Global Navigation Satellite Systems in Forest Management

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NAVSTAR GPS (United States)

In 1983, the United States made the decision to provide GPS service free of charge, and openly, to the world. The system became fully operational in 1995.

The system was initially funded by the U.S. Department of Defense.

The official name of the system is NAVSTAR GPS.

The system is managed by the U.S. Air Force, 50th Space Wing, at Schriever Air Force Base, Colorado Springs, CO.

The cost of maintaining the system is approximately $1.5 billion per year.

NAVSTAR satellites orbit at an elevation of approximately 12,900 miles above earth.

As of May 19, there were 30 satellites in the NAVSTAR GPS system, yet a new one was launched on May 15.
GLONASS (Russian Republic)

Global Orbiting Navigation Satellite System

Developed by the former USSR in 1982, and now maintained by the Russian Republic (Russian Space Forces).

Control stations are entirely within the former USSR, and the control center is located in Moscow.

The system was expected to be fully functional last year.

24 satellites are included in the system, orbiting at an elevation of approximately 11,800 miles above earth.

Signal reception is freely available around the world.

Some receivers available in the U.S. marketplace can use GLONASS signals.
GALILEO (European Union)

European Navigation System

Evolved from the Global Navigation Satellite System (GNSS), a European effort for world-wide satellite navigation coverage.

Developed by the European Union.

Control stations are in Germany and Italy.

30 satellites in 3 orbital planes (planned), orbiting at an elevation of approximately 14,400 miles above earth.

4 satellites are currently in orbit; planned completion is 2019.

Signal reception is planned to be freely available around the world.
BeiDou Navigation System (COMPASS) (China)

Compass Navigation System

30 orbiting satellites and 5 geostationary satellites, with two signal services (open and restricted).

10 satellites are in orbit; planned completion is 2020.

Four signal transmission frequencies will overlap those proposed for use in the GALILEO program.

This will replace their older, subscription-based program.
Other components and associates

Control stations
Base stations
WAAS / LAAS / DGPS
Receiver manufacturers
How is GPS used in forest management?

For purposes related to the accuracy and efficiency of operations

- Determining areas
- Developing and maintaining base maps (stand lines, roads)
- Navigating to, and recording the location of, timber cruising plots
- Collecting information related to wildlife habitat
- Recording historical information
- Identifying and marking sensitive areas
Questions of concern when using GNSS (GPS) in a forested condition:

How good is the point, line, or boundary being mapped?

How much error does the feature contain?

Is the error biased?
How good is the point, line, or boundary being mapped?

Garmin Oregon 450t

Hardwood forest (deciduous)

150 waypoints captured
All within ~8 minutes

Flint

Hardwood forest (deciduous)

2.2 acres walked
One circuit within ~5 minutes
How much error does it contain?

Unfortunately, without an accuracy assessment performed every time data is collected, one never really knows.

Consumer-grade year-long test in 2009.
Is the error biased?

Is the error, as noted in the previous slide, consistently oriented in one direction?

Juxtaposition test in summer 2012.
Types of accuracy assessments

Static (Points)
Dynamic (Lines, Areas)

Horizontal (Northing, Easting coordinates)
Vertical (Elevation)
Measures of static horizontal accuracy

Methods:
A high-quality control is necessary
Repeated visits are necessary
Randomization of points visited is necessary
Other protocols are needed as well

Computations include:
Root mean squared error (RMSE)
Circular error probable (CEP)

RMSE = 6.33 m
CEP<sub>50</sub> = 5.97 m
Measures of dynamic horizontal accuracy

Methods:
A high-quality control is necessary
Repeated visits may be necessary
Other protocols are needed as well

Computations include:
Percent of vertices within $X$ m of true lines
Deviation in area from true area
Area of agreement

1 m = 77%
2 m = 12%
3 m = 7%
4 m = 4%

Deviation in area = 0.17 ac
Area of agreement = 91%
Potential sources of error

- Outer space interference
- Weather / atmospheric conditions
- System parameters / ephemeris / clocks
- Satellite geometry
- Obstructions
- Multipathed signals
Outer space interference

Consumer-grade year-long test in 2009.

289 days - no correlation between solar wind speed and GPS accuracy
**Weather / atmospheric conditions**

Consumer-grade year-long test in 2009.

289 days - no correlation between common measures and GPS accuracy
Weather / atmospheric conditions

Winter mapping grade study in 2010.

Receiver Configurations

Trimble GeoXT (2008)
TDS Ranger / Crescent A100 antenna

Forest Conditions

Older pine
30-40% canopy closure
60-70 yr old loblolly / shortleaf pine

Hardwood
40-90% canopy closure
60-70 yr old southern hardwoods

Results

Within a forest type, there was no significant relationship between GPS accuracy and:

- Relative humidity
- Atmospheric pressure
**Satellite geometry**

The least amount of atmospheric interference occurs when NAVSTAR satellites are directly overhead a GPS receiver. However, this also implies a high PDOP, given the poor satellite geometry, and thus lower quality data might be collected.

<table>
<thead>
<tr>
<th>PDOP value</th>
<th>Comment on data quality</th>
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<tbody>
<tr>
<td>1</td>
<td>This PDOP provides the highest possible confidence in data accuracy, and is used for applications that demand the highest level of precision.</td>
</tr>
<tr>
<td>2-3</td>
<td>In this range, the positional measurements are accurate enough for all but the most sensitive applications.</td>
</tr>
<tr>
<td>4-6</td>
<td>This is the minimum level for mapping applications and for making business decisions.</td>
</tr>
<tr>
<td>7-8</td>
<td>Here, positional measurements could be used, but a better configuration of satellites is suggested.</td>
</tr>
<tr>
<td>9-20</td>
<td>Positional measurements with this PDOP provide low confidence in data quality.</td>
</tr>
<tr>
<td>21-50</td>
<td>Measurements using this PDOP range may be inaccurate by more than 150 feet.</td>
</tr>
</tbody>
</table>
Satellite geometry

Unfortunately, satellite geometry has not been associated with measurement error in recent tests.

   
   No correlation between actual PDOP and accuracy

   
   No correlation between planned PDOP and accuracy
**Multipath**

**Multipath Signals**

These errors occur when satellite signals bounce off of other landscape features, such as buildings, trees, people, or the ground, before entering the GPS receiver.

Some GPS receivers have the technology to understand that certain signals from certain satellites are delayed, as compared to other signals it has already received from the satellite.
Multipath
In general, what have we learned?
Synthesis of recent research

- Type of receiver

The type of receiver matters with regard to accuracy.

Survey-grade
Mapping-grade
Recreation-grade
Synthesis of recent research

- Type of forest

Most tests have shown that the forest type does matter with regard to accuracy.
Synthesis of recent research

- Time of year

Some tests have indicated that the time of year, particularly in hardwood forests, does have an influence on positional accuracy.
Synthesis of recent research

- Multipath error

In forested conditions, multipath can account for over half of the horizontal position error (Danskin et al. 2009a).

The ability of a GPS receiver to reject multipath signals may be the main reason why consumer-grade GPS receivers have lower static horizontal position accuracy than mapping-grade GPS receivers.
Synthesis of recent research

- Configuration of vegetation

One test indicated that perhaps this is an issue.
Synthesis of recent research

- Ground slope position

Upper slope positions generally have higher horizontal position accuracy (lower error) than lower slope positions.

The position of the collected data with regard to ground slope (e.g., upper vs. lower slope positions) has been shown to be significant (Deckert and Bolstad 1996, Danskin et al. 2009a, 2009b).
Synthesis of recent research

- Number of position fixes

The number of position fixes (epochs) necessary to increase static horizontal position accuracy under tree canopies is questionable.

Sigrist et al. (1999) first suggested that 300 instant times of observation (position fixes, or epochs) were appropriate for tests conducted in forested conditions.

However, Bolstad et al. (2005) later suggested that the position determined from a single fix may generally be no less accurate than one determined from an average of 300 position fixes.

Wing and Karsky (2006) suggest that the position determined from a single fix may generally be no less accurate than one determined from an average of 60 position fixes.

Danskin et al. (2009a) also suggest that horizontal position accuracy with one mapping-grade GPS receiver remained relatively constant between 10 and 200 position fixes.
Synthesis of recent research

- Differential correction

Differential correction (either post-processing of GPS data or near real-time differential correction using a space-based augmentation system) continues to be necessary to improve horizontal position accuracy in southern U.S. forests based on recent tests.

However, some receivers are not well-suited to post-process differential correction.
Synthesis of recent research

- Atmospheric conditions

Lower atmospheric conditions seem to have little effect on static horizontal accuracy in forested conditions during recent U.S. studies.

However, some assert that high-precision GPS applications may be affected by propagation delay due to atmospheric conditions (Chen et al. 2008), particularly during the passage of weather fronts (Ghoddousi-Fard et al. 2009).
Summary

A number of forestry operations can be made more efficient and data can be collected with reasonable accuracy using the latest technology.

Unfortunately, it takes observational studies to provide the information most practitioners value.

- People want to understand the general accuracy of the technology

Since technology continuously changes, these types of issues will remain important.

There are few funding sources to support a thorough and continuous assessment of new technology.