GPS:
Global Positioning System

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Sevilleta LTER

GPS Basics

- What is GPS?
- How does it work?

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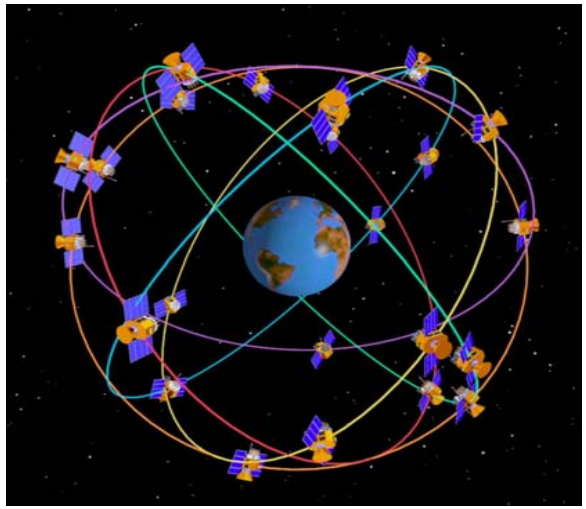
What is GPS?

- Global Positioning System:
  - Precise worldwide radio-navigation system consisting of a constellation of satellites and their ground stations operated and maintained by the US Department of Defense (DoD).
  - Navigation Satellite Timing & Ranging System (NAVSTAR): At least 24 Satellites orbiting the earth.
  - **Positioning, Navigation & Timing**
  - Operates 24 hrs/day, in all weather

GPS Segments

Space



User

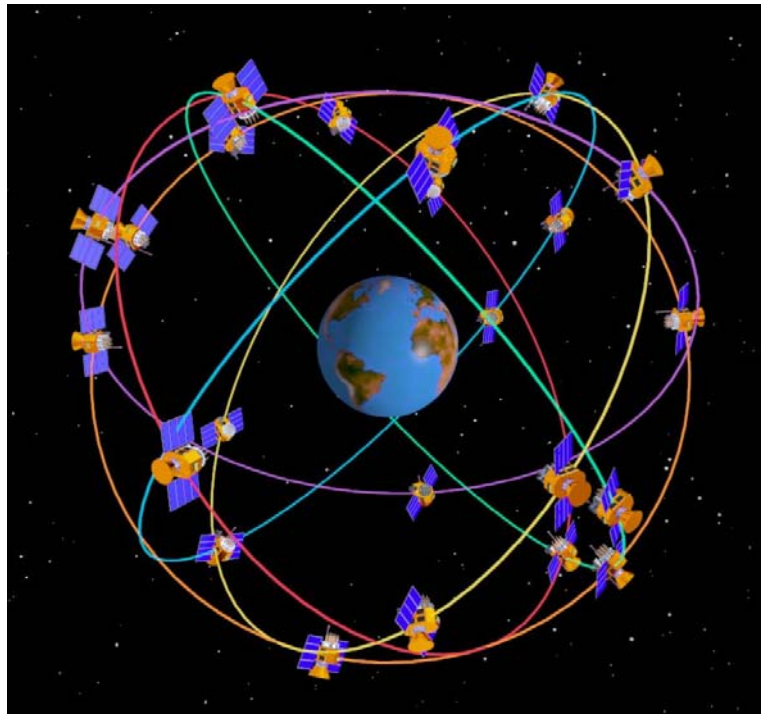
Control

Space Segment: GPS Satellites

- Power
  - Sun-seeking solar panels
  - Nicad batteries
- Timing
  - 4 atomic clocks

Satellite Orbits

- 24 satellites in 6 orbital planes
  - Orbit the earth at ~20,200 km (11,000 nautical miles)
  - Complete an orbit in ~12 hours
  - Rise & set ~4 minutes earlier each day



Satellite Signals

- GPS satellites broadcast messages via radio signals on 2 frequencies
  - L1: 1575.42 Mhz (C/A & P/Y code)
  - L2: 1227.60 Mhz (P/Y code)
- Two levels of service
  - Standard Positioning Service (SPS)
  - Precise Positioning Service (PPS)

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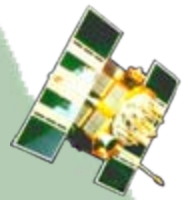
Satellite Signals

- Satellite signals require a direct line to GPS receiver
- Signals cannot penetrate water, soil, walls or other obstacles:



Satellite Almanac

- Sent along w/ position & timing messages
- Prediction of all satellite orbits
- Needed to run satellite availability software
- Valid for about 30 days

```
******** Week  269 almanac for PRN-01 ********
ID:                         01
Health:                     000
Eccentricity:               0.5405902863
E-002Time of Applicability(s):  61440.0000
Orbital Inclination(rad):   0.9813845822
Rate of Right Ascen(r/s):   -0.7577458489E-008SQRT(A)
(m 1/2):            5152.601074
Right Ascen at Week(rad):   0.3902550488E+000
Argument of Perigee(rad):    -1.695816885
Mean Anom(rad):             -0.1712506416E+001
Af0(s):                     0.3681182861E-003
Af1(s/s):                   0.3637978807E-011
week:                       269
******** Week  269 almanac for PRN-03 ********
ID:                         03
Health:                     000
Eccentricity:               0.6181240082E-002
Time of Applicability(s):   61440.0000
Orbital Inclination(rad):   0.9281326789
Rate of Right Ascen(r/s):   -0.8000333246E-008SQRT(A)
(m 1/2):            5153.644531
Right Ascen at Week(rad):  -0.2857742542E+001
Argument of Perigee(rad):    0.554986085
Mean Anom(rad):             -0.7420111497E+000
Af0(s):                     0.5340576172E-004
Af1(s/s):                   0.3637978807E-011
week:                       269
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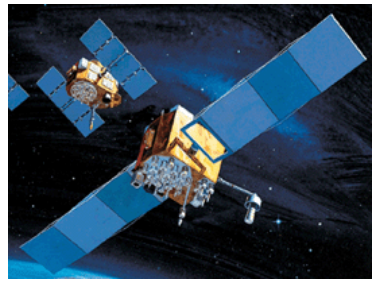
Control Segment: US DoD Monitoring

U.S. DoD Monitoring

- Orbits are precisely measured:
  - Discrepancies between predicted orbits (almanac) & actual orbits transmitted back to satellites

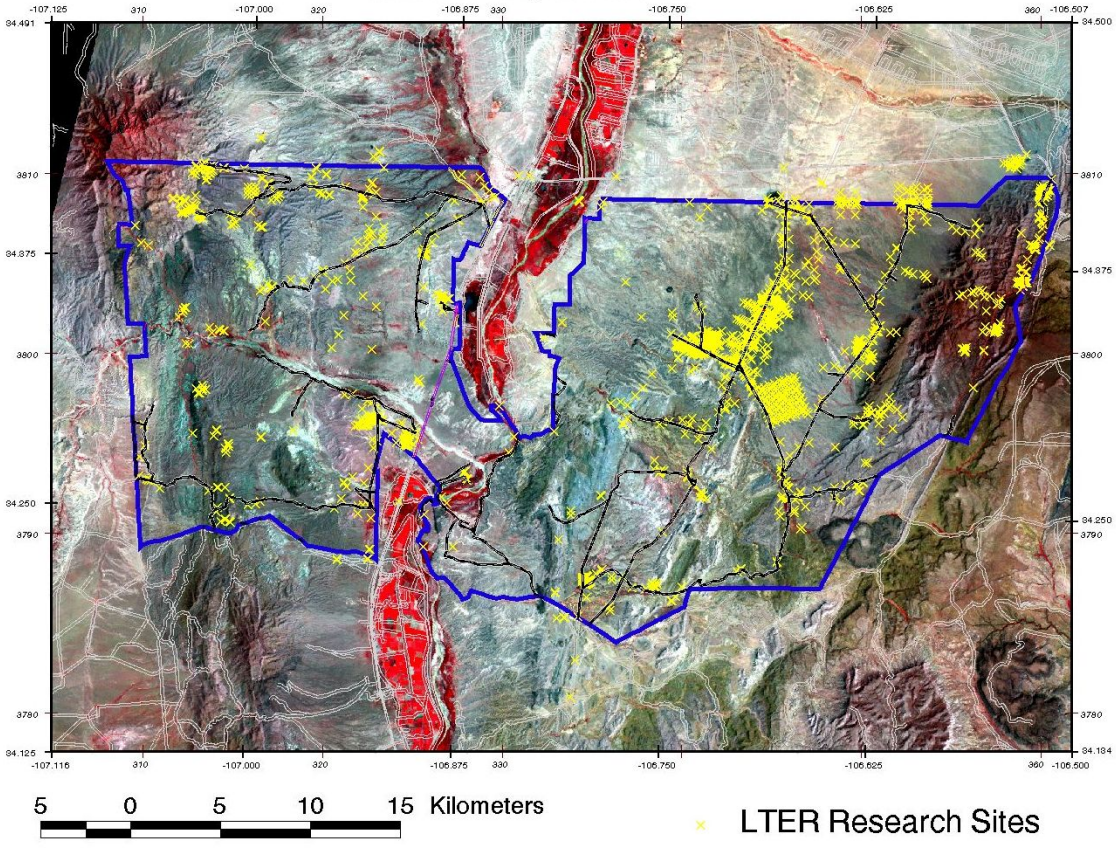
User Segment: Civilian Applications



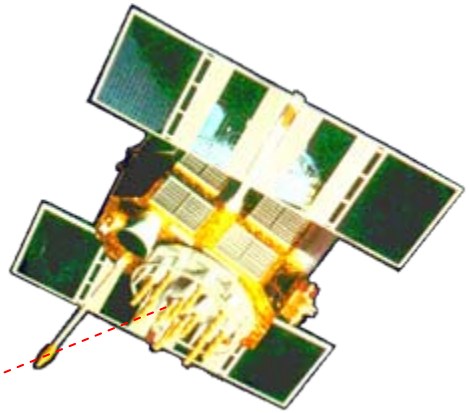
GPS at SevLTER

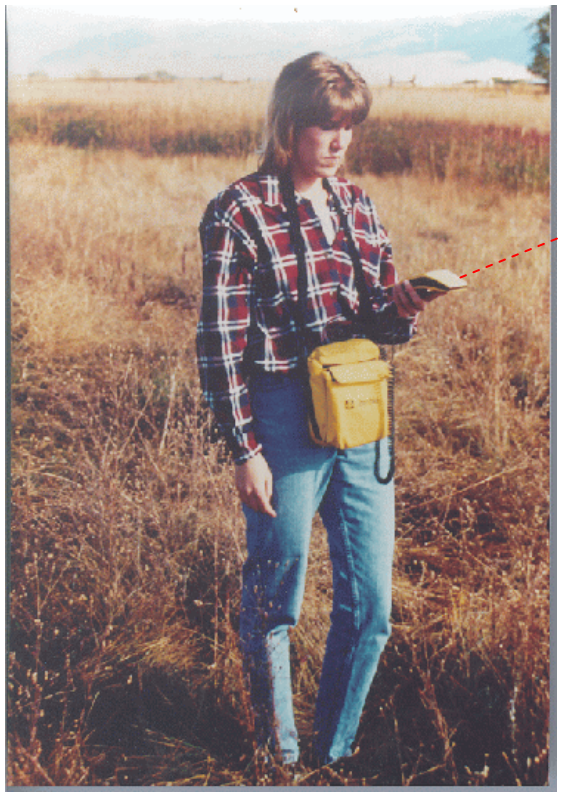
Sevilleta LTER Research Sites

Sevilleta National Wildlife Refuge,
Socorro County, New Mexico



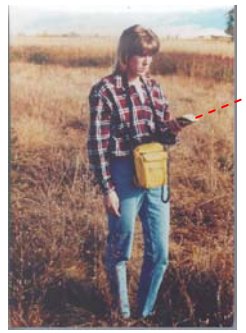
How Does GPS Work? Calculating a Position

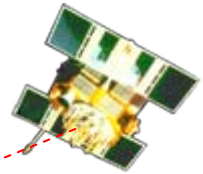




- GPS receiver calculates its position by measuring the distance to satellites (satellite ranging)

Measuring Distance to Satellites

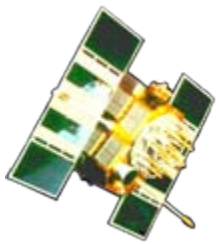


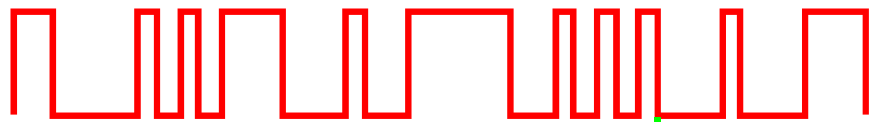


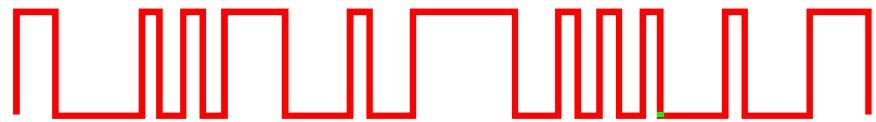
1. Measure time for signal to travel from satellite to receiver
2. Speed of light x travel time = distance
3. Distance measurements to 4 satellites are required to compute a 3-D position (latitude, longitude & altitude)

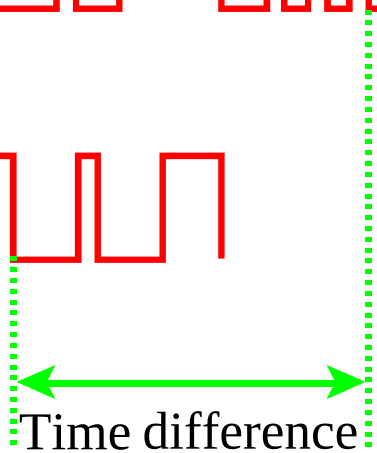
Measuring Satellite Signal Travel Time

- *How do we find the exact time the signal left the satellite?*
  - **Synchronized codes**



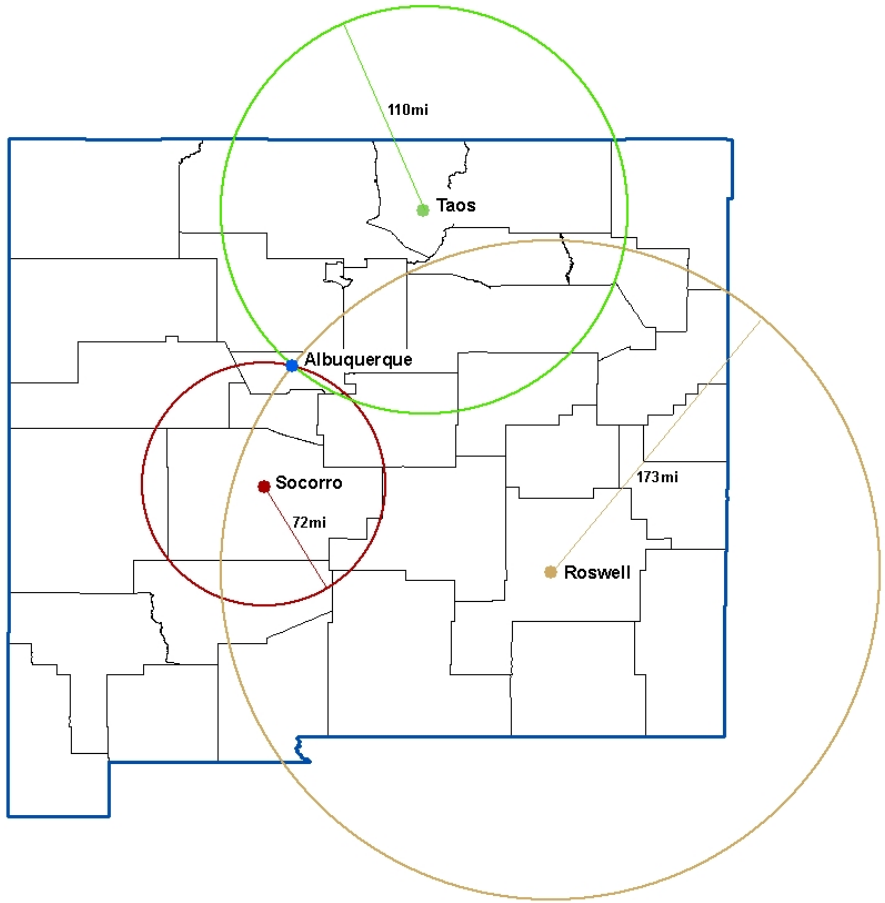




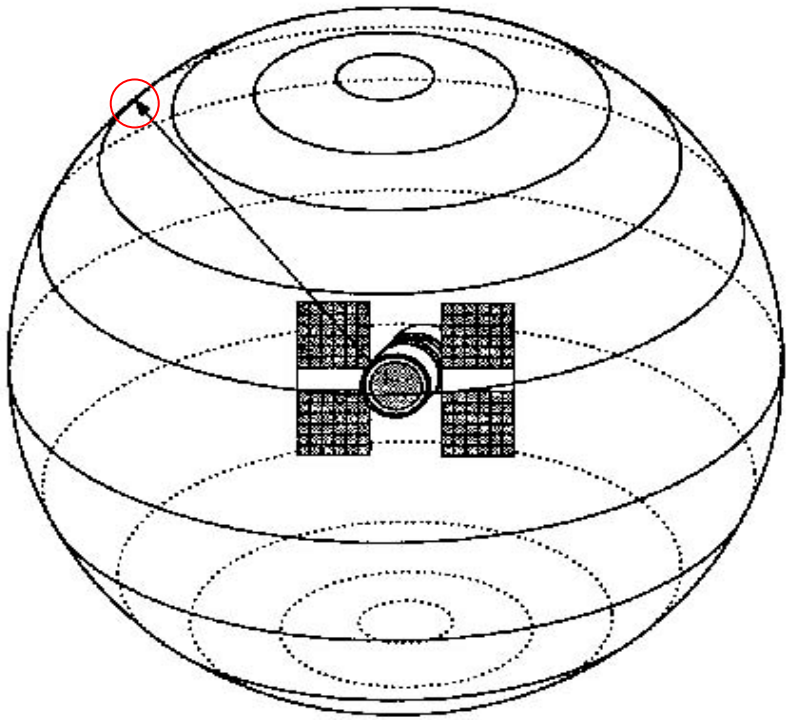


Positions Established with Trilateration: 3 Distance Measurements

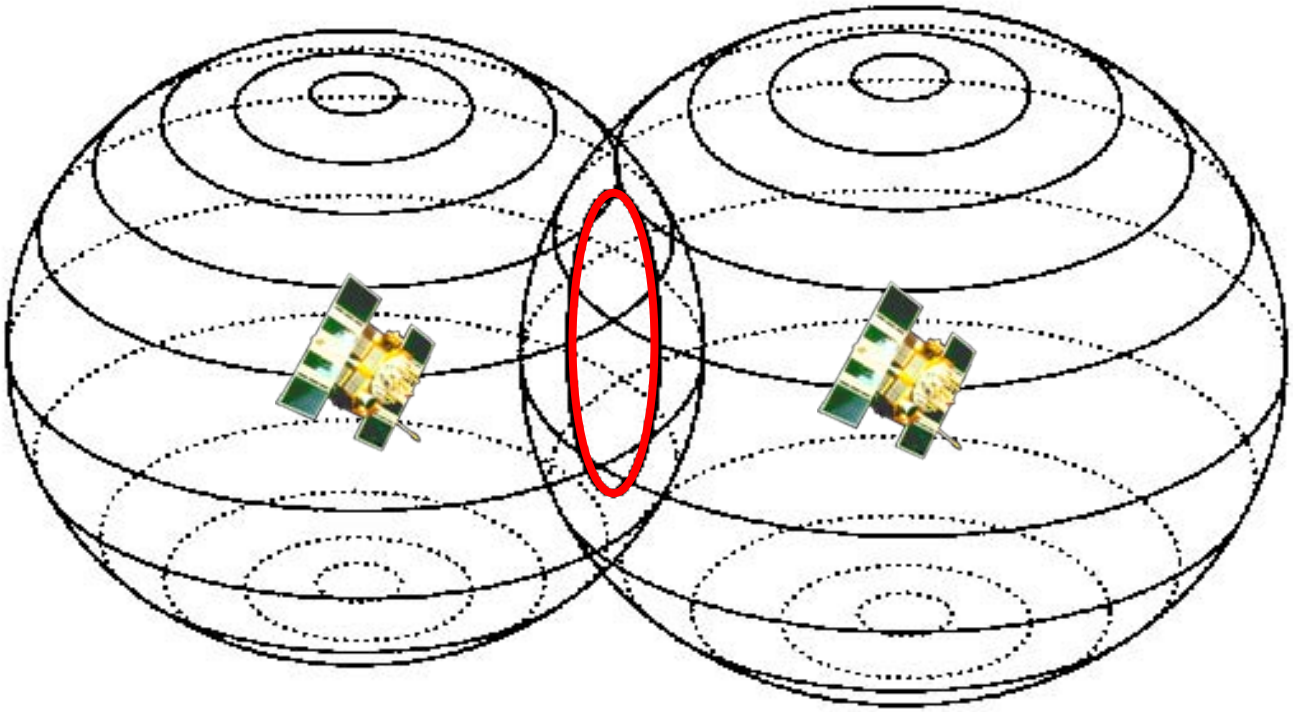
An Example in two dimensions:



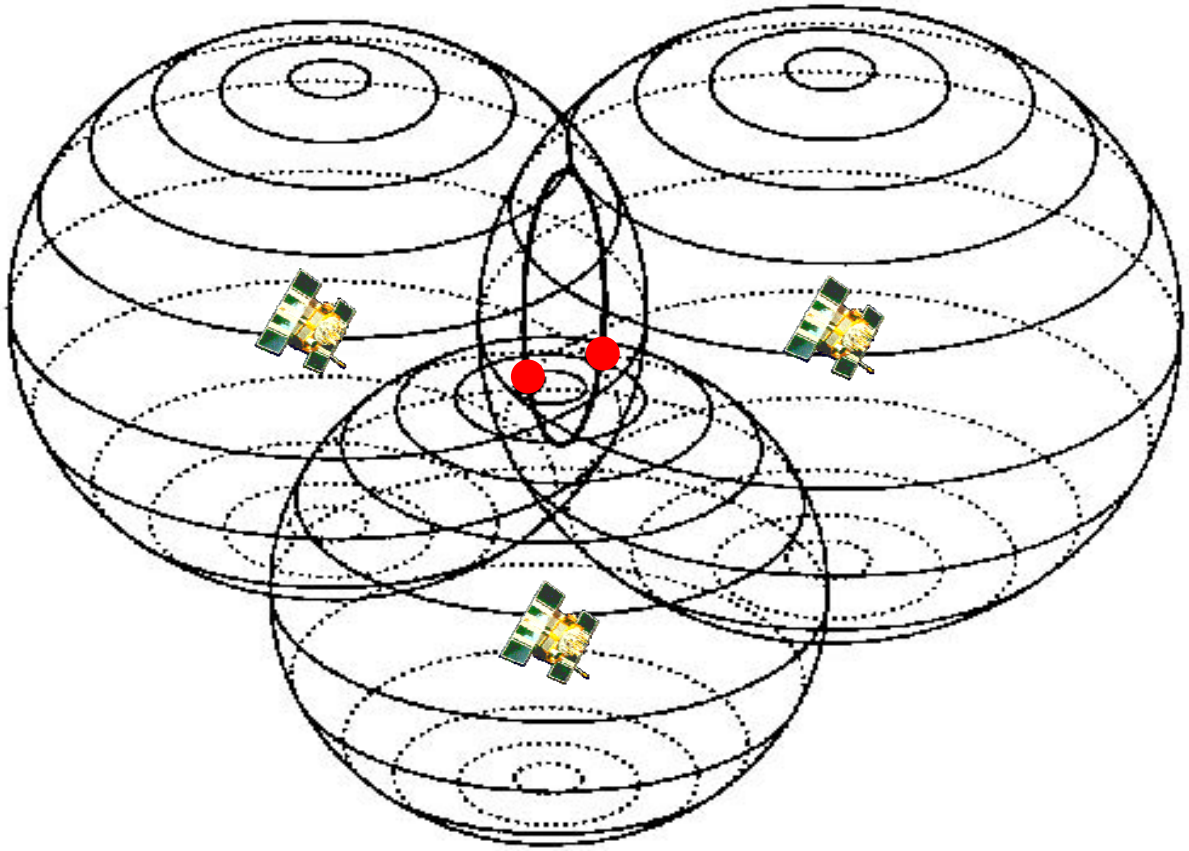
One measurement narrows our position to surface of a sphere



Second measurement narrows our position to intersection of two spheres



Third measurement narrows our position to two points



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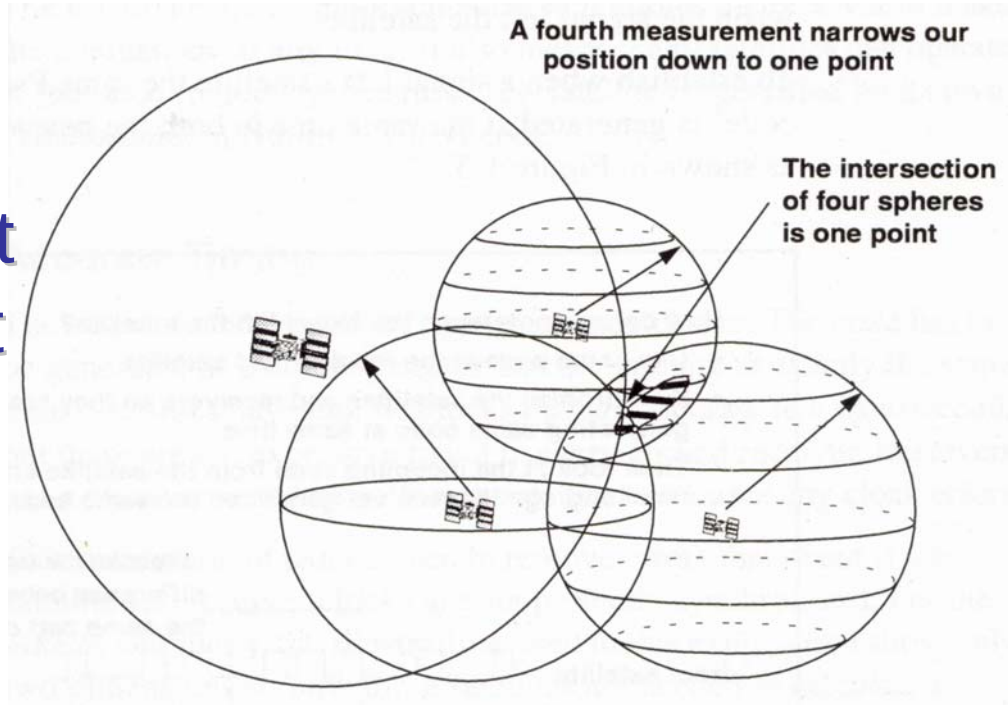
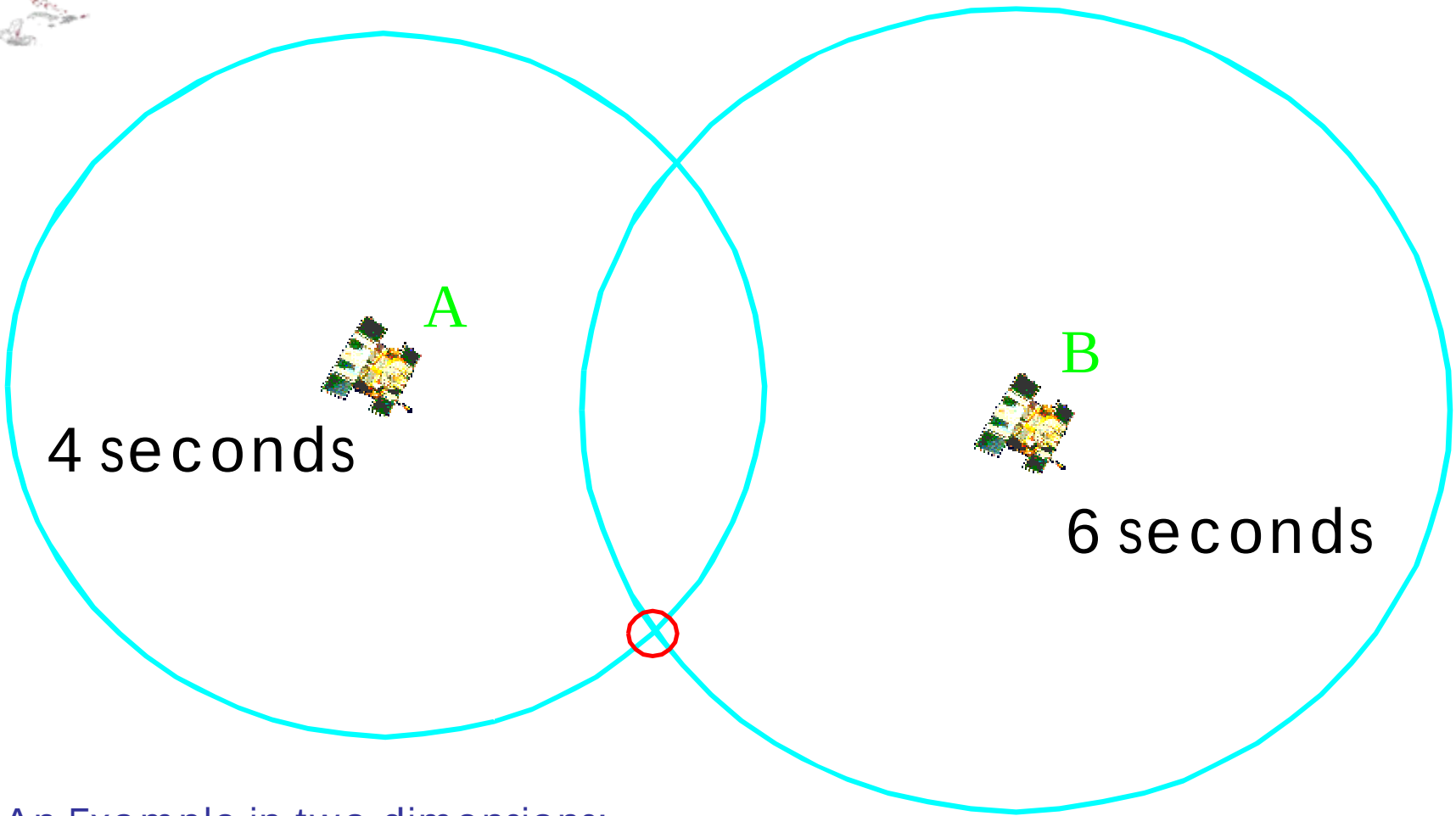
Correcting for Timing Offset

- First three measurements narrow down our position…

- Fourth measurement is needed to correct for **timing offset**:
  - difference in synchronization between satellite & receiver clocks…

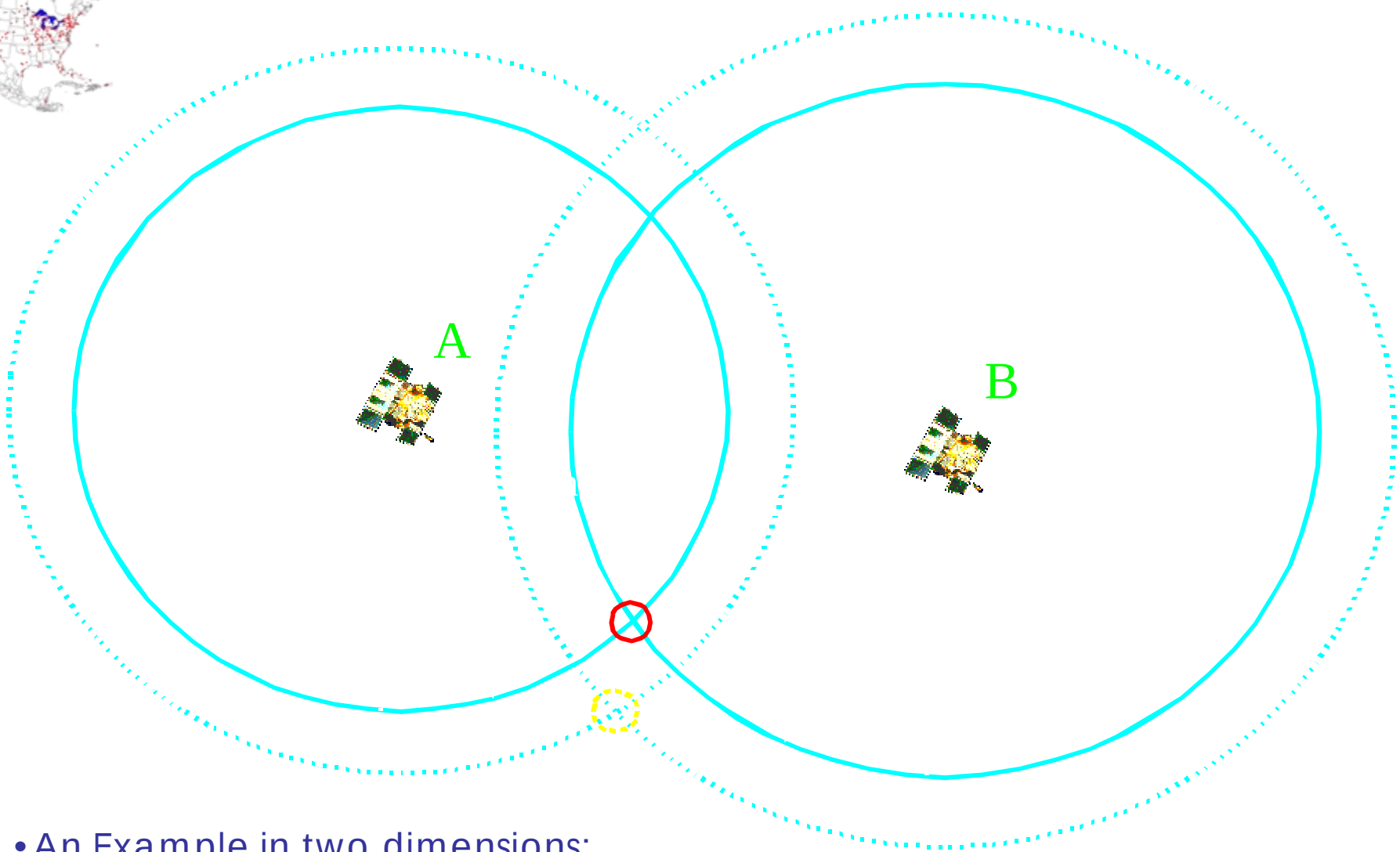


Correcting for Timing Offset



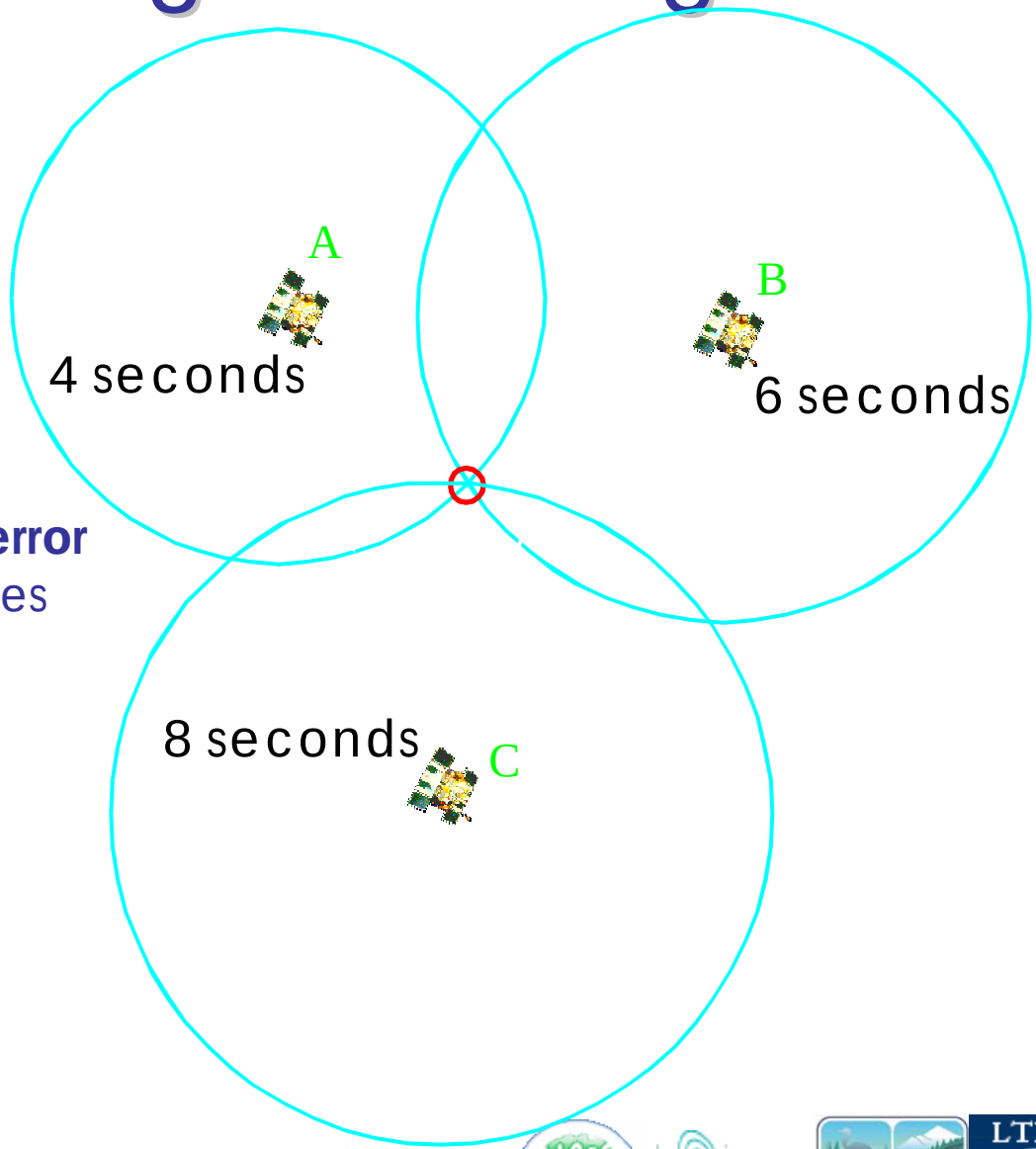
- An Example in two dimensions:
  - Ideal situation **w/ no timing error**

Correcting for Timing Offset



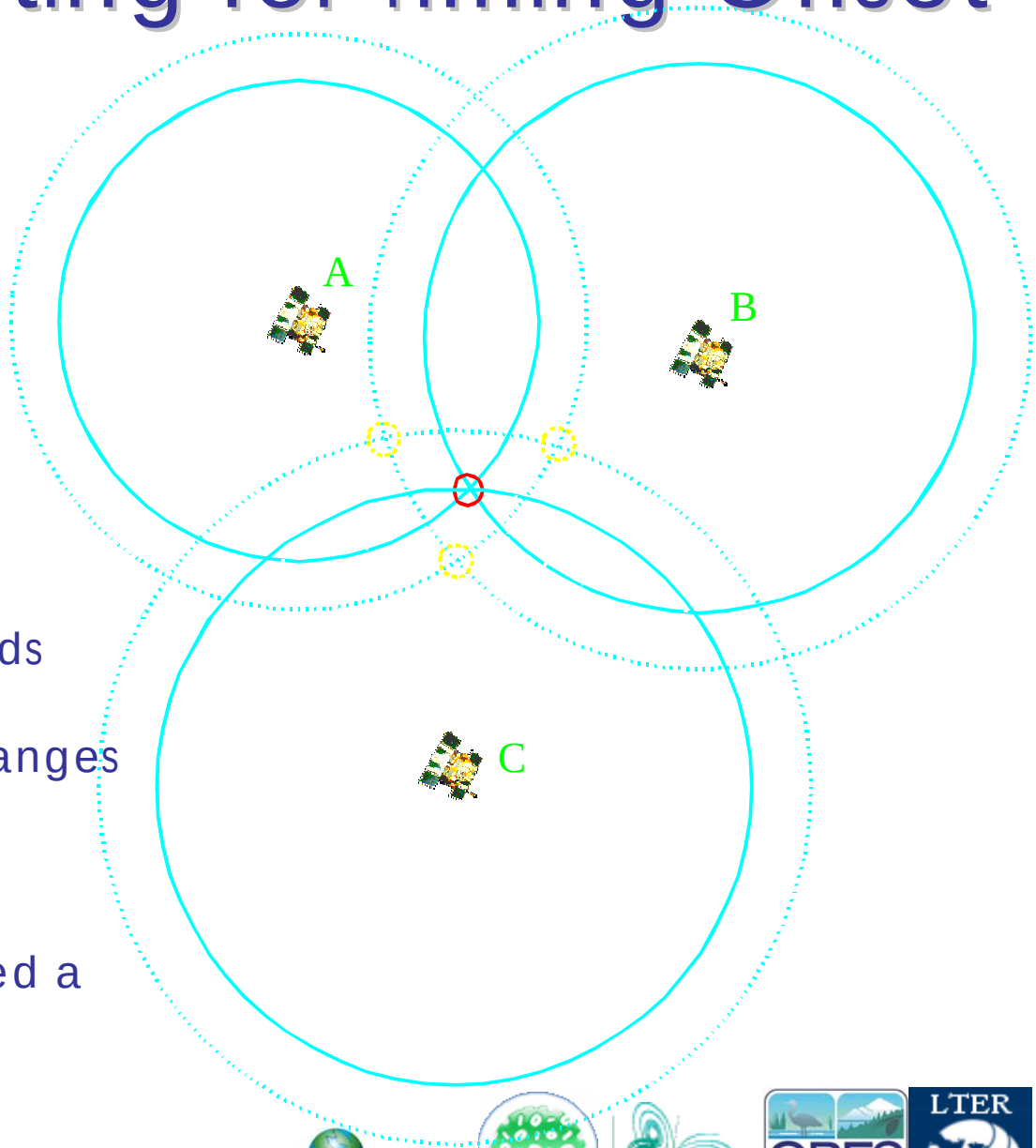
- An Example in two dimensions:
  - Typical situation **w/ timing error**

Correcting for Timing Offset



- Ideal situation: **no timing error**
  - Add a 3rd satellite, 3 circles intersect at correct point

Correcting for Timing Offset

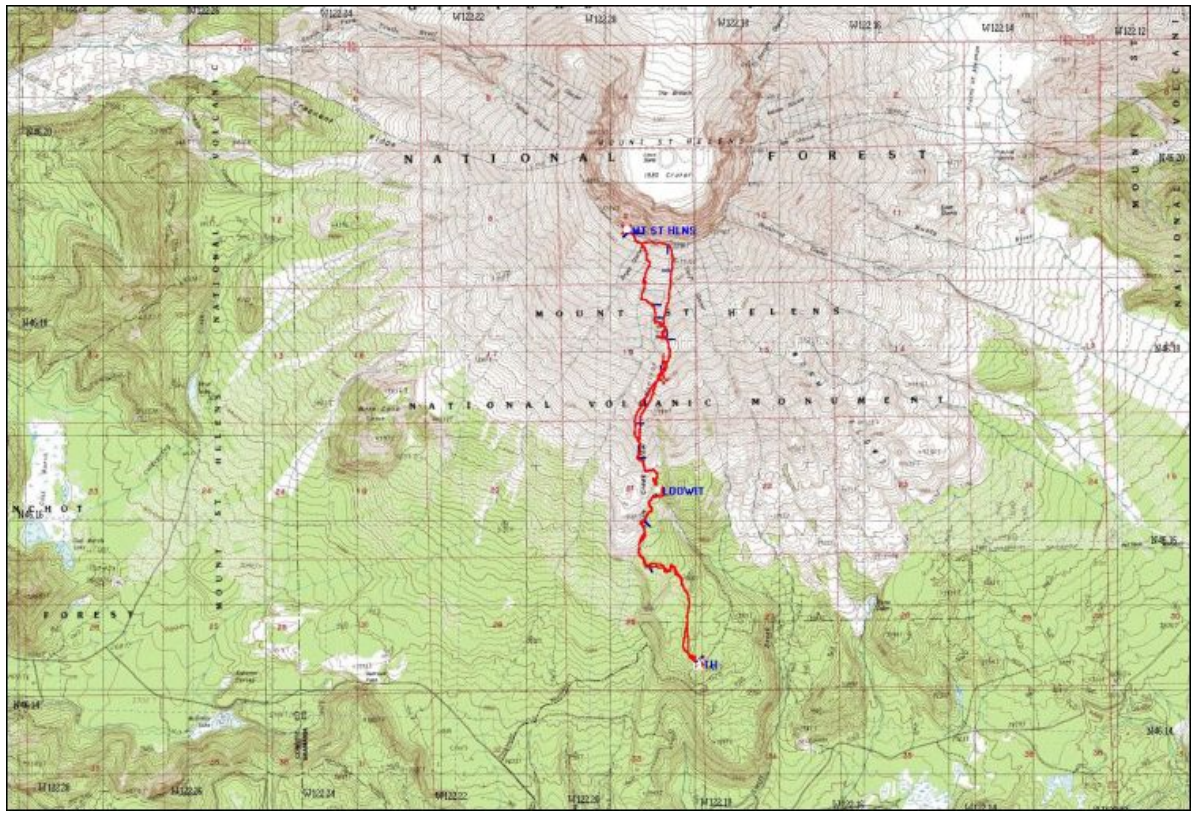


- 3 satellites **w/ timing error**
  - Circles cannot intersect
  - Receiver takes error & finds adjustment to all measurements that lets ranges go through single point

- This is 2D!
  - In reality, in 3D we need a 4th satellite

4 Measurements = 4 Variables

1. Latitude
2. Longitude
3. Altitude
4. Time



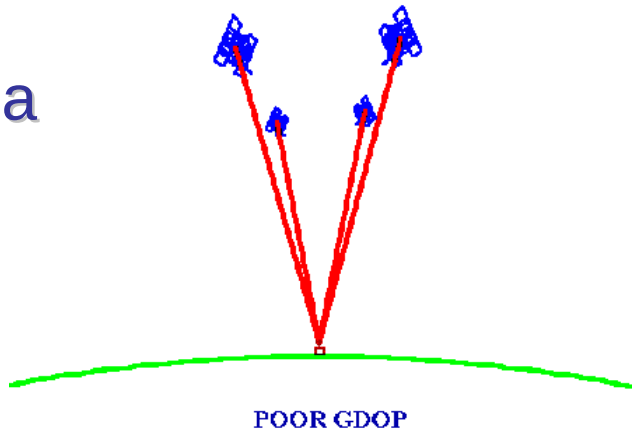
More Sources of Error

- Gravitational pull of other celestial bodies on satellite, affecting orbit
- Atmospheric effects: Signals travel at different speeds through ionosphere & troposphere
- Obstruction!!
- Multipath: Bouncing of signals may confuse receiver
- Selective Availability – Not as of 2000
- ****Satellite Geometry: **GDOP, PDOP...**

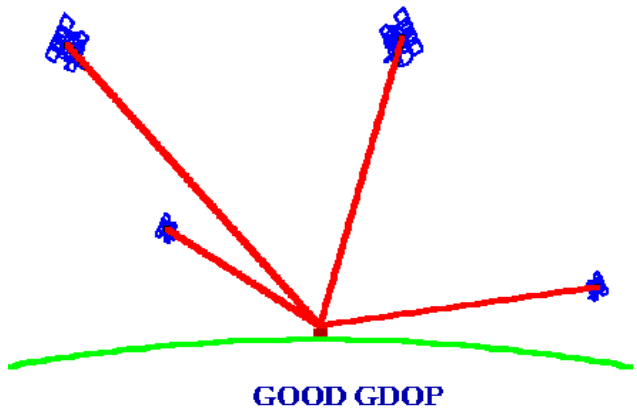
Geometric Dilution of Precision (GDOP)

- GDOP Components
  - **PDOP** = Position Dilution of Precision, a 3D measure for acceptability of signal quality:
    - **HDOP** = Horizontal Dilution of Precision (Lat, Lon)
    - **VDOP** = Vertical Dilution of Precision (Height)
    - **TDOP** = Time Dilution of Precision (Time)
    - **PDOP mask typically set at 6; lower is better; greater than 8 is poor!!**

- **Poor GDOP**:
  - Large value representing a small unit vector-volume; results when angles from receiver to the set of SVs used are similar

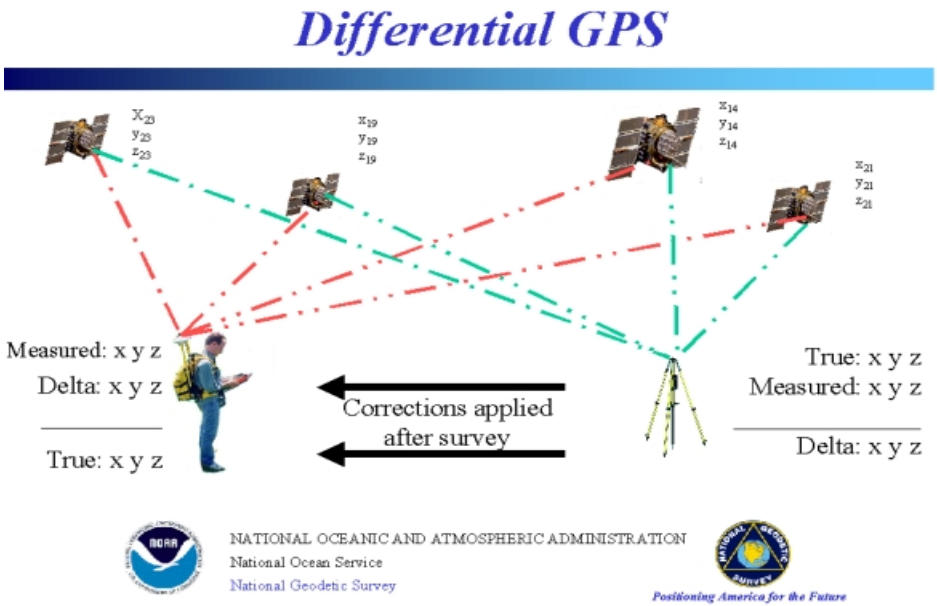


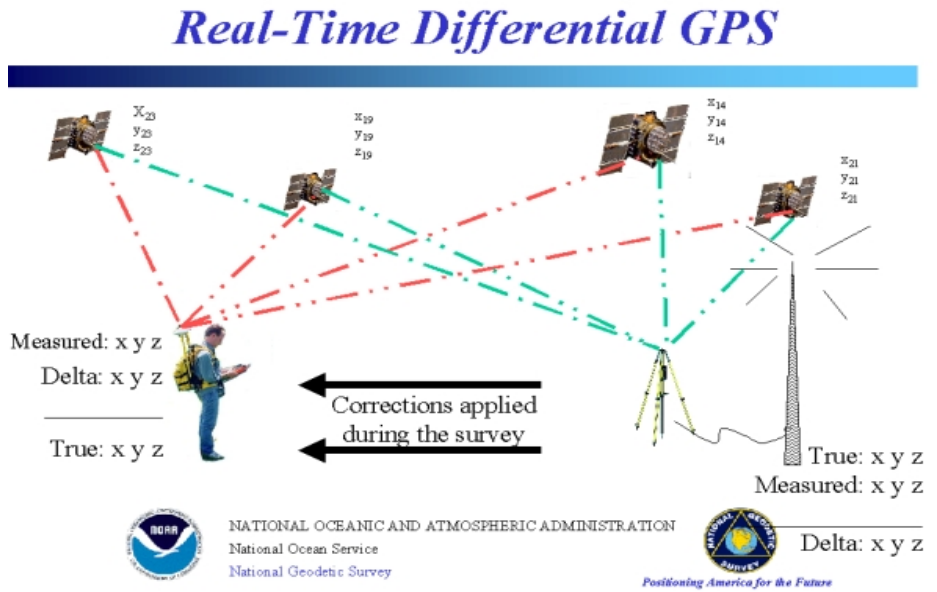
- **Good GDOP**:
  - Small value representing a large unit-vector-volume, results when angles from receiver to SVs are different



Differential GPS (DGPS)

- The use of second GPS receiver located at fixed & known point to remove or minimize effect sources of position error.





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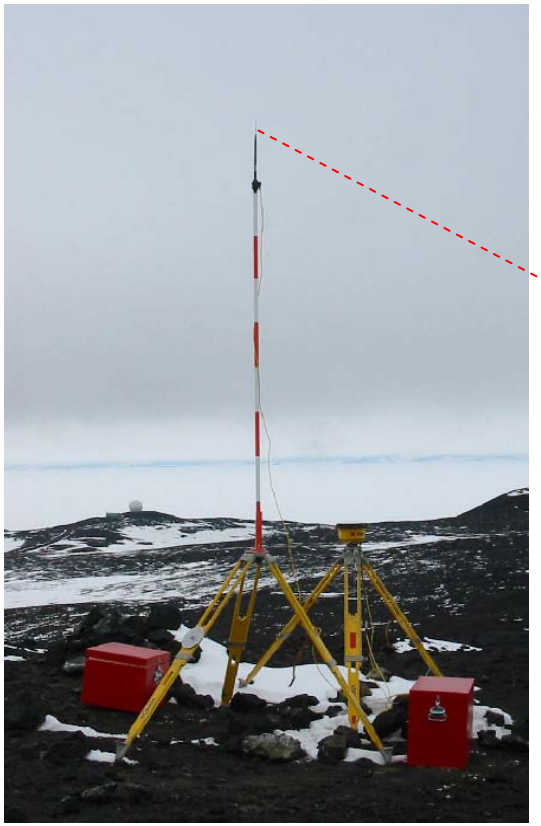
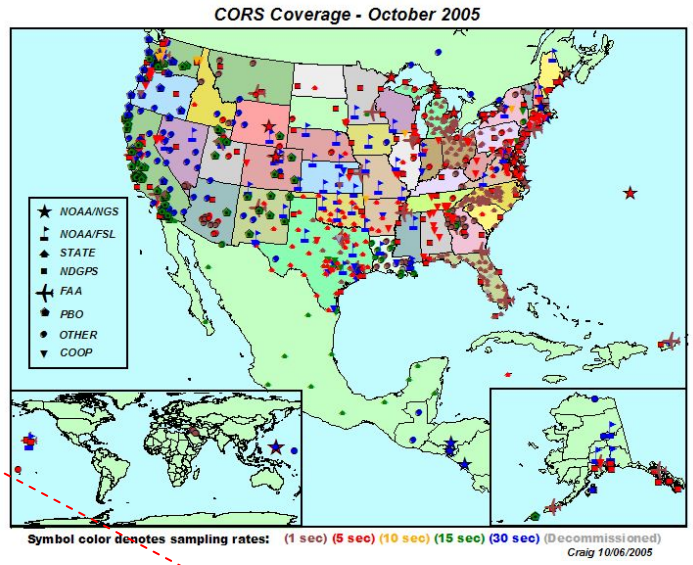
Differential GPS (DGPS)



Portable Base Station

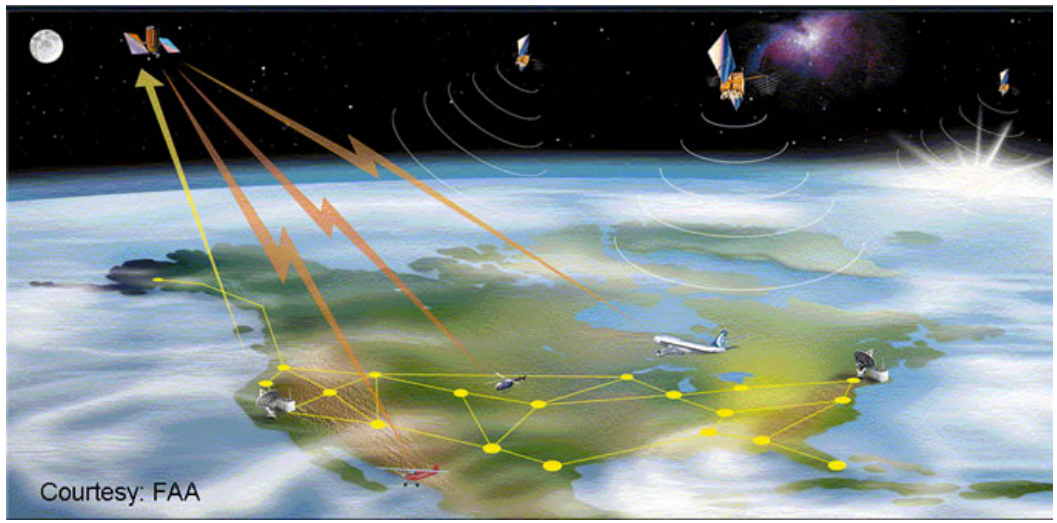


Rover GPS Receiver

Fixed Base Station

Wide Area Augmentation System (WAAS)

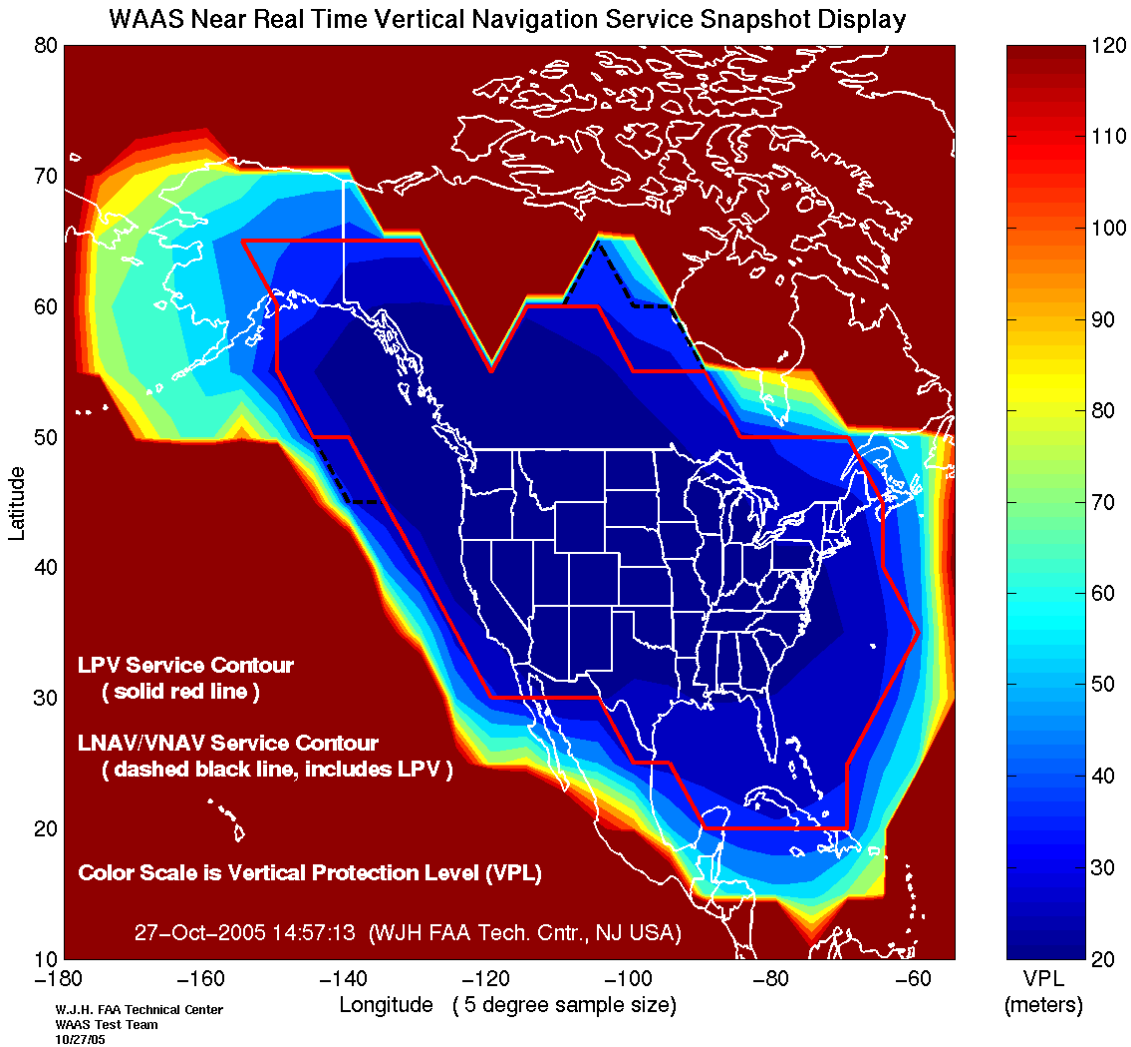
- An extremely accurate navigation system developed for civil aviation in the US
- Uses a network of precisely-located ground reference stations the monitor GPS SV signals
- WAAS master stations collect reference station info & develop a WAAS correction message that is sent to user receivers via geostationary satellites



WAAS Coverage

- Using WAAS, GPS signal accuracy is improved from 20 m to ~3 m in both horizontal & vertical dimensions
  - WAAS IS HERE

But not there



Choosing a GPS Receiver: 4 Questions

1. What features (real world items) will I be mapping?
2. What are my project accuracy needs?
3. What GIS resources (skills) do I have available?
4. How much money do I have? …

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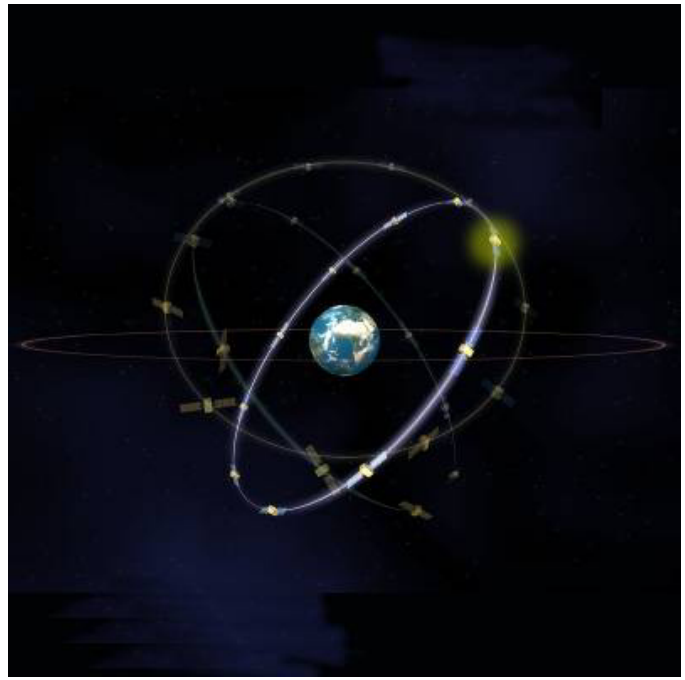
How much money?

Not an Exhaustive List!	Recreational \ Consumer Grade	Mapping Grade	Survey Grade
Cost	<$1000	$2000 - $10000	>$10000
Features	waypoints and tracklogs/routes	point, line, and area	generally collected as positions and processed later
Horizontal Accuracy (in ideal conditions w/ DGPS)	~1 meter and up	submeter to ~5 meters	millimeter to decimeter (Vertical accuracy - centimeters)
Attribute recording electronically	only with additional hardware & software	in most cases	yes
Amount of work to merge with GIS Datasets	depends on if you use additional hardware & software while collecting	moderate	varies
Receiver examples	Garmin handhelds, Trimble Pocket, Magellan	Trimble's Pro XL, ProXRs & GeoXT	Trimble 4600, 5700

Other Global Navigation Satellite Systems (GNSS)

- GLONASS
  - Russia

- Galileo
  - European Union



Useful URL's (Acknowledgements)

- http://www.trimble.com/index.html
- http://www.nps.gov/gis/gps/gps4gis/assessing.html
- http://www.ncgc.nrcs.usda.gov/branch/risb/technical/gps/dgps.html
- http://www.navcen.uscg.gov/dgps/coverage/Default.htm
- http://www.ngs.noaa.gov/CORS/
- http://www.google.com