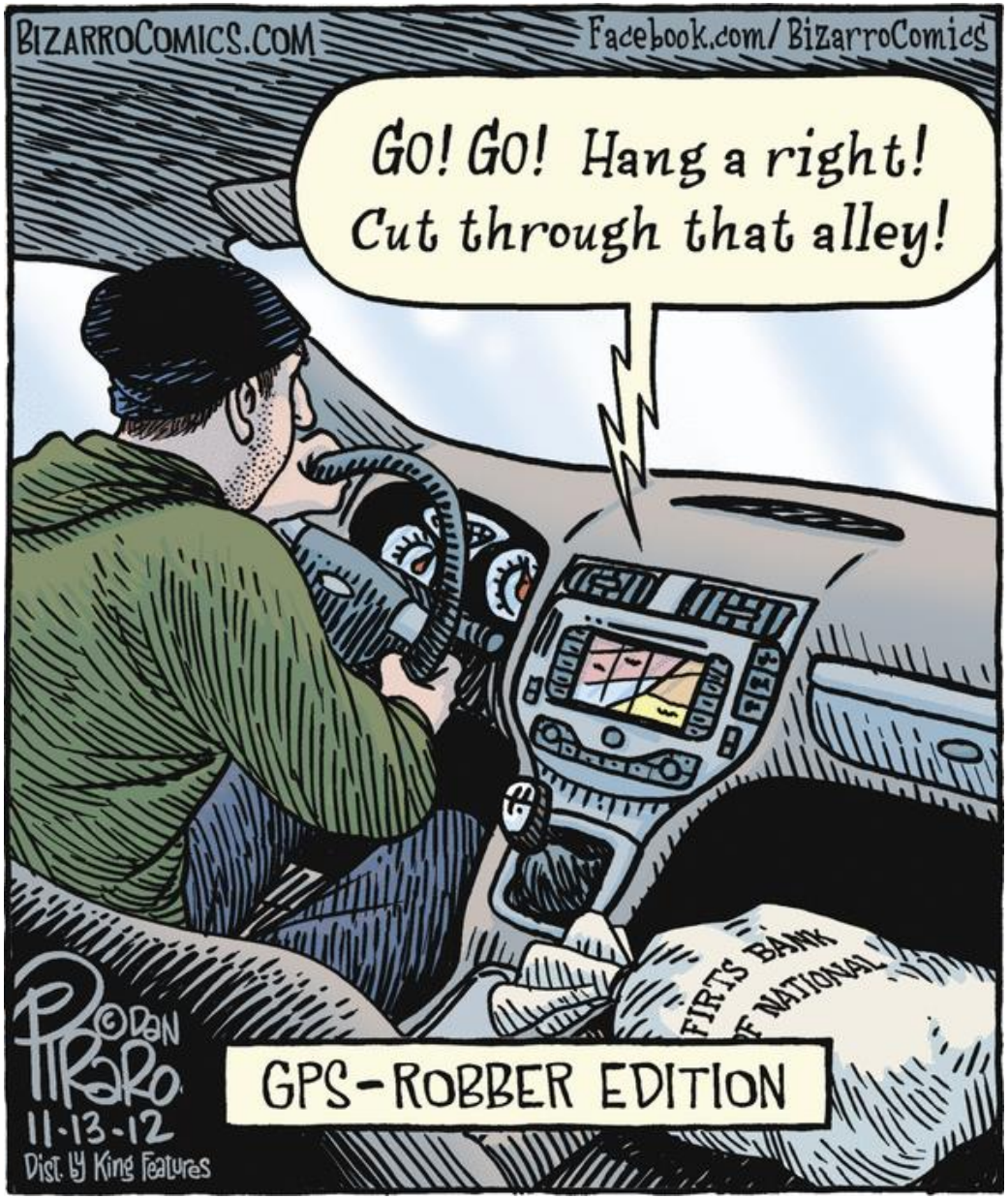
How in the World Does GPS Work?

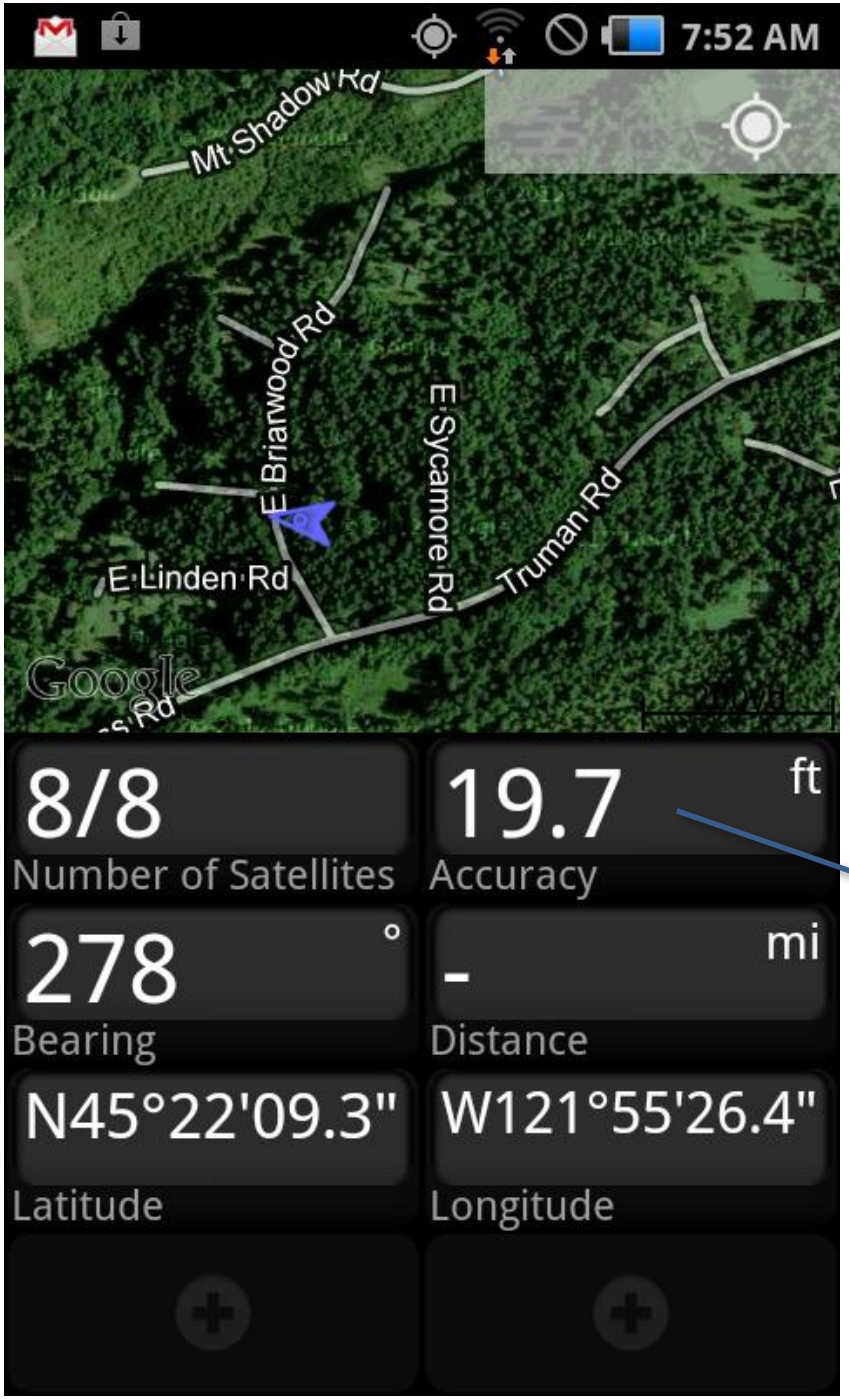


By Steve Wilent
Editor, *The Forestry Source*

5th Annual Field Technology for Data Collection in Forestry, Fisheries, and Natural Resources

Western Forestry and Conservation Association

Portland, Oregon
November 19-20, 2015



It's All About Accuracy

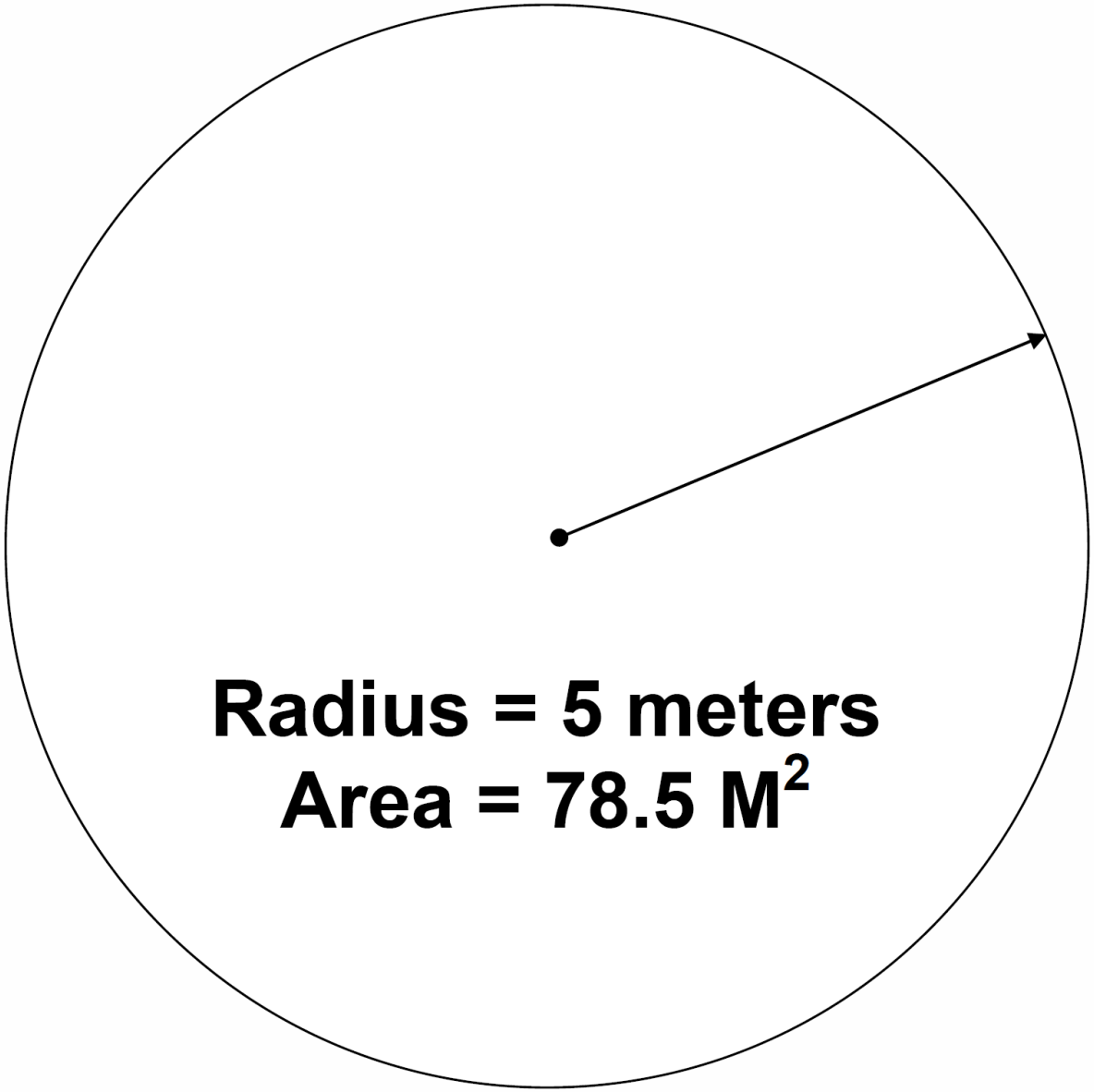
Calculated by the phone

DT Research claims that its **DT391GS** rugged tablet, with a unique flip-up GPS antenna, is capable of **half-meter accuracy** when using SBAS.

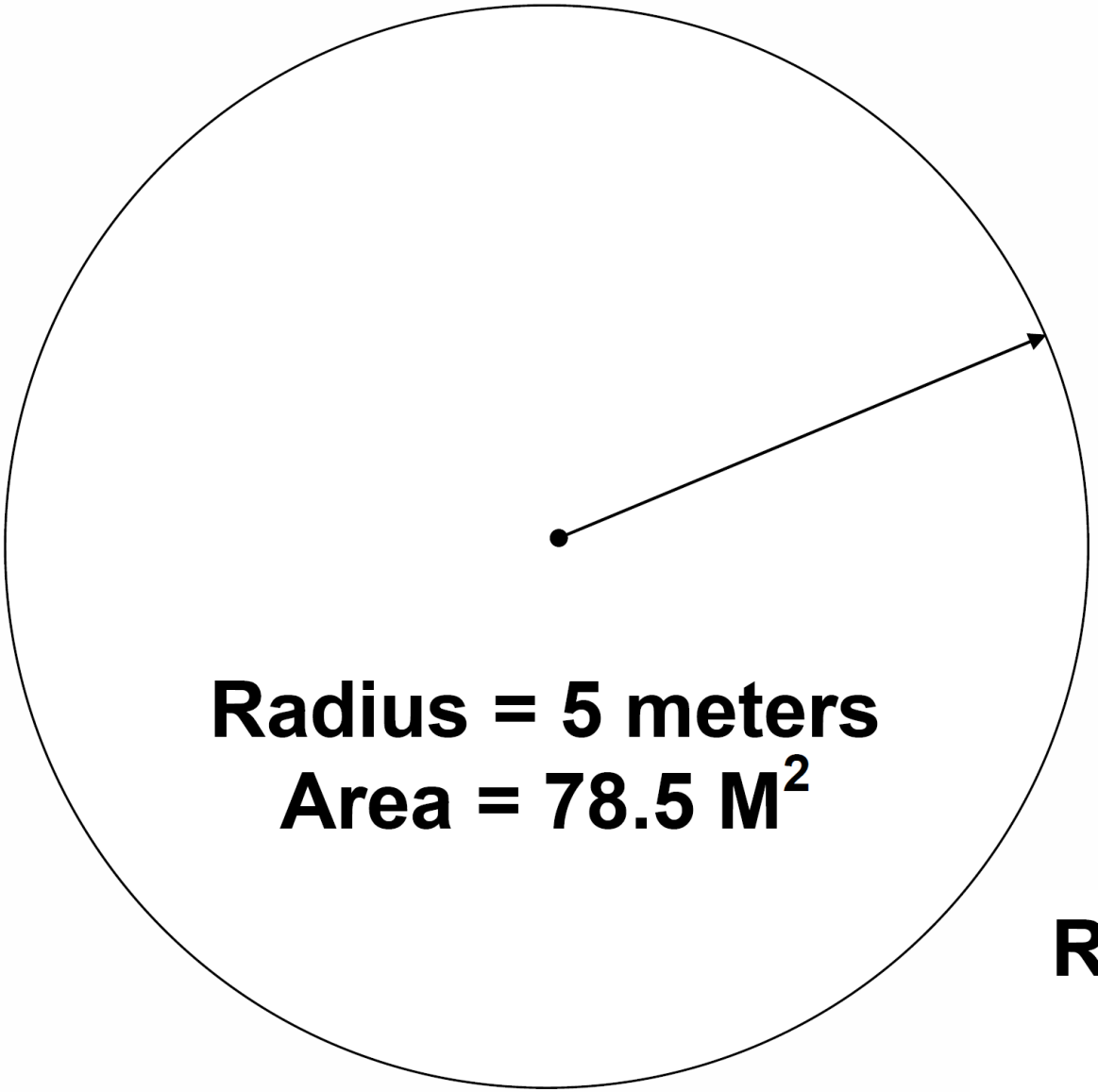
Centimeter accuracy with post-processing.

GARMIN

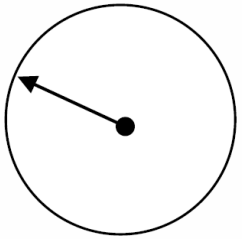
Why is Accuracy a Big Deal?



Where's the Plot?



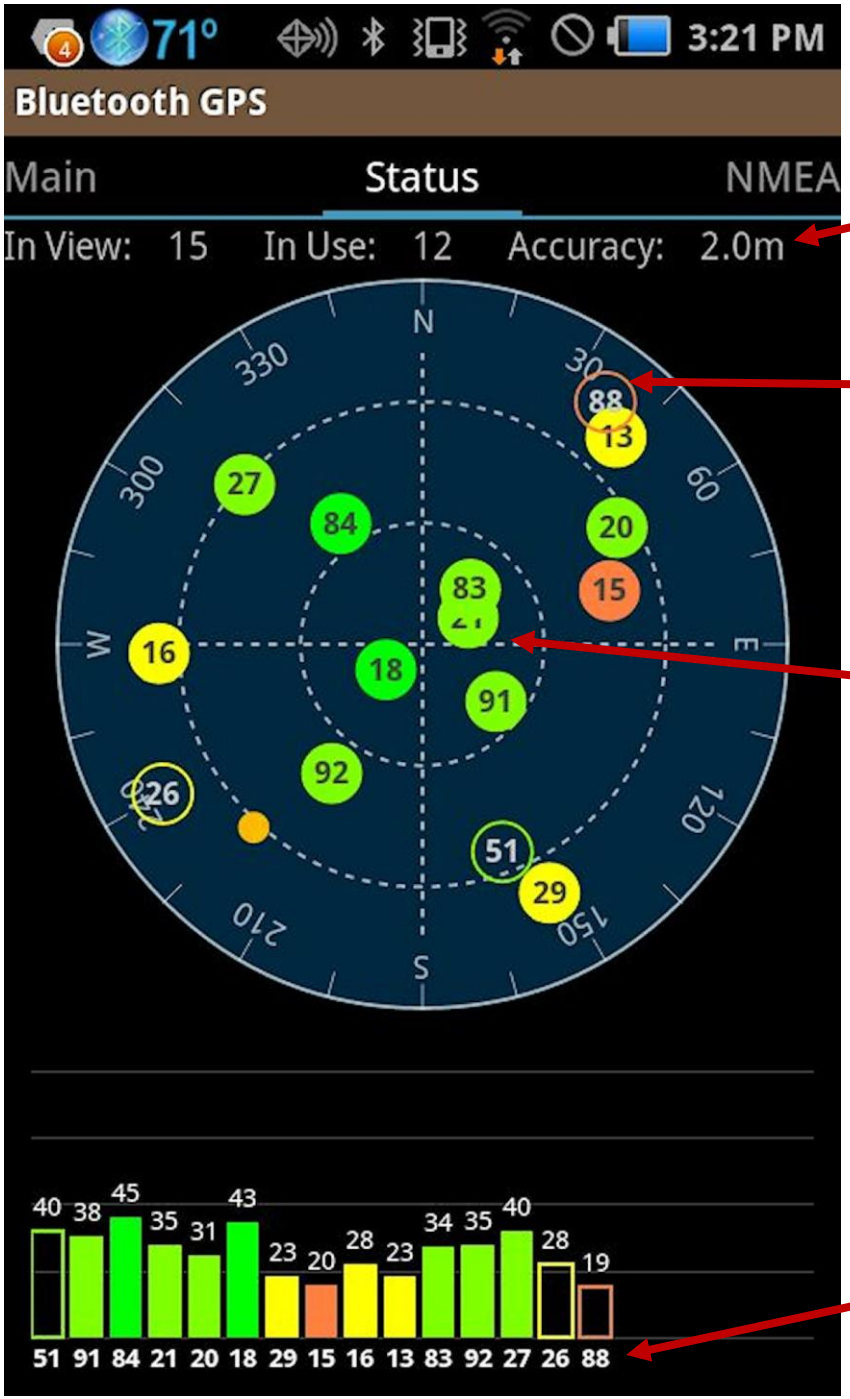
Radius = 5 meters
Area = 78.5 M^2



Radius = 1 meter
Area = 3.14 M^2

Take your pick: 5-meter GPS or 1-meter GPS

Photo: Michael Shephard, U.S. Forest Service/Bugwood.org



- 15 satellites in “view”
- 12 satellites used
- **Calculated accuracy: 2 meters**

- Satellite too low on horizon or signal weak

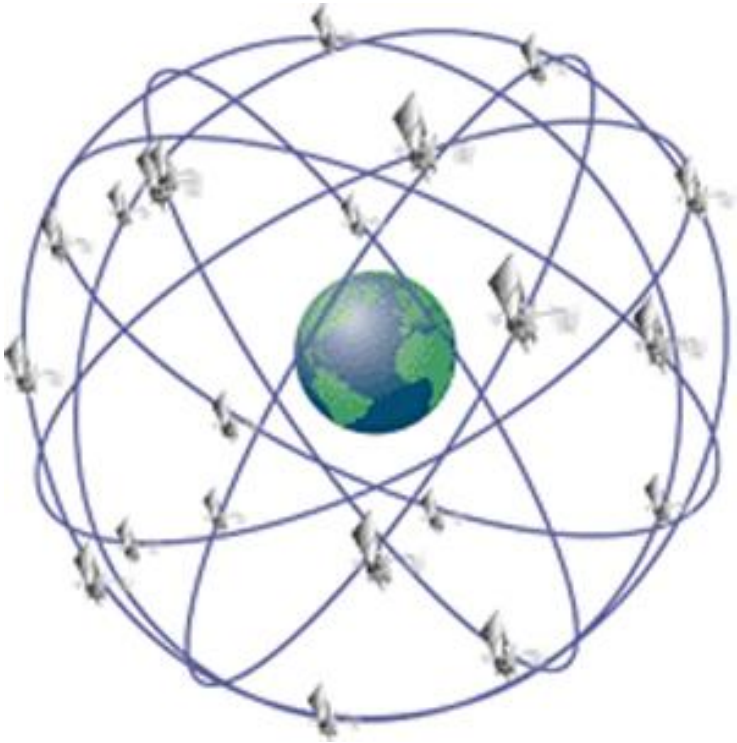
- Good satellite geometry

Satellite ID Numbers

- US GPS: 1 to 32
- WAAS (SBAS): 33 to 64
- GLONASS: 65 to 96

- 9 GPS, 1 WAAS, 5 GLONASS

Global Navigation Satellite System (GNSS)



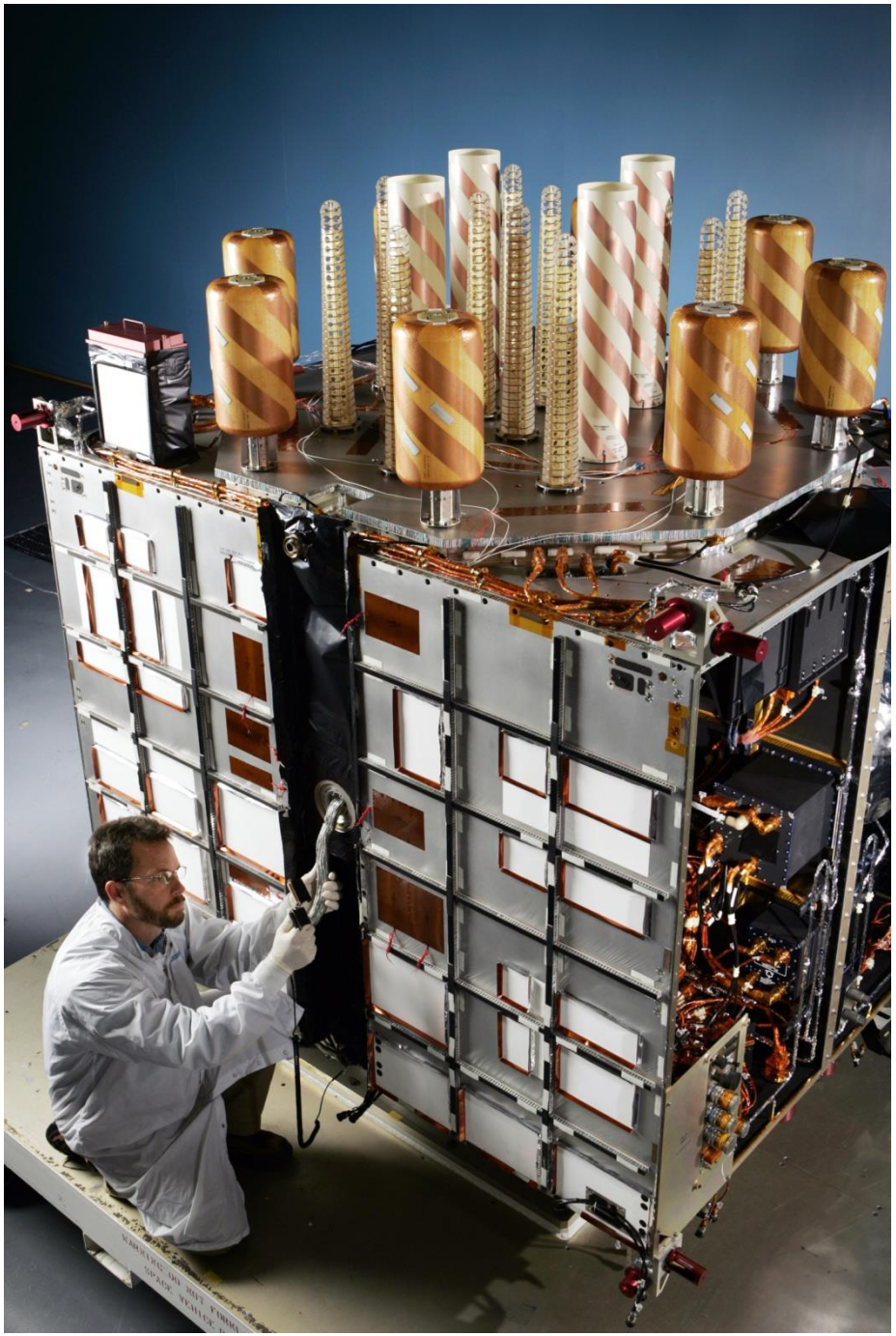
- 31 US GPS Satellites
- New GPS III Sats by 2017?

- GLONASS (Russian): 27

- Galileo (EU) – 3 Satellites, 5 in Progress

- BeiDou (China) – 17 now, 35 Planned

- QZSS (Japan): 1 Sat., So Far



A GPS II Satellite

Images: Lockheed Martin

Last of 8 GPS IIF Satellites Launched Oct. 2014

Image: Credit: United Launch Alliance, October 29, 2014

Prototype GPS III Satellite

New GPS Signals... 2017?

Image: Lockheed Martin

Three Elements of GPS

1. **Space Segment**: Satellites
2. **User Segment**: You and Your Receiver
3. **Control Segment**: 1 Master and 4 other control stations (**red**), plus 6 Monitoring stations added in 2005 (**pink**). The master and control stations correct the atomic clocks on board the satellites to within a few nanoseconds of each other and update the ephemeris data (status of the satellites' operational health).

NASA

671 Million Miles Per Hour

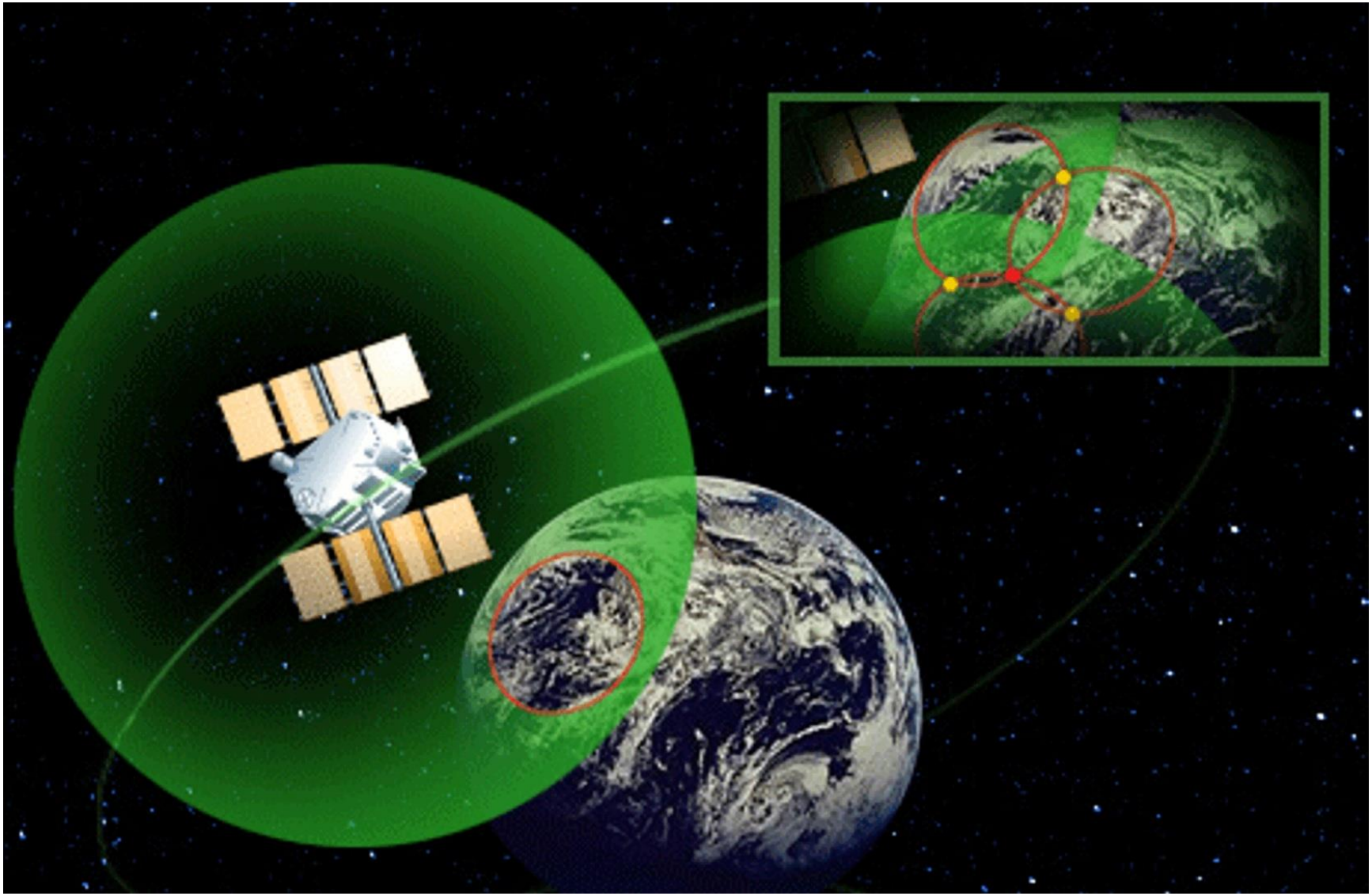
Key Principle: Radio waves from GPS satellites travel at the speed of light:

186,282 miles per second (671 million miles per hour)

Velocity x Time = Distance

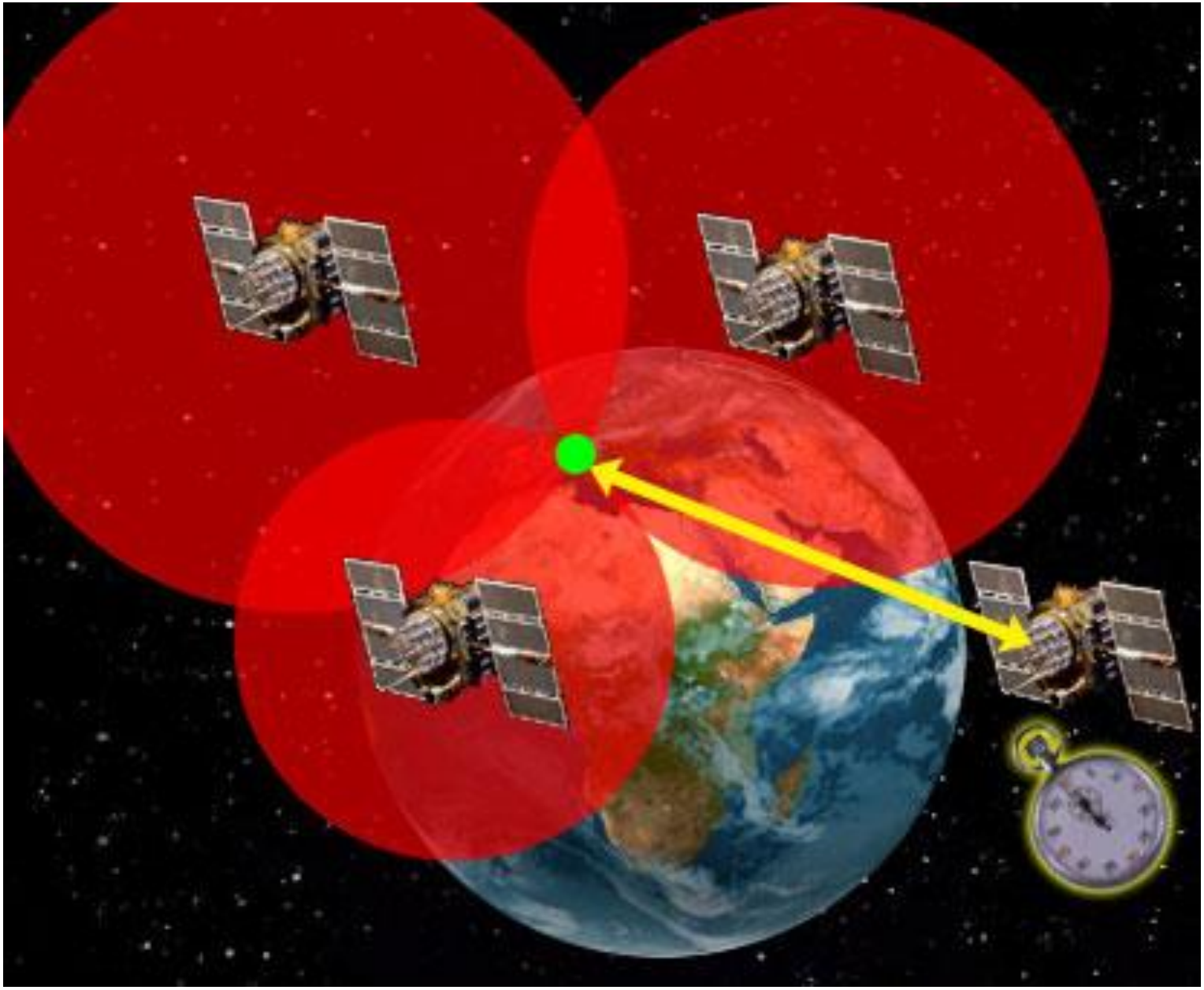
Distance calculated between a satellite and a receiver....

Unilateration?



PC Magazine, June 2008

Trilateration



http://gpsbasedsolutions.info/trilateration.php

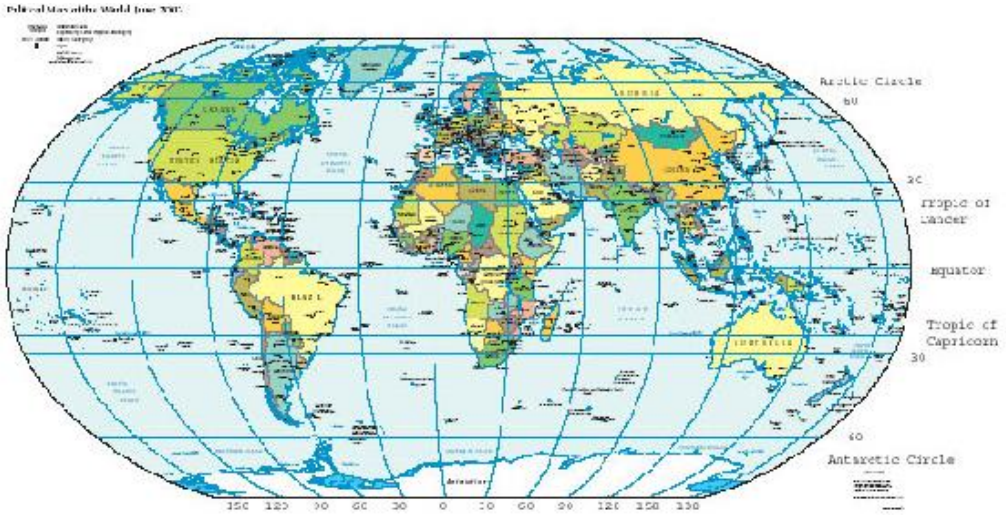
The 3-Satellite Minimum

- Signals from 3 Satellites Required for **Horizontal** Position

- 4 Satellites Required for **3D Position** (Lat/Long or UTM Coordinates, Plus Elevation)

- 5 or 6 Sats is Better

- 7 or More is Awesome … Maybe



Three Terms to Know:

- SBAS/WAAS
- DOP or PDOP
- Multipath Error

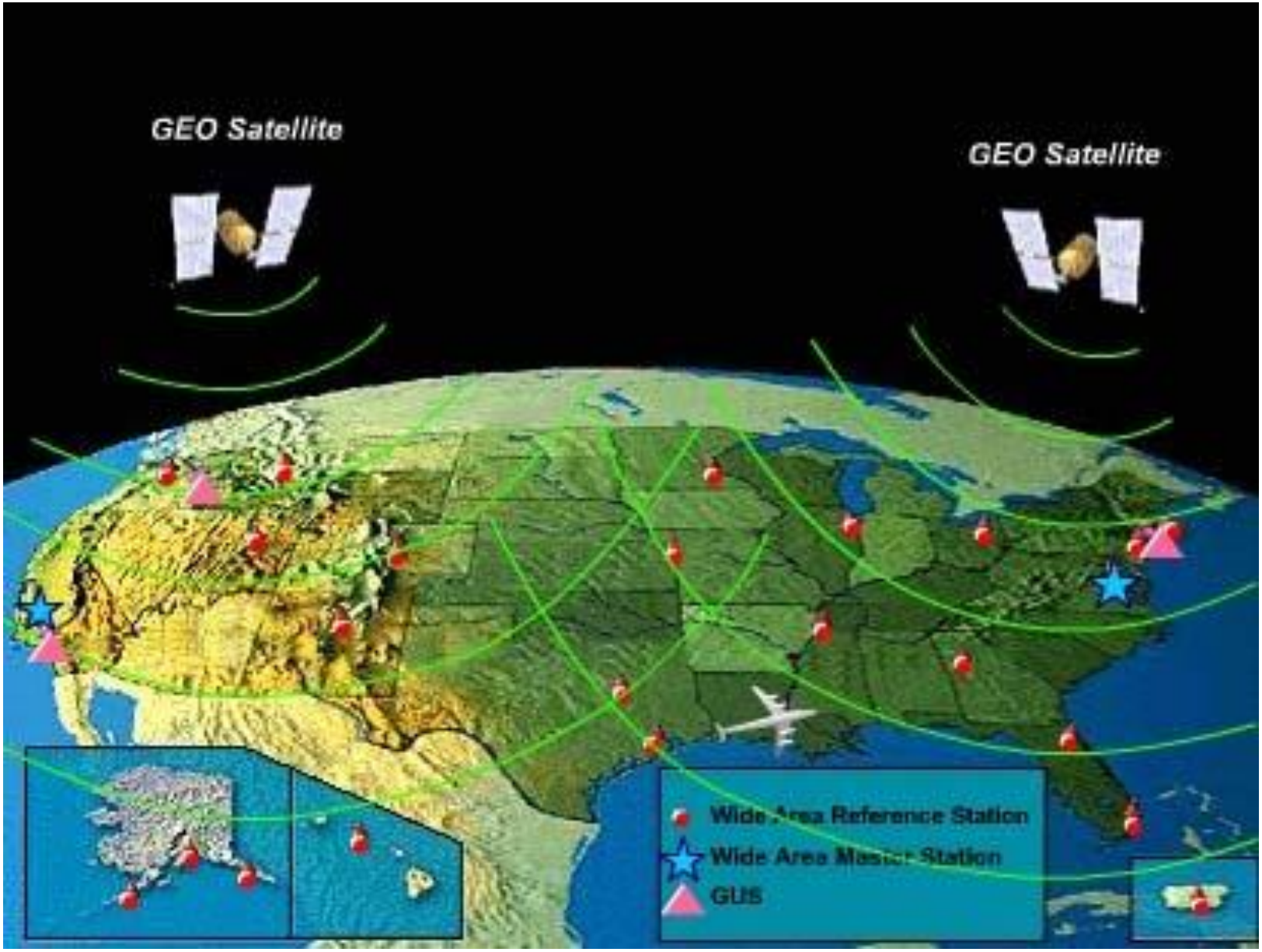
One SBAS is WAAS
WAAS is an SBAS

• The US's **Wide Area Augmentation System** (WAAS) is one of the available **Space Based Augmentation System** (SBAS) systems.

• 2 WAAS satellites cover the continental US

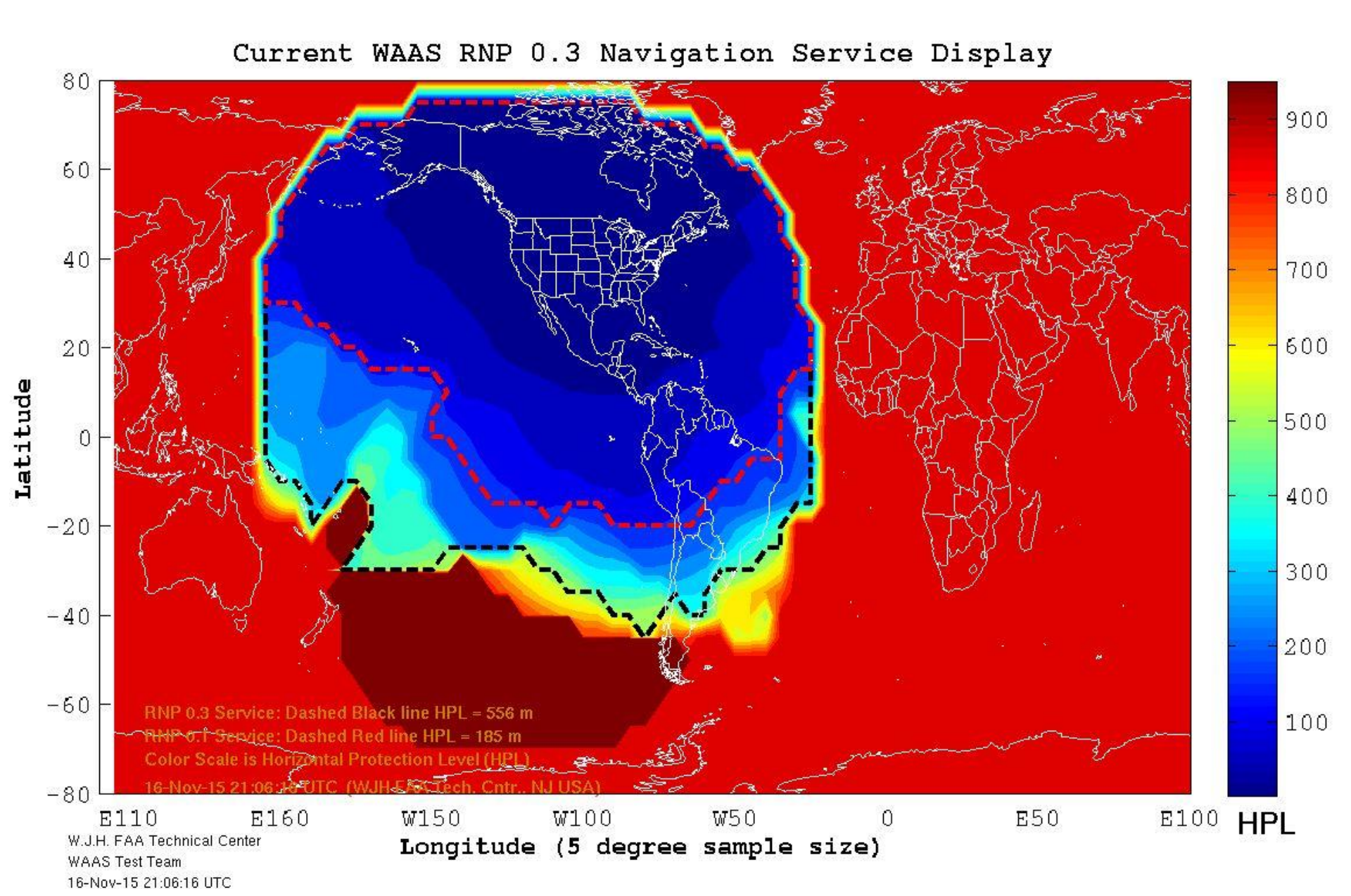
• Others: The European Geostationary Navigation Overlay Service (**EGNOS**) and the Japanese Multi-functional Satellite Augmentation System (**MSAS**)

WAAS: Wide-Area Augmentation System Satellites

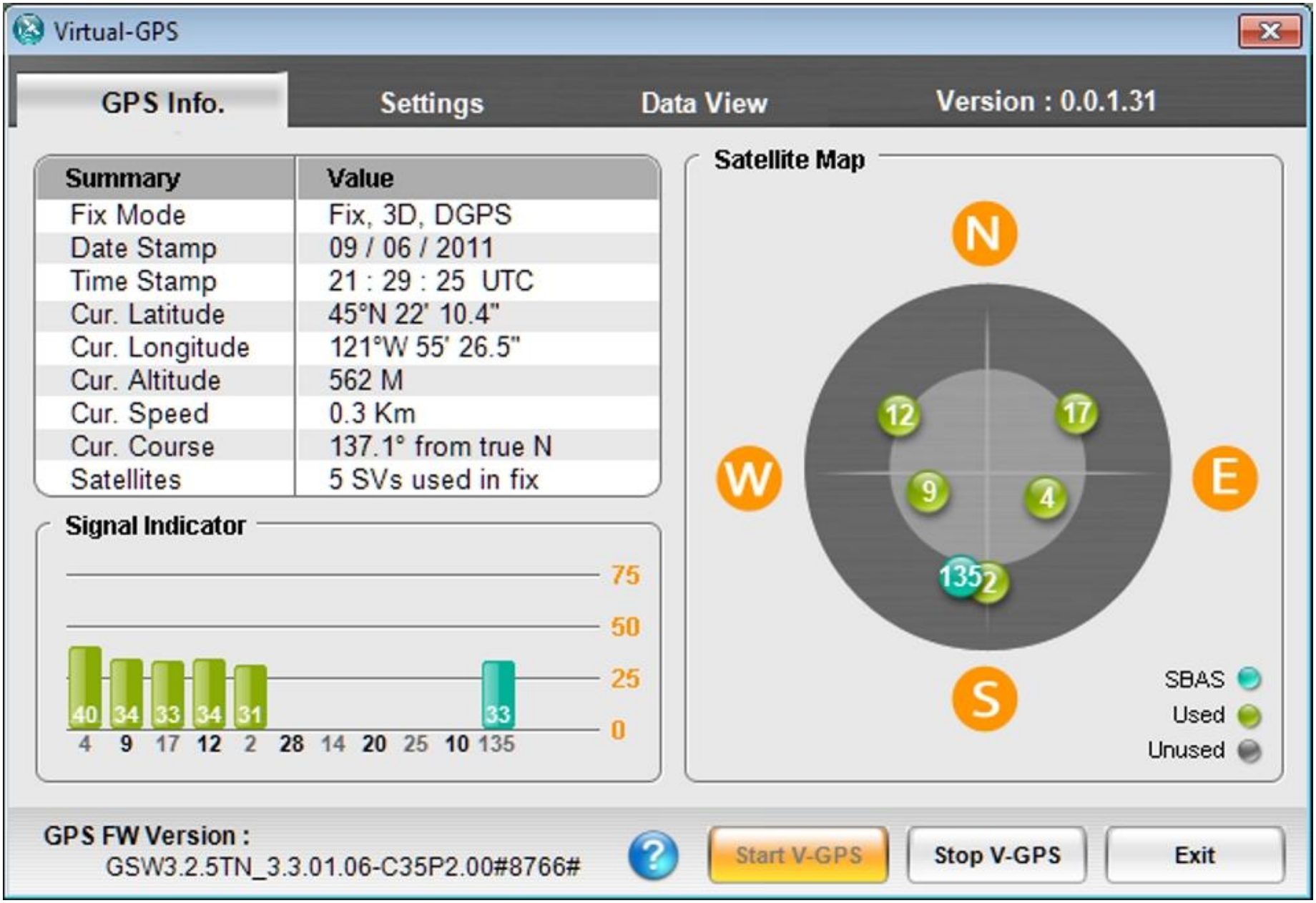


GUS = Ground Uplink Station

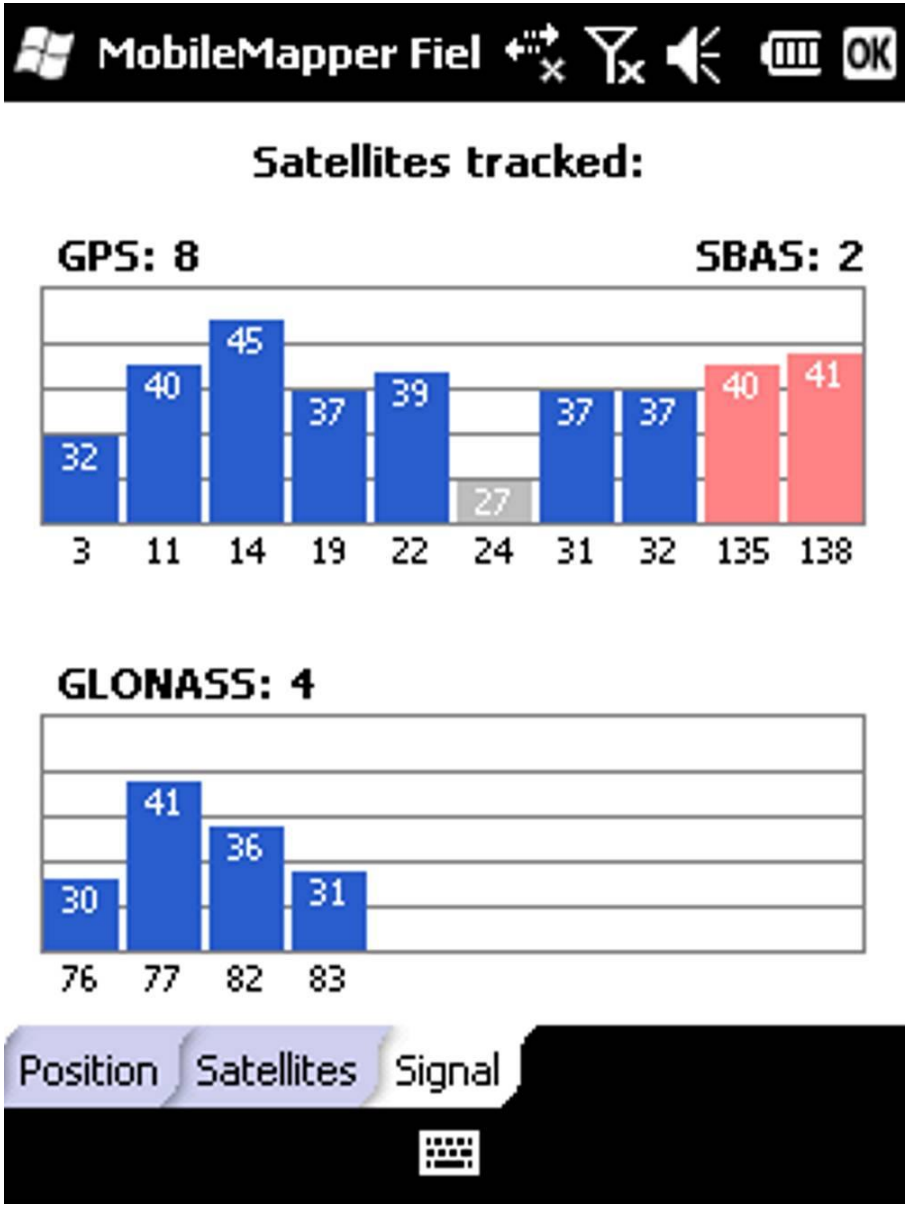
Image: Federal Aviation Administration



WAAS System Coverage, Nov. 15, 2015 - FAA



135 = pseudo-random noise (PRN) number, another type of ID



Ashtech's Mobile Mapper 100

12 GNSS Sats
(8 GPS, 4 GLONASS)

2 SBAS Sats

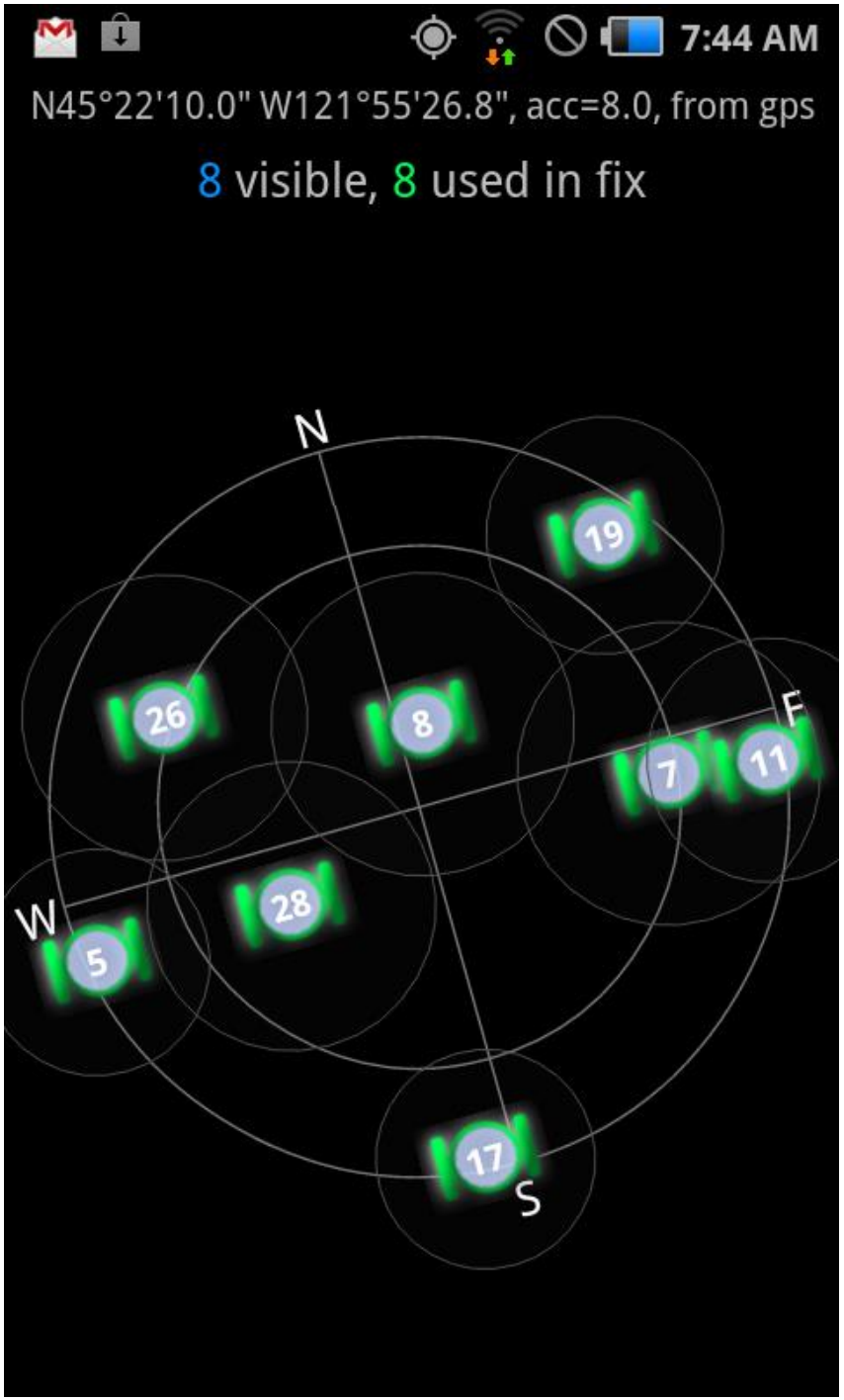
PRN numbers 120 to 158 are SBAS Satellites

PDoP: Position Dilution of Precision = Satellite Geometry

- When GPS satellites are close together in the sky, the geometry is poor and the Dilution of Precision (DOP) value is high.

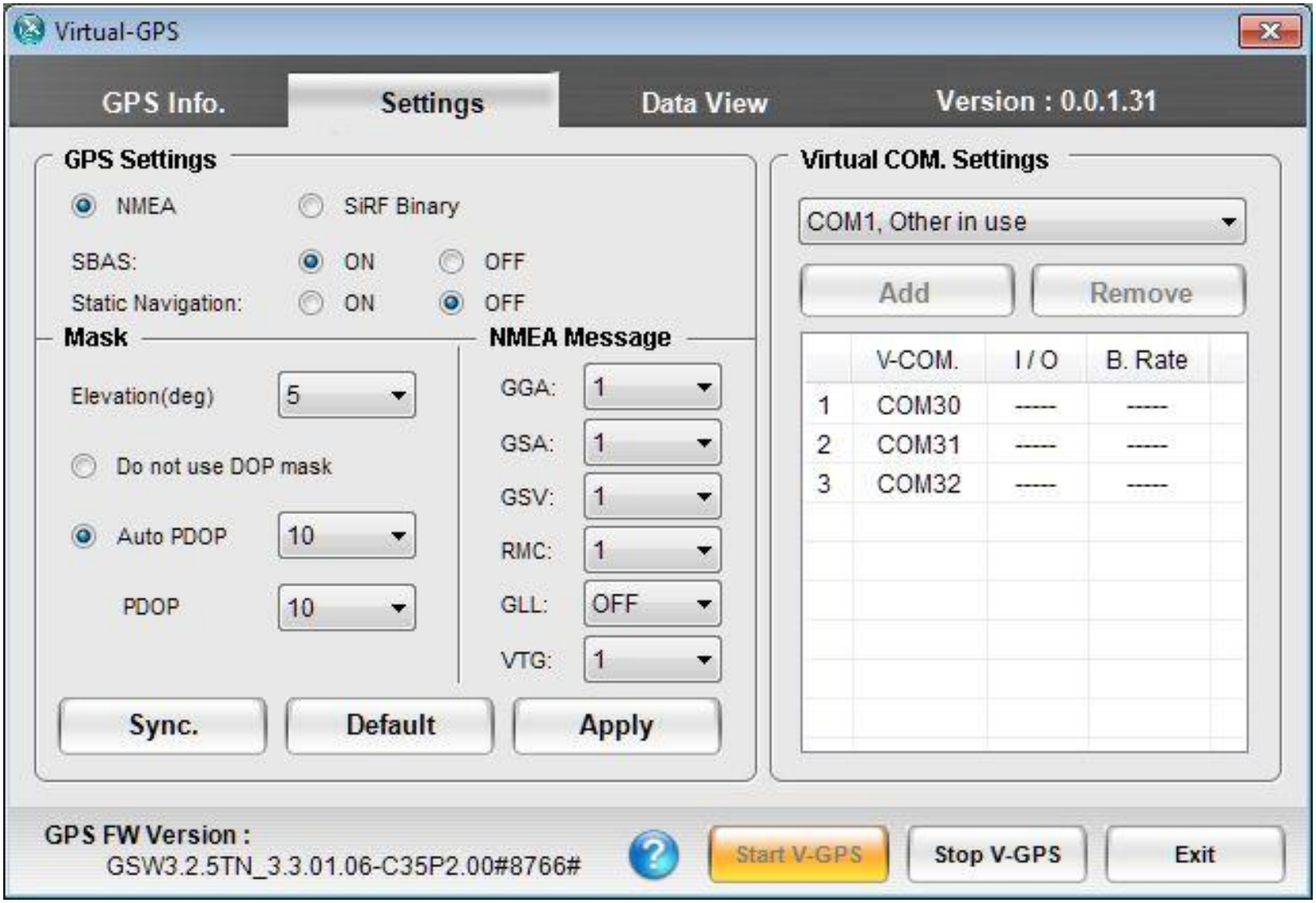
- When satellites widely scattered, the geometry is good and the DOP value is low.

DOP Value	Rating
1	Ideal
2	Excellent
3-5	Good
5-10	Moderate
10-20	Fair
>20	Poor



Good PDoP, man!

Or is it?



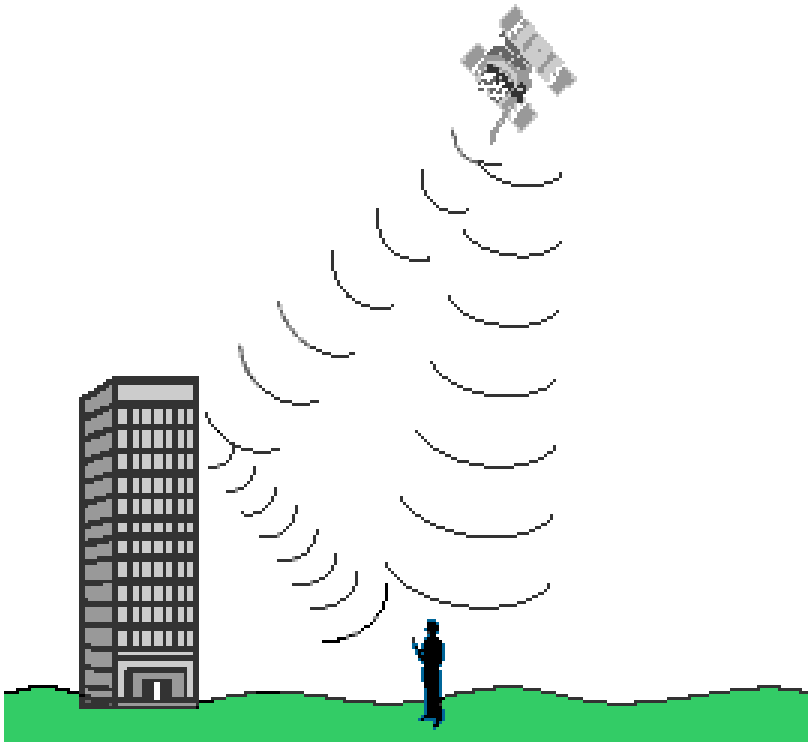
PDoP Mask: If the PDoP exceeds the mask setting, the receiver stops logging positions.

GPS in the Field:

GeoAssist GPS Utility on an F4Devices Flint rugged field computer.

- 1- to 3-meter accuracy.
- 1 to 2 meters when using SBAS.

- **PDoP: 4.3**



Reflecting on Multipath Errors

Sophisticated GPS receivers filter out reflected signals and accept only the earliest arriving signals (the direct ones). Trimble's GeoExplorer 6000 series uses the company's Everest "multipath rejection technology."

Illustration: www.pdhcenter.com

To Err is Not Only Human

- Radio signals do not pass directly through your body.
- They won't penetrate buildings, either.
- And heavy forest canopy can reduce GPS accuracy.

How Accurate?

Typical Manufacturer Specifications:

- Recreational/Consumer Grade — 3- to 15-meters
- **Mapping/Resource grade** — **<1-meter to 5-meters**
- Survey grade — ~1 centimeter

Qualifier: The Root Mean Squared Statement (Quadratic Mean)

"HRMS refers to Horizontal Root Mean Squared accuracy,1-sigma (68%). Except in conditions where most GNSS signals are affected by trees, or buildings, or other objects."

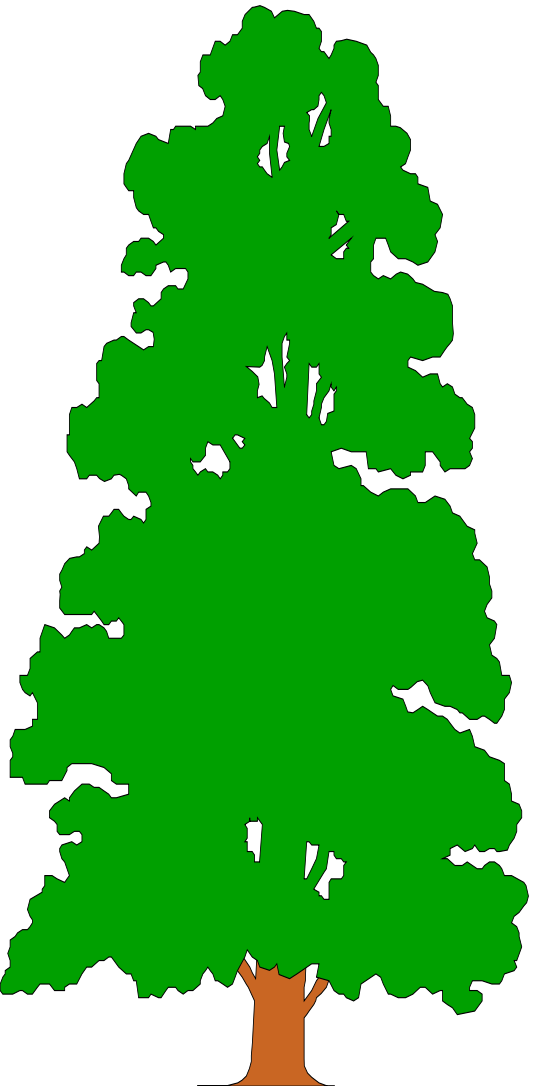
Translation: Stated accuracy is achieved 68 percent of the time under good conditions

Working Under Forest Canopy

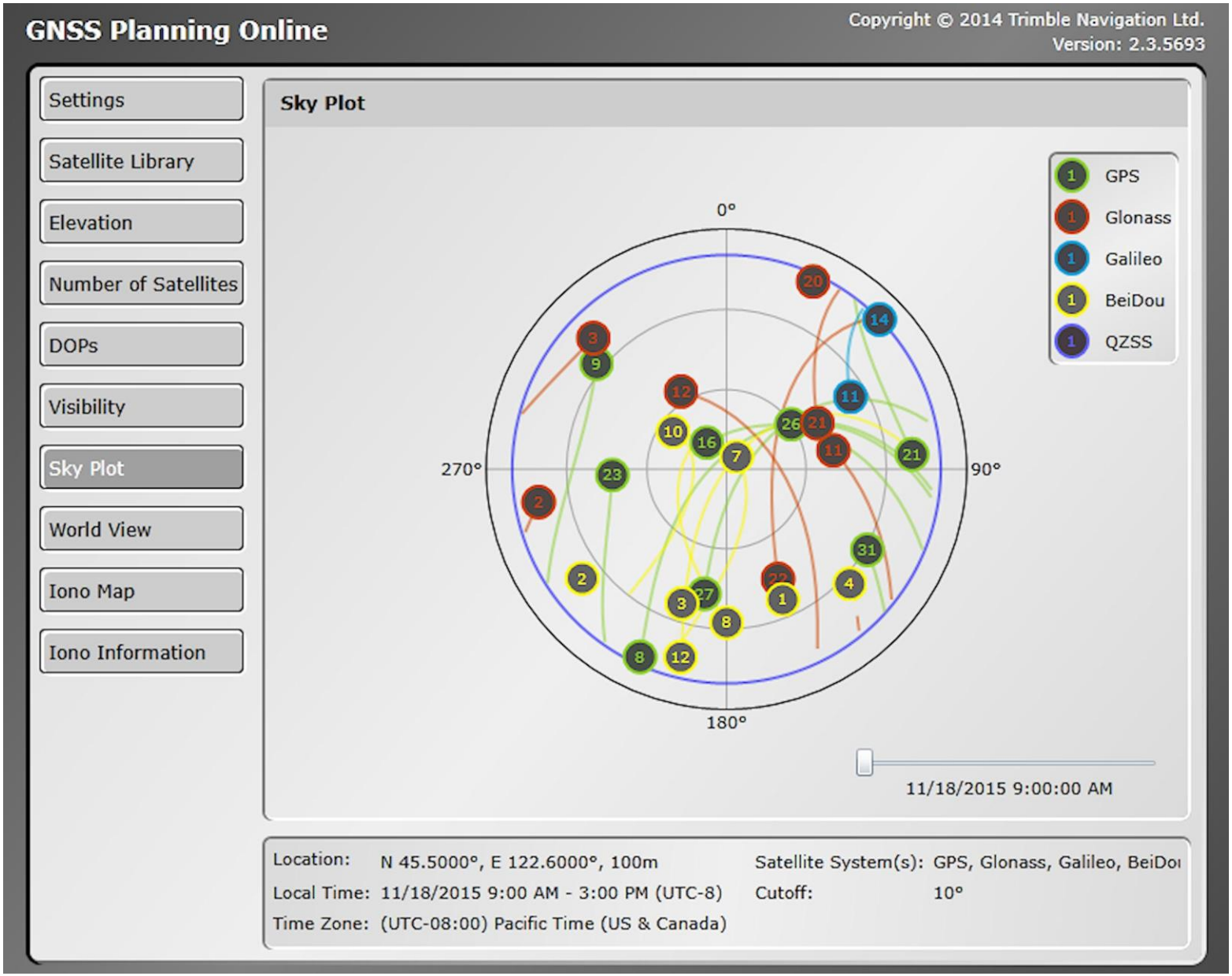
Garmin GLO under open sky: 3 meters

Garmin GLO: Clackamas GPS Test Site Results	
Station 2	2.3 meters
Station 2A	1.4 meters
Station 2B	11.5 meters
Station 3	5.1 meters
Average	**5.1 meters**

Tips for Higher Accuracy Under a Forest Canopy:



- Use a GPS receiver with multipath-filtering technology
- Use **mission-planning tools** to determine the time(s) with lowest possible PDoPs.
- For critical point features, record many positions – as many as 250 to 500.
- For line and polygon features, set the receiver to record a position every second.



http://www.trimble.com/GNSSPlanningOnline/

The Languages of GPS III

- L1 — Military Use Only
- L2 — Military Use Only

Civilian Signals

- L1 C/A — All GPS Satellites; All Civilian GPS Receivers

- L2C — 13 Sats Since 2005; Dual-Frequency GPS Receivers

- L5 — 8 GPS Satellites Since 2010; Aeronautical Radio Navigation, Safety-of-Life Applications

- L1C — Block III Satellites Starting in ~~2014~~ ~~2016~~ 2017. Dual-Frequency GPS Receivers?

(L = Link; C = Civilian; C/A = Coarse Acquisition)

More, Better Signals = Greater Accuracy

- All existing GPS receivers use L1 C/A
- Dual-Frequency GPS Receivers — L1 C/A + L2C
- Future: Multi-Frequency GPS Receivers — L1 C/A + L2C + L1C?

"More effective power means L2C will easier to pick up in difficult environments like urban canyons, under significant tree cover, or even indoors."

— Digital Trends, www.digitaltrends.com/mobile/gps-iii-explained-everything-you-need-to-know-about-the-next-generation-of-gps/

“GPS III, with the L1C signal — a much more capable signal, one that is less prone to multipath — will certainly benefit foresters.”

— Richard B. Langley, professor, Geodetic Research Laboratory, University of New Brunswick’s Department of Geodesy and Geomatics Engineering, in “GPS Modernization: Sooner or Later, You’ll Want to Upgrade,” *The Forestry Source*, November 2014.

Comments? Questions? GPS Jokes?

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www.eforester.org

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