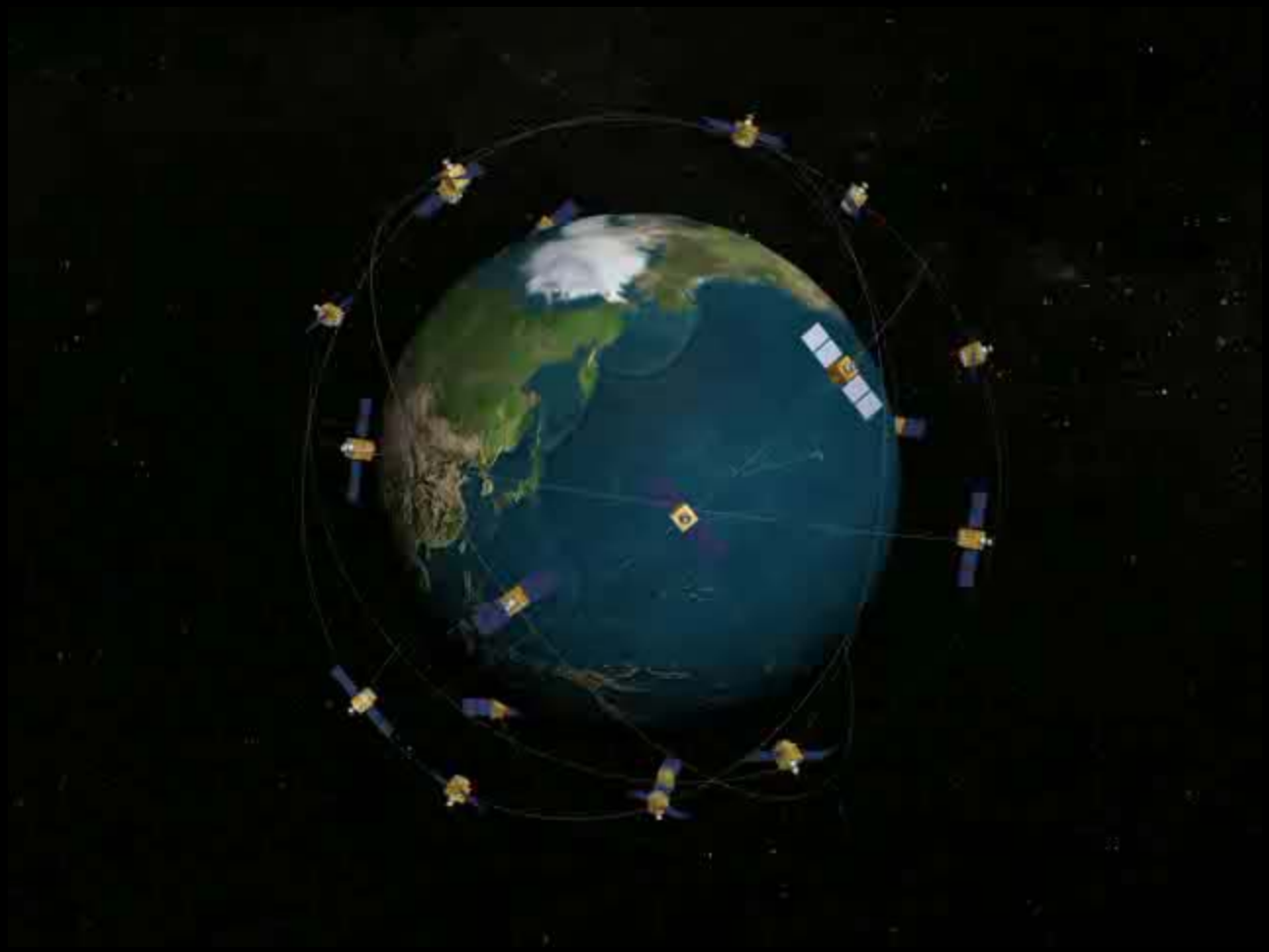
GPS Tutorial # 1

Overview



Darren Sessions

GPS Overview

- GPS System
- Calculating a Position
- Receiver Outputs
- Accuracy and Availability

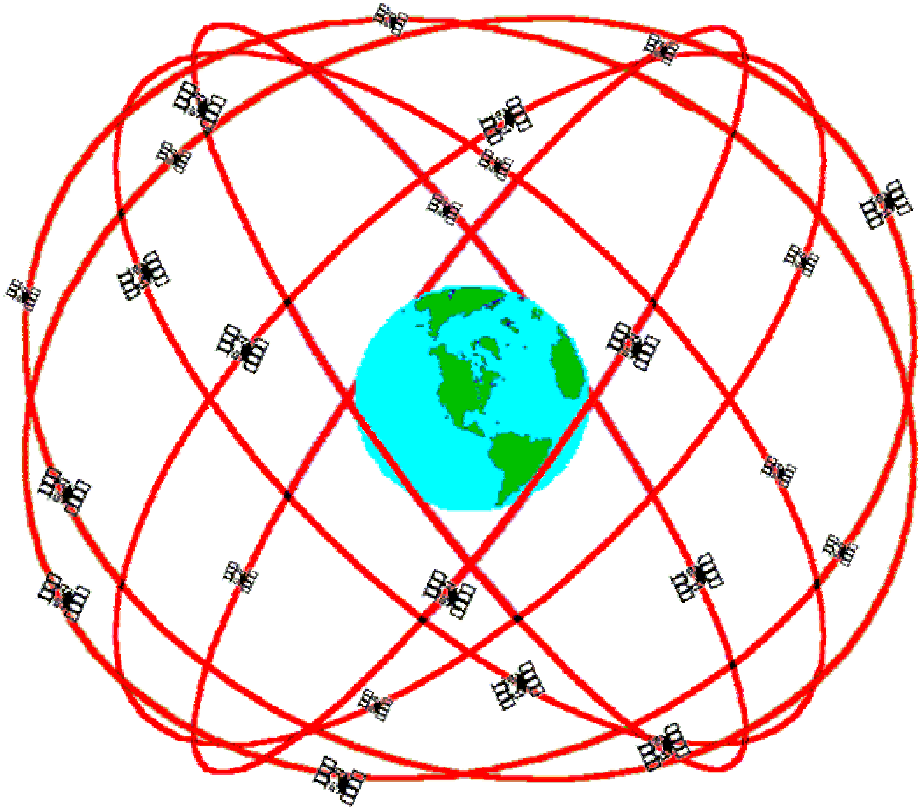
GPS System

- NAVSTAR GPS
  - Navigation Satellite Timing and Ranging Global Positioning System
  - Funded and controlled by U. S. Department of Defense.
- Comprised of three segments
  - Space Segment
  - Control Segment
  - User Segment

Space Segment

- Space segment consists of the GPS space vehicles (SVs).
- Nominally 24 SVs plus spares.
  - Each vehicle has a12 hour orbit.
  - Repeats same ground track daily.
  - 6 orbital planes with 4 vehicles each.
  - Planes are equally spaced 60 degrees apart.
  - Inclined 55 degrees from equatorial plane.
  - 20,200 km above the earth.
  - 5 to 8 SVs visible from anywhere on earth.

Space Segment



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

Control Segment

- SVs are controlled by five system tracking stations

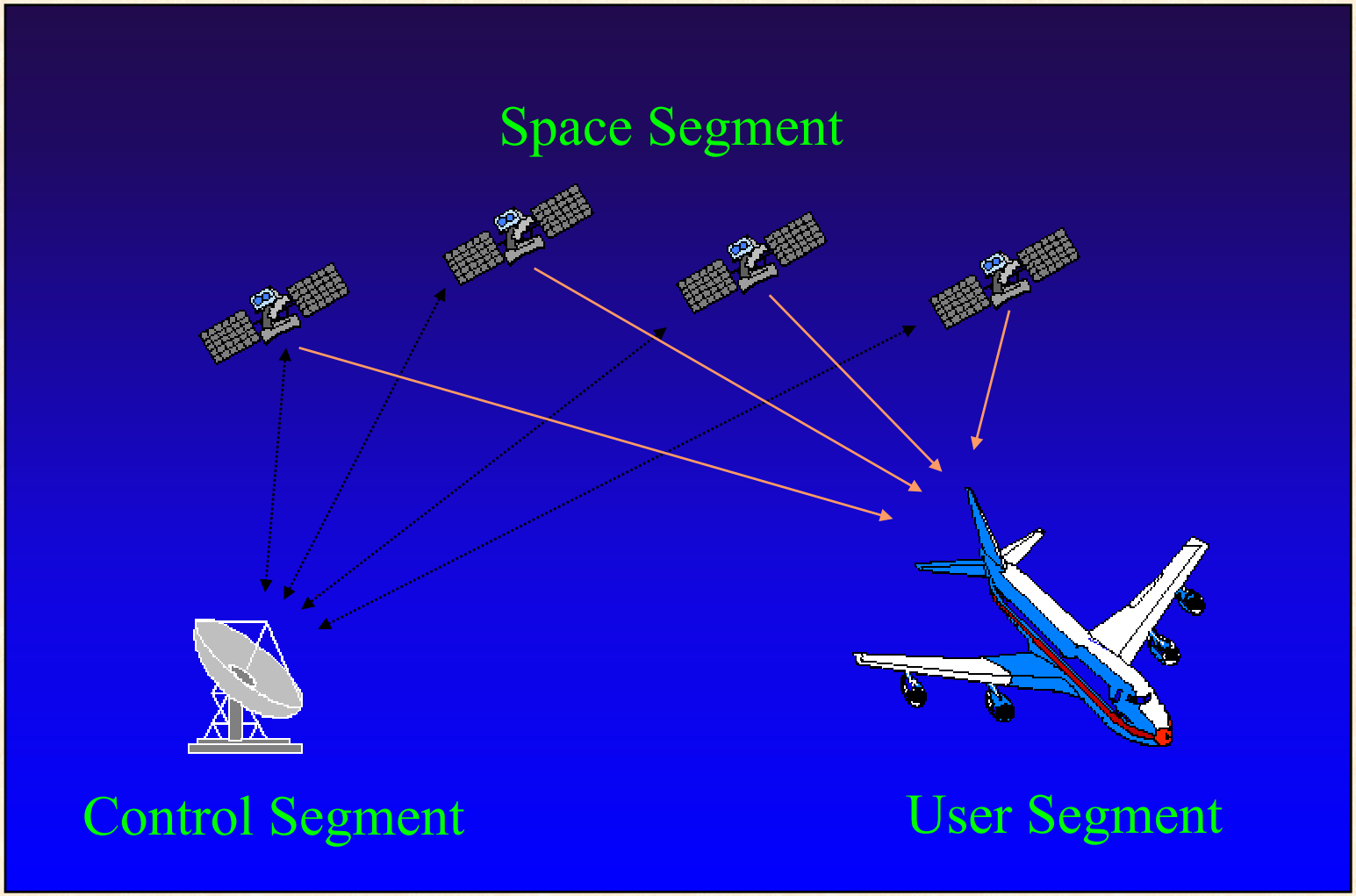
Control Segment

- Stations monitor and measure signals from the SVs which are incorporated into orbital models for each of the satellites.
- The models compute precise orbital data (ephemeris) and SV clock corrections for each satellite.
- The Master Control station uploads updated ephemeris and clock data to the SVs.

User Segment

- Civilian
  - SPS - Standard Positioning Service
    - Uses single frequency L1
    - Uses C/A code only
- Military
  - PPS - Precise Positioning Service
    - Uses two frequencies L1/L2
    - Uses C/A code and P-code

GPS System Review



GPS Overview

- GPS System
- Calculating a Position
- Receiver Outputs
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Calculating a Position

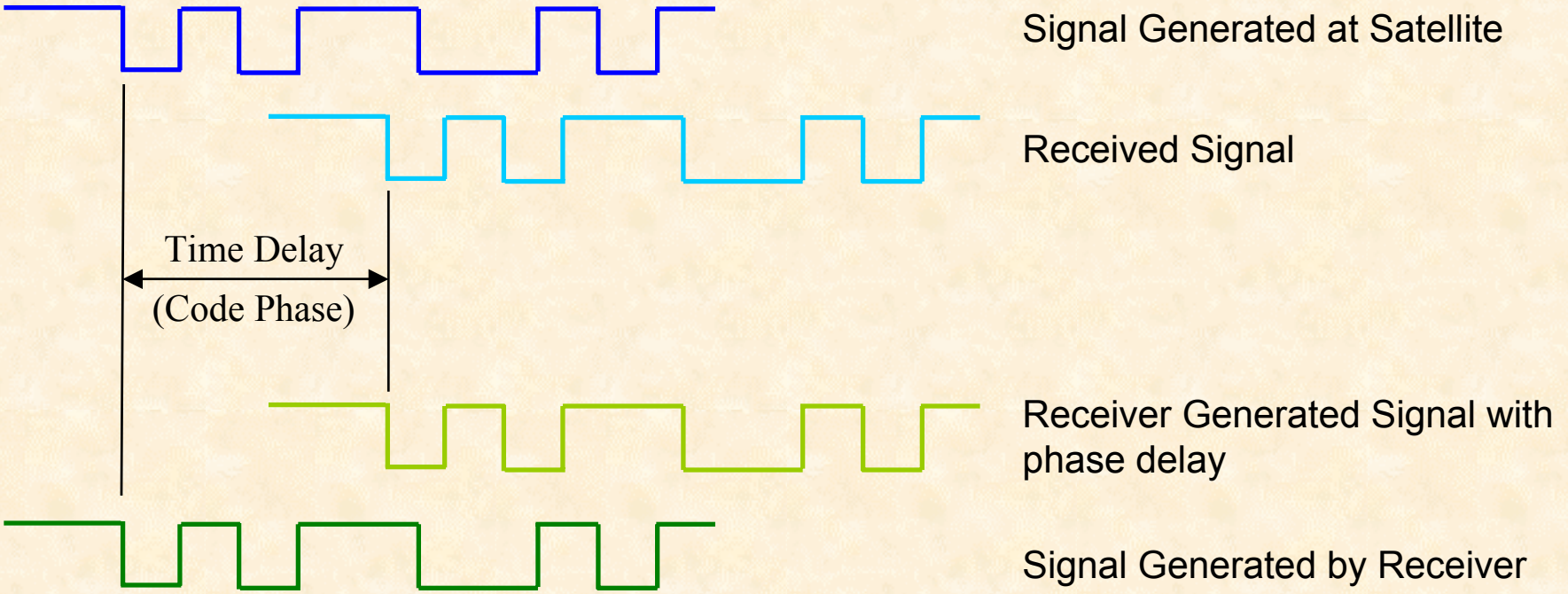
- Measure distance to satellites.
- Obtain satellite positions.
- Perform triangulation calculations. (Trilateration)
- Adjust local clock bias.

Measuring Distance

- Distance = Velocity * Time
  - Velocity is that of a radio wave.
  - Time is the travel time of the signal.
- Measure the travel time.
  - Receiver generates the same codes as the satellite (PRN codes).
  - Measure delay between incoming codes and self generated codes.
  - D = Speed of light * measured delay.

Measuring Distance

Distance = Time Delay * Speed of Light



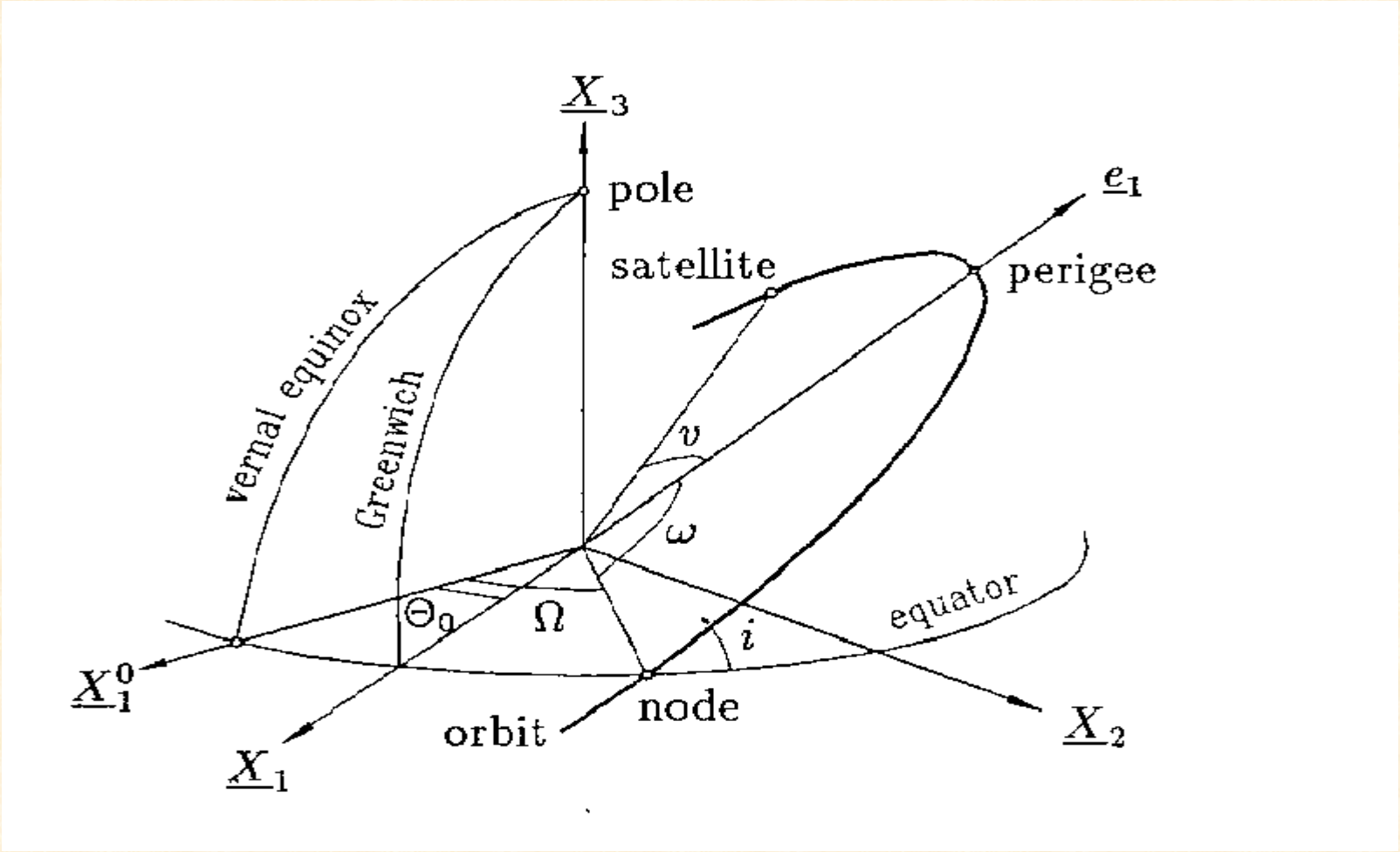
Calculating a Position

- Measure distance to satellites.
- Obtain satellite positions.
- Perform triangulation calculations.
- Adjust local clock bias.

Satellite Positions

- Orbital data (Ephemeris) is embedded in the satellite data message.
- Ephemeris data contains parameters that describe the elliptical path of the satellite.
- Receiver uses this data to calculate the position of the satellite. (X,Y,Z)

Elliptical path of Satellite

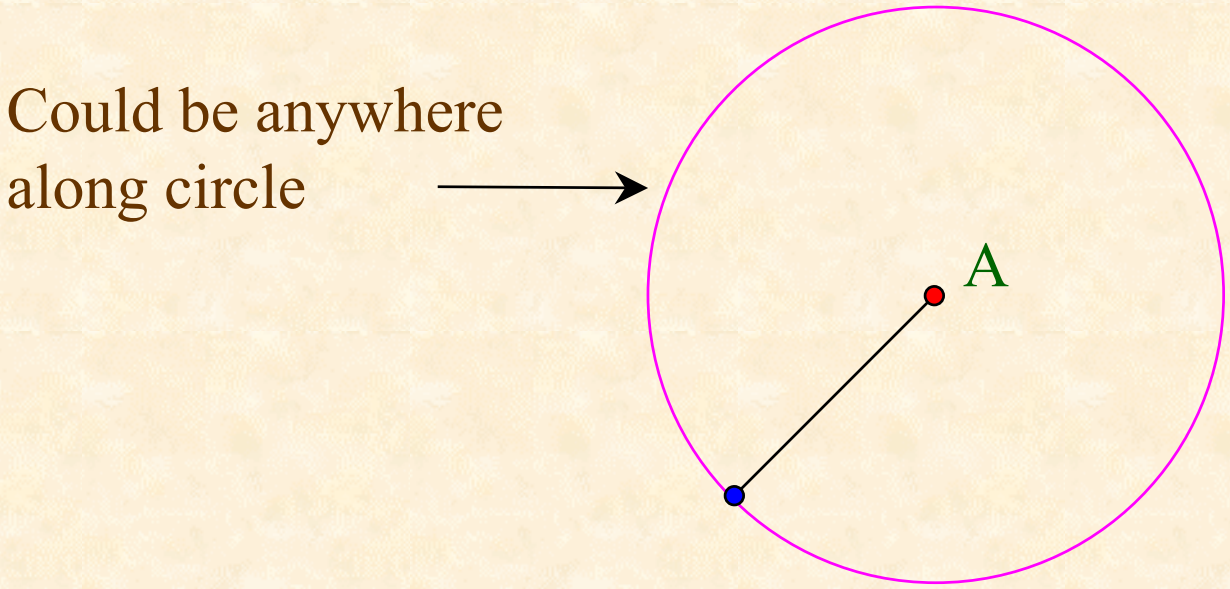


Calculating a Position

- Measure distance to satellites.
- Obtain satellite positions.
- Perform triangulation calculations.
- Adjust local clock bias.

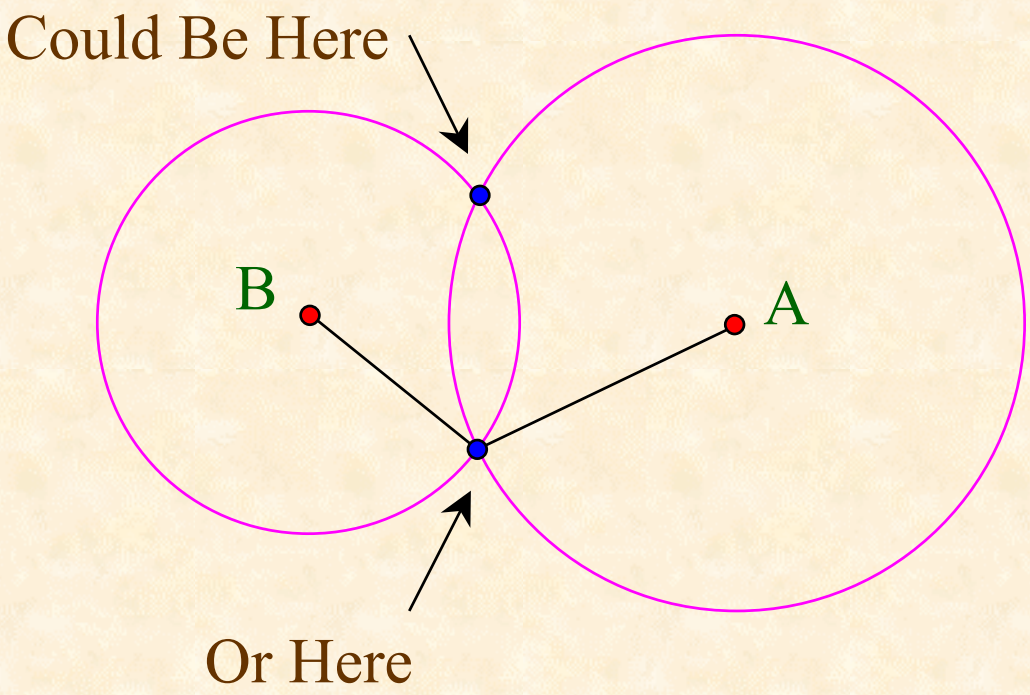
Triangulation in 2D

- If location of point A is known, and the distance to point A is known, desired position lies somewhere on a circle.



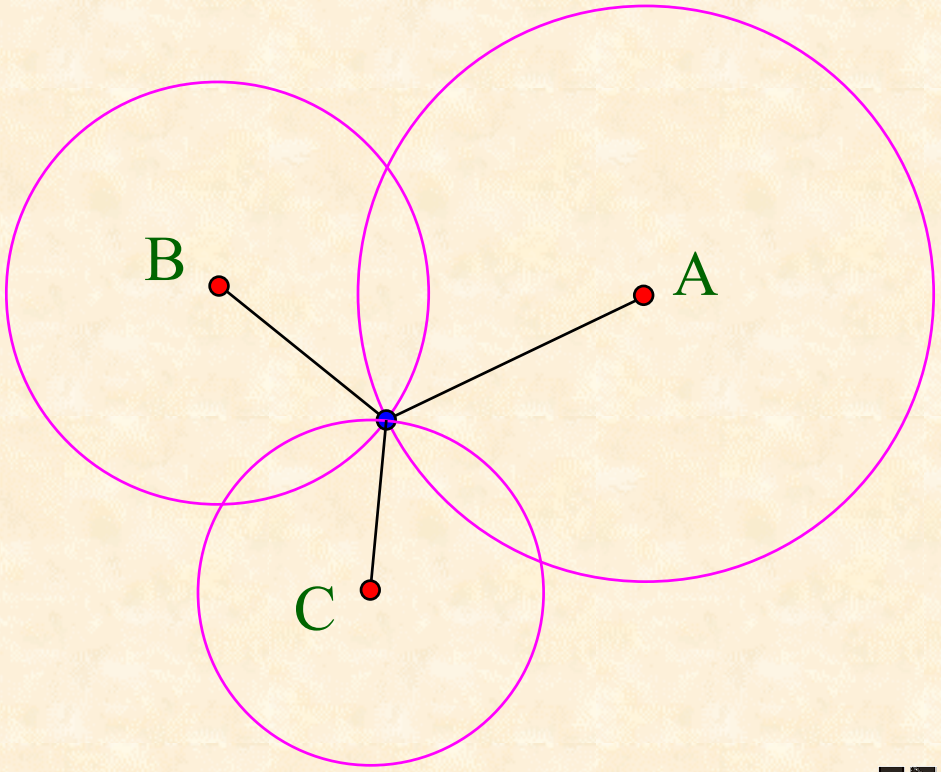
Triangulation in 2D

- Distance to two points are known.
- Desired position is in one of two locations.



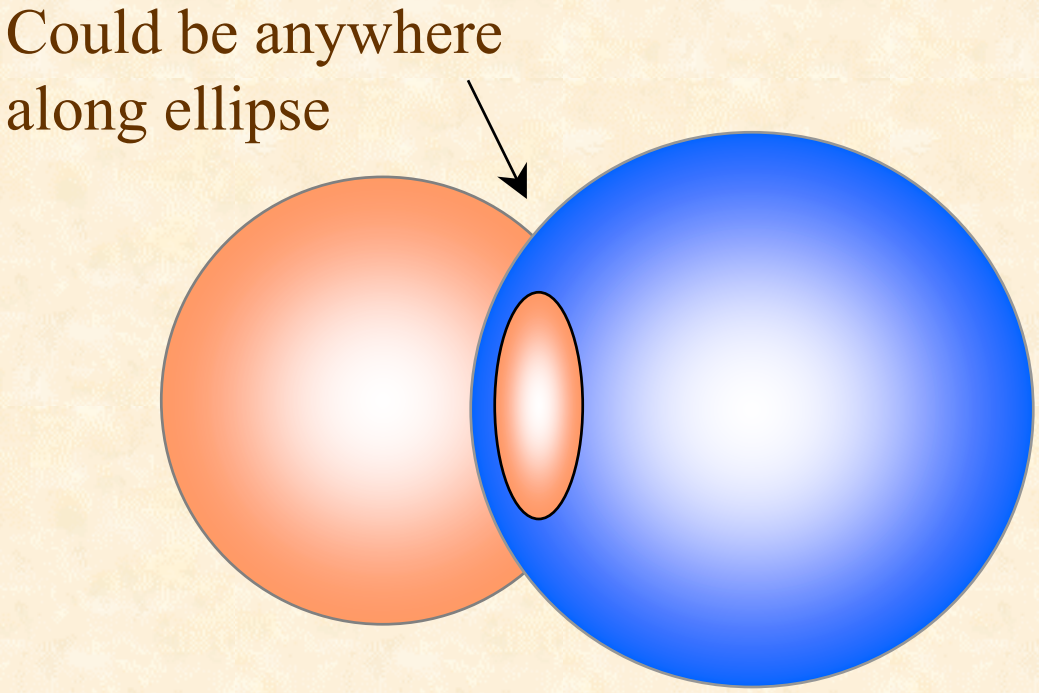
Triangulation in 2D

- Distance to three points are known.
- Position is known!



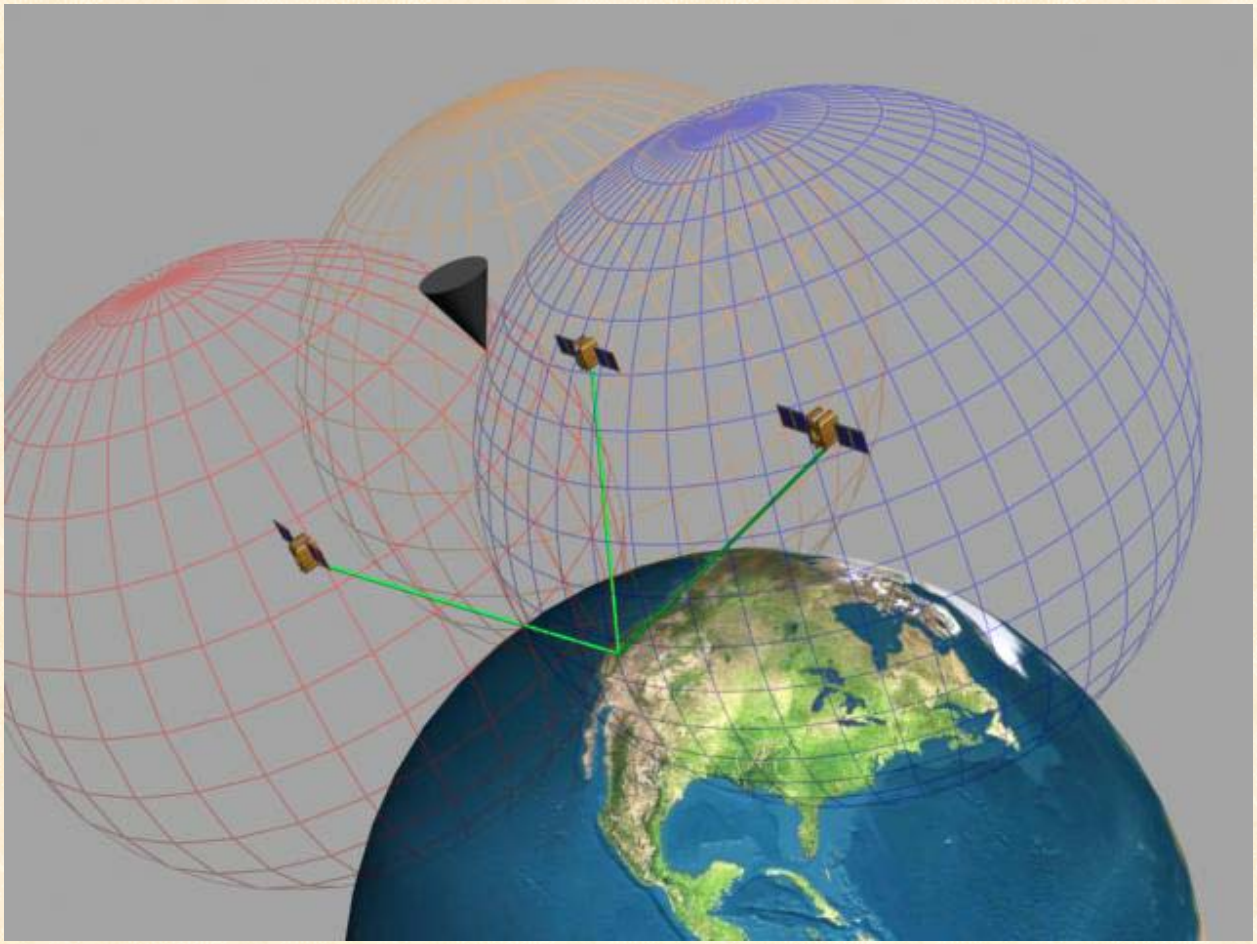
Triangulation in 3D

- Distance to two points is known.



Triangulation in 3D

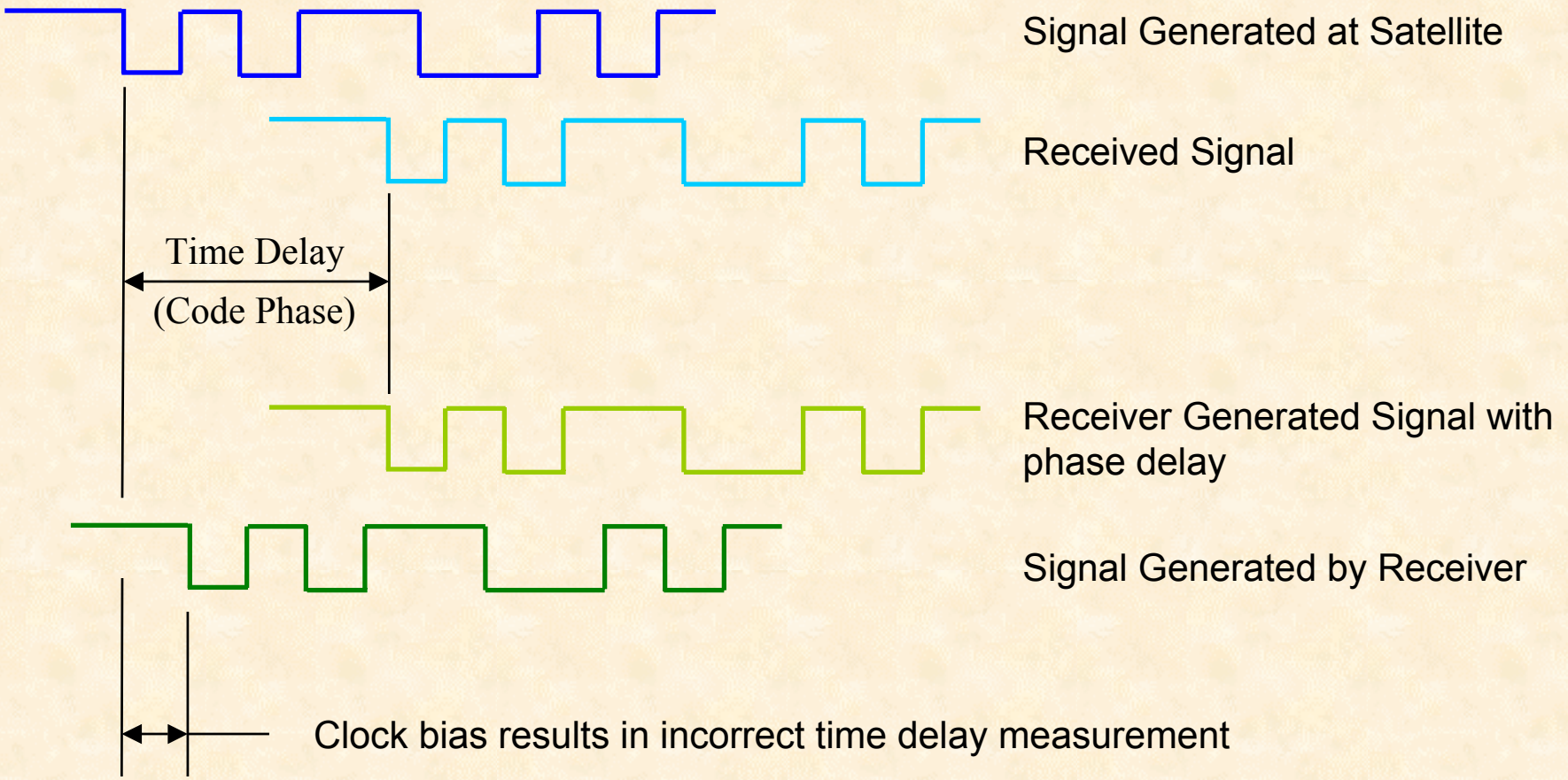
- Distance to 3 points are known.
- Intersects at 2 points.



Calculating a Position

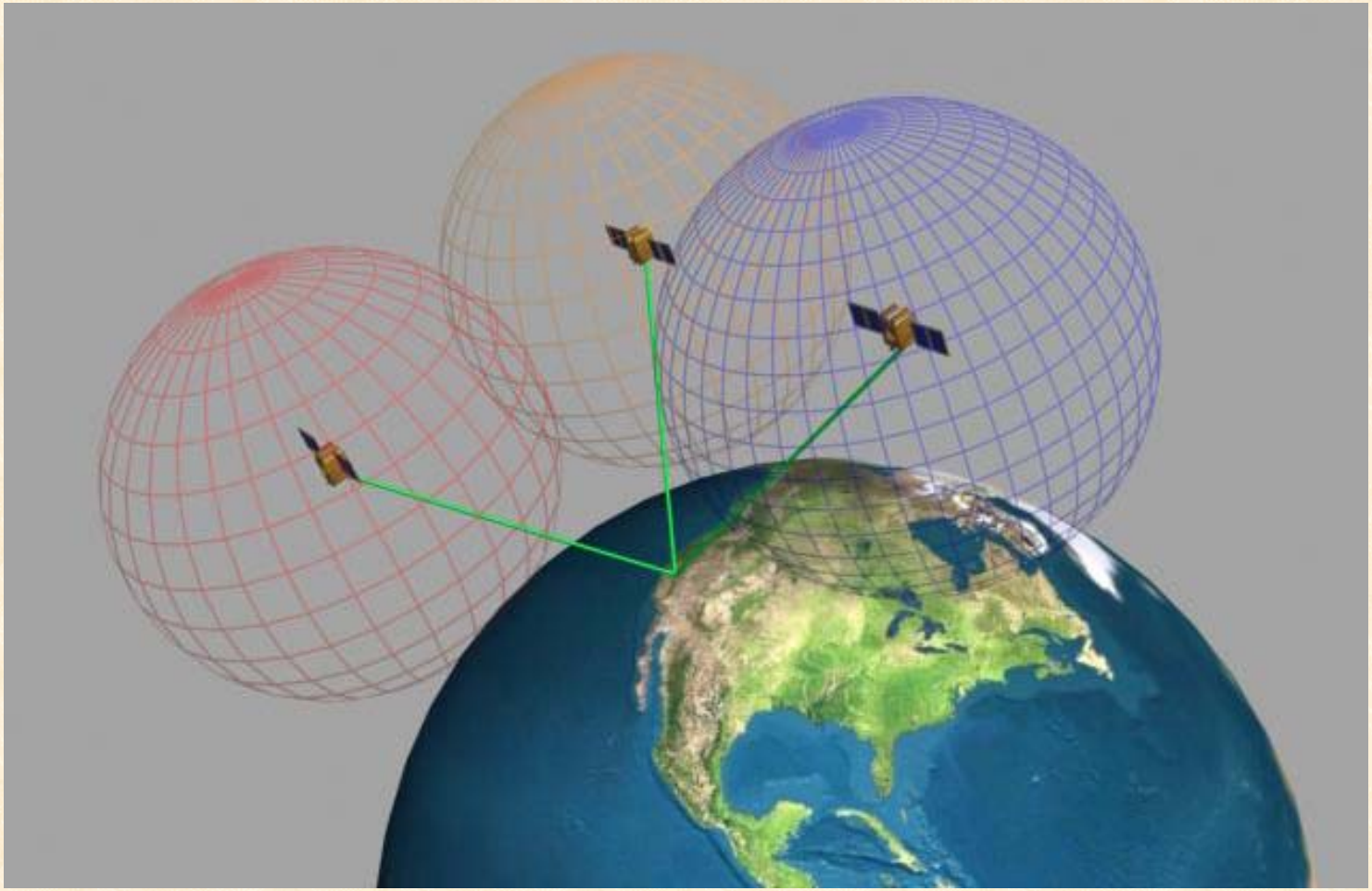
- Measure distance to satellites.
- Obtain satellite positions.
- Perform triangulation calculations.
- Adjust local clock bias.

Clock Bias


Signal Generated at Satellite
Received Signal
Time Delay
(Code Phase)
Receiver Generated Signal with phase delay
Signal Generated by Receiver
Clock bias results in incorrect time delay measurement

Time Error

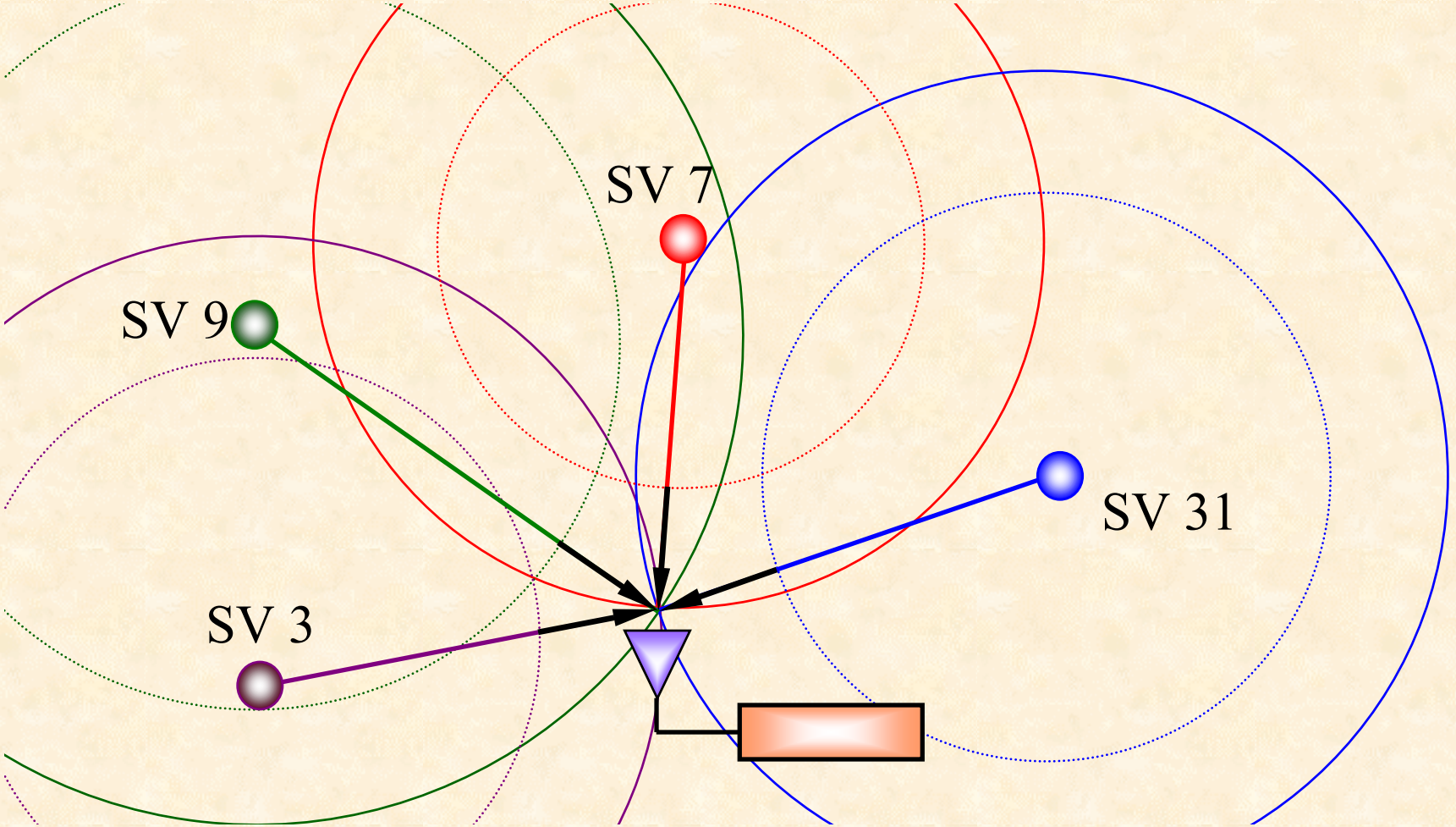
- Local clock and Satellite clock are not synchronized.



Clock Bias

- Fourth satellite will not intersect with the first three.
  - Local clock is not synchronized to SV clocks.
- Clock error is from a single source.
  - Common to all satellites.
- Apply a clock bias
  - Add or subtract a constant to all SV pseudo ranges.

Clock Bias



Calculating a Position Review

- Measure distance to satellites.
  - Use pseudo ranges
- Obtain satellite positions.
  - Decoded ephemeris from satellite message.
- Perform triangulation calculations.
  - Need at least 3 satellites for triangulation.
- Adjust local clock bias to find position.
  - Need 4^{th} satellite to adjust bias.
- Position is now known!

GPS Overview

- GPS System
- Calculating a Position
- Receiver Outputs
- Accuracy and Availability

Receiver Outputs

- Typically receivers provide two different formats.

- NMEA (Nation Marine Electronics Association)
  - ASCII Format
  - Defines a set of standard messages.

- Proprietary Format
  - Typically Binary
  - No limit on information transmitted.

Receiver Outputs

- Position, Velocity, Time (PVT)
  - Position
    - Latitude ddmm.mmmm
    - Longitude dddmm.mmmm
    - Altitude m
  - Velocity
    - Speed knots
    - Heading degrees
  - Time (UTC)
    - Date dd/mm/yy
    - Time hh/mm/ss.sss

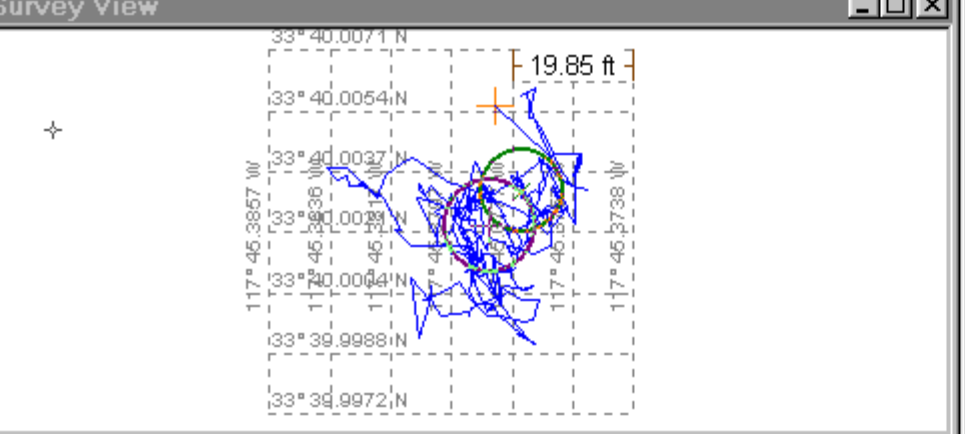
Receiver Outputs

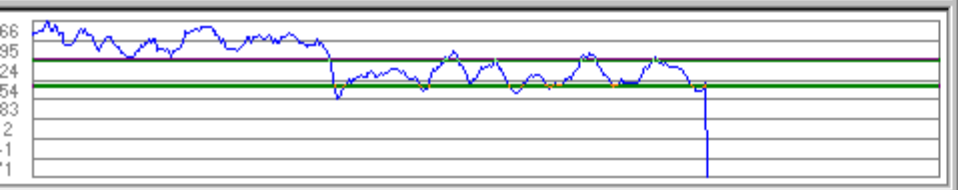
- Satellite information
  - Satellite ID or PRN
  - Azimuth
  - Elevation
  - Signal Strength
- Dilution of precision (DOP)
  - PDOP
  - HDOP
  - VDOP

Settings Window Help

Comm Navigation Satellites Signal Raw Data Command Survey About Help

Survey View





n Average:
at: 33° 40.0023 N Dev 7.928 ft
on: 117° 45.3784 W Dev 7.785 ft
e: 172.91 ft Dev 31.388 ft

Least Squares Average:
Lat: 33° 40.0032 N Dev 7.081 ft
Lon: 117° 45.3773 W Dev 7.127 ft
Ele: 132.69 ft Dev 21.095 ft

tion of precision:
OOP = 2.20 HDOP <= 1.0 (%0.0)
OOP = 1.40 HDOP <= 2.0 (%100.0)
OOP = 1.70 HDOP > 2.0 (%0.0)

Samples
Lat/Lon Samples:362
Elevation Samples:362

```
PGSV,3,2,09,14,01,087,00,20,73,312,45,22,44,125,47,25,39,044,46*77
PGSV,3,1,09,01,44,306,46,04,01,327,00,11,24,215,45,13,11,284,43*7D
PZDA,184607,12,10,2001,,*45
PRMC,184607,A,3340.0029,N,11745.3786,W,000.4,203.5,121001,,*03
PGLL,3340.0029,N,11745.3786,W,184607,A*37
PGGA,184607,3340.0029,N,11745.3786,W,1,07,01.4,0049,M,,M,000,000
PVTG,203.5,T,,M,000.4,N,000.8,K*68
CNY,0,00,05,500,06,06,06,06*14
PGSA,A,3,11,29,20,13,25,01,22,,,,,02.3,01.4,01.8*02
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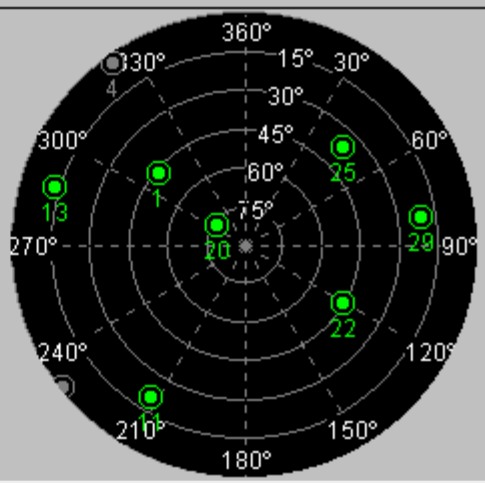
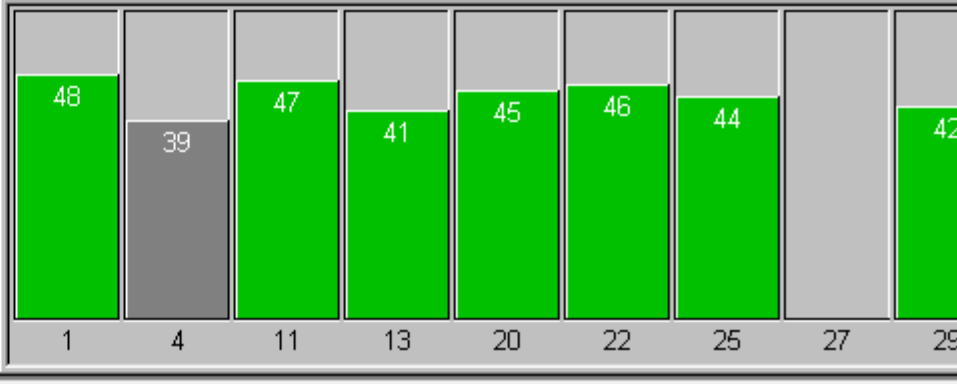
Satellite View



Navigation Data

UTC Date:	10/12/2001
UTC Time:	18:53:31.000
Latitude:	33° 40.0055 N
Longitude:	117° 45.3782 W
Altitude:	0.00 m

Signal Strength



3° 39.9967 N Lon:117° 45.3713 W Distance = 119.06 Feet Fix Time: 00:1

GPS Overview

- GPS System
- Calculating a Position
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- Accuracy and Availability

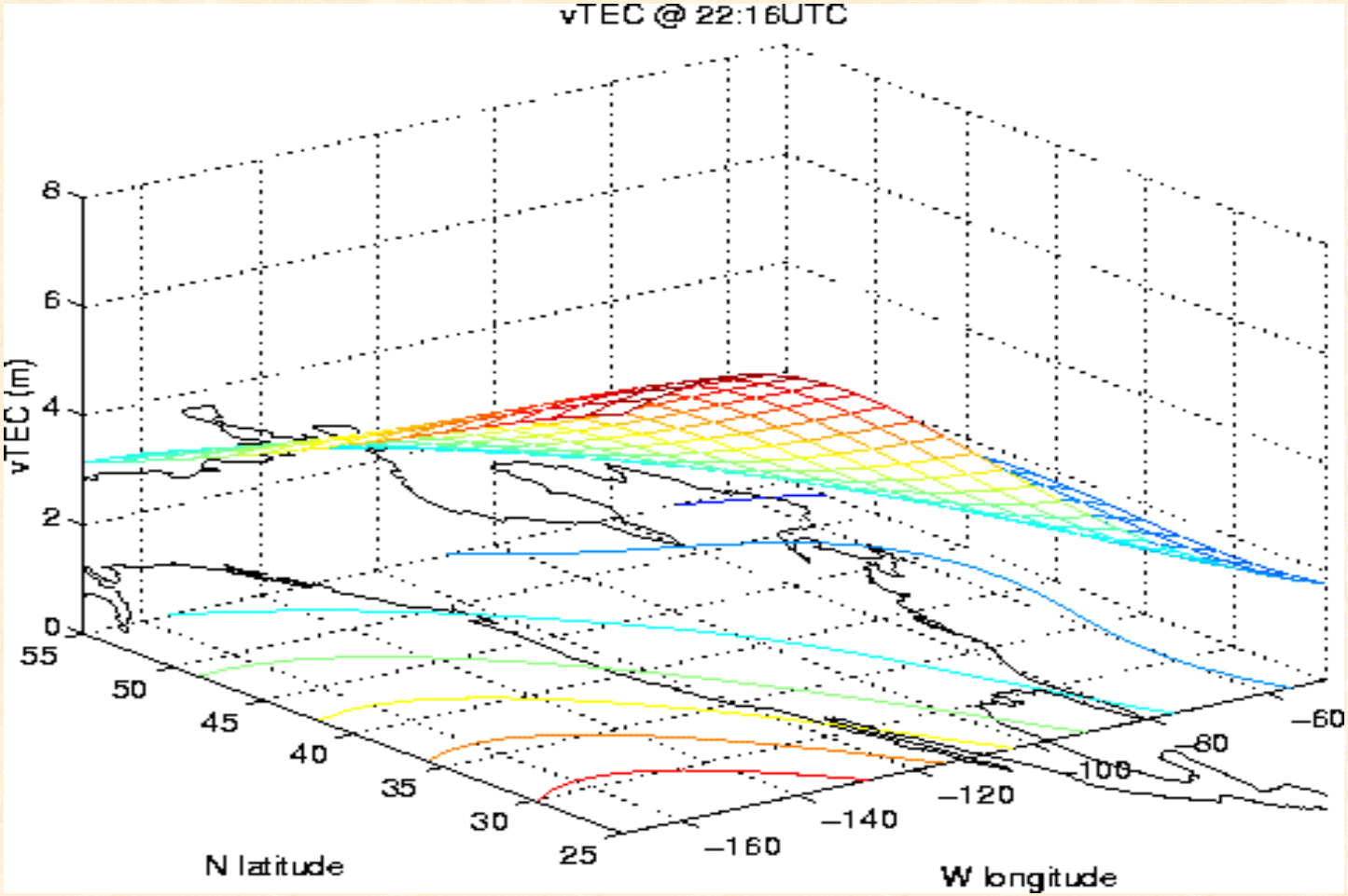
Differential GPS

- Maritime Differential GPS (DGPS)
  - Managed by the U.S. Coast Guard (USCG)
  - Employs ground stations along the coasts with known fixed locations.
  - Corrections are transmitted from ground stations at low frequencies (200-500kHz).
  - Requires an additional Differential Beacon Receiver (DBR) and an additional antenna.
  - Accuracy is a function of the distance from the ground station.

Differential GPS

- Wide Area Augmentation System (WAAS)
  - Managed by the FAA
  - Communicates with several ground stations.
  - Provides atmospheric corrections.
  - Early warning of GPS failures.
  - Same frequency as GPS
  - Higher data rate 250 Hz
  - Satellites are in geostationary orbits.

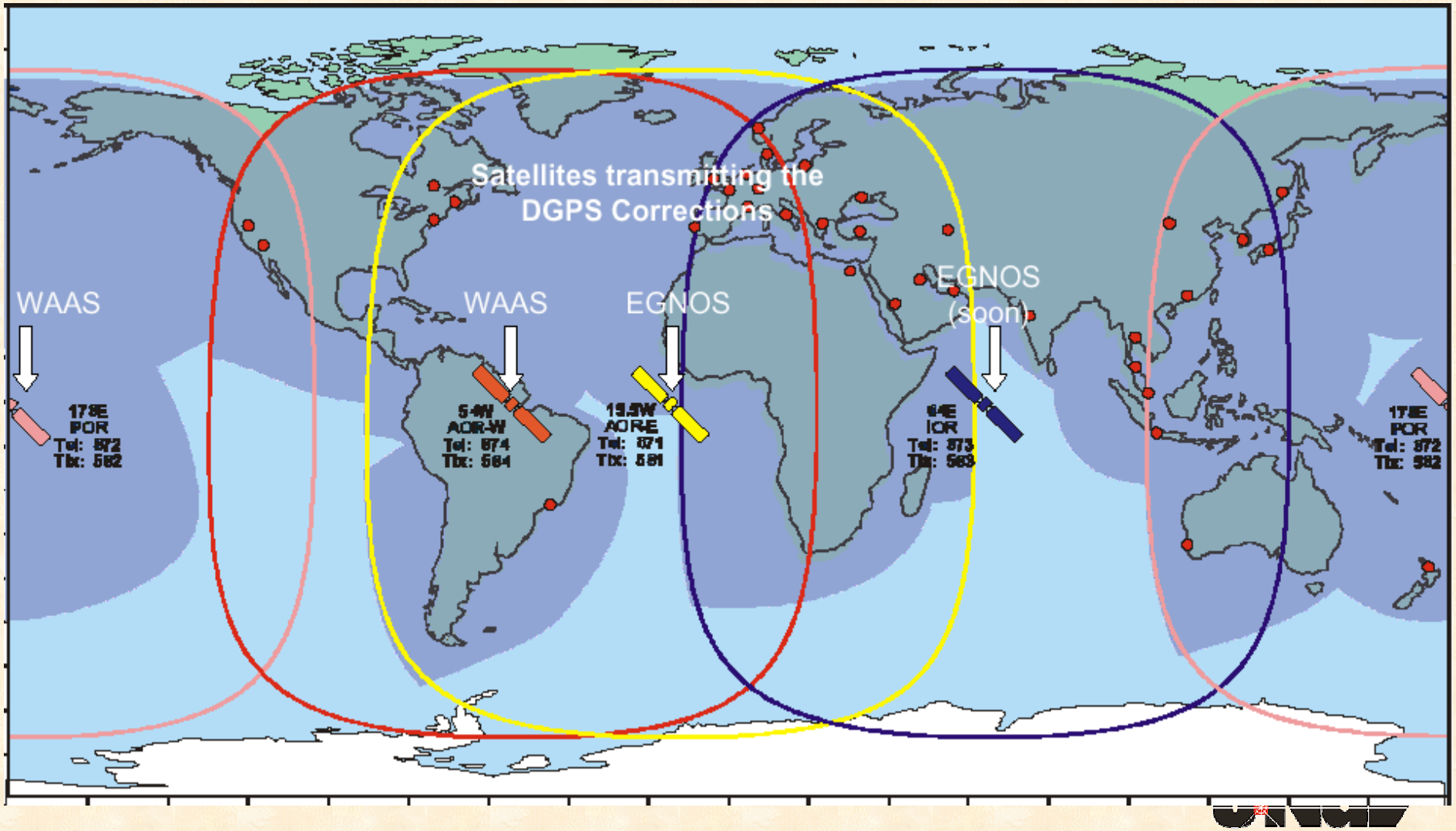
Ionoshperic Delay



Differential GPS

- European Gestationary Navigation Overlay System (EGNOS)
  - Managed by the European tripartite group
  - Corrections for GPS and GLONASS
- Multi-Function Transport Satellite Space Based Augmentation System (MSAS)
  - Managed by the Japanese Civil Aviation Bureau (JCAB)

Geostationary Satellites



Accuracy

Parameter	GPS with SA	GPS w/o SA	WAAS
Horizontal Position Accuracy (2σ)	**100 m**	**20 m**	**7.6 m**
Vertical Position Accuracy (2σ)	**140 m**	**30 m**	**7.6 m**
Time Accuracy to UTC (2σ)	**340 ns**	**40 ns**	**25 ns**

Signal Availability

Conditions	Navigation Users		
	GPS SPS (CIVIL)	GPS PPS (MIL)	WAAS/EGNOS/ MSAS Signals
Normal GPS Service Under Standard Conditions	C/A, No SA (Navigation Solution <10 m, Time Error ~100 nanosecs)	P(Y)	C/A w/o SA, even if SA is On, DGPS Corrections (Navigation Solution <7.6 m)
Foreign Tactical Conflict (USA Jams GPS C/A in Local Battlefield Area)	No GPS C/A (SPS Goes Down in Local Jammed Area)	Normal PPS P(Y) Continues (Need Direct P(Y) Acquisition Receivers for Cold-Start in Jammed area)	No WAAS/ EGNOS/MSAS C/A in local Jammed area (Civil Navigation goes down in the local area only)

Signal Availability

Conditions	Navigation Users		
	GPS SPS (CIVIL)	GPS PPS (MIL)	WAAS/EGNOS/ MSAS Signals
Broader Foreign Conflict (Satellite SA is On and cranked High)	C/A with sever SA (Navigation Solution 1000 m?? Time Error >1 sec ??)	Normal PPS P(Y) Continues Increased SA does not materially affect P(Y)	C/A w/o SA from Inmarsat, but DGPS Corrections may be out of 7.6 m Spec (Most SA is filtered by DGPS Grd. Sta.) USA may ask EGNOS/MSAS to be turned off because it filters out SA
Strategic Conflict (C/A is Unavailable from Satellite, unthinkable scenario, but possible)	No GPS C/A (SPS Goes Down Worldwide)	Normal PPS P(Y) Continues (Need Direct P(Y) Acquisition Receivers for Cold-Start)	GPS/WAAS/EGNOS/ MSAS Civil Aviation Navigation goes down Worldwide. (GUS generated C/A continues to transmit "Don't Use" message)

Further Reading

- Elementary
  - http://www.trimble.com/gps/index.html
- Novice
  - http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html
- Expert
  - http://www.gmat.unsw.edu.au/snap/gps/gps_survey/principles_gps.htm