management work requires a receiver that tracks just the C/A code and that can tolerate signal interruptions.

Land surveyors in each Forest Service region were responsible for implementing survey-grade GPS technology. MTDC was given the responsibility for implementing GPS technology in resource management activities throughout the Forest Service.

In 1986, a workshop was held for GPS manufacturers, Forest Service users, and representatives from the DOD's GPS Joint Program Office. Nine manufacturers participated in the workshop, as did 25 Forest Service employees representing most resource functions. This workshop gave the GPS industry a better understanding of the requirements and needs of Forest Service field employees.

GPS Test Courses

MTDC established a GPS test course at the Lubrecht Experimental Forest northeast of Missoula, MT, by surveying geodetic control points under a typical forest canopy. These control points were used to evaluate the accuracy of GPS systems being tested. This course, established in 1986, was the first of its kind for the Forest Service. The course also was used to help instructors teach students GPS procedures and methods. This course has been used extensively by MTDC over the years for testing the accuracy of new receivers.

Other test courses have been located and surveyed across the United States (figure 4). In 1991, an eastern test course was established under a heavy canopy of mixed oak, hickory, and beech at the Hoosier National Forest near Bedford, IN. A West Coast test course was set up in 1995 at the Clackamas District of the Mount Hood National Forest. This course is in a stand of dense, second-growth Douglas-fir and western hemlock. In 1998, a northeastern hardwood test course was established at Ridley Creek State Park, PA. In 2000, a test course was established at Powell, ID, under a canopy of old growth cedar on the Montana-Idaho border (figure 5). Another test course was established at the El Yunque National Forest in Puerto Rico to test receivers in a tropical forest ecosystem (figure 6). These courses allow MTDC to evaluate GPS equipment under canopy conditions representative of those that Forest Service users could expect to encounter.

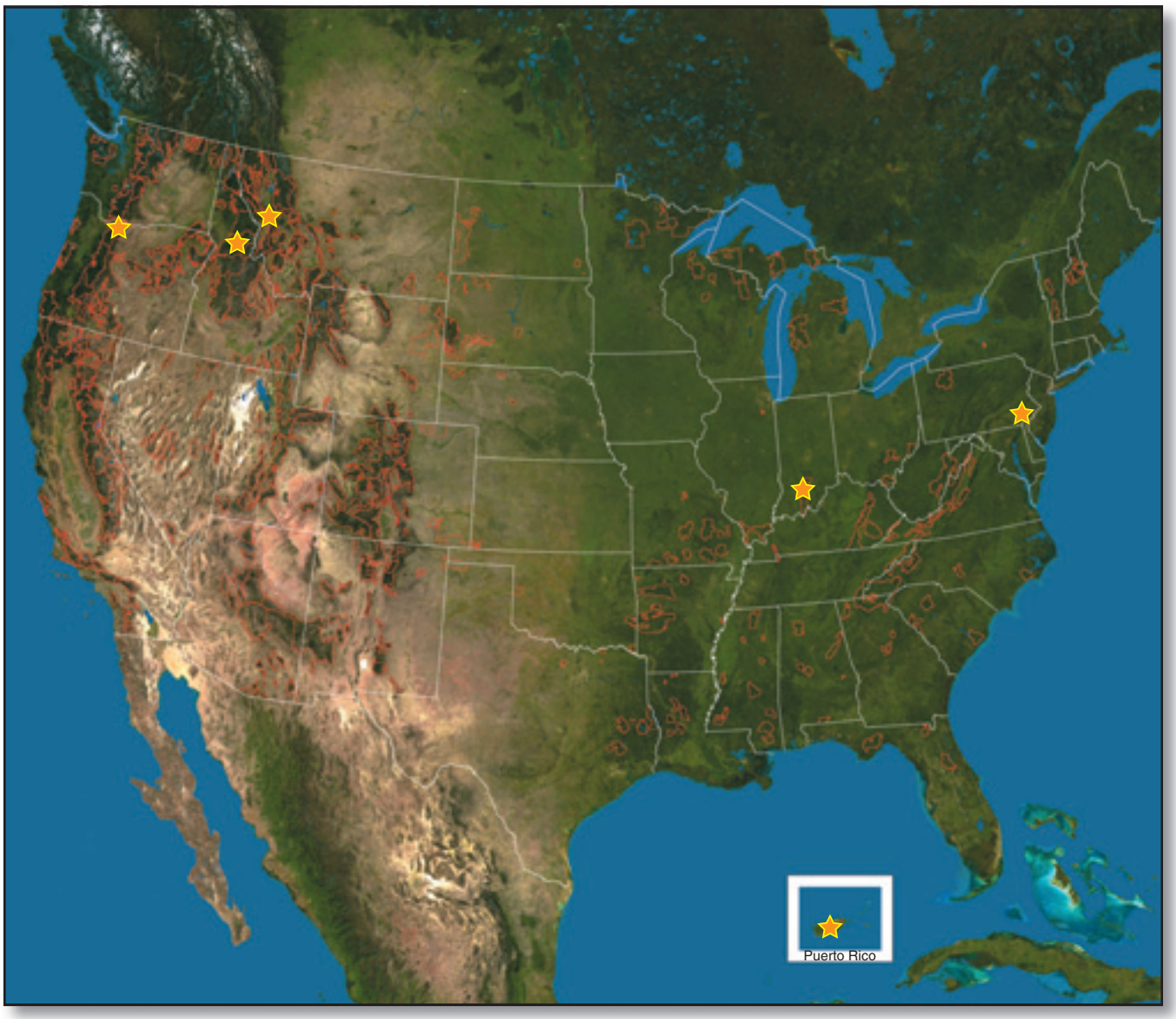

Figure 4—Six courses are set up across the United States to test GPS receivers under different canopy types. Tests conducted at these courses help Forest Service employees know how much accuracy to expect when using GPS receivers under different types of forest canopies.

Figure 5—The old growth cedars at the Powell, ID, test course form an especially dense forest that is a challenge for many GPS receivers.

Figure 6—A test course in the El Yunque National Forest in Puerto Rico allows Forest Service employees to test GPS receivers under a tropical canopy.

PPS Receiver Support

In 1994, the Forest Service and several other civilian agencies were authorized to acquire and operate military precise positioning service (PPS) receivers through a memorandum of understanding with the DOD. These receivers are accurate within 9 to 10 meters under a dense forest canopy. The security modules in these receivers must have a decoding key installed each year. MTDC established a communication security (COMSEC) account with the National Security Agency. This account allows the center to acquire the classified keying material. In 2007, hundreds of PPS receivers were in use throughout the Forest Service.

Each PPS receiver contains a code module that must receive a "key" to be activated. This key is changed on a date that is kept secret by DOD. Without this key, the receivers cannot access the P(Y) code. All Forest Service PPS receivers (figure 7) must be inventoried and rekeyed at least once a year at the Missoula COMSEC facility. In addition, some receivers must be keyed more than once a year because their battery fails or the key is canceled inadvertently.

Figure 7—Some Forest Service employees use the Rockwell PLGR, a precision lightweight GPS receiver. This receiver needs to be keyed annually by MTDC so it can receive the military P(Y) code that allows increased accuracy in dense forests and in deep canyons.

Current Program Objectives

The MTDC GPS program is directed by a steering committee that meets annually to review progress and provide direction for the program. The committee includes individuals from across the country who serve as representatives of their region or resource area. The steering committee's current guidance for MTDC's GPS program is to:

- Provide field support for GPS technology.
- Test and evaluate new GPS receivers and technology.
- Provide support for PPS GPS receivers used by the Forest Service.
- Provide support for GPS technical approval and blanket purchase agreements.
- Maintain the Forest Service national GPS Web site.
- Support new applications of GPS.

GPS Receiver Testing and Evaluation

The focus of MTDC's GPS program has shifted as the technology has matured. In the early days, receivers were changing dramatically and the Forest Service was one of the major users of the equipment. MTDC helped test and evaluate the equipment and provided specifications to the manufacturers so their equipment met the agency's needs. As the technology has matured, MTDC's ability to steer development has decreased. However, Forest Service personnel still need to know the capabilities of GPS receivers, especially when they are used under a forest canopy. Now MTDC's GPS program focuses mainly on product evaluation (figure 8).

Most manufacturers test their receivers in open canopies and report the results as expected accuracy. This accuracy can't be achieved when the GPS receiver is used under a forest canopy. MTDC tests many new GPS receivers at Forest Service test courses and posts the tested accuracies in a spreadsheet that is available at *http://www.fs.fed.us/database/gps*. MTDC also tests GPS receivers for their ease-of-use, ruggedness, and other characteristics that are important for field users. Additionally, MTDC will evaluate new equipment such as cameras and personal digital assistants that include GPS receivers and other new technologies incorporating GPS.

Figure 8—MTDC GPS Program Leader Dick Karsky (foreground) testing several GPS receivers.

CIO GPS Technical Approval and Blanket Purchasing Agreement

Forest Service employees must have technical approval to purchase GPS receivers and associated software (Forest Service Manual, section 6615.01c1, USDA Moratorium on Information Technology Acquisitions). MTDC works closely with the Forest Service Chief Information Office (CIO) mobile computing program to ensure that the GPS equipment and software listed in the standard technical approval meet the needs of Forest Service employees. Otherwise, individual technical approvals would have to be completed for specific hardware or software, sent to the CIO, and reviewed by qualified personnel. The process is time consuming and costly to the agency. The CIO, with MTDC's assistance, is preparing blanket purchase agreements for GPS and other mobile computing technologies.

National Forest Service GPS Web Site

MTDC maintains and hosts a national Forest Service GPS Web site. The Web site (*http://www.fs.fed.us/database/gps*) includes:

- Links to CORS base stations operated by the National Geodetic Survey, Trimble Navigation Limited, and the Forest Service. The Web site includes the database for the Forest Service base stations, allowing users to postprocess GPS data for improved accuracy.
- A section with GPS training material assembled by Forest Service GPS experts and trainers over the years.
- A section on GPS hardware and software that includes links to the latest hardware and software available from companies, training information, software upgrades, and user FAQs (Frequently Asked Questions).
- A section with Forest Service GPS receiver testing reports and a spreadsheet with the latest GPS receiver accuracies based on Forest Service tests.
- A section with a table of the latest regional GPS and base station coordinators.

Aerial Spraying

For pilots to apply insecticides, herbicides, and fertilizers accurately, safely, and efficiently, they must be able to identify spray plot boundaries and position the aircraft correctly for each spray swath. Atmospheric conditions such as temperature, wind direction, and windspeed affect the drift of spray droplets. Systems that incorporate GPS and meteorological equipment in the aircraft's guidance system can optimize aerial application. Some systems integrate mechanical information such as spray pressure, flow rate, and droplet size to help account for spray drift (figures 9a and 9b).

MTDC has evaluated and tested precision aircraft spray systems incorporating GPS for more than a decade. Systems continue to become more sophisticated, incorporating new technology and modeling systems that improve the spray accuracy, even on sprayers used on all-terrain vehicles (ATVs, figure 10) and utility vehicles (UTVs).

Figure 9a—Aerial applicators now use GPS systems when spraying. The GPS coordinates of the area being sprayed, windspeed, and wind direction are used to put the spray aircraft on a path that ensures the spray is applied where it belongs.

Figure 9b—The GPS unit's screen is mounted where the pilot can use it to position the aircraft precisely where it needs to be.

Figure 10—MTDC has developed a sprayer for ATVs (and UTVs) that will apply a set rate of herbicide even when the ATV speeds up or slows down. The controller uses GPS information to estimate ground speed. That estimate is used to adjust the sprayer's pressure.

Future of GPS in the Forest Service

GPS technology has advanced tremendously during the past two decades. GPS receivers that were very expensive and bulky are now affordable, hand-held units with predicable accuracy. MTDC has helped the Forest Service during this period by evaluating and testing GPS receivers, installing the decoding key for military-grade receivers, and providing training and technical support.

Although GPS receivers are now a consumer product, significant changes planned soon mean the Forest Service will continue to need evaluations, testing, and training.

Galileo Satellite Network

The European Union and the European Space Agency are developing a global navigation satellite constellation that will greatly increase the number of satellites available to users and also perform better (in theory) than the GPS system now used in the United States. The European system, called Galileo, is not based on military needs, although certain channels from the satellites can be turned off during times of "extreme circumstances." The constellation will include 30 satellites. New receivers that receive signals from both the GPS and Galileo satellite constellations should be able to provide higher accuracy.

GLONASS

The Russian Space Agency is committed to reestablishing and modernizing its GLONASS system. Receivers are available that use a combination of GPS and GLONASS satellites to establish position fixes. Extra satellites can help under difficult field conditions, such as under dense tree canopies and in deep canyons.

GPS III

The United States is planning a new GPS satellite constellation called GPS III. The new system is being developed to improve GPS accuracy and availability for all users. GPS III will have new ground stations and 30 to 32 new satellites, with additional navigation signals for both civilian and military users. The GPS III system is expected to have about 500 times the transmitter power of the current system, providing more robust signal transmissions. The new system is expected to have real-time accuracy within 1 meter without any additional corrections.

MTDC will be testing and evaluating the new Global Navigation Satellite System (GNSS) receivers that will receive both the GPS and Galileo signals and receivers that receive both the GPS and GLONASS signals. MTDC also will be testing and evaluating the new GPS III receivers as they become available.

About the Authors

Andy Trent is a project engineer at MTDC. He received his bachelor's degree in mechanical engineering from Montana State University in 1989. Before coming to MTDC in 1996, Andy worked as a civilian engineer for the Department of the Navy.

Dick Karsky has been program leader for forest health protection, GPS, and the air portion of the watershed, soil, and air program since the fall of 1999. Dick has been a project leader at MTDC in the resource areas of GPS, range, cooperative forestry, engineering, fire, reforestation and nurseries, residues, recreation, and forest health protection. He received a bachelor's degree in agricultural engineering from North Dakota State University and a master's degree in agricultural engineering from the University of Minnesota. He worked for private industry before coming to MTDC in 1977.

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Since 1983, MTDC has been testing and evaluating GPS (global positioning system) technology for use in the Forest Service, U.S. Department of Agriculture. In the early days, when GPS systems were expensive, bulky, and difficult to use, MTDC worked with the manufacturers to suggest improvements. Now that the technology has matured, MTDC is more involved with testing GPS receivers in typical Forest Service settings to help determine how well they meet the Forest Service's needs. As GPS systems are improved, MTDC will continue testing and evaluating the newest technologies to see how well they meet the Forest Service's needs.

Keywords: accuracy, aerial application, aerial spraying, C/A, COMSEC, CORS, DGPS, Galileo satellite system, GNSS, GLONASS, GPS III, history, PPS, P(Y), surveying, surveying instruments, WAAS

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