MTDC and GPS

In August of 1983 the Forest Service's Washington Office Division of Engineering assigned MTDC a project to investigate GPS technology. Engineering and Timber staff groups were the first sponsors of this program. They recognized the potential of GPS technology for resource management activities. The program is currently sponsored by Forest Service staff groups responsible for engineering, timber management, fire and aviation management, forest health protection, recreation, law enforcement, research, lands and mineral management, and wildlife.

Before the advent of GPS, MTDC examined other radio-navigation systems such as Loran, local radio-beacon matrix, and microwave. Loran-C was investigated as a possible spray-aircraft guidance system for Forest Health Protection. Its coverage area was too limited and it was not accurate enough. Other technologies using local networks tended to be exorbitantly expensive, because they needed to be configured and constructed for each project site.

GPS had a proposed accuracy of 16 meters (3-D) spherical-error probability (SEP) and 8 meters (2-D) circular-error probability (CEP), with 24 hour-a-day availability and worldwide coverage. The role of MTDC has been to evaluate whether this new technology could be applied to Forest Service operations. Responses to a Servicewide questionnaire in 1984 identified 140 possible resource applications. These varied from locating oil well heads, to guiding spray aircraft and marking wildlife nesting trees.

A workshop was held by the Center in May 1986 for GPS manufacturers, Forest Service users, and representatives from the Department of Defense's GPS Joint Program Office (JPO). Nine manufacturers participated, as did 25 Forest Service personnel representing most resource functions. This meeting produced an exchange of ideas between manufacturers and field users that gave the GPS industry a better understanding of Forest Service requirements and needs.

In July 1986, Rockwell Collins demonstrated its NAVCORE I receiver at MTDC. This system weighed 10 pounds without batteries and had to be carried in a backpack. The battery pack added another 10 pounds and only provided for 3 hours of operation. Even with these limitations, the system was impressive when it was evaluated a year later by MTDC on the University of Montana's Lubrecht Experimental Forest near Missoula, Montana. Field personnel especially liked its ability to digitize road locations for mapping. The forest canopy's tendency to attenuate the signal and degrade horizontal accuracy was noted during these early tests. MTDC issued a report and overall evaluation of the system.

The NAVCORE I evaluation pointed up the need for a test and training facility. In June 1987 a memorandum of understanding with the University of Montana School of Forestry was signed establishing such a facility at the Lubrecht Experimental Forest (Figure 4). That same year MTDC contracted with GPO Hydro, Inc., to bring geodetic control (1-250,000) to the site. The test site represented a forest canopy typical of the Northwest. From this control survey several closed traverses were surveyed with known coordinates determined for each station (Figure 5). These known coordinates were used to evaluate the accuracy of GPS systems being tested at the site. The test site would also help instructors teach students GPS procedures and methods.

After the 1986 manufacturer-user workshop, Trimble Navigation asked MTDC to evaluate its prototype TANS GPS receiver. This was a 2-channel portable unit weighing 10 pounds with batteries. This unit's accuracy was 8 meters, with the possibility of differential correction down to 2 to 5 meters. This level of accuracy was considered excellent at this time. Selective Availability (SA) had not yet been turned on. MTDC eventually acquired a Trimble TANS receiver, the Center's first GPS system.

In June 1988 the first of 26 GPS training sessions was conducted at Lubrecht

Figure 4—In 1987 a cooperative agreement was signed with the University of Montana establishing a GPS test and training facility at the University's Lubrecht Experimental Forest.

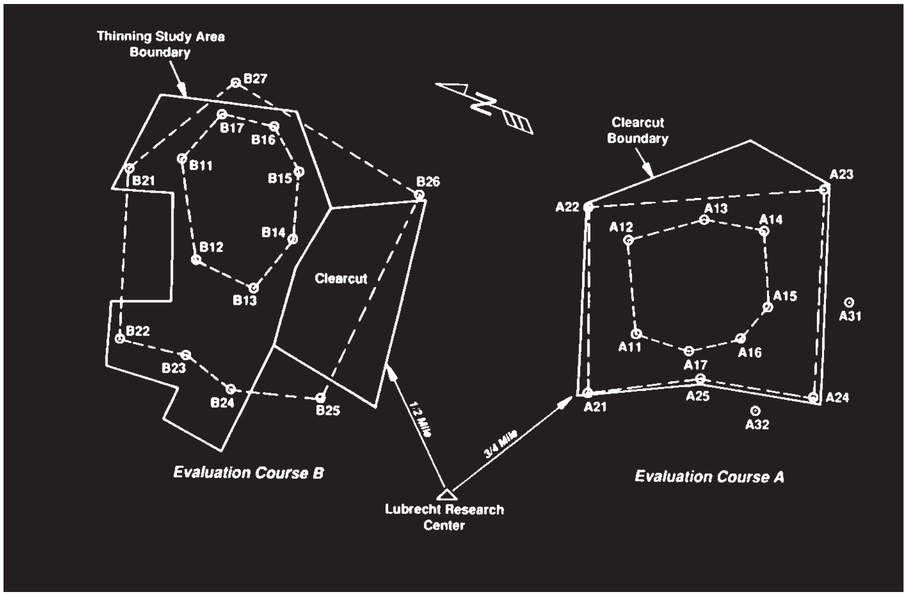

Figure 5—A control survey established several closed traverses with known coordinates at the Lubrecht test site.

under the auspices of the University and the Center. These 3-day sessions included about 15 to 20 students, and were scheduled four times a year (Figure 6). They provided realistic hands-on training in a typical resource-management environment. GPS manufacturers were invited to attend and demonstrate their products to the students. This interaction led GPS manufacturers to develop lighter receivers tailored to Forest Service needs that were capable of better accuracy under forest canopies. These classes also helped expose many Forest Service personnel to the possibilities of GPS technology.

MTDC prepared the specifications for a contract for 50 TANS receivers that was let in June of 1989. MTDC subsequently asked that this Trimble receiver be made available through the General Services Administration (GSA). GPS technology was rapidly becoming more sophisticated at this time. A 6-channel receiver was evaluated by MTDC. It had improved efficiency under a dense canopy. The Center prepared specifications for this advanced system. Trimble again won the bid. By October 1992, Trimble had supplied over 500 6-channel units. By 1993 many GPS manufacturers had arranged to have their equipment available through GSA.

In July 1989 a GPS Steering Committee was formed to guide implementation of GPS technology in the Forest Service. The committee developed a Servicewide plan that directed the Center to provide direction in GPS training and procurement, establish test and evaluation sites, and test equipment to ensure that field users had the best possible GPS equipment.

Three additional GPS test sites were located and surveyed. In April 1991, an eastern site was established under a heavy canopy of mixed oak, hickory, and beech on the Hoosier National Forest near Bedford, Indiana. A West Coast site was set up in 1995 on the Clackamas District of the Mount Hood National Forest. This site is in a stand of dense, second-growth Douglas-fir and western hemlock. In 1998, a northeastern hardwood site was established at Ridley Creek State Park, Pennsylvania. In 2000 another site will be operational under an old-growth cedar canopy on the Montana-Idaho border. These sites allow MTDC to evaluate GPS equipment under canopy conditions representative of those that Forest Service users could expect to encounter.

Figure 6—In June 1988 the first of 26 GPS training sessions was conducted at Lubrecht under the auspices of the University of Montana and MTDC.

In May 1994, the Forest Service and several other civilian agencies were authorized to acquire and operate the military Precise Positioning Service (PPS) receivers through a memorandum of agreement signed with the Department of Defense. These receivers provide resource managers with a GPS unit capable of an autonomous accuracy of 9 to 10 meters under a dense forest canopy. PPS receivers require that their security modules be keyed each year. MTDC established a Communications Security Account (COMSEC) with the National Security Agency. This account allows the Center to acquire the classified keying materials. Today over 500 PPS receivers are in use throughout the Forest Service. All receivers are rekeyed annually and serviced by the COMSEC facility at MTDC.

Figure 7—The GPS Support Program has evaluated data loggers capable of downloading data into Arc/Info and other GIS software.

Operational GPS Support

MTDC has supported GPS throughout the Forest Service by working with the electronics industry to obtain equipment that is more suitable for Forest Service operations. The Center's GPS program personnel are active members of all GPS user committees within the Forest Service and represent the Forest Service at GPS meetings sponsored by the DOD and civilian governmental agencies. The Center lobbied DOD in 1997 for a relaxation of user restrictions for PPS P(Y) code receivers. This relief was granted, allowing GPS technology to be used in Forest Inventory and Analysis (FIA) operations.

The GPS Support Program has evaluated data loggers (Figure 7) and pen-plotter equipment capable of downloading data into Arc/Info and other GIS software. The program worked with law enforcement in the early 1990's on a method of tracking log rafts in the Gulf of Alaska using the ARGOS satellite system. The Center has evaluated Wide Area GPS Enhancement (WAGE) and conducted a number of user surveys to determine the types of GPS equipment that is needed in the field.

Experience with GPS receivers has shown that topography and vegetation (such as a tree canopy) may block or attenuate satellite signals. The signal can be fairly strong where no foliage interferes, but be completely blocked only a few meters away (Figure 8). Signals that bounce off nearby cliffs before reaching a GPS receiver (multipath signals) create positional errors. Even when the receiver is stationary, the amount of foliage in the signal path can change rapidly due to wind in the canopy. Movement of the receiver and of the satellites in and near canopies or in

Figure 8—Early tests at Lubrecht showed the effect a tree canopy had on GPS receiver performance and how horizontal accuracy was degraded.

complex terrain affect the signal due to the spatial variability of these obstructions. As the signal gets weaker, the receiver has a harder time tracking it and begins to lose the signal in the background noise, degrading accuracy. The efficiency and accuracy of a GPS receiver under heavy canopy depends on its signal-tracking ability. The more capable receivers are more expensive. Rapid technological advancements in signal-tracking circuitry and signal processing have improved the efficiency of GPS systems in the past few years. Even so, some GPS receivers do not work well under a dense forest canopy.

Forest Service personnel need to know the capabilities of available equipment before buying expensive GPS systems. They need verification of manufacturer's claims, and reasonable assurance that the equipment will perform in their work environment. The GPS test sites established across the United States allow MTDC to evaluate GPS equipment and procedures under the most adverse conditions Forest Service personnel may encounter. Results of these evaluations are distributed throughout the Forest Service in MTDC's Tech Tips. The Center has published 20 Tech Tips and other reports on GPS equipment since 1986.

International Forestry and GPS

In 1993 the U.S. Agency for International Development (USAID) and the Forest Service's International Forestry Program asked MTDC to develop and provide a GPS training program for natural-resource managers in Indonesia and later in the Philippines.

The GPS training was designed to meet the needs of both natural-resource managers and field workers. The course emphasized the basics of GPS, operation of GPS receivers under field conditions typical of resource-management tasks, and operation of the postprocessing software for data reduction.

From 1993 to 1995 eight training sessions were conducted in Indonesia, four for Indonesia Ministry of Forestry personnel (Figure 9) at a site near Bogor, and four for USAID personnel in Manado and Pontianok. These sessions trained about 120 personnel on GPS operations. Three employees of the Indonesia Ministry of Forestry came to Missoula, Montana, for training. One training session was conducted for the National Resources Management Program in the Philippines.

Figure 9—In 1993 the U.S. Agency for International Development (USAID) asked MTDC to develop and provide GPS training for natural-resource managers in Indonesia.

The Philippine training was conducted at a site on the old U.S. Naval Base at Subic Bay. MTDC personnel spent 3 days setting up a temporary base station, laying out a course, and collecting data for the field portion of the instruction. The 23 students who attended this session were from organizations such as the Department of Environment, the Forestry Support Organization, and regional governments. The majority were involved in boundary work dealing with delineation of ancestral lands and illegal logging. No geodetic control existed in any of these areas.

Differential GPS and Aerial Spray Operations

The rapidly evolving technology of Differential GPS-based (DGPS) navigation has had a great impact on agricultural and forestry aerial spray operations. Applying insecticides, herbicides, and fertilizers accurately, safely, and efficiently depends on a pilot's ability to identify spray plot boundaries and to correctly position the aircraft for subsequent spray swaths. Good block marking and aircraft positioning are necessary to reduce the risk of applying spray materials to sensitive nontarget areas such as watercourses, and to ensure uniform application to the intended plot.

Let us first of all try to understand the difficulties of aerial navigation as faced by the ordinary balloonist. One of the principal problems is the difficulty of ascertaining the direction during the night or when above the clouds. It is hard, perhaps, for the person who has never been in a balloon or a flying-machine to understand this. In day-time, and when the earth is in sight, it is quite a simple matter, with the aid of the compass, to take the line of the balloon's course. At night, if no fixed lights on the earth be visible, or if the balloon be over the sea, it is impossible. The compass-needle points to the north, but the aeronaut has no means of ascertaining the direction the balloon is taking. And it is equally impossible in daylight when above the clouds, for the clouds may be moving in the same direction as the balloon, or in some totally different direction. Only if one could be quite sure that they were stationary would it be possible to ascertain the direction.

from *Aerial Navigation of Today,*
Clark C. Turner
Seeley and Co. Limited,
London, 1910.

In flatland agricultural spraying, flagmen and ground markers were commonly used to mark blocks. In a forest setting these methods are difficult to use. Alternative marking techniques included tethered balloons, crepe paper streamers dropped from aircraft, and paint sprayed on treetops from helicopters. These methods were labor intensive and sometimes dangerous or ineffective. DGPS almost eliminates the spray block-marking problem. In addition, DGPS provides for more uniform application of spray product throughout the block. DGPS aerial application systems can record the spray aircraft's path, exact flow rate, and whether the product is being applied or not. They can also report other variables of interest to an aerial applicator. These data enable the spray pilot and the Forest Service operational manager on the scene to determine whether the spray block has received full coverage. The spray coverage as recorded by the DGPS system in a computer file is available for GIS archiving or subsequent analysis.

When the Forest Service began using GPS guidance in spray operations during 1993 and 1994, problems arose with the systems themselves, with the training level of the operators, and with system integration. Though DGPS had been used in aerial pesticide application over uniform terrain since the early 1990's, the technology was changing rapidly and many of the systems supplied by the manufacturers to Forest Service spray projects were prototypes. In some cases, operating manuals were not available to pilots. Inexperience with the systems and their methodology for file storage resulted in the loss of spray data. In some systems logged data was difficult to convert into a GIS format. These problems prompted the Forest Health Protection (formerly Forest Pest Management) staff and MTDC to schedule a series of demonstrations and evaluations of DGPS aerial spray systems.

The evaluations were designed to acquaint Forest Service personnel with system capabilities and to acquaint equipment manufacturers with the unique requirements of aerial spraying in forested, complex terrain (Figure 10).

MTDC scheduled the first demonstration for the week of October 9, 1994, and canvassed the GPS aircraft-navigation industry for potential demonstrators. Two firms agreed to participate. About 75 personnel from Federal and State agencies in the United States, and from Canada, New Zealand, and Australia attended this demonstration. Two afternoons of technical discussions addressed many of the startup problems associated with the new DGPS systems.

Subsequent demonstrations involved both fixed-wing and helicopter operations and investigated the accuracy claims made by the manufacturers and problems associated with system update rates. Pilots complained of slow position updating after a turn. Spray project managers had problems with “castling” on plot edges. The advantages and disadvantages of automated spray on-off features were examined. Problems associated with integrating the DGPS archival information with GIS were worked out and a pest-management software package developed by the Forest Service (GYPSES) was successfully integrated with an aircraft DGPS system.

These demonstrations were well attended by Forest Service and State personnel. Many leading aerial application DGPS equipment manufacturers participated. The dialog between pilots, operational personnel, and electronic-systems manufacturers facilitated widespread acceptance of this technology (Figure 11). Forest Service personnel were better able to write viable spray contracts, and manufacturers learned the unique requirements of forest spray operations. The ability of Forest Service managers to take full advantage of DGPS guidance in aerial spray operations over complex terrain is due in large part to these demonstrations and evaluations.

Aircraft-mounted meteorological measuring equipment has also been

Figure 10—Forest Service operations over complex terrain posed unique problems for GPS guidance equipment originally designed for applications on flat agricultural land.

Figure 11—The dialog between pilots, operational personnel, and electronic systems manufacturers at MTDC demonstrations helped GPS guidance systems become accepted in Forest Service operations.

investigated by MTDC. This equipment has potential applications in aerial spraying and in wildland firefighting operations. A Canadian system using a device mounted on a light aircraft (Figure 12) was evaluated by the Center in 1997. This system transmitted the flight altitude profile, temperature, dew point, wind speed, and wind direction to a PC screen on the ground while simultaneously plotting the aircraft's position on an overlay map. Current work includes integrating aerial spray dispersion and deposition modeling with DGPS guidance systems so that the aerial applicator has an idea of the coverage rate during application and has an idea how much material is moving off-target. Aircraft positional information needs to be integrated with weather data, system mechanical information such as droplet size and flow rate, and a GIS system to provide real-time guidance to the applicator.

Figure 12—An aircraft-mounted meteorological sensor package was evaluated by the Center in 1997. Sensors transmitted the temperature, dew point, wind speed, and direction to a ground-based PC while simultaneously plotting the aircraft's position on an overlay map.

PPS P(Y) Code Receiver Support

Under the guidance of the National Security Agency (NSA), MTDC established a Communications Security account and rekeying facility at Missoula, Montana, in 1995.

The COMSEC account custodian oversees the security of P(Y) code receivers and works with Air Force Space Command at Peterson Air Force Base in Colorado Springs and with the National Security Agency at Fort Meade, Maryland, to ensure that Forest Service organizations are aware of the security issues involved with these devices. The custodian secures permission from the National Security Agency for Forest Service personnel to travel overseas with P(Y) code receivers, and coordinates with the Defense Courier Service when receiving new DOD key codes.

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 can not access the Y code.

All Forest Service PPS P(Y) code receivers must be rekeyed at least once a year at the Missoula COMSEC facility. In addition, about one-fourth of the receivers are keyed more than once a year because of battery failure or inadvertent cancellation of the key.

Conclusions

GPS technology has facilitated substantial advances in resource management over the last decade. The ability to inventory natural resources over large, remote areas has been dramatically improved. The ability to arrive or return to an exact location on the ground in a remote setting has improved by over two orders of magnitude in some cases. These abilities have benefited scientific investigation, search and rescue, fire spotting, forest pest outbreak evaluation, and many other areas of Forest Service endeavor. Navigational abilities, whether on foot, by ground vehicle, or by air, have been revolutionized. Resource managers have been given the ability to electronically archive a positional history, whether it be of a flightline or spray plot in aerial spraying, or of a new trail or campground for a recreational manager.

Perhaps the most profound impact of this technology for the Forest Service is that it allows remote forest lands to be accessed and enjoyed with an added degree of safety and security by a wider segment of the public.

Applications and ideas based on this technology are still emerging and continue to be evaluated by the Missoula Technology and Development Center.

About the Authors…

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Tony Jasumback is a Senior Project Engineer working on projects in the Forest Health Protection, Engineering, Fire and Aviation, and Reforestation and Nurseries Programs. He received a bachelor's degree in mechanical engineering from the University of Missouri at Rolla in 1961. He joined the Forest Service in 1963, working for the Architecture Department in the Northern Region and later for the Colville National Forest in road design. He came to MTDC in 1965 as a design and test engineer.

Harold Thistle received a Ph.D. in plant science specializing in forest meteorology from the University of Connecticut in 1988. He is certified by the American Meteorological Society as a Certified Consulting Meteorologist, and worked as a consultant in private industry before joining MTDC in 1992. As the Center's Program Leader for Forest Health Protection, he develops modeling techniques that accurately describe transport of pesticides in the atmospheric surface layer and he evaluates meteorological instrument systems for environmental monitoring.

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Describes the role of the Missoula Technology and Development Center in adapting Global Positioning System (GPS) technology for natural resource applications in the Forest Service.

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