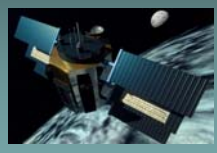
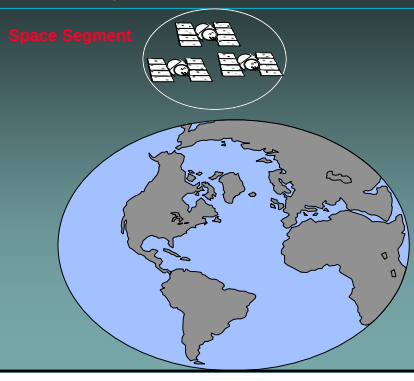
How GPS Works



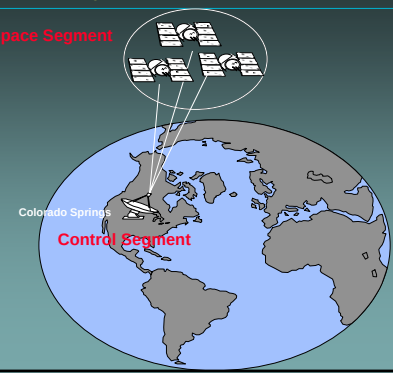
What is GPS?

- A Constellation of Satellites Providing World-Wide Positionally Accurate Coordinates
- Developed and Maintained by the Department of Defense
- Available 24 Hours a day, in any Weather Conditions.

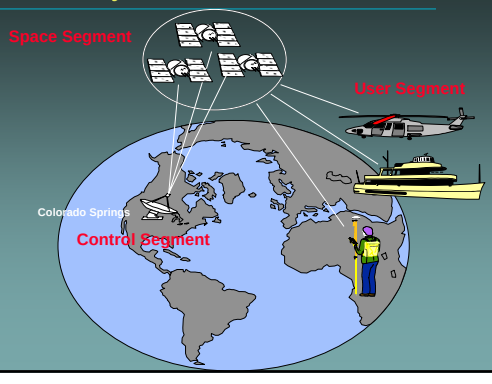
The GPS System



The GPS System



The GPS System

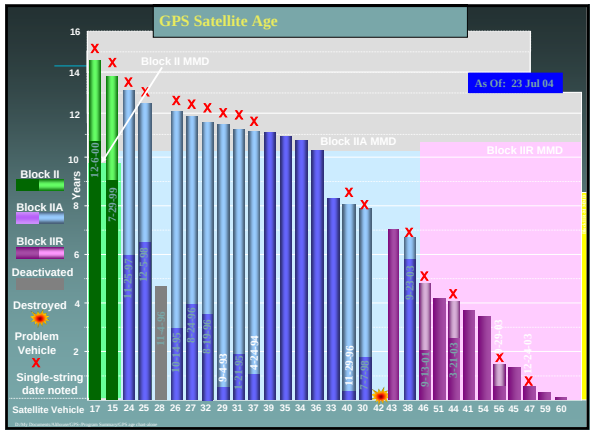


Space Segment

- 24 Satellites
  - 6 Planes with 55° Rotation
  - Each Plane has 4 or 5 Satellites
- Very High Orbit
  - 20,000 km
  - 1 Revolution in Approximately 12 hours
  - For Accuracy
  - Survivability
  - Coverage

Constellation Summary

- 29 Operational On-Orbit Satellites
- 2 Satellites Launched (SVN 59: 20 Mar 04)
  (SVN 60: 23 Jun 04)
- 1 Satellite Disposed (SVN 13: 12 May 04)



Control Segment

- DOD Tracking and Uploading Facilities
- Master Control Station - Colorado Springs
- 5 Monitoring Stations
- Actual Position Compared to Intended Position
- Uploads New Navigation Message to Satellite
- Repositions and Replaces Satellites as Necessary

Control Segment Stations

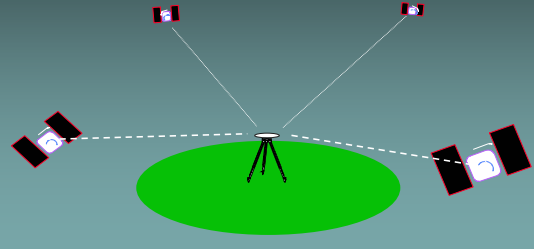
User Segment

Multiple Applications:
GIS Data Capture
Vehicle Tracking
Marine/ Vehicle Navigation
Surveying
Emergency Services
Aviation
Precise Positioning
Agriculture
Photogrammetry
Recreation (hiking etc.)
Weather Forecasting
Many more

... and more to follow

How is GPS Position Calculated?

Simplification: Distance = Speed of Light x Time



How It Works

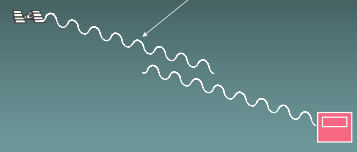
Satellite Transmits Pseudo Random Signal

Signal Travels At The Speed Of Light

How It Works

Satellite Transmits Pseudo Random Signal

Signal Travels At The Speed Of Light

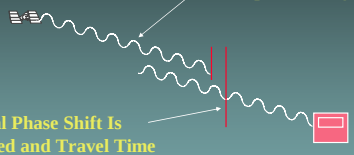


Receiver Generates Same Signal At The Same Time

How It Works

Satellite Transmits Pseudo Random Signal

Signal Travels At The Speed Of Light

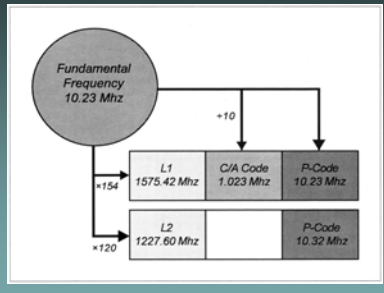


The Signal Phase Shift Is Determined and Travel Time Computed. The Distance Is Then Computed:

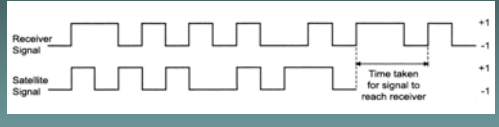
Speed of Light x Time

Receiver Generates Same Signal At The Same Time

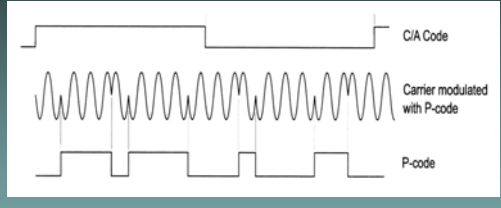
GPS Signals – Frequencies/Codes



GPS Signal – Phase Measurement

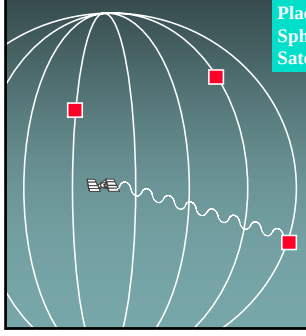


Signals – Code Modulation



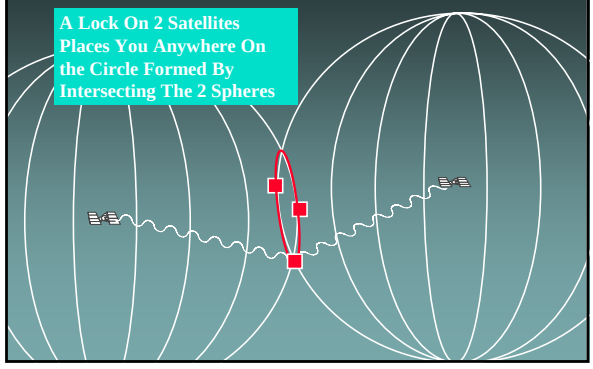
How It Works

A Lock On 1 Satellite Will Place You Anywhere On A Sphere Centered At The Satellite



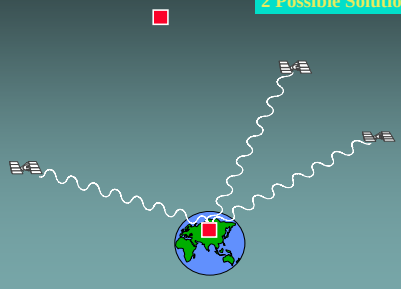
How It Works

A Lock On 2 Satellites Places You Anywhere On the Circle Formed By Intersecting The 2 Spheres



How It Works

3 Satellites Give You 2 Possible Solutions



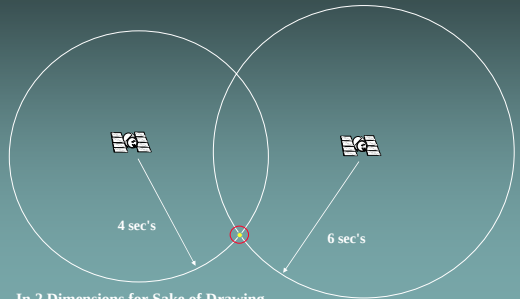
Accurate Clocks

Necessary to Measure Travel Time

- Making Sure Both Receiver and Satellite are Synchronized
- Whole System Depends on Very Accurate Clocks
- Satellites Have Atomic Clocks
  - Accurate but Expensive
- Ground Receivers Just Need Consistent Clocks
  - The Secret is in the Extra Satellite Measurement That Adjusts the Receiver Clock

The Ideal Situation

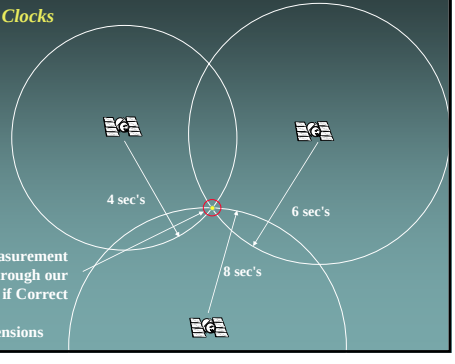
Accurate Clocks



In 2 Dimensions for Sake of Drawing

Adding a Third Measurement

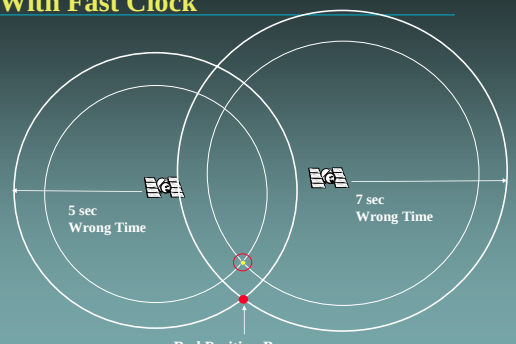
Accurate Clocks



Third Measurement Would go Through our Position if Correct

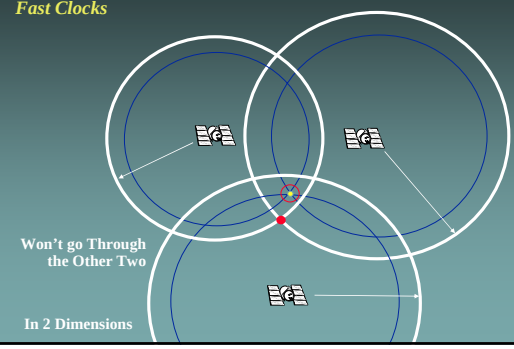
In 2 Dimensions

With Fast Clock



Third Measurement

Fast Clocks



Knowing Where the Satellites Are

After all, They're 20,000 km Up

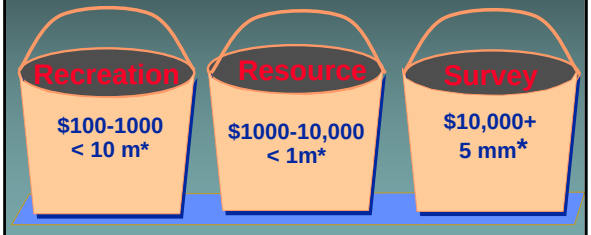
- High orbit
  - Very Stable Orbits
  - No Atmospheric Drag
  - Survivability
  - Earth Coverage
- Monitored by US Defense Department
  - DOD Transmits Corrections Back to Satellite
- Corrections Transmitted from Satellites to Receiver
  - Status Message

Types of Receivers

- Recreational (or Navigation) Grade
- Resource (or Mapping) Grade
- Survey Grade

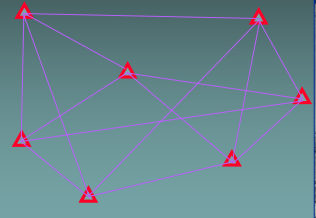
Comparison of Receivers

Cost and Accuracy



*Accuracies listed assume open canopy sites

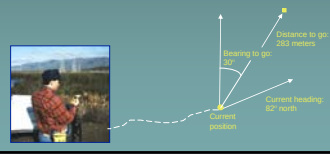
Survey Grade (Control Surveys)



Resource Grade (Precise GIS)

Recreational Grade (Navigation)

- Relocation of Existing Features in the Field
  - Take Coordinates from GIS and Create a Waypoint File
- Finding an Existing Asset for:
  - Maintenance and Repair
  - GIS Update and Information Verification
- Follow Directions

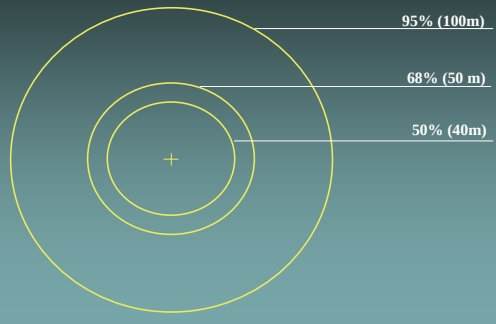


How Accurate is It?

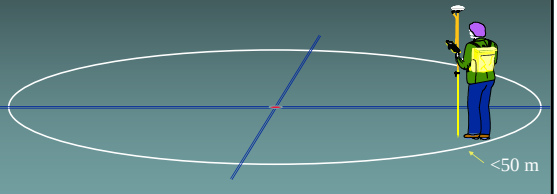
Three Methods of Positioning

- Autonomous
  - No Corrections Applied
  - Up to 100 meters
- Differential
  - Corrections Applied
  - Sub-meter to 5 meters
- Phase Differential
  - 10 - 100 Centimeters Phase Processing (mapping)
  - 5 millimeter Wave Processing (surveying)

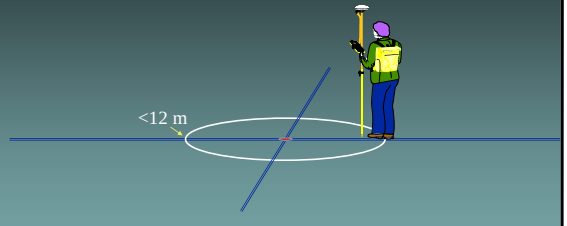
Autonomous Accuracy of Any GPS Receiver



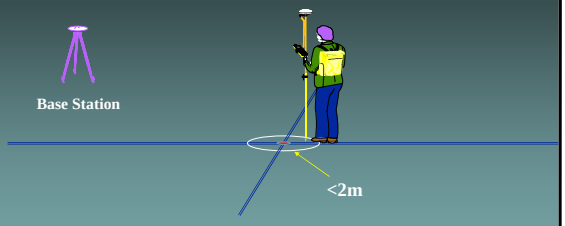
Standard Positioning Service -SPS (C/A-Code) - Autonomous GPS



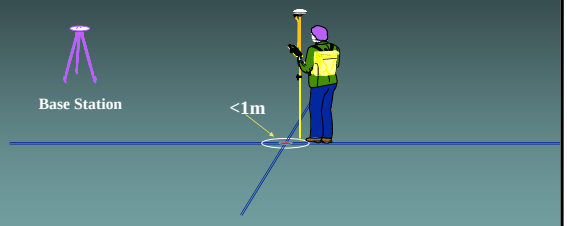
Precise Positioning Service-PPS P(Y) Code GPS



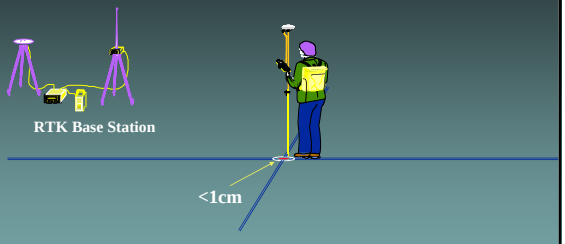
Mapping Grade Receiver-DGPS



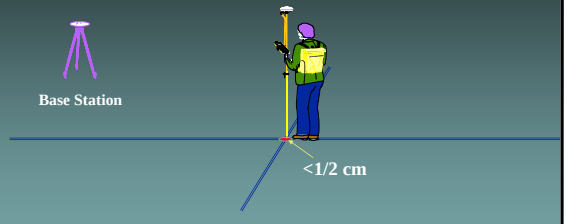
High Quality Mapping Receiver SPS-DGPS



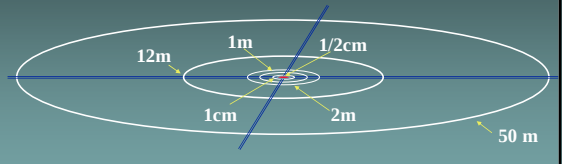
Real-Time Kinematic Surveying



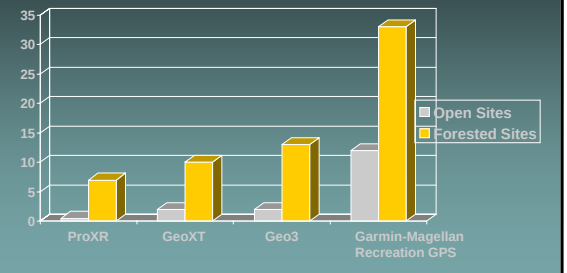
Survey Grade GPS



Where Do You Need to Be?



USFS GPS Accuracy Tests



www.fs.fed.us/database/gps/gpsusfs.htm

Sources of Error

- Selective Availability (S/A)
- Multipath
- Cycle Slips
- Atmospheric
- Ionosphere
- Ephemeris
- Receiver Noise
- others

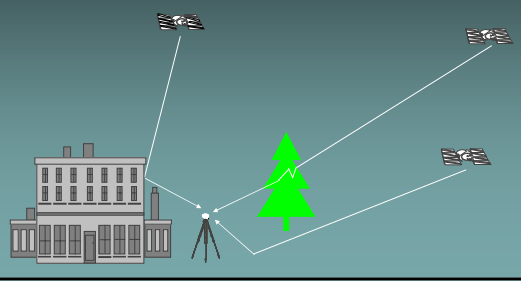
Selective Availability (S/A)

Government Introduces Artificial Errors to Reduce GPS Position Accuracy

- Discourages Hostile Forces from Using GPS
- The Largest Source of Error
- S/A is the sum of two Effects:
  - Epsilon - Ephemeris "fibbing"
  - Dither - Clock Variations

Multipath

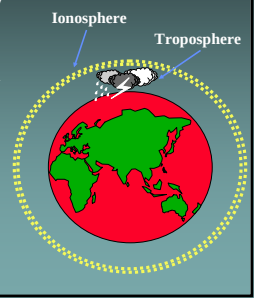
- Occurs When the GPS Signal is Reflected off an Object Before it Reaches Your Antenna



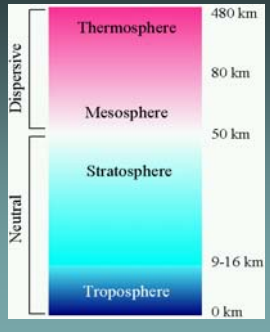
Atmospheric Corrections

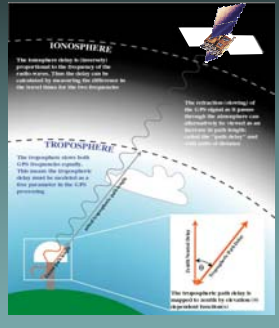
Apply Estimated Corrections

- The Signals are Delayed by the Ionosphere and Troposphere
- Receiver Makes Estimated Corrections for These Delays

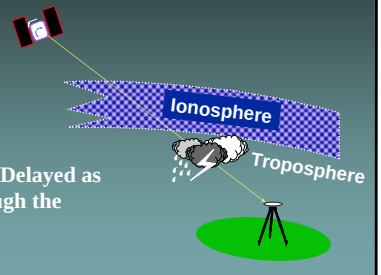


How Does the Atmosphere Effect the GPS Signals?





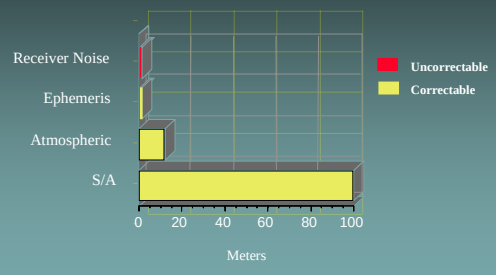
Atmospheric Delay



GPS Signals are Delayed as They Pass Through the Atmosphere

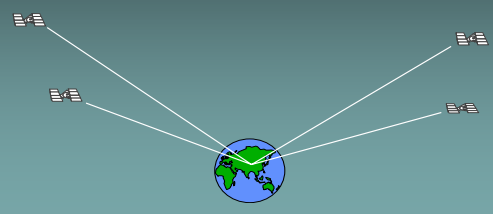
GPS Error Types

- System-Wide Errors - DGPS Correctable



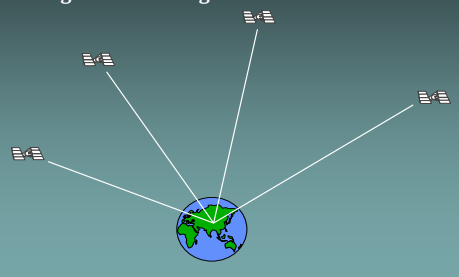
Vertical Accuracy

- Horizontal Accuracy is 1 to 3 times Better Than Vertical Accuracy



Vertical Accuracy

- Vertical Accuracy Is Better With Satellites At High Vertical Angles



Examples of Different Accuracy Requirements

Code Phase GPS

- 40 m - Navigation at Sea
- 10 m - Navigation to Section Corners
- 2 m - Rural GIS Data Capture
- 1 m - Municipality GIS Data Collection

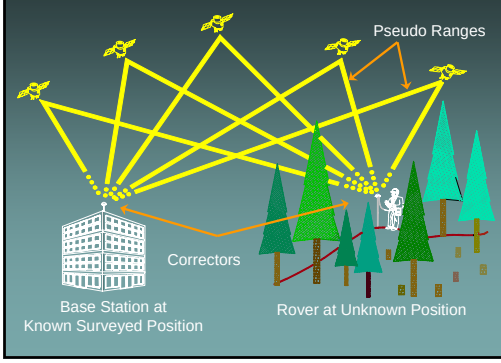
Carrier Phase GPS

- 1 cm - Stake out
- 1/2 cm - Control Surveys

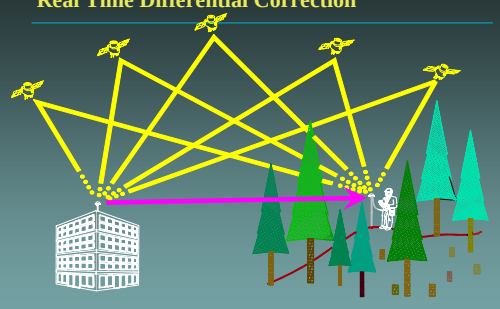
Differential Correction

- Base Station Generates Corrections for all Satellites in View
- A Roving GPS Receiver Uses These Corrections to Remove Correctable Errors
- Differential Correction can be Performed in Either Real-Time or Post-Processed Mode

Post Process Differential Correction



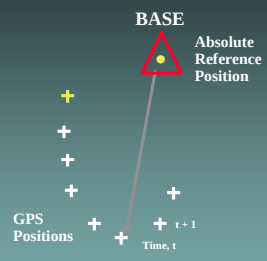
Real Time Differential Correction



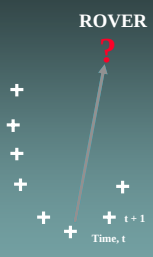
Corrections Broadcast Real Time to Rover

Differential Correction (Simplified)

- If you Collect Data at One Location, There Will be Errors
- Each of These Errors are Tagged With GPS Time

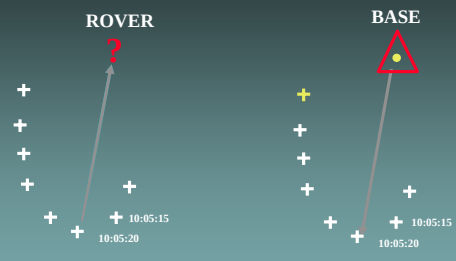


Differential Correction (Cont.)

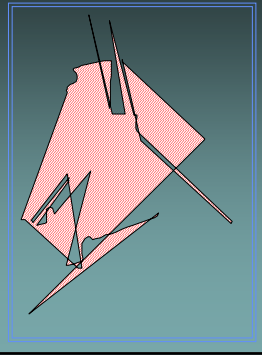


- At the Same Time, the Errors Occurring at One Location are Occurring Everywhere Within the Same Vicinity

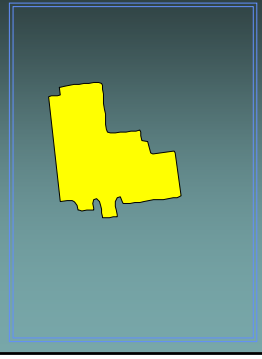
Differential Correction (Cont.)



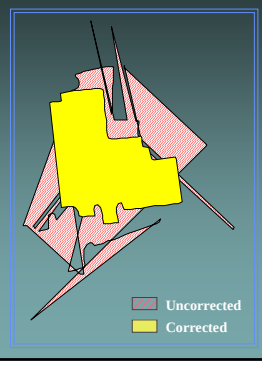
Uncorrected Data



Corrected Data



Uncorrected vs. Corrected Data



Sources of Base Data for Postprocessed DGPS

Where Does One Get Differential GPS Base Station Data?

- Community Base Stations (CBS)
  - Government, Commercial or Public (Universities)
- Internet
- Set up Your Own
  - GPS Pathfinder CBS
  - Universal Reference Stations (URS)

Sources of Real-Time Corrections

Where Does One Get "Real-Time" Differential GPS Base Station Data?

- Commercial Real-Time DGPS providers
- Government
  - Coast Guard
  - Mapping Agencies
- Set up Your Own Real-Time DGPS
  - Required
    - A Source of DGPS Correction in RTCM-SC-104 Format
    - A Data Link - for example: a Data Radio (Modem and Transmitter)

WAAS
FAA's Wide Area Augmentation System

WAAS
FAA's Wide Area Augmentation System

- **WAAS is a Wide-Area Differential GPS Service, Using Satellite Broadcast Techniques, Being Developed by the FAA to Aid Aircraft Navigation.**
- **May Have Trouble Receiving Receptors in Rough Terrain and Tree Canopy Due to Low Elevation Satellites Broadcasting Correctors.**
- ***WAAS Was Never Designed with Ground GPS Users in Mind.***

Nationwide DGPS

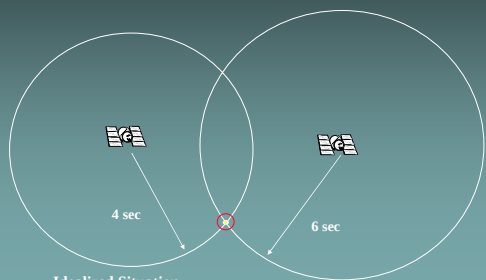
Typical NDGPS Site

Dilution of Precision (DOP)

- A Measure of Satellite Geometry
- Indicates the Quality of Position Fix
- Can be Expressed in Different Dimensions
  - for example: PDOP – Position
  - GDOP – Geometric
  - VDOP – Vertical
  - HDOP - Horizontal

Dilution of Precision (DOP)

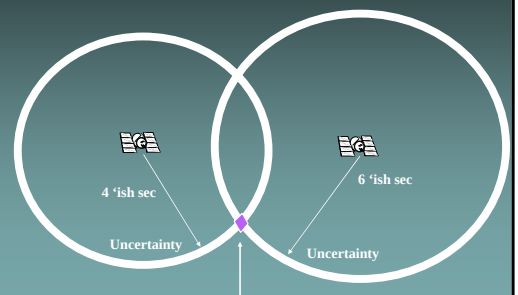
Relative Position of Satellites Can Affect Error



Idealized Situation

Dilution of Precision (DOP)

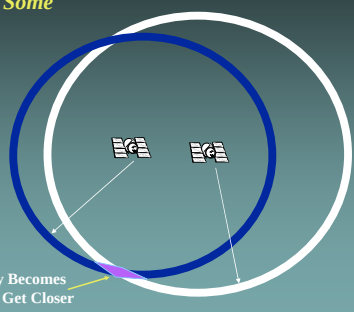
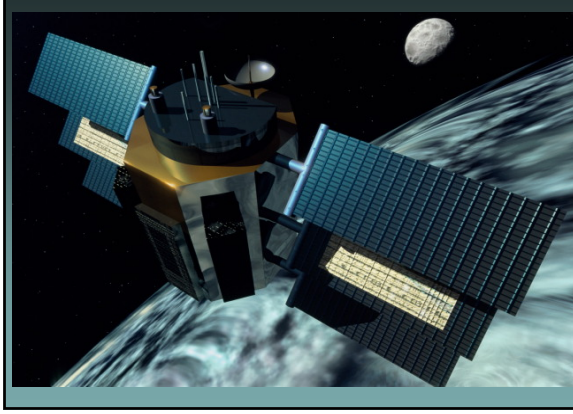
Real Situation - Fuzzy Circles



Point Representing Position is Really a Box

Dilution of Precision (DOP)

Even Worse at Some Angles



Area of Uncertainty Becomes Larger as Satellites Get Closer Together