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**Technology &
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5300 Law Enforcement
5400 Lands
6700 Safety & Health
7100 Engineering
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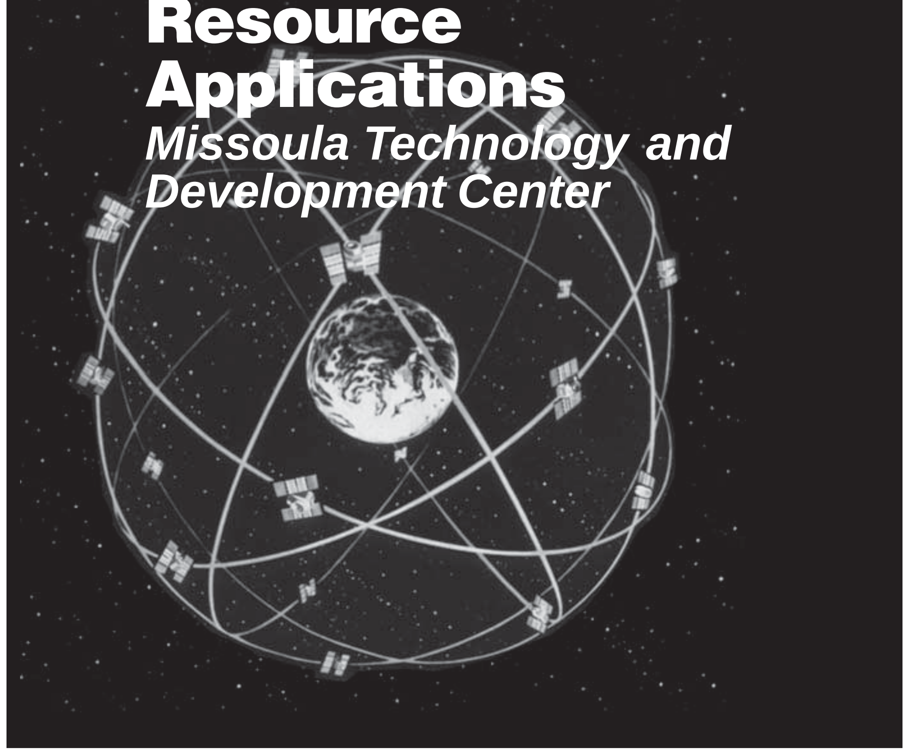
Two Decades of Development and Evaluation of GPS Technology for Natural Resource Applications

Missoula Technology and Development Center



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**USDA Forest Service
Technology and Development Program
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Table of Contents

Author's Notes

The idea for this publication came from requests to summarize the large number of Missoula Technology and Development Center documents relating to GPS technologies. The use of GPS technology and related applications has been one of the most active areas of development at MTDC over the past 15 years. The history of MTDC's development work is a history of the applications of GPS technology in natural resource management. As applications of this technology continue to appear, MTDC plans to maintain a strong technical role in developing, directing, and evaluating these applications to meet Forest Service needs.

Acknowledgments

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Introduction

Global Positioning System (GPS)-based positioning and navigation has had a great impact on resource management operations. The Department of Defense first declared the system fully operational in 1995. Since then, GPS has been accepted as a primary tool in many areas of Forest Service activity.

GPS receivers are used to pinpoint Forest Inventory and Analysis plots, nesting tree locations, and resources along forest roads. GPS technology has taken the place of ground markers to delineate spray block boundaries in pest suppression and to plot the location of new trails for recreation managers. Fire and Aviation Management uses GPS for aircraft guidance and to position camps and equipment.

This summary document describes how GPS works, and records the history of its use within the Forest Service. It recounts the Missoula Technology and Development Center's early involvement with GPS and the many contributions the Center has made to the acceptance of GPS in all areas of resource management.

GPS History

In 1957, scientists at the Johns Hopkins Applied Research Laboratory were tracking the newly launched Russian Sputnik and determining its orbit by measuring the Doppler shift in frequency received from the satellite. While doing this, they reasoned that if an unknown orbit could be determined from a known point on earth, then the reverse should also be possible. This observation led to the Navy's TRANSIT satellite navigation program designed for the exclusive use of Polaris ballistic missile submarines. The TRANSIT constellation was in place by the end of 1962, and demonstrated the 24-hour, all-weather capability of a satellite navigation system. In 1967, a limited number of nonmilitary users were given access to TRANSIT. The Navy decommissioned this system in 1996.

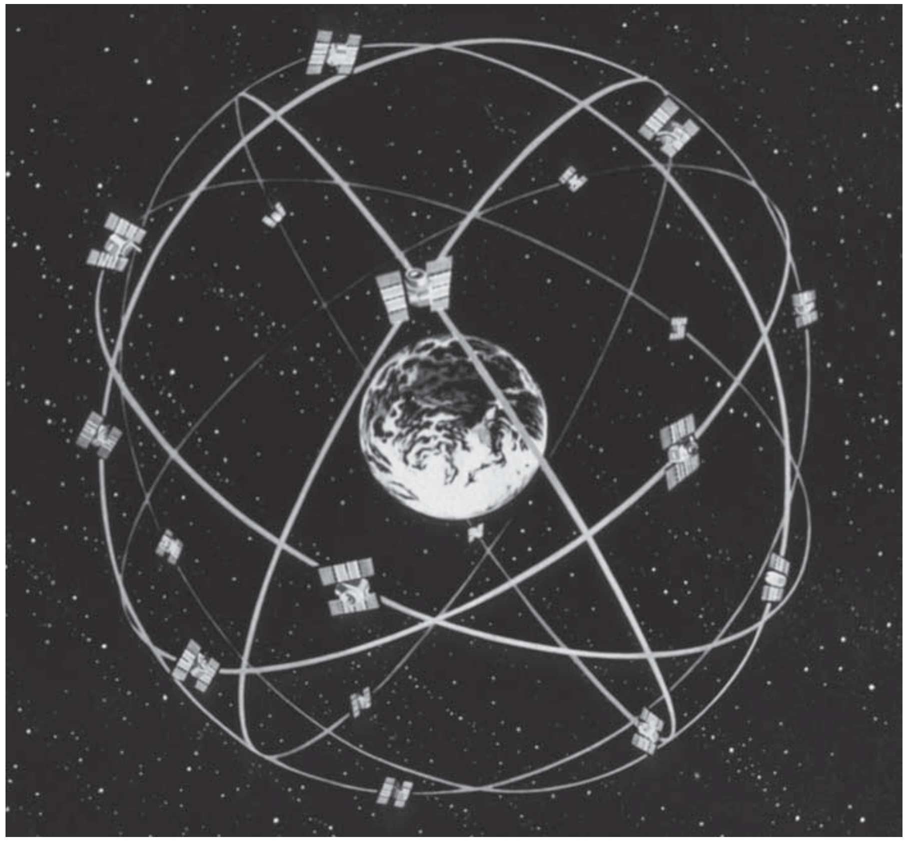


Figure 1—The operational GPS satellite constellation consists of 24 NAVSTAR satellites arranged in six 55° planes around the Earth so that a minimum of four satellites would always be in view above the horizon.

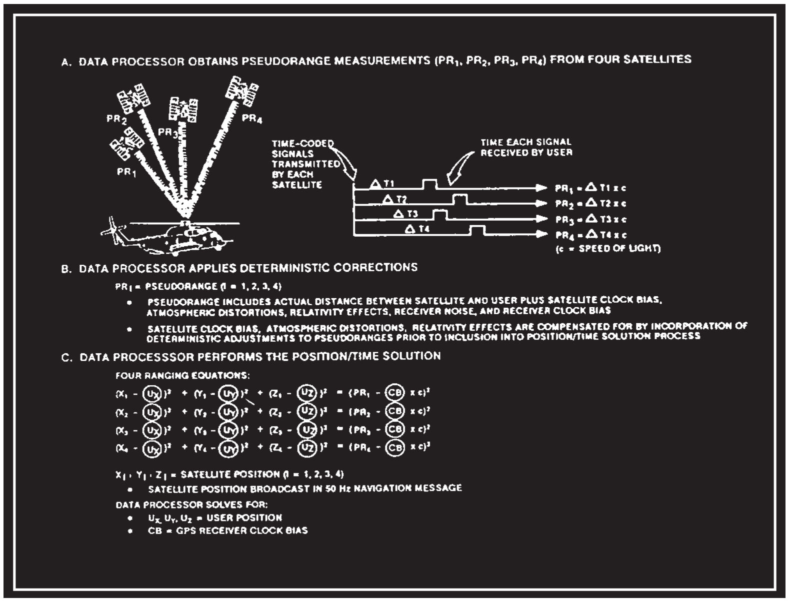
The Global Positioning System

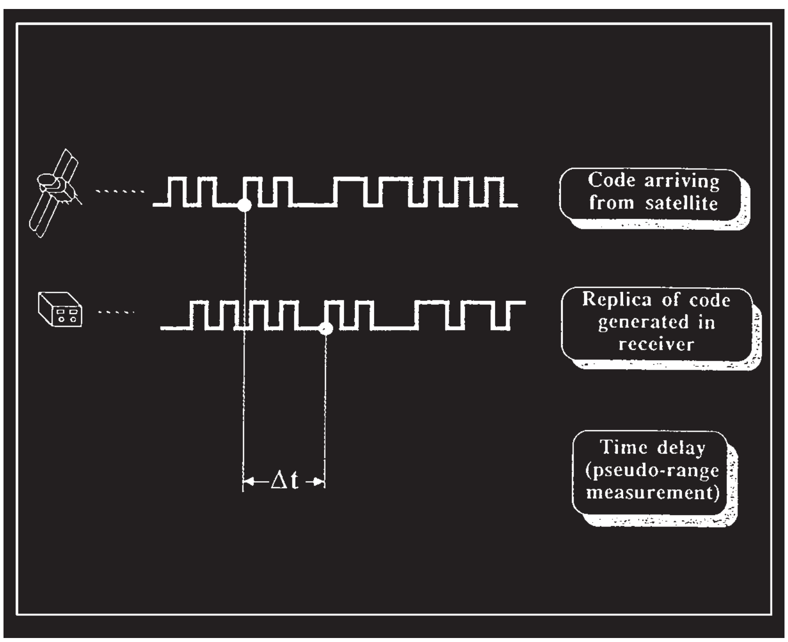
The Department of Defense (DOD) launched the first Global Positioning System satellite in 1978. GPS evolved from the earlier technology of TRANSIT but was designed to be available to all branches of the military. It took 17 years from launch of the first test satellite to a fully operational satellite constellation, control segment, and user equipment segment. DOD declared GPS fully operational in 1995.

The initial concept included 24 NAVSTAR satellites in the Global Positioning System constellation, (Figure 1) with 21 operational and 3 as active spares. The satellites are arranged in six orbital planes at an inclination angle of 55° with four satellites in each plane. The orbit altitude is 20,200 km. The orbit period for each satellite is about 12 hours. This arrangement ensures that a minimum of four satellites will always be in view above the horizon at any time from any point on earth.

The signal broadcast from each satellite (Figure 2) identifies the satellite, its status, its location and 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 based on the satellite identification and the almanac. 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, a position in three dimensions can be determined. If more satellite signals are available, more distances can be calculated and the position can be optimized.

Figure 2—From the launch of the first satellite in 1978, 17 years passed before the GPS constellation was declared fully operational in 1995.





To calculate its position, the GPS receiver determines the time it takes the satellite signal to travel from the satellite to the receiver. The receiver must receive at least four satellite signals simultaneously to resolve its position. The receiver compares the received signal to that of a replica signal generated in the receiver. The time shift necessary to synchronize these two signals within the receiver represents the transit time for the received signal. This is done simultaneously for each satellite signal received. The pseudorange to each satellite is determined by multiplying the transit time of each satellite signal by the speed of light. The satellites transmit their positions in Cartesian coordinates (x, y, and z) with the center of mass of the Earth at 0,0,0. With the satellite position and the pseudorange to the four satellites known, four ranging equations can be written and solved for the receiver clock bias and the receiver position.

The signal is broadcast on two frequencies: the primary L1 at 1575 MHz, and a second L2 at 1227 MHz. Most civilian users, are afforded access only to the L1 Coarse Acquisition code (C/A) modulated at a chipping rate of 1.023 MHz. This signal is unencrypted. However, DOD purposely degrades its accuracy. The Department of Defense guarantees that C/A positional accuracy will be within 300 meters 99.9% of the time and within 100 meters or less 95% of the time. This is called the Standard Positioning Service (SPS). Civilian users have asked for access to the L2 signal for ionospheric calibration purposes.

The Precise Positioning Service (PPS) signal is intended for military use only. In 1995, the DOD began allowing some civilian government agencies access to PPS receivers. The PPS signal is broadcast on both the L1 and L2 frequencies. The PPS precision code is a long code modulated at a chipping rate of 10.23 MHz, 10 times faster than the C/A code (1.023 MHz). When this P code is encrypted, as it is under current DOD policy, it is referred to as the Y code. Because of the Y code's higher chipping rate, it is inherently more precise than the C/A code. Military P(Y) code receivers are guaranteed 16 meters maximum horizontal error.

Selective Availability

Because of security concerns, DOD denies nonmilitary users the highest accuracy of the GPS system by purposely degrading the C/A code. This signal degradation is called Selective Availability (SA). SA is achieved by introducing a fluctuating timing error and satellite location error into the signal broadcast by each satellite. The L1 frequency contains two codes, the Precision (P) code and the Coarse/Acquisition (C/A) code. The L2 carrier contains only the P(Y) code. Dual-frequency military receivers can access the P(Y) codes on both frequencies, while civilian receivers are limited to the L1 C/A codes.

DOD has turned off SA only once. During the Gulf War, the Armed Forces were short of military GPS receivers and made an emergency purchase of off-the-shelf commercial units. DOD had to turn off SA to allow field units with these receivers to acquire the accuracy they needed. Selective Availability has been on continuously since then.

Differential GPS

The civilian GPS community developed Differential GPS (DGPS) to overcome the errors induced by SA. DGPS involves siting a reference (or base) station at a surveyed position. Computer software compares the surveyed position to the GPS-derived position and computes corrections (vectors) that can then be applied to other receivers. This correction factor can be archived for future use or transmitted to nearby GPS receivers for real-time correction. It can also be incorporated into GPS data at a later date (postprocessing). However, navigation and guidance functions such as those used in aerial pesticide application require real-time correction. Recent developments in broadcasting differential corrections include ground-based beacons as well as commercial satellites that broadcast corrections over a wide area. Many DGPS systems are accurate to less than a meter. Survey-grade accuracy of a few centimeters is possible using differential corrections and the appropriate equipment.

Precise Positioning Service P(Y) Code

The DOD has authorized some civilian governmental agencies to purchase the military Precise Positioning Service (PPS) receivers capable of operating with the P(Y) code. The Forest Service began buying these receivers in February 1995. The Forest Service was allowed to purchase the Trimble Centurion and the Rockwell Precision Lightweight GPS Receiver (PLGR). Both are hand-held units containing a code module that must be "rekeyed" at least once a year. While they are not classified, they are accountable items of equipment because of the security module they contain. Program coordinators must implement special handling procedures with the P(Y) code receivers.

Surveying

The first GPS receivers in the Forest Service were used for surveying in the mid-1980's. A company provided the receivers, processing software, and technical knowledge for the Forest Service. These receivers cost around $75,000 each. A minimum of three receivers were required to bring the geodetic control from a known location into the desired area.

These first survey-grade GPS receivers were large, heavy, and power hungry (Figure 3). A 12-volt automotive battery would only operate the unit for 3 to 4 hours. It took 45 to 90 minutes to obtain accurate data at each station. This required considerable preparation as the satellite constellation in the early days included only four to five satellites, the minimum required for positioning. The data had to be collected simultaneously from all the satellites. All satellites were available only for $3^1/_2$ to $4^1/_2$ hours a day.

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 signal phase continuously. This requires a clear view of the sky 10° to 15° above the horizon to prevent losing the lock and to prevent cycle slip. This type of receiver does not work for resource-management activities where much of the work is under the forest canopy. Resource-management work required a receiver that tracked only C/A code and that could tolerate signal interruptions caused by the canopy.

The land surveyors in each Region were responsible for implementing survey-grade GPS technology. MTDC was given the responsibility for implementing GPS technology into resource management activities Servicewide.

Figure 3—The first GPS receivers were large, heavy, and power hungry.

GPS Documents Produced by MTDC

- *Global Positioning System Canopy Effects Study,* September 1989
- *Satellite Tracking of Log Rafts,* September 1992
- *Evaluating GPS Under Dense Tree Canopy,* April 1993
- *GPS Use Survey Results,* March 1994
- *GPS Use in Wildland Fire Management,* May 1994
- *Spray Block Marking,* September 1994
- *Trimble Centurion GPS Receivers,* February 1995
- *Military PLGR GPS Receiver,* June 1995
- *Philippine GPS Training,* November 1995
- *Indonesian GPS Training,* November 1995
- *Forest Health Through Silviculture—Proceedings of 1995 National Silviculture Workshop,* May 1995
- *DGPS in Aerial Spraying in Forestry: Demonstration and Testing,* September 1995
- *Differential GPS Aircraft Navigation, Resource Inventory, and Positioning Demonstration, Missoula, Montana—October 1995,* May 1996
- *Real-Time Global Positioning System (GPS) Evaluation,* July 1996
- *GPS Evaluation: West Coast Test Site,* September 1996
- *Harrisonburg Spray Aircraft Navigation Demonstration Test Plan,* December 1996
- *GPS Traverse Methods,* February 1997
- *Demonstration of the Aventech Aircraft-Mounted Meteorological Measurement System,* May 1997
- *GPS Walk Method of Determining Area,* May 1997
- *Wide Area GPS Enhancement (WAGE) Evaluation,* August 1997
- Practical Application of G.P.S. Technology: Differential GPS Spray Aircraft Guidance, March 1998
- Resource Applications of GPS Technology, August 1998
- Evaluation of the Trimble ProXRS GPS Receiver Using Satellite Real-Time DGPS Corrections, May 1999

Copies of the most current of these documents can be ordered from MTDC. Electronic copies of some of the documents are available to Forest Service employees on the Forest Service's internal computer network at the FSWeb address: http://fsweb.mtdc.wo.fs.fed.us.