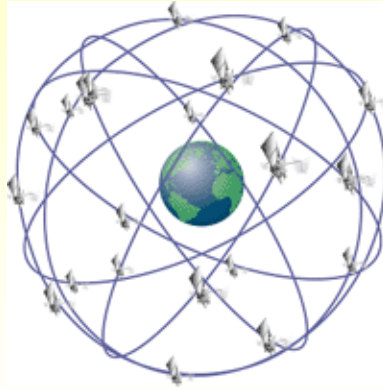
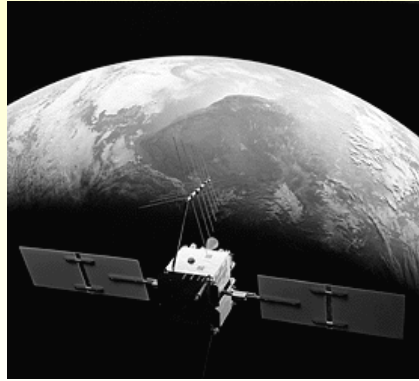


## ***GPS – Global Positioning Systems***

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## ***Road Map***

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- GPS - differential
- Digital Orthophotography: concepts & generation
- GIS and analysis of DOQ's - analysis project to provide information to decision makers
- Overview of RS data acquisition for GIS
- Digital data quality and error
- Other airborne systems - "time permitting"

## **Global Positioning Systems - References**

Trimble - Differential GPS explained - layman's coverage of the subject

Numerous good web pages:

<http://www.trimble.com/index.html>

<http://www.aero.org/publications/GPSPRIMER/>

[http://www.colorado.edu/geography/gcraft/notes/gps/gps\\_f.html](http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html)

Wolf & Brinker, Chpt. 20 - library

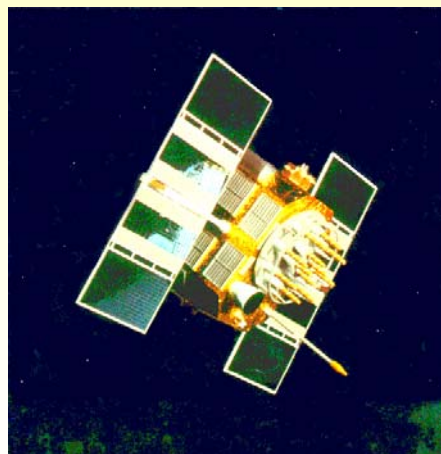
## **What is GPS ?**

An system of satellites, receivers, and software for .....

navigating  
around the  
landscape

and

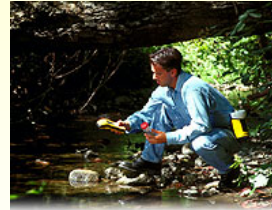
mapping  
landscape  
features



GPS is a Satellite Navigation System funded by and controlled by the U. S. Department of Defense (DOD).

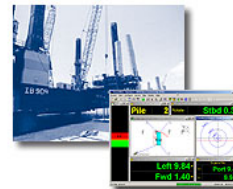
## ***GPS Uses***

Becoming common tool in diversity of applications (cars, boats, harvesters, laptops, construction equipment, hiking, natural resource management, agriculture, military)



### In natural resource management

Boundary mapping and location  
Fire boundary mapping  
Location of inventory or permanent plots  
Mapping roads, trails, streams  
Mapping wildlife nest or observation locations



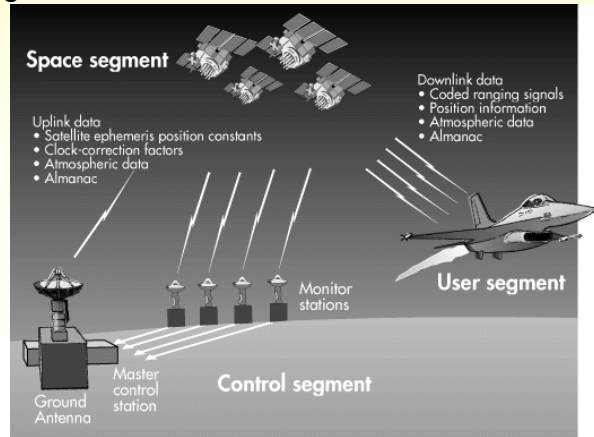
## ***GPS Advantages?***

- No line of sight required - control/basestation network
- Day or night operation
- Continuous real-time information
- All weather
- Accurate! - positions in almost any common map projection
- Support to an unlimited number of users and areas
- Light & portable - batteries biggest weight

## GPS Architecture

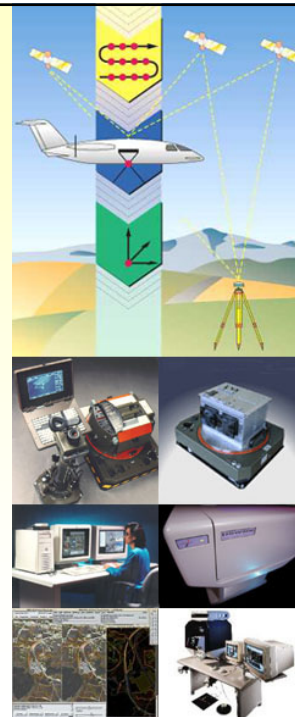
- Operated by the USAF
- Available worldwide
- An independent system
- Consists of three segments:

- 1) Space
- 2) Control
- 3) User



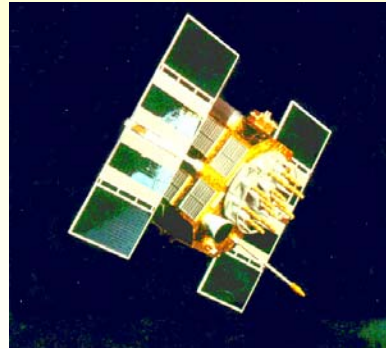
## GPS Space Segment

- ❖ U.S. Dept. of Defense - \$12 Billion investment  
Space Segment consists of 24 operational satellites in six circular orbits 20,200 km (11,000 nm) above the earth, with a 12-hour period.
- ❖ This guarantees that at least four satellites, but on average, the user will experience between five and eight satellites in view of your GPS receiver anywhere in the world, 24 hours a day.
- ❖ These space vehicles (SV) send radio signals from space; they continuously broadcast position and time data to users all over the world.



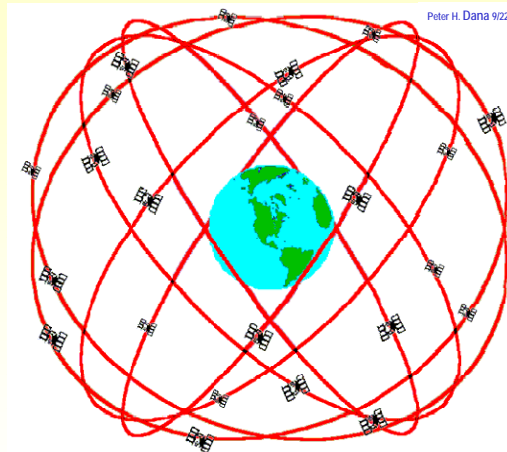
## GPS Space Segment (Cont.)

- ❖ The US DoD has called to this constellation as NAVSTAR (NAVigation Satellite Timing and Ranging)
- ❖ First launch - 1978, constellation completed – 1994
- ❖ Design life - 6 years

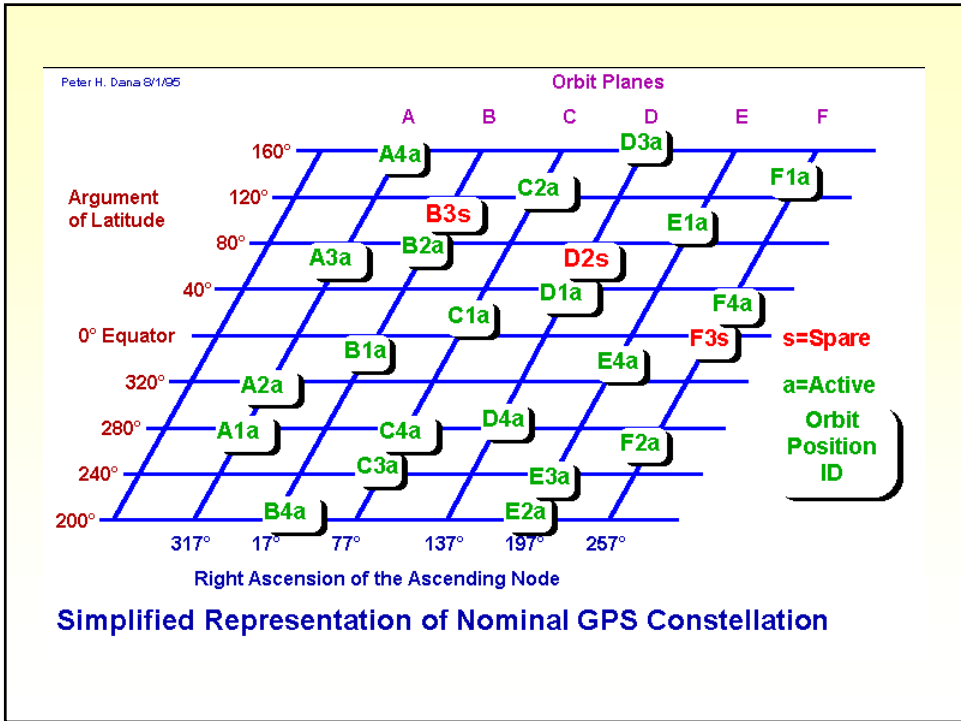
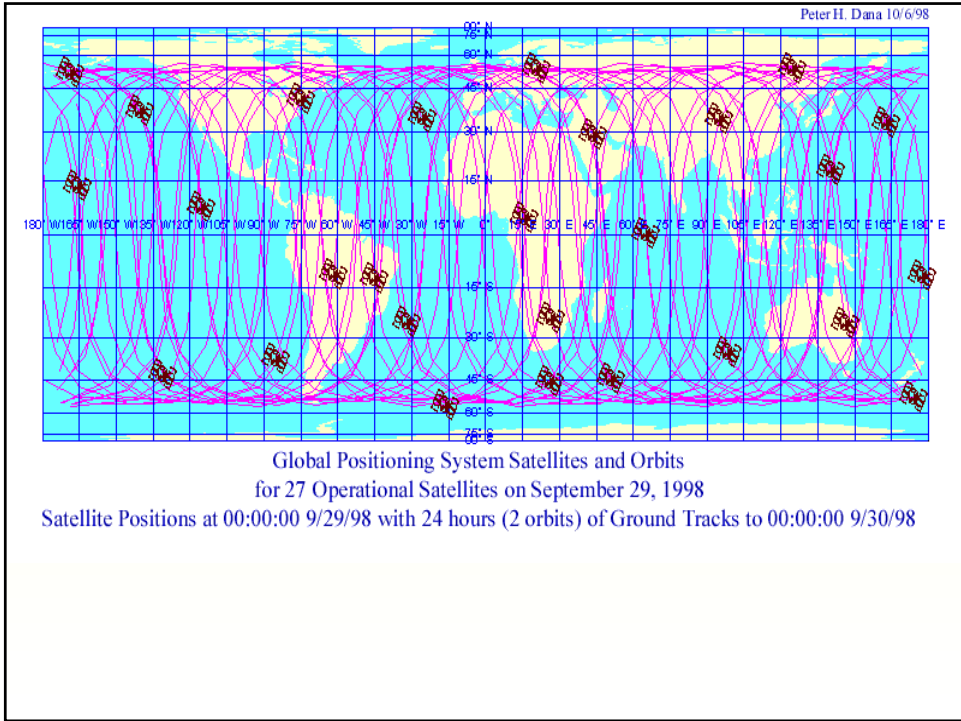


## GPS Space Segment (Cont.)

- Nominal GPS Operational Constellation consists of 24 satellites that orbit the earth in 12 hours.
- The satellite orbits repeat almost the same ground track (as the earth turns beneath them) once each day.
- The orbit altitude is such that the satellites repeat the same track and configuration over any point approximately each 24 hours.
- There are 6 orbital planes (with nominally 4 space vehicles in each), equally spaced (60 degrees apart), and inclined at about 55 degrees with respect to the equatorial plane.



**GPS Nominal Constellation**  
**24 Satellites in 6 Orbital Planes**  
**4 Satellites in each Plane**  
**20,200 km Altitudes, 55 Degree Inclination**



## ***GPS Control Segment***

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- The Control segment of NAVSTAR GPS is composed of:
  - Master Control Station  
Processes and updates the **orbital parameters** for each satellite, and then those data are broadcast as "almanacs" which GPS receivers can use to calculate positions
  - Monitor Stations  
Are very precise GPS receivers **located at well-known surveyed positions**. They track and collect data of the shapes of satellite orbits, which sometimes are disturbed by the gravitational fields of the Earth and the Moon. Data collected by Monitor Stations are processed at the Master Control Station at Colorado Springs.

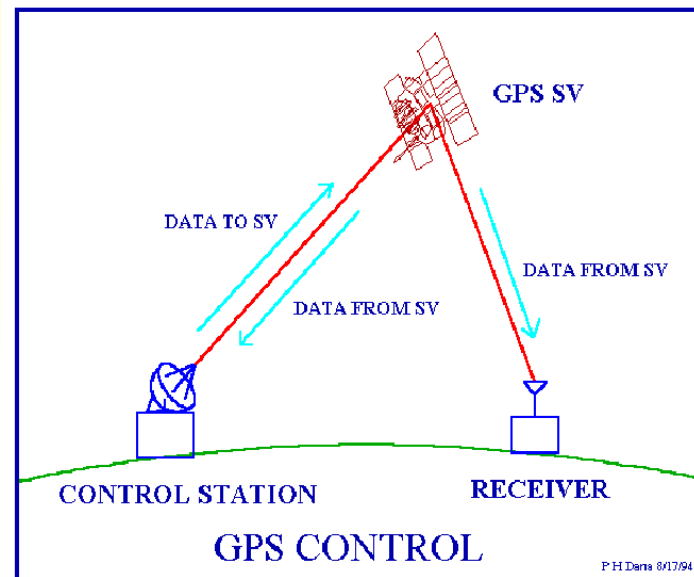
## ***GPS Control Segment (Cont.)***

---

### **GPS Satellite Almanac**

ID:	001
Health:	000
Eccentricity:	4.000186920e-03
Time of Applicability(s):	1.474560000e+05
Orbital Inclination(rad):	9.558881812e-01
Rate of Right Ascen(r/s):	-7.966046104e-09
SQRT(A) (m <sup>1/2</sup> ):	5.153576660e+03
Right Ascen at TOA(rad):	9.758529636e-03
Argument of Perigee(rad):	-1.655733397e+00
Mean Anom(rad):	-9.759915312e-02
Af0(s):	4.005432129e-05
Af1(s/s):	0.000000000e+00
week:	945

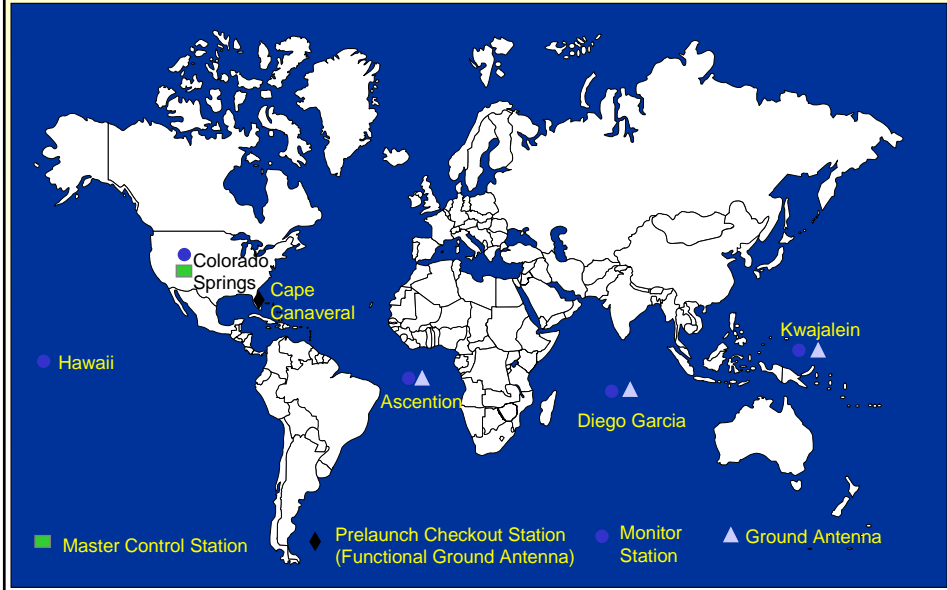
## ***GPS Control Segment (Cont.)***



## ***GPS Control Segment (Cont.)***

- Ground Antennas  
Transmit the updated control data to each satellite from the Master Control Station
- Prelaunch Control Station  
Supports satellite prelaunch compatibility tests, and serves as a ground antenna when needed

## GPS Control Segment (Cont.)

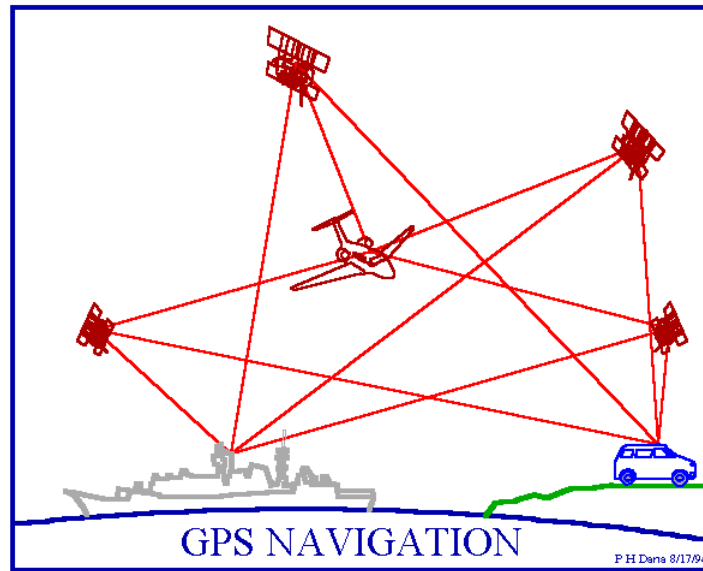


## GPS User Segment

– GPS receivers

- Military Operations
- Aviation
- Vehicle Navigation
- Precision Agriculture
- Natural Resources Species Habitat Mapping
- Recreation
- Mining
- Fishing

## GPS User Segment (Cont.)



## GPS Equipment - Receivers



## GPS Equipment - Receivers



## GPS Equipment - Receivers



## ***GPS Equipment - Antennas***

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Mounted on a roof, a pole, a truck, or a person.



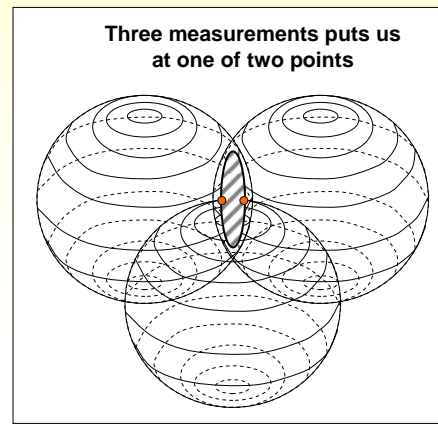
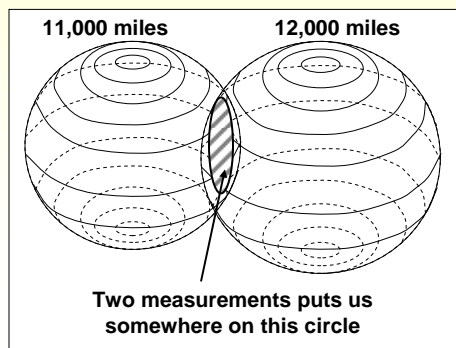
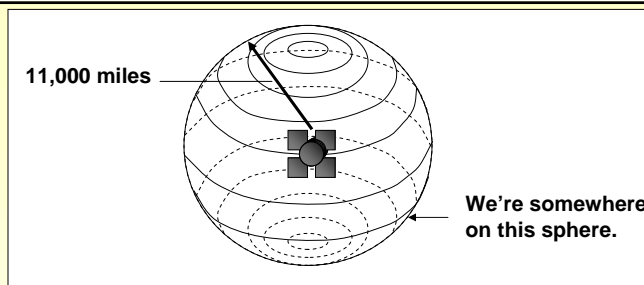
## ***How GPS Works → 5 Steps***

---

1. Basic principal - triangulation from satellites
2. GPS receiver measures distance using travel time of radio signals
3. Travel time measurement using accurate timing
4. Knowledge of satellite positioning
5. Corrections due to atmospheric influences

## 1. → *Triangulation from Satellites*

- Position is calculated from distance measurements (ranges) to satellites
- Mathematically we need four satellite ranges to determine exact position
- Three ranges are enough if we reject ridiculous answers or use other tricks
- Another range is required for technical reasons (discussed below)



## 2. → Measuring Distance

- Distance to a satellite is determined by measuring how long a radio signal takes to reach us from that satellite
- Achieved by assuming both the satellite and receiver are generating the same pseudo-random codes at exactly the same time
- By determining the delay in the pseudo-random code, we determine how long it took to reach us
- Multiply travel time by speed of light = distance

## 2. → Measuring Distance

**Velocity x Time = Distance**



1 second

2 seconds

3 seconds

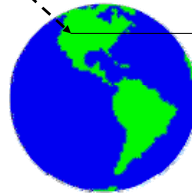
4 seconds

Example:

"If a car goes 60 miles per hour for two hours, how far does it travel?"

**Velocity (60 mph) x Time (2 hours) =  
Distance (120 miles)**

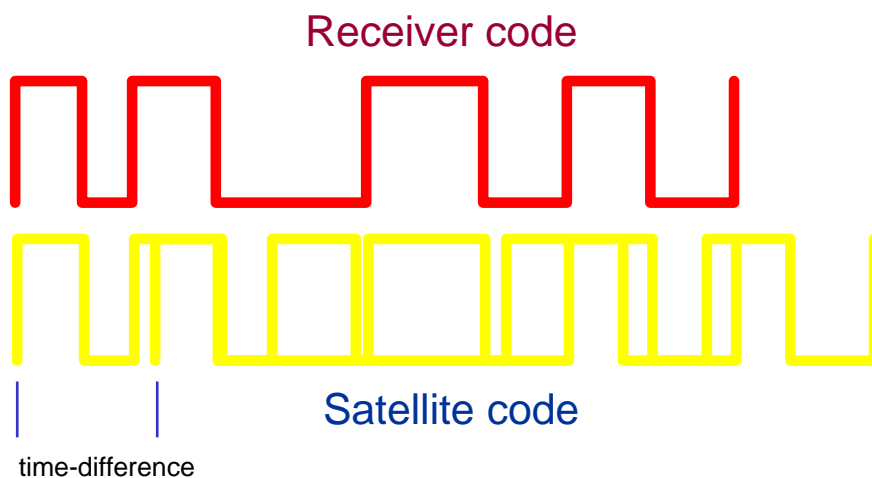
We measure a radio signal where the velocity equals the speed of light or roughly 186,000 miles per second.



## 2. → *Measuring Distance – satellite signals*

- Each satellite transmits two signals - L1 & L2 microwave frequencies/wavelengths pseudo-random noise (PRN) codes are carried by the signals - unique sequences of binary values (0,1) that appear random - but in fact are generated by a special mathematical algorithm
- Each satellite has it's own PRN code - differentiate
- L1 - frequency (1575.42 MHz) carries precision code (P-code) along with a coarse acquisition code (C/A-code) - status info
- L2 - frequency (1227.60 MHz) carries only the P-code
- P-code much higher frequency - generates a much more accurate position (anti-spoofing - scrambling by the military)

### *Pseudo-range Determination*



## **2. → Measuring Distance**

---

GPS provides two levels of service: Precise Positioning Service (PPS) and the Standard Positioning Service (SPS).

- The PPS is a highly accurate military positioning, velocity and timing service that will be available on a continuous, worldwide basis to users authorized by the U.S.
- The PPS is comprised of both L1 and L2 signals (and PRN codes) and is mainly reserved for the military and authorized users.
  
- The SPS is a positioning and timing service, which will be available to all GPS users on a continuous, worldwide basis with no direct charge.
- The SPS is available to all civilian users, is free of charge, and is comprised of accessing the L1 signal and the C/A code.

## **2. → Measuring Distance**

---

Precise Positioning Service (PPS) Predictable Accuracy

- 22 meter horizontal accuracy
- 27.7 meter vertical accuracy
- 100 nanosecond time accuracy

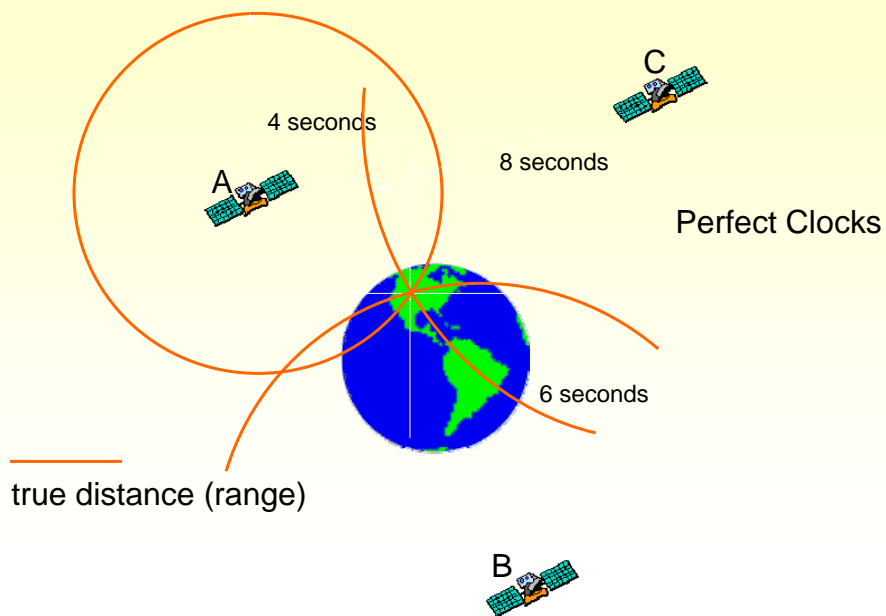
Standard Positioning Service (SPS) Predictable Accuracy

- 100 meter horizontal accuracy
- 156 meter vertical accuracy
- 340 nanoseconds time accuracy

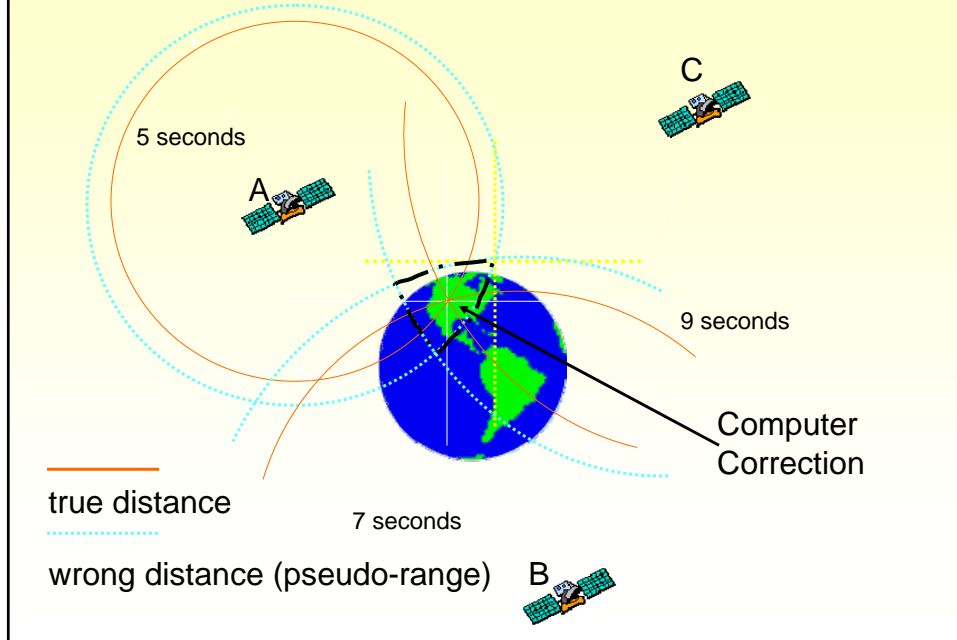
### 3. → Getting Perfect Timing

- Accurate timing is the key to measuring distance to satellites
- Satellites are accurate because they have atomic clocks on board
- Receiver clocks don't have to be too accurate because an extra satellite range measurement can remove errors

### Effects of clock bias



## Effects of clock bias (Cont.)



## 4. → Satellite Positions

- To use the satellites as references for range measurements we need to know exactly where they are
- GPS satellites are high up so that orbits are very predictable
- Minor variations in their orbits are measured by DOD (radar tracking - altitude, position, speed)
- Error information is sent to the satellites, to be transmitted along with the timing signals

## 5. → Correcting Errors

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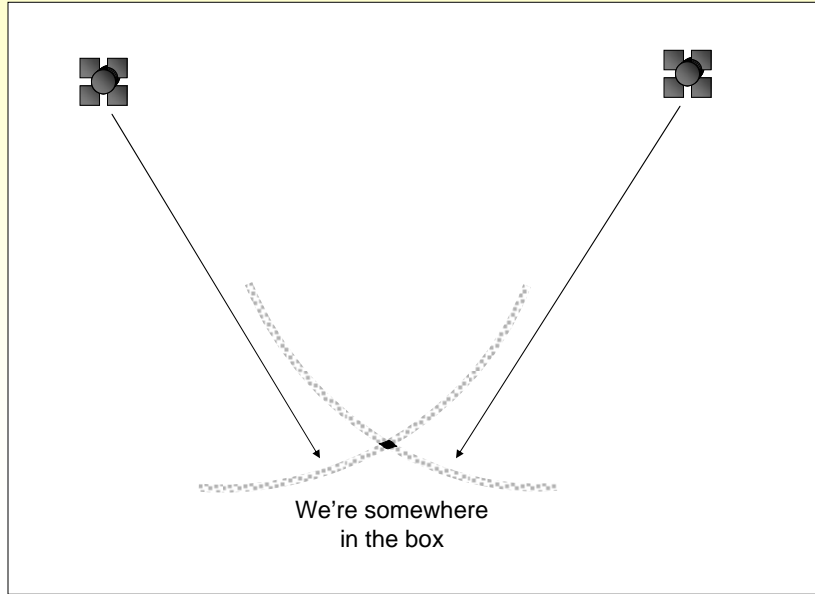
- The earth's ionosphere and atmosphere cause delays in the GPS signal that translate into position errors
- Some errors can be factored out using mathematics and modeling
- The configuration of the satellites in the sky can magnify other errors
- Differential GPS (DGPS) can eliminate almost all error

## What are GDOP and PDOP?

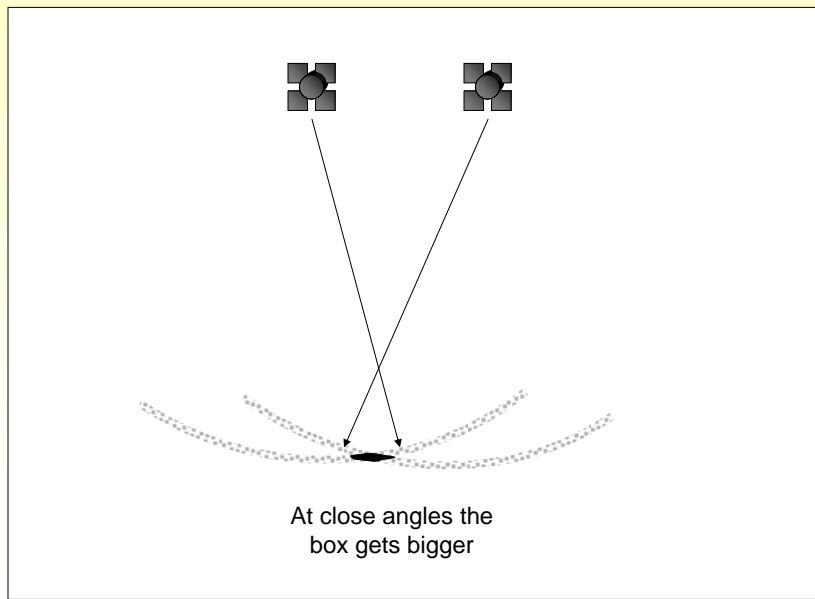
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- The quality of satellites geometry and the magnitude of the error in a position have been quantified by the term Geometric Dilution of Precision (GDOP) – lawyer's way of saying “we've got some errors here”.
- The components of the GDOP and the effects are specific to the noted parameters.
  - Horizontal Dilution of Precision (HDOP) – Horizontal = Latitude and Longitude
  - Vertical Dilution of Precision (VDOP) – Vertical = Elevation
  - Position Dilution of Precision (PDOP) – Position = Three dimensions
  - Time Dilution of Precision (TDOP)
- The larger the PDOP value, the greater the error in an estimated position.

## GDOP?



## GDOP?



### ***Typical Error Budget (m)***

---

<u>Per satellite accuracy</u>	<u>Standard GPS</u>
Satellite clocks	1.5
Orbit errors	2.5
Ionosphere	5.0
Troposphere	0.5
Receiver noise	0.3
Multipath (reflections)	0.6
SA	30.0

#### Typical positional accuracy

Horizontal	50-30=20
Vertical	78
3-D	93

### ***How GPS Works → 5 Steps***

---

1. Basic principal - triangulation from satellites
2. GPS receiver measures distance using travel time of radio signals
3. Travel time measurement using accurate timing
4. Knowledge of satellite positioning
5. Corrections due to atmospheric influences

## **Other GPS → GLONASS**

- The GLONASS - Global Navigation Satellite System (GLObal'naya Navigatsionnay Sputnikovaya Sistema), sponsored by the Russian Federation Ministry of Defense.
- GLONASS is a counterpart to the U.S. GPS and both systems share the same principles in the data transmission and positioning methods.
- First launch - 1982, constellation completed – 1996
- The GLONASS, like GPS, consists of three segments (Space, Control, and User).

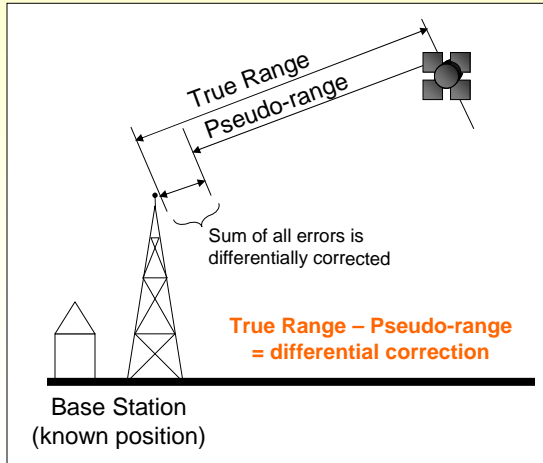
## **Other GPS → GLONASS**

- GLONASS is formed by 24 satellites located on 3 orbital planes.
- Orbital planes are separated by 120 degrees, having 8 satellites (separated by 45 degrees).
- Orbits are circular (19,140 Km), with an inclination of 64.8 degrees and a period of 11 hours 15 minutes 44 seconds.
- Transmits coded signals in two frequency bands (same as GPS)
- The maintenance of the system has been limited the last couple of years resulting in a decreasing number of orbiting satellites.

• <http://www.mich.com/~buffalo/rhp/gps.html>

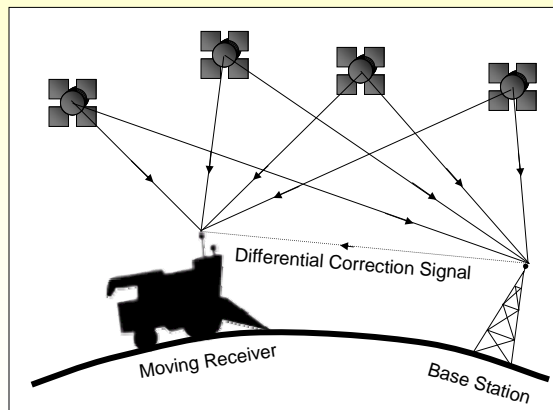
## What is Differential GPS (DGPS)

- Differential correction employs stationary GPS receivers located at a known surveyed location (Base Station).
- Base Station knows the true position of each satellite,
- Base station calculates the pseudo-range or distance to each satellite in its view and determines the error in each measurement.



## Differential GPS (DGPS)

- Involves use of two receivers - one that's stationary (reference) and another rover
- errors are a compounding of factors, but receivers within 100km usually have same errors
- stationary receiver sits on a known location and back calculates what the timing should be, compares with what they are and develops "error correction" factor



## ***Types of Differential GPS Correction***

- **Post processing** - To correct the errors in recorded data differential correction is made after field data collection.
- **Real-time DGPS corrections** – connects a differential corrections receiver to a GPS receiver
  - The stationary receiver transmits the differential correction to the moving receiver via another radio signal.
  - Many units incorporate GPS receivers and differential corrections receivers into the same unit.
  - Some of the newest DGPS receivers combine the capability of receiving differential signals from several sources such as Omnistar, DGPS beacon stations, WAAS, or directly an external RTCM SC-104 source.

## ***Local Area and Wide Area DGPS Corrections***

- Wide Area DGPS (WADGPS) uses stationary satellites (geo-referenced) to covers a large area (entire continental U.S.)
  - advanced techniques are used to optimize troposphere error algorithms by choosing the same satellites for correction
- Local Area DGPS (LADGPS) covers smaller area (USCG Beacon signals, FM signals, and private user correction signals)

## ***Sources of Real-Time DGPS***

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- U.S. Coast Guard Beacon signals (AM)
- Local FM signals
- Satellite-based differential corrections
- WAAS (Wide Area Augmentation System)
- User purchased base station.

## ***U.S. Coast Guard “Beacon”***

---

GPS base stations are installed at selected seaport cities along the Atlantic and Pacific coasts, the Great Lakes and several inland waterways.

The differential corrections are broadcast by radio beacons similar to AM radio stations in a frequency range of 125 – 375 kHz.

The beacon signals generally fade between 125 to 300 miles from the transmitting tower.

The closer that a user is to the radio beacon, the more accurate the correction process will be (there is no charge).

The radio waves travel as “ground waves” and follow the curvature of the earth (hills or bluffs don’t block ground waves).

## **Local FM Differential Correction Sources**

Differential Corrections Incorporated (DCI), Cupertino CA, has established a group of GPS base stations, existing FM radio stations, around the country to broadcast the correction data on their assigned frequency.

Coverage limited to typical FM radio reception distance (range < 60 miles ) depending on the power of the transmitting station.

FM radio signals are about 1000 times higher in frequency than AM radio signals (88 to 108 MHz).

FM waves travel as “space waves” and only in a straight line (Hills and valleys or even large trees or buildings between the broadcasting station and the DGPS receiver may block the signal).

## **Satellite-Based Differential GPS Correction**

Satellite-based differential GPS correction is transmitted from a geo-stationary satellite.

Geo-stationary satellites are similar to TV satellites and they orbit over the same point on the earth at all times. (are not part of the GPS).

The corrected data from a GPS base stations on the ground is transmitted to a waiting geo-stationary satellite which re-transmits the correction data to earth down linking data for use in DGPS.

To receive service annual fee is charged.

Signals cover much larger area than the other sources.

Omnistar and Satloc provides WADGPS coverage in U.S. RACAL is a WADGPS service provider with international coverage.

## ***Wide Area Augmentation System (WAAS)***

---

The WAAS is a signal controlled by the U.S. Federal Aviation and it is based on a network of approximately 25 ground reference stations.

Coverage for this system includes the entire U.S. and some outlying areas such as Canada and Mexico, and is a free service.

System availability through the use of geo-stationary communication satellites (GEOs)

Federal Aviation Administration (FAA) lists WAAS accuracy as approximately 7 meters horizontally and vertically. As a comparison, the published specification of the US Coast Guard beacon system is 10 meter.

## ***User Purchased Base Station for DGPS Correction***

---

This option requires purchase of a second GPS receiver to operate as a reference (or base) station.

The base station is placed at a known location (usually a benchmark) while another GPS receiver is placed on the mobile unit.

Radio communication between the two receivers corrects the location in real time.

## Control for DGPS Operations

- Traditionally only large projects with \$\$\$ for establishment of ground control and radio transmission links from reference to rover
- currently, many public agencies are transmitting corrections (FM radio bands - US Coast Guard) from established basestation networks - Forest Service, BLM, USGS, DOT
- Omnistar, RACAL - commercial companies with own basestations and satellite transmitters
- many new GPS receivers can accept corrections and many now with built-in radio receivers
- can be achieved by post-processing collected data - becoming method of the past

The screenshot displays three overlapping web browser windows from Microsoft Internet Explorer. The leftmost window is titled 'USFS GPS PAGE' and shows the 'GLOBAL POSITION' section with a satellite icon and a 'What's New' section. The middle window is titled 'USDA Forest Service McCall CBS' and displays 'McCALL, IDAHO GPS Base Station' information, including a search form for CBS, Year, and Month, and station details like latitude, longitude, and receiver type. The rightmost window is titled 'CBS Clickable Map Page' and shows a 'Map of GPS Community Base Stations' of the United States with red dots indicating station locations. A legend identifies CBS Locations, National Forest Lands, National Grasslands, and National Parks. The map includes a scale bar and navigation controls.

## ***Why Do We Need DGPS?***

---

### **Little errors add up**

- **Satellite errors** (predicable orbits, precise clocks)
- **The atmosphere** (water vapor in the troposphere, charged particles in the ionosphere)
- **Multipath error** (signal deflected before it reaches the receiver's antenna)
- **Receiver error** (rounding, resolving the pseudo random code, depends on type of receiver (code, carrier, dual freq.), small error (1 meter))
- **Selective availability** (DoD randomly and intentionally limits the accuracy of the NAVSTAR GPS by transmitting a false signal (different time, different position))

## ***Typical Error Budget (m)***

---

<u>Per satellite accuracy</u>	<u>Standard GPS</u>
Satellite clocks	1.5
Orbit errors	2.5
Ionosphere	5.0
Troposphere	0.5
Receiver noise	0.3
Multipath (reflections)	0.6
SA	30.0
 <u>Typical positional accuracy</u>	
Horizontal	50-30=20
Vertical	78
3-D	93

## ***What Accuracy is needed?***

---

Does the foresters really need to be able to mark the position within 0.5 inches of its true position on a second-by-second basis when marking boundaries?

Sub-meter accuracy may be desirable for some activities such as:

- Boundary mapping and location
- Fire boundary mapping
- Mapping roads, trails, streams
- Mapping wildlife nest or observation locations

## ***Multipath Rejection Technology***

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Trimble's EVEREST multipath rejection technology provides a high-accuracy solution for code-based mapping. EVEREST rejects random errors in GPS measurements caused by multipath 1 before they are stored. This results in more accurate, better quality data.

## ***Positional Accuracies/Cost Trade-offs and Differential Correction Methods***

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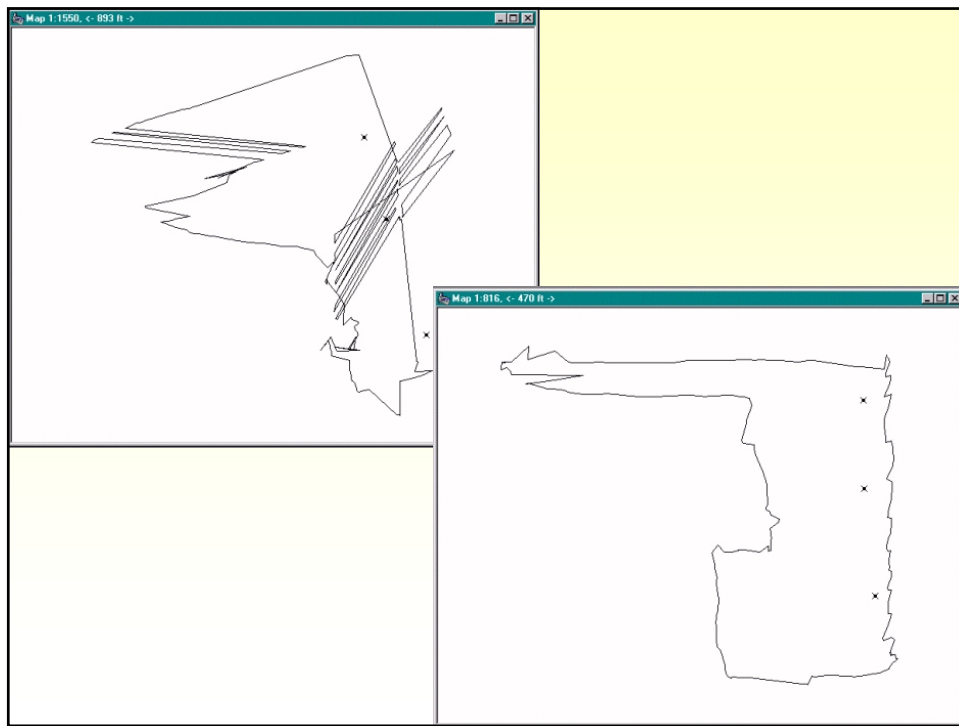
- Simple “Walmart version”
- Geo Explorer
- Pro XRS
- Geodetic – carrier phase, survey grade

## ***Impulse Laser Rangefinders***

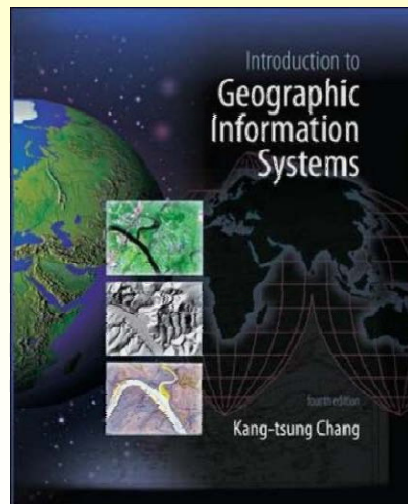
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- Distance and Height Measurement
- GPS Offset Mapping & GIS Data Capture (Interfaces directly with Trimble Pro XR GPS, through its built-in RS232 interface)
- Timber Cruising
- GIS data capture
- Wildlife locations





## Questions???



Ch. 13 – Raster Data Analysis