GNSS
Chronological Evolution, Modernization & Augmentation

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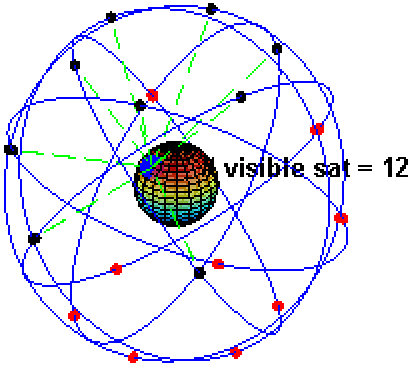
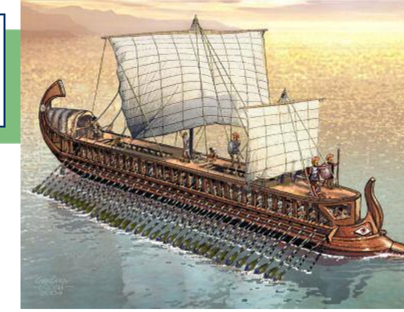


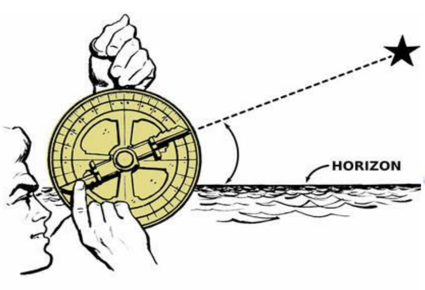
Outline

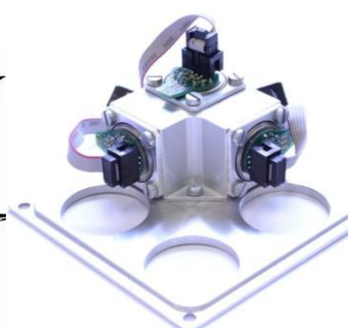
- Navigation Systems – Introduction
- Evolution of Radio Nav/GNSS
- GNSS Overview & Functionality
- GPS, GLONASS, Galileo, BeiDou
- Augmentation & Modernization
- GNSS User Equipment & Applications
- Q & A

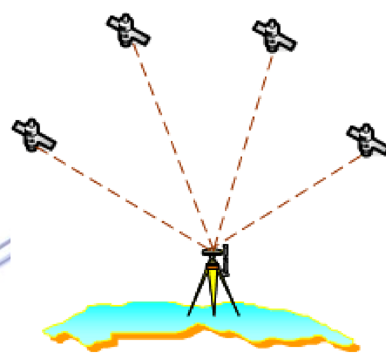
Navigation



- **Navigation:** Latin **noun navis** (ship) and the Latin **verb agare** (drive).
- Methods of determining **position and course** of the moving body using observations, sensors, geometry, astronomy, radio signals etc.
- Estimation of **position, velocity, and/or attitude** of the moving body in real time, with respect to some known reference.







Importance of Navigation

- NAVIGATION has played an important role for the mankind

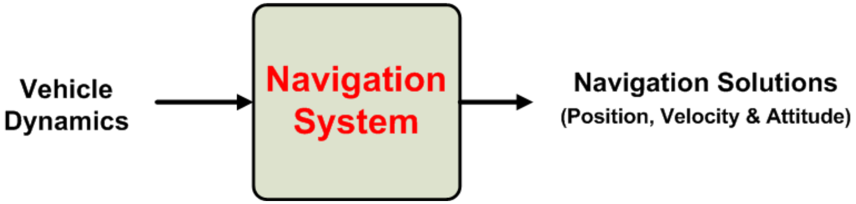
- Individuals, groups and nations who could reliably travel to/from distant places have been successful militarily and politically.

The winds and waves are always on the side of the ablest NAVIGATORS

(**Edward Gibbon**)

Navigation Systems

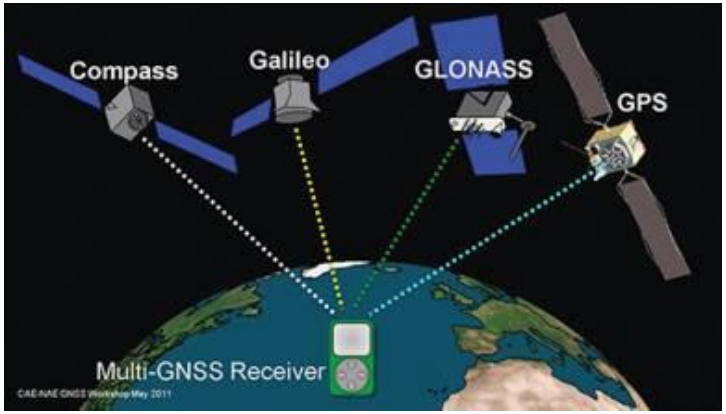
- A mechanism which provides navigation solution (position, and/or velocity and/or attitude)



- Navigation system may be completely self-contained aboard the navigating body, e.g. ***Inertial Navigation System***

Or

- It may require external infrastructure besides components aboard navigating body, e.g. ***GNSS***



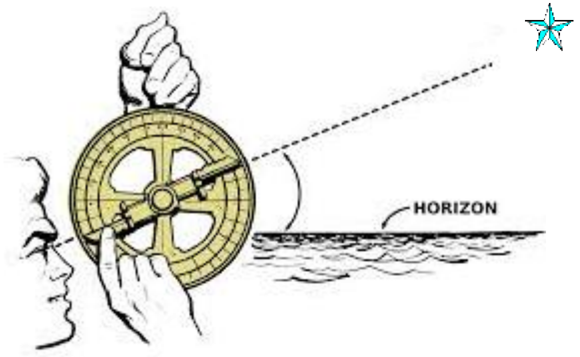
Types of Navigation

Pilotage

Visually recognizing landmarks to determine position and course

Celestial Navigation

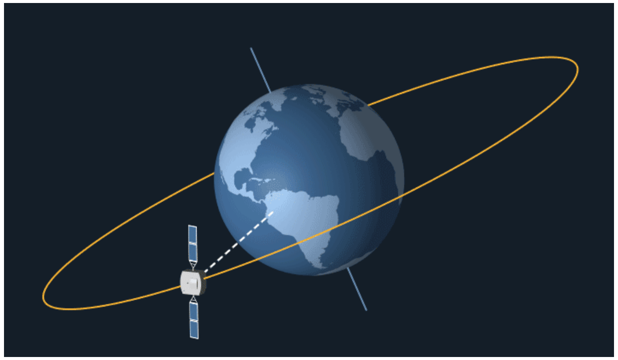
Computing position and orientation by estimating angles between local vertical/horizon and the line-of-sight to known celestial objects



Radio navigation

Relies on transmitting beacons with known locations.

- GNSS: Beacons in space
- LORAN/Pseudolites: Beacons on ground

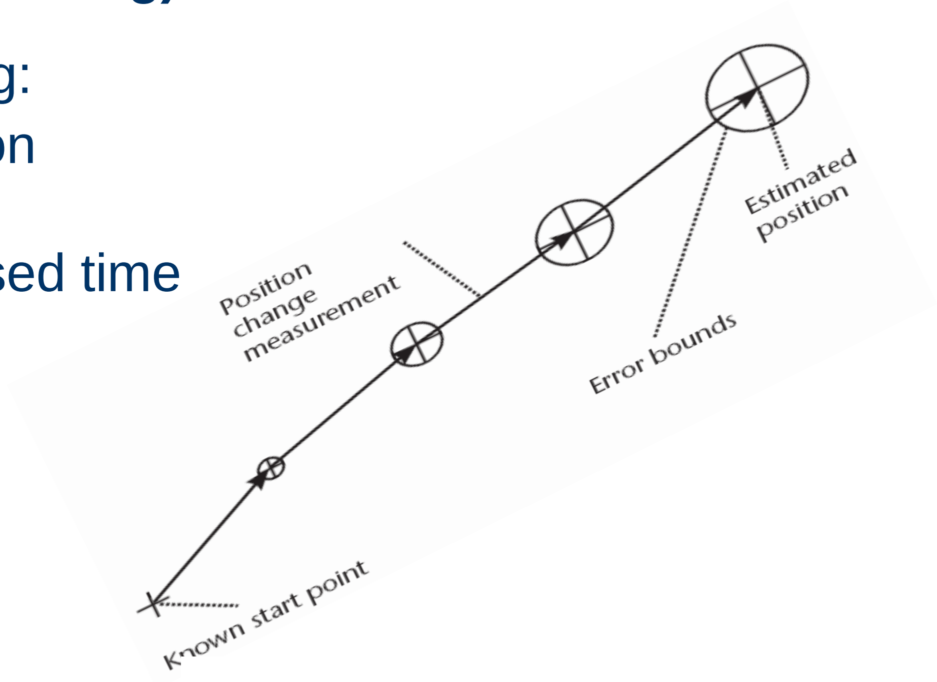


Types of Navigation

Dead Reckoning (Deduced Reckoning)

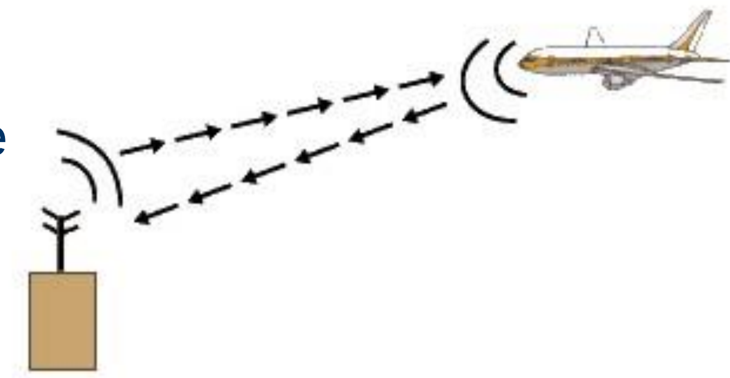
Current position is computed using:

- A previously determined position
- Estimated velocity
- Heading information over elapsed time



Radio Navigation

Application of radio SIGNALS to determine position.

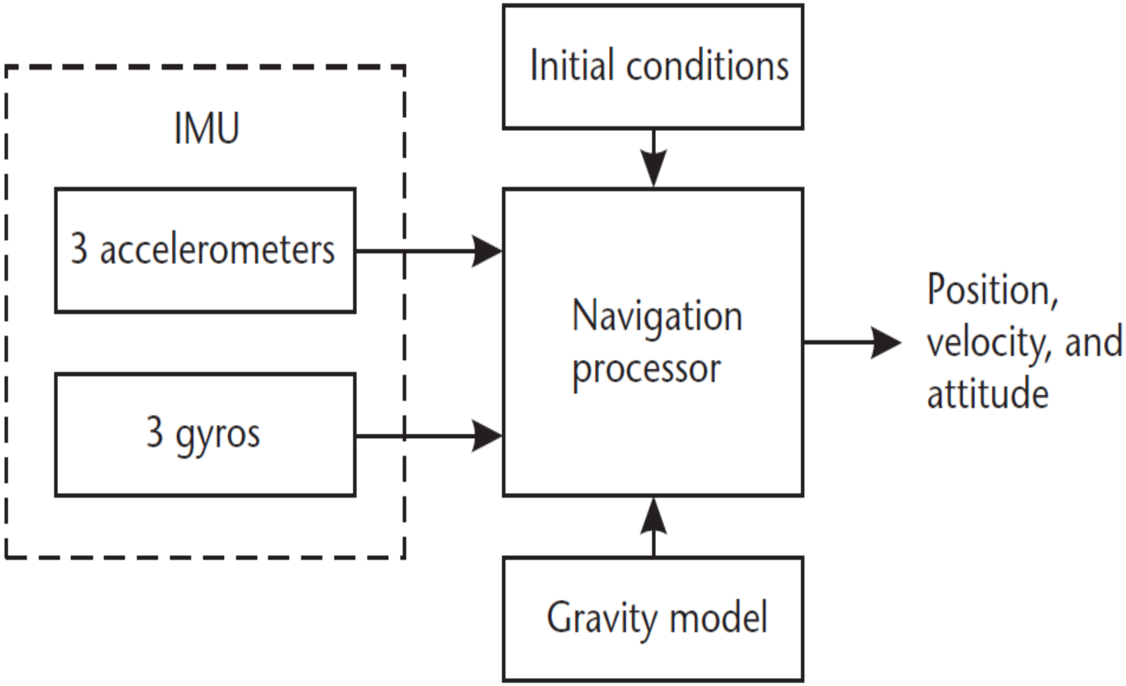


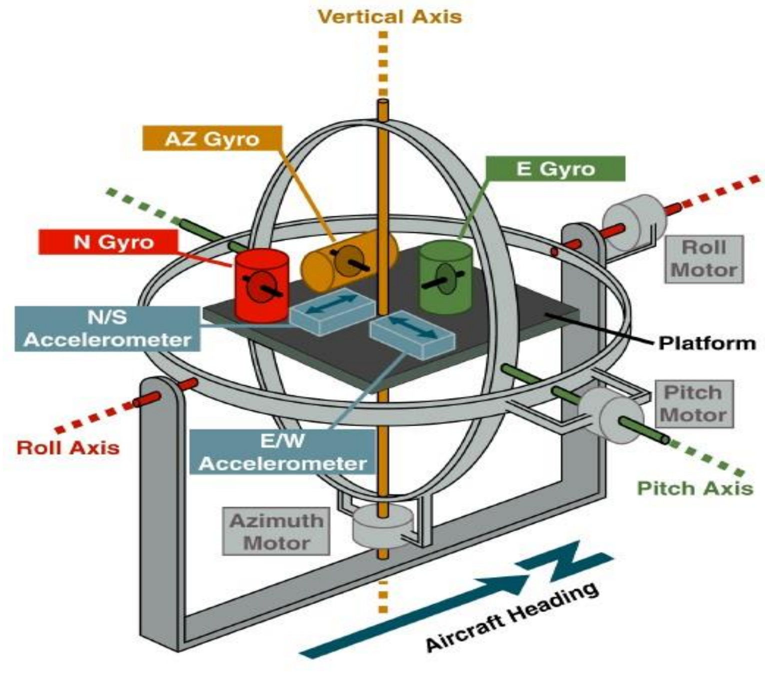
Types of Navigation

Inertial navigation

Relies on initial state (position, velocity, attitude) and thereafter on measuring angular-rates (by gyroscopes) and accelerations (by Accelerometers).

- Self contained
- No external reference/signal required
- Complete Navigation System (provides POSITION, VELOCITY and ATTITUDE)

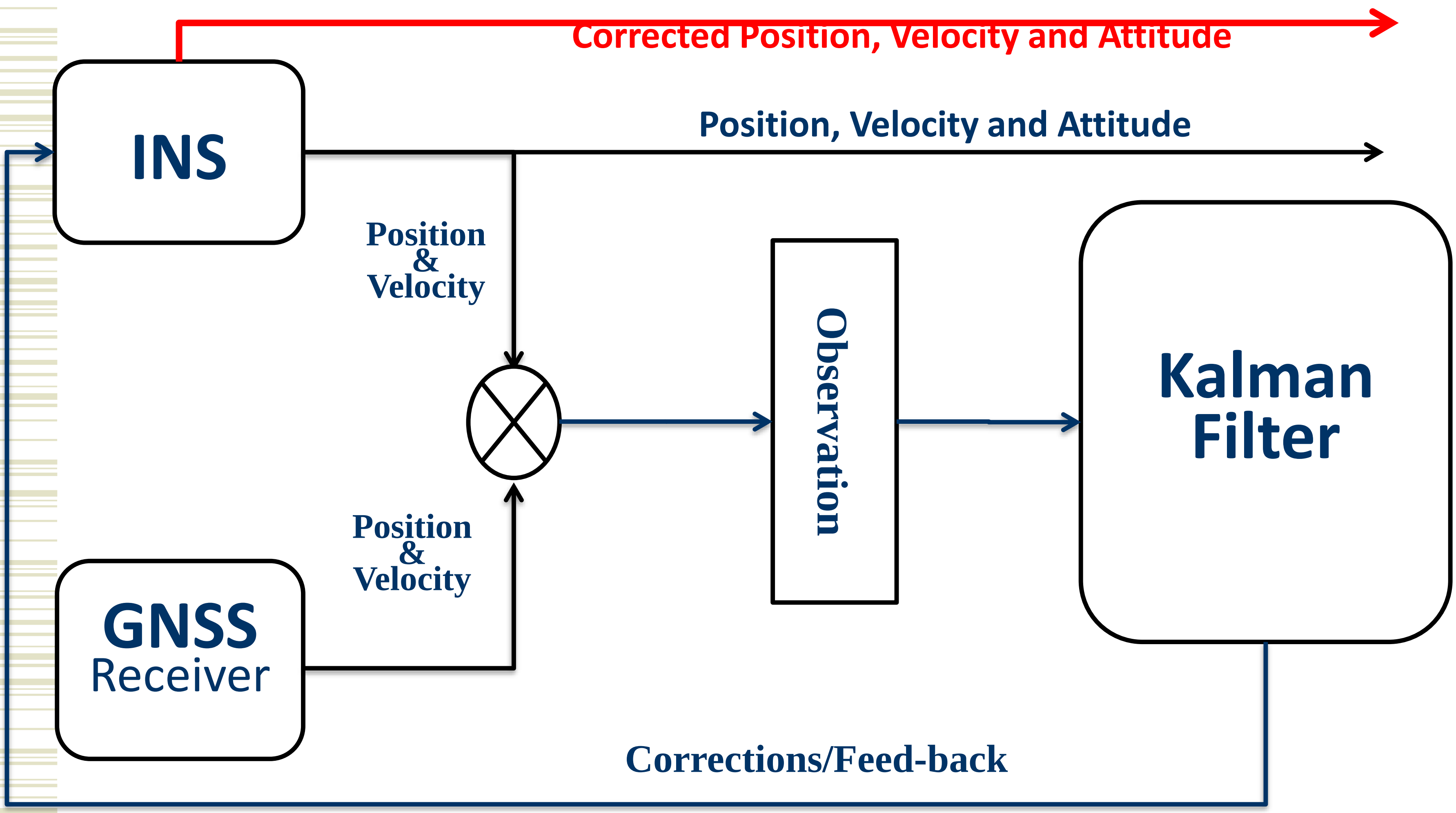




Types of Navigation

Integrated/Augmented Navigation

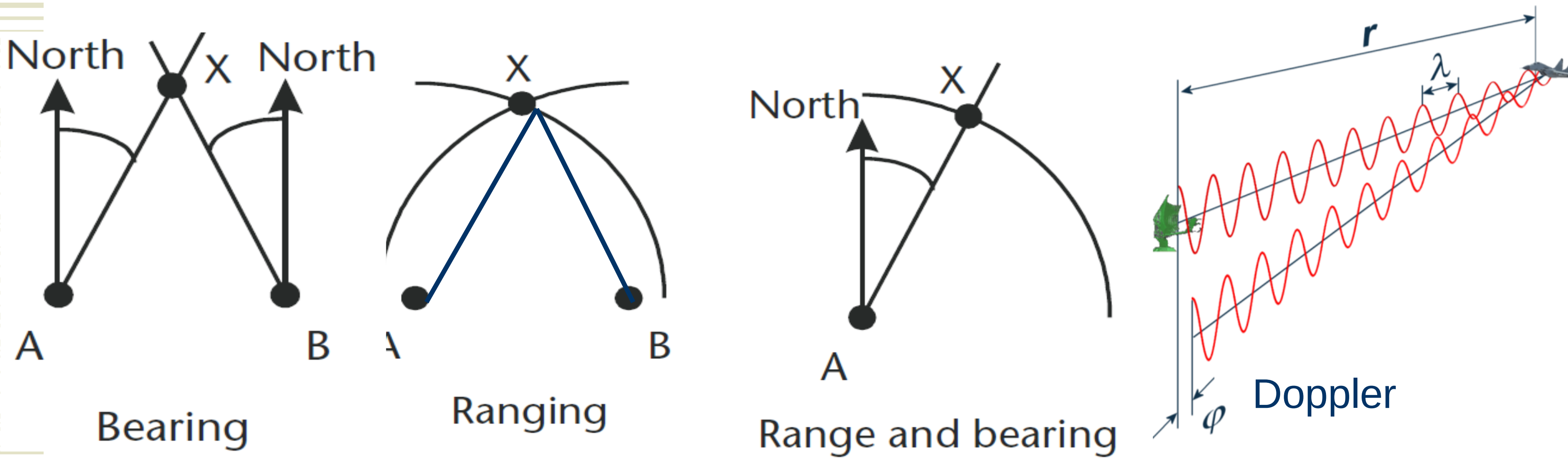
Combination of 2 or more Nav Systems



Types of Navigation

Radio Navigation is the application of radio SIGNALS to determine position.

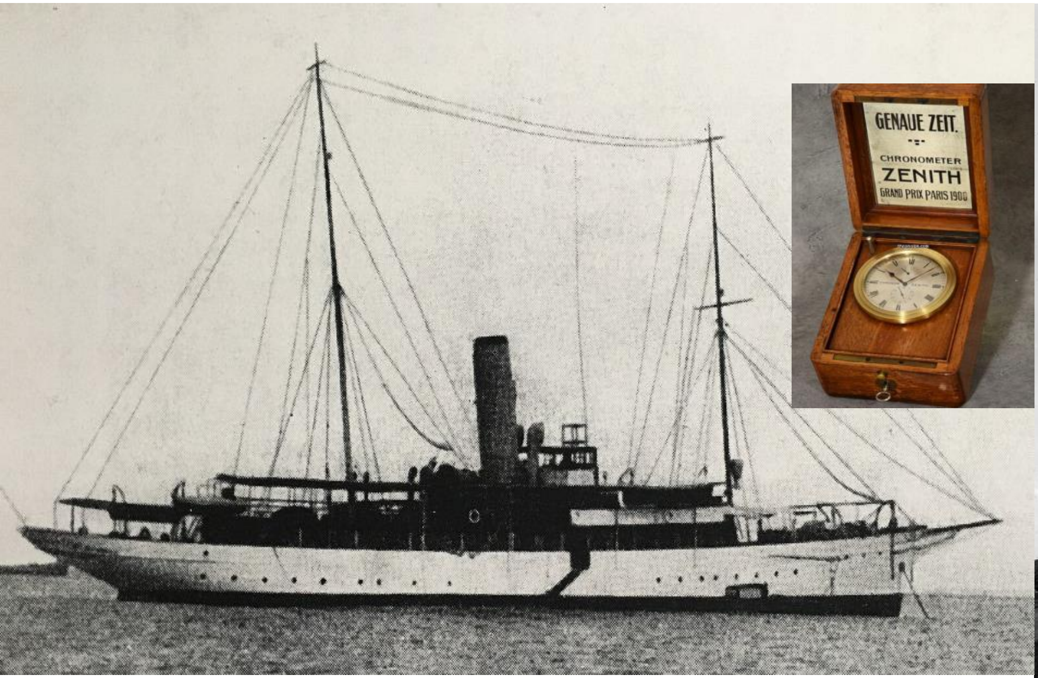
- **Bearing:** Finding the angular directions with respect to north line
- **Ranging:** Distances using time of flight between one transmitter and receivers
- **Distance differences:** Measurement of times of arrival of signals from one transmitter to multiple receivers or vice versa
- **Velocity: V**elocity by means of radio Doppler Shift

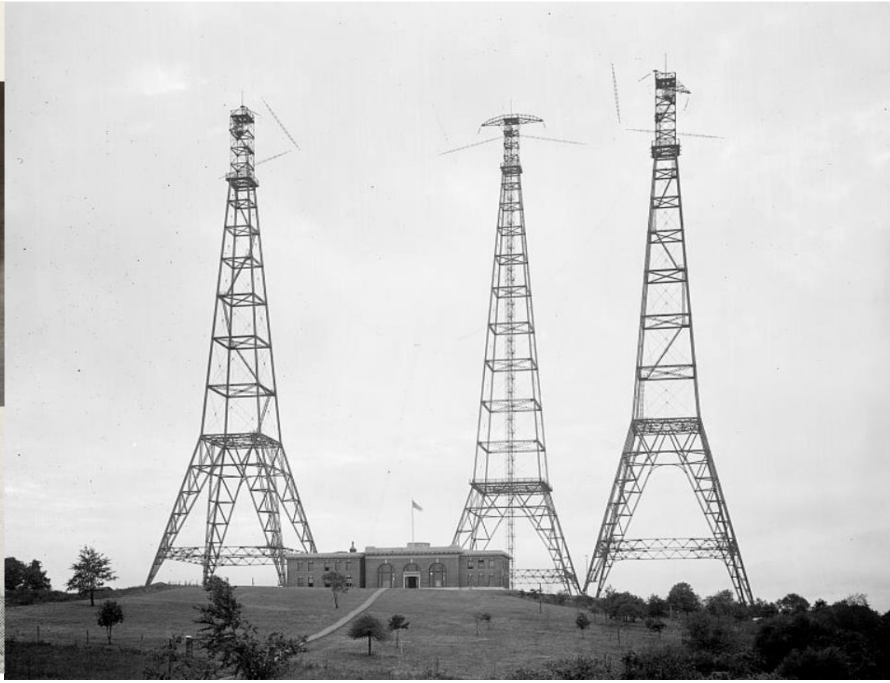


Evolution of Radio Navigation

1900s

Time signals were sent to ships for correction of chronometers.



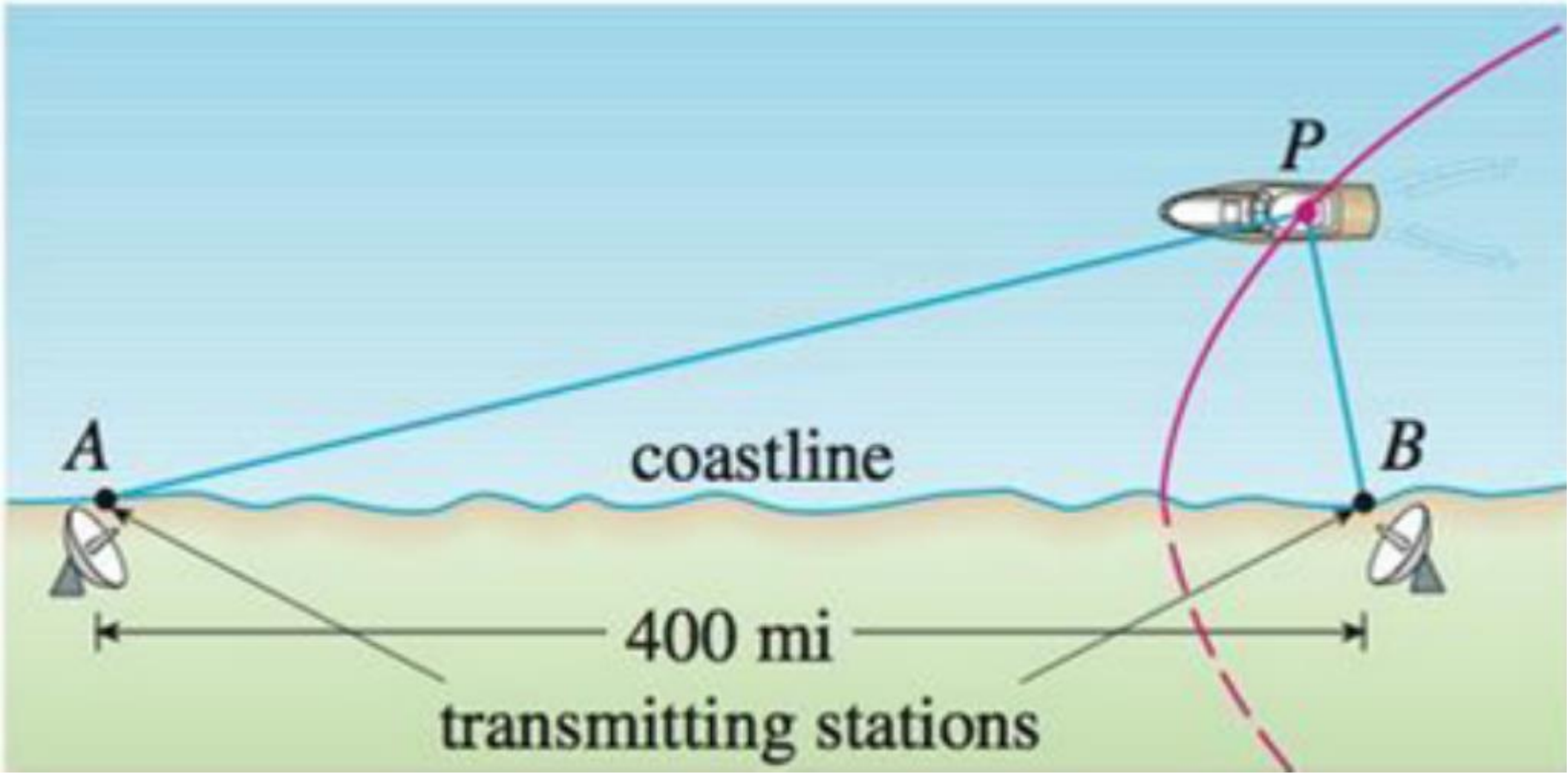


Evolution of Radio Navigation

1940s

LORAN (LOng-RANge Navigation System)

Triangulate position using radio signals from LORAN stations



Evolution of Satellite Navigation

Friedwardt Winterberg

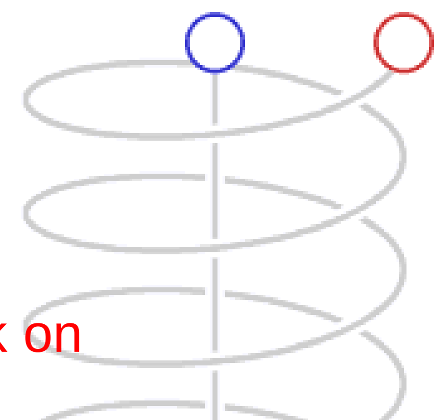
1955: Time Dilation

Time slows:

- At Stroger Gravitation Field
- At Higher Velocities

Gravity Effect : +45 µSec (time gets faster at lower gravity)

Velocity Effect: -07 µSec (time slows at higher velocity)



Time passes more quickly farther from a center of gravity

Net: GPS Satellite clock runs **38 µSec faster** than clock on ground observer

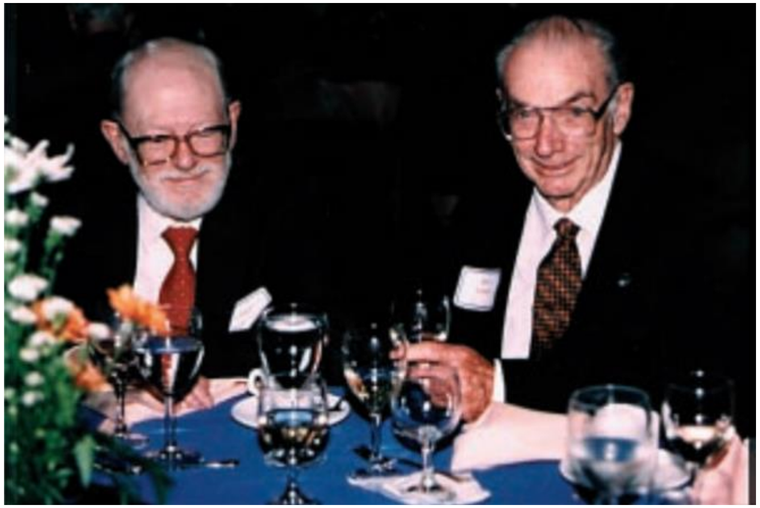
Evolution of Satellite Navigation

1957: SPUTINIK-1
Launch of 1st Artificial Satellite

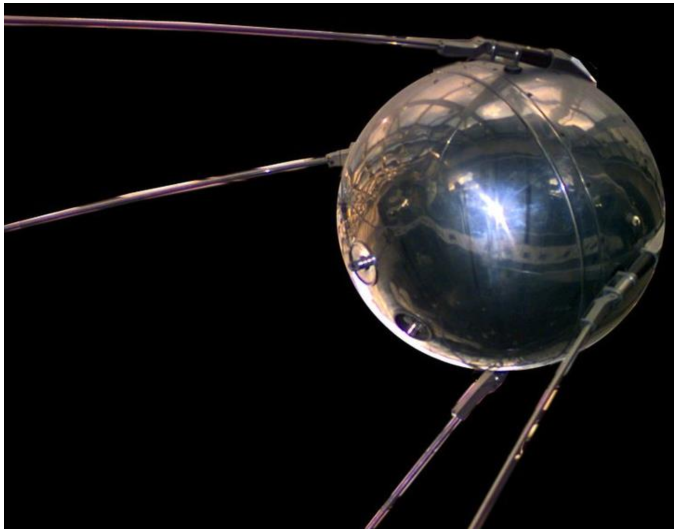
Monitoring the Doppler effect, SATELLITE LOCATION could be estimated, along the orbit .

Semi-major axis	6,955.2 km
Eccentricity	0.05201
Perigee altitude	215 km
Apogee altitude	939 km
Inclination	65.10°
Period	96.20 minutes
Mission duration	22 days
Orbits completed	1440

1958
Guier and Weiffenbach investigated the inverse problem: pinpointing the user's location, if the satellite's position is known



William Guier & George Weiffenbach



Evolution of Satellite Navigation

1960

TRANSIT successfully tested. It used a constellation of 5 satellites and could provide a navigational fix once per hour. (Retired: 1996)

1963

MOSAIC (MObile System for Accurate ICBM Control)

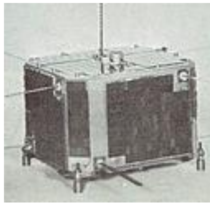
Project 57: GPS concept was born. Concept was pursued as Project 621B, which had many of the attributes that we now see in GPS

1964

1st Sequential Collation of Range (SECOR) Satellite for geodetic surveying.

SECOR included **3 ground-based transmitters** at known locations for sending signals to the **satellite transponder in orbit**.

4th ground-based station, at an **undetermined position**, then used those signals to fix its location.



Evolution of Satellite Navigation

1967

Timation Satellite developed, proving the feasibility of placing accurate clocks in space, a technology required for GNSS.

1970

The ground-based **OMEGA** navigation system, based on phase comparison of signal transmission from pairs of stations

The first worldwide radio navigation system.

Limitations of these systems drove the need for a more universal navigation solution with greater accuracy

1972

Developmental **tests of 4 prototype GPS receivers** in a Y configuration using ground-based **pseudo-satellites**

Evolution of Global Positioning System

1970 to 1973

A superior system could be developed by synergyzing the best technologies from **621B**, **Transit**, **Timation**, and **SECOR**

1973

- Defense Navigation Satellite System (**DNSS**).
- GPS was created out of this program.
- The DNSS program was named **NAVSTAR**.

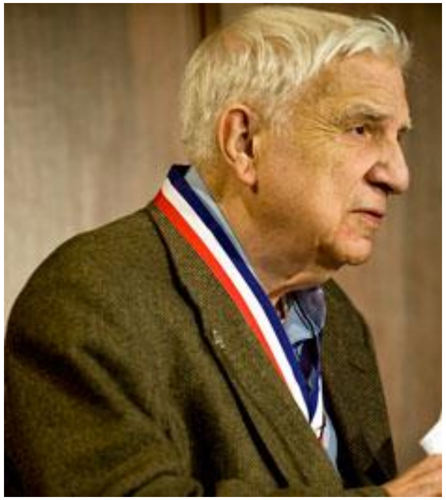
1974

- **Klobuchar Model developed** for computing ionospheric corrections
- Launch of 3rd **Timation Satellite** carrying the first atomic clock into orbit

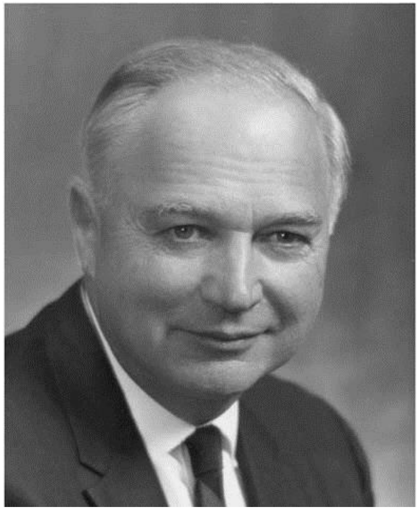
Evolution of Global Positioning System

GPS – Hall of Fame

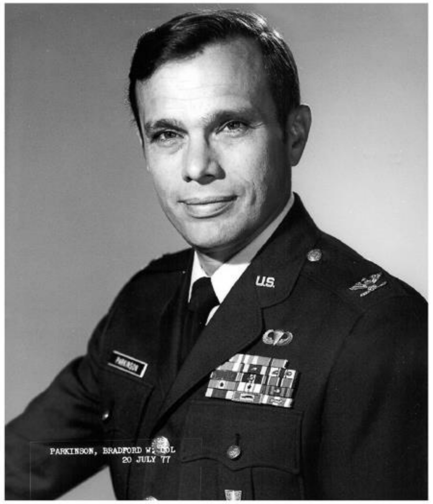
Gladys West



Roger L. Easton



Ivan A. Getting

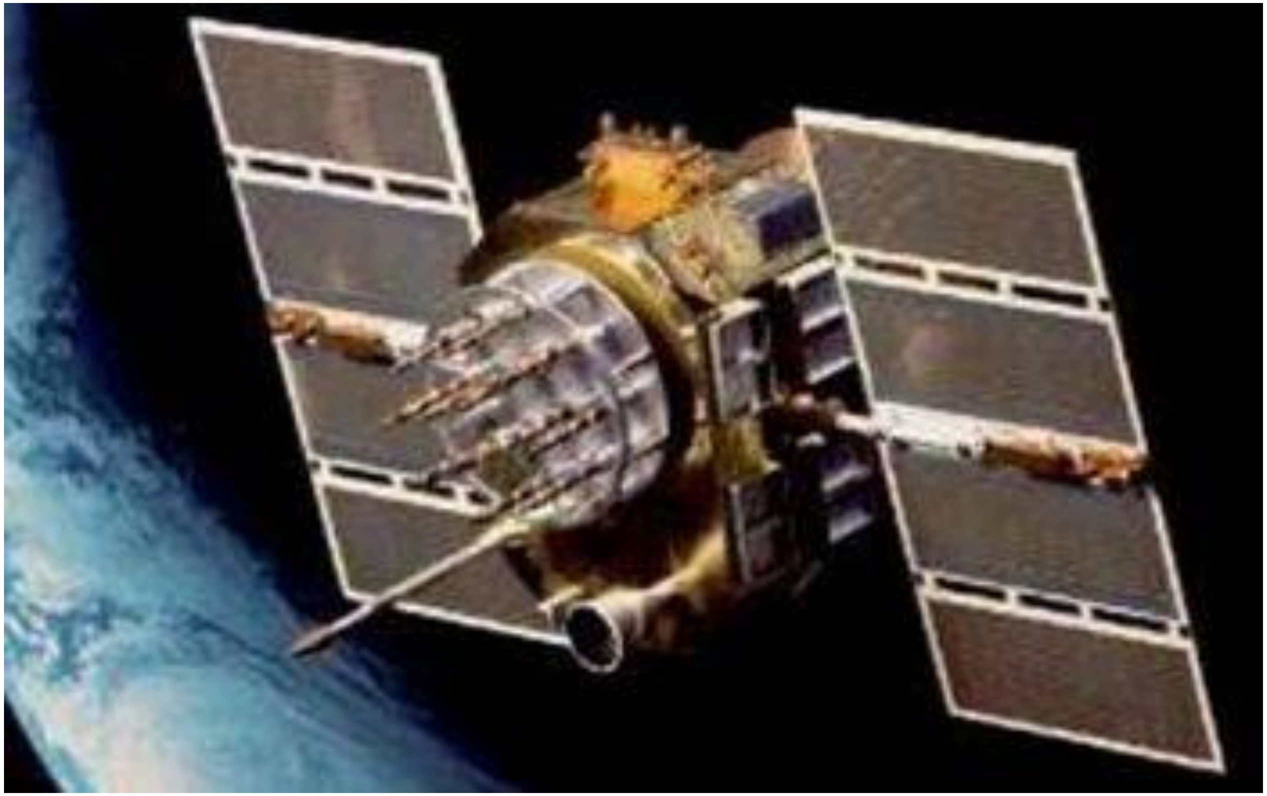


Bradford Parkinson

Evolution of Global Positioning System

1978

The first experimental Block-I GPS satellite was launched

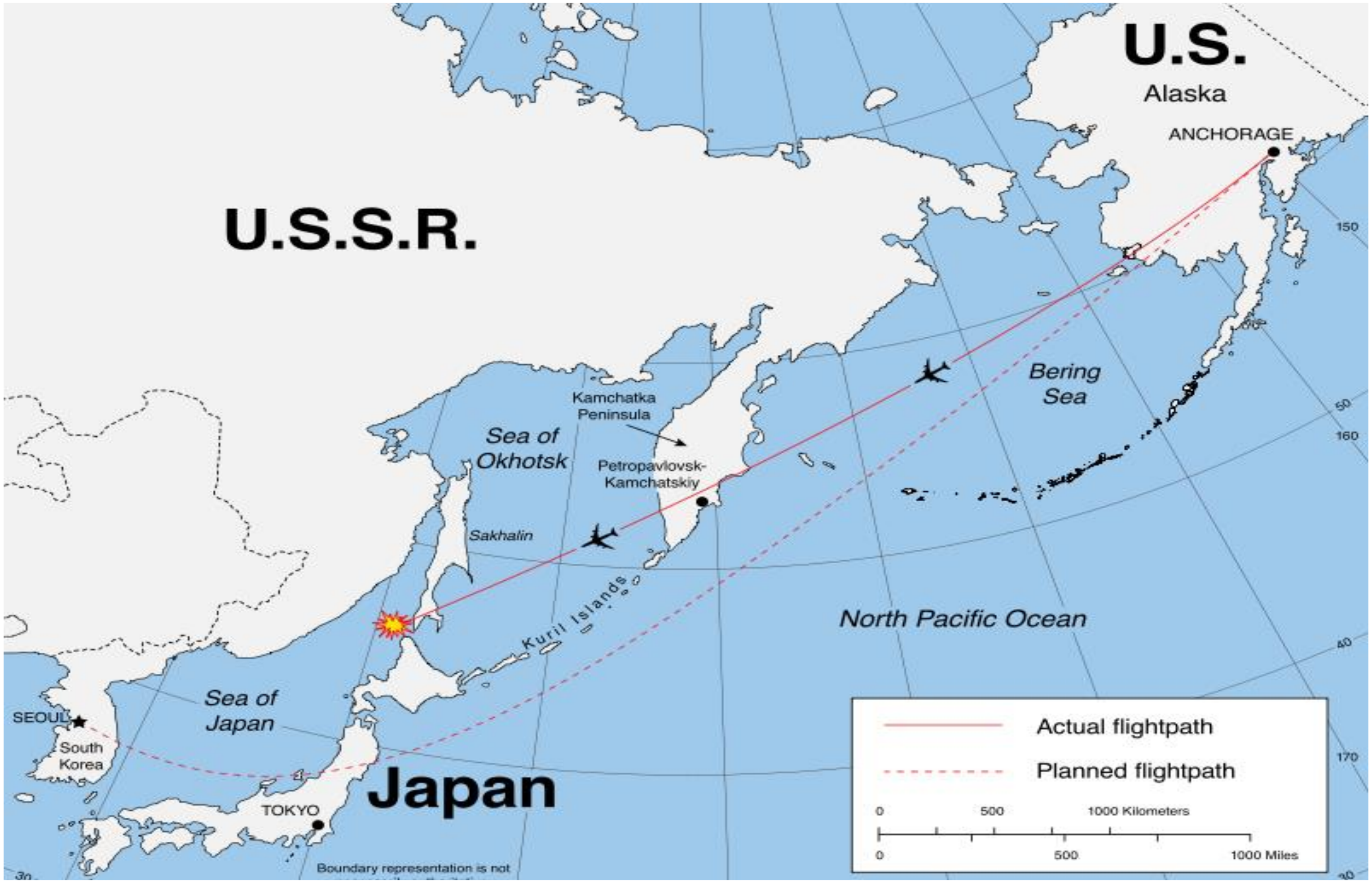


Evolution of Global Positioning System

1983

Shooting of Korean Airlines Flight 007

President Reagan directive: GPS to be freely aval to civilian



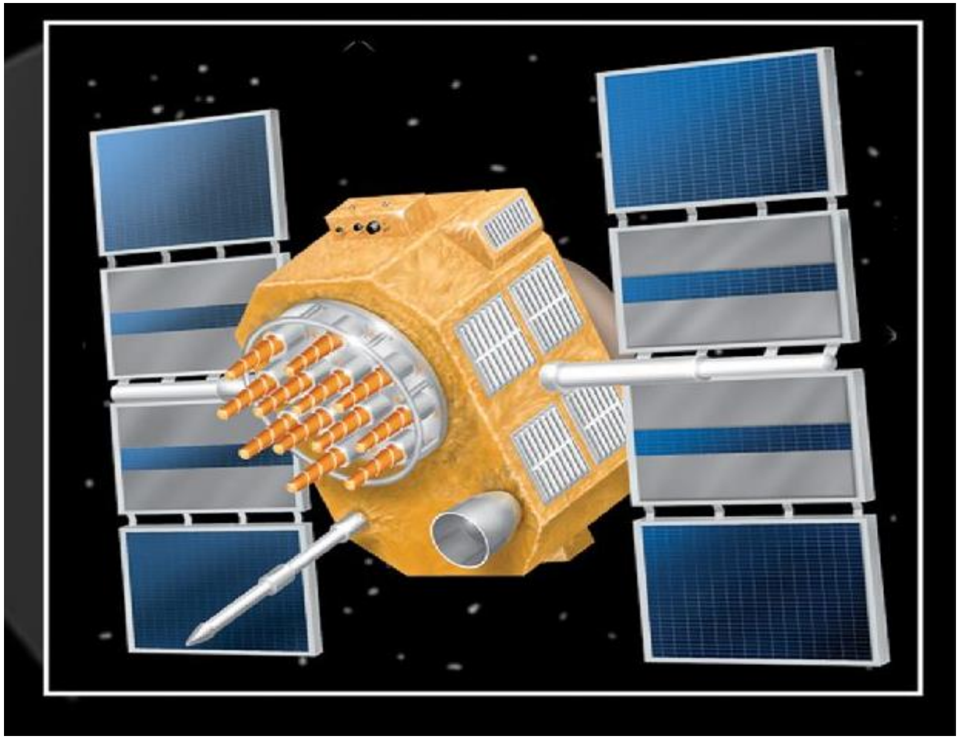
Evolution of Global Positioning System

1985

10 more experimental Block-I satellites launched

1989

The first modern Block II satellite launched



Evolution of Global Positioning System

1990-91

The Gulf War: US Military widely used GPS

Miniature GPS receiver developed, replacing the 16 kg receivers with a 1.25 kg

Evolution of Global Positioning System

1993-94

GPS achieved initial operational capability (IOC), with a full constellation (24 satellites) providing the Standard Positioning Service (SPS)

1995

Full Operational Capability (FOC) was declared

1996

President Clinton directive: GPS a dual-use (civilian & military) system

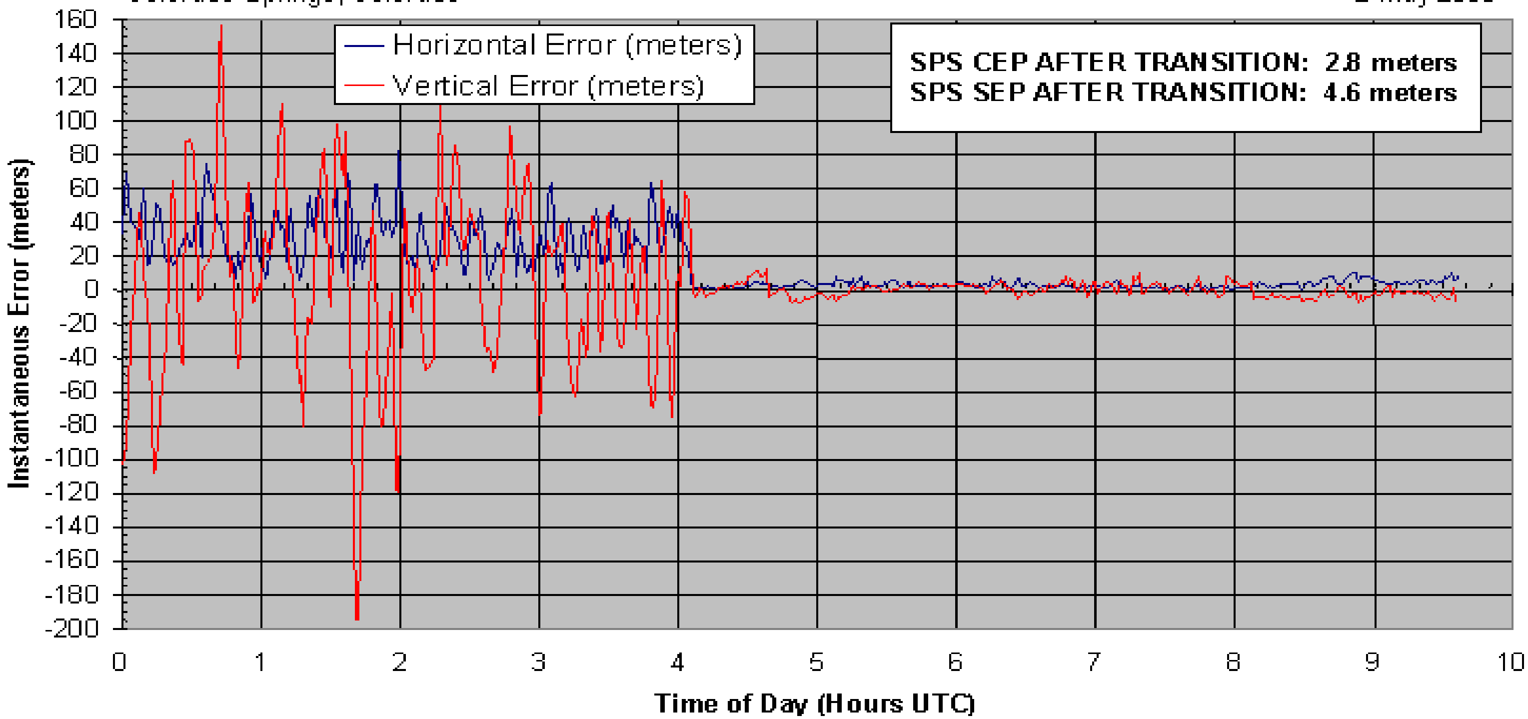
Evolution of Global Positioning System

1998

Vice President Al Gore announced plans to upgrade GPS with **two new civilian signals** for enhanced user accuracy and reliability, particularly with respect to aviation safety.

2000

- United States Congress authorized development of **GPS III**
- US President ordered to **Turn-off Selective Availability (2 May)**



Evolution of Satellite Navigation

2005

The first modernized GPS satellite was launched transmitting a second civilian signal (L2C) for enhanced user performance.

2010

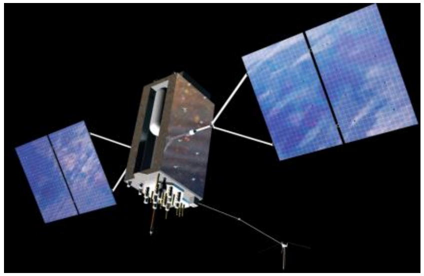
Contract awarded: **Next Gen Operational Control System (OCX)**

Launch of 12 Block IIF satellites

Evolution of Satellite Navigation

2016

The last of the Block IIF satellites launched

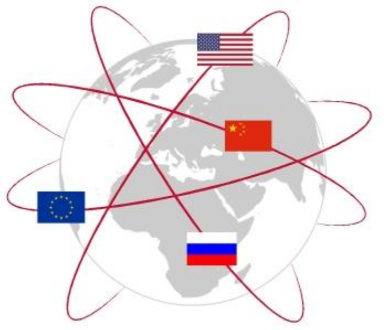


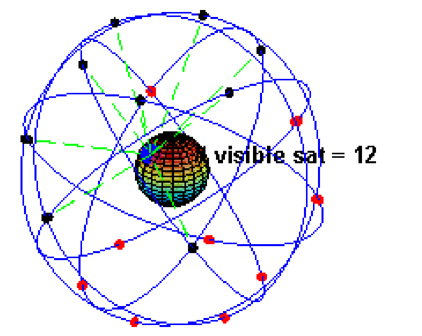
2018

The 1st GPS III satellite launched

2019

The 2nd GPS III satellite was launched





Global Navigation Satellite Systems

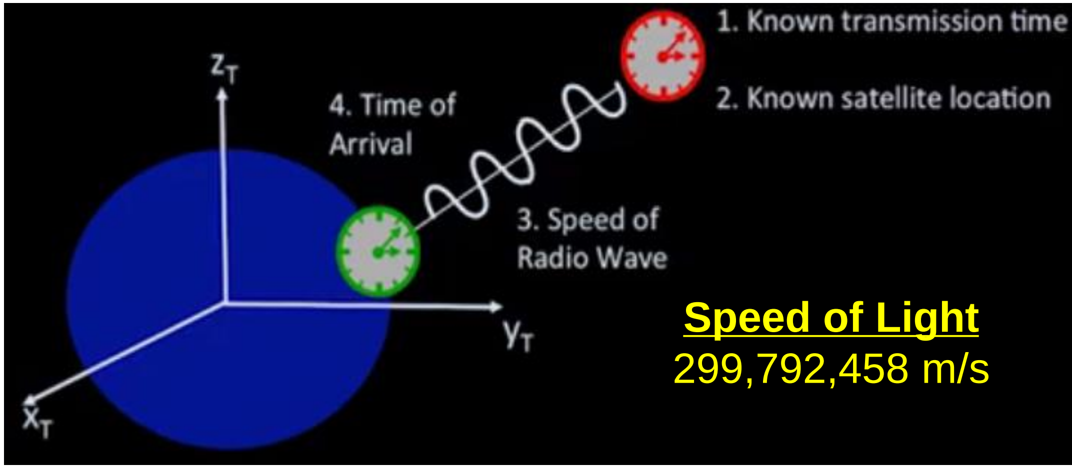
Overview

GNSS – Foreword

- GNSS is impacting us in ways that we do not even know about...
- GNSS applications are innumerable and incredible
- There's a GNSS supported application for just about everything....
- The applications are limited only to our imagination…

GNSS Overview

- A system used to find the location of a user's receiver anywhere on or above the Earth.
- Receivers determine the **Position** (latitude, longitude, altitude), **Velocity** and **Time** (PVT) by using signals from satellites
- Receivers do not require to transmit and operates independently of any cellular or Internet reception



Distance = Velocity x Time

Trilateration

Implementation require *incredible precision* and state of the art multidimensional cluster of technologies

Global Navigation Satellite Systems

GPS (NAVSTAR)

(Global Positioning System)

GLONASS

(Globalnaya Navigatsionnaya Sputnikovaya Sistema)

BeiDou2

(Běidǒu Wèixīng Dǎoháng Xìtǒng)

Fully Operational And Globally Available

Galileo

(Galileo Satellite Navigation)

Near to achieve FOC Global Coverage

Regional Satellite Navigation Systems

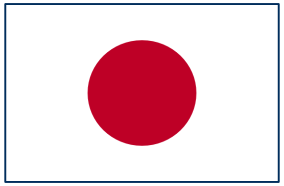
NavIC or IRNSS

Nav with Indian Constellation

3 x Geo St
4 x G Sync

QZSS (Michibiki)

Quasi Zenith Satellite System

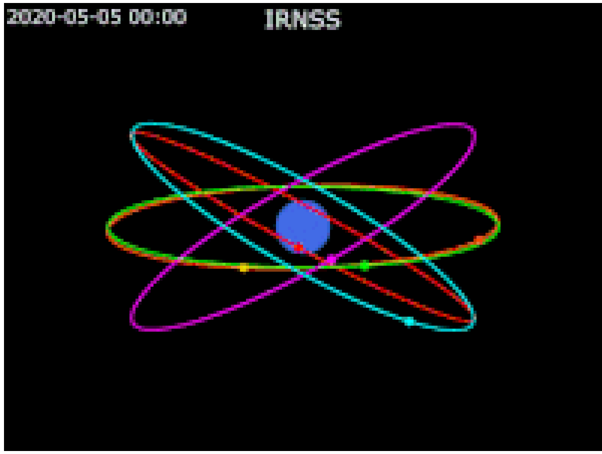


Incl HEO and Geo Orbiting Satellites

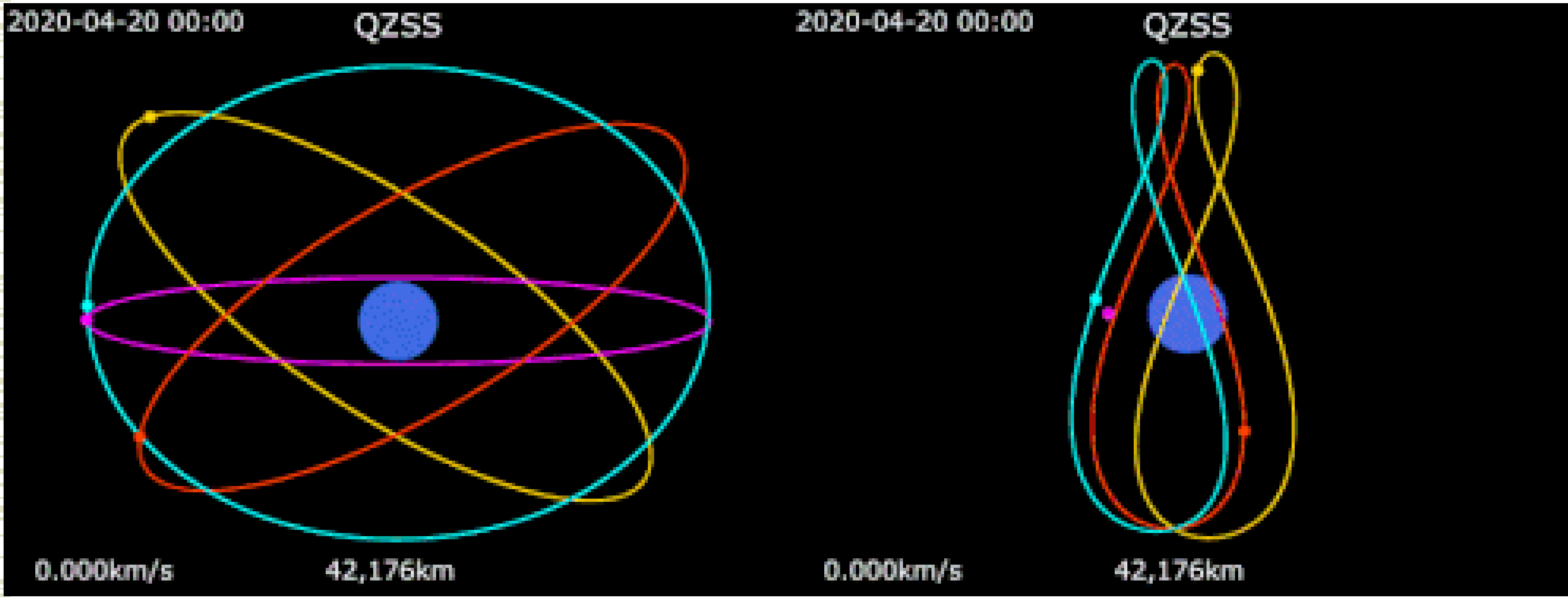
- 1 Geo and 3 HEO geosynchronous orbits.
- Ground traces are asymmetrical figure-8 patterns
- One is almost directly overhead (elevation > 70°) over Japan at all times.

Geo-Stationary Satellites

Orbital Period	=	23.934461223 h
Orbital Velocity	=	3074.6 m/s
Orbital Radius	=	42,164 km



Highly Elliptical – Geosynchronous Orbits

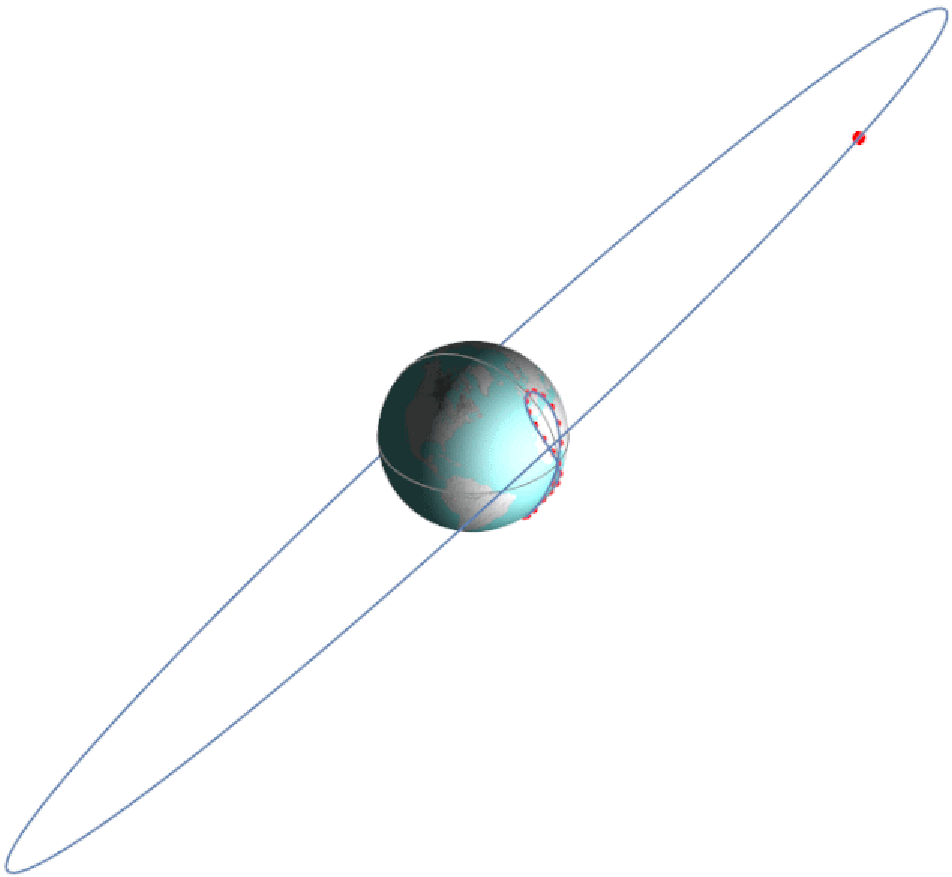


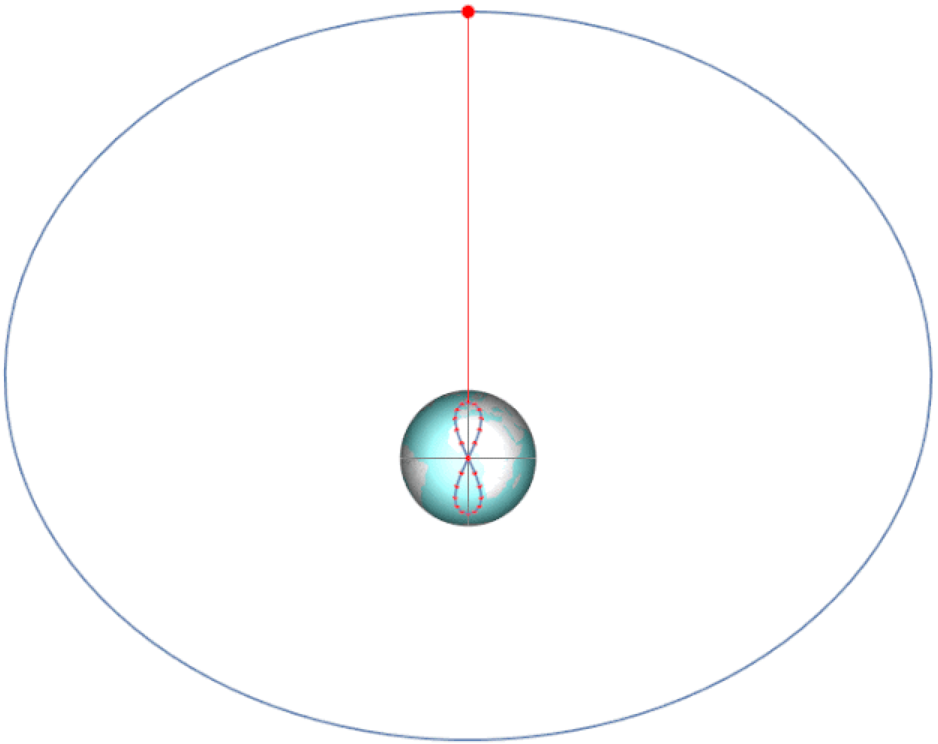
Around the Earth - Oblique view

Earth fixed frame - Equatorial view, front

Earth · QZS-1 · QZS-2 · QZS-3 · QZS-4

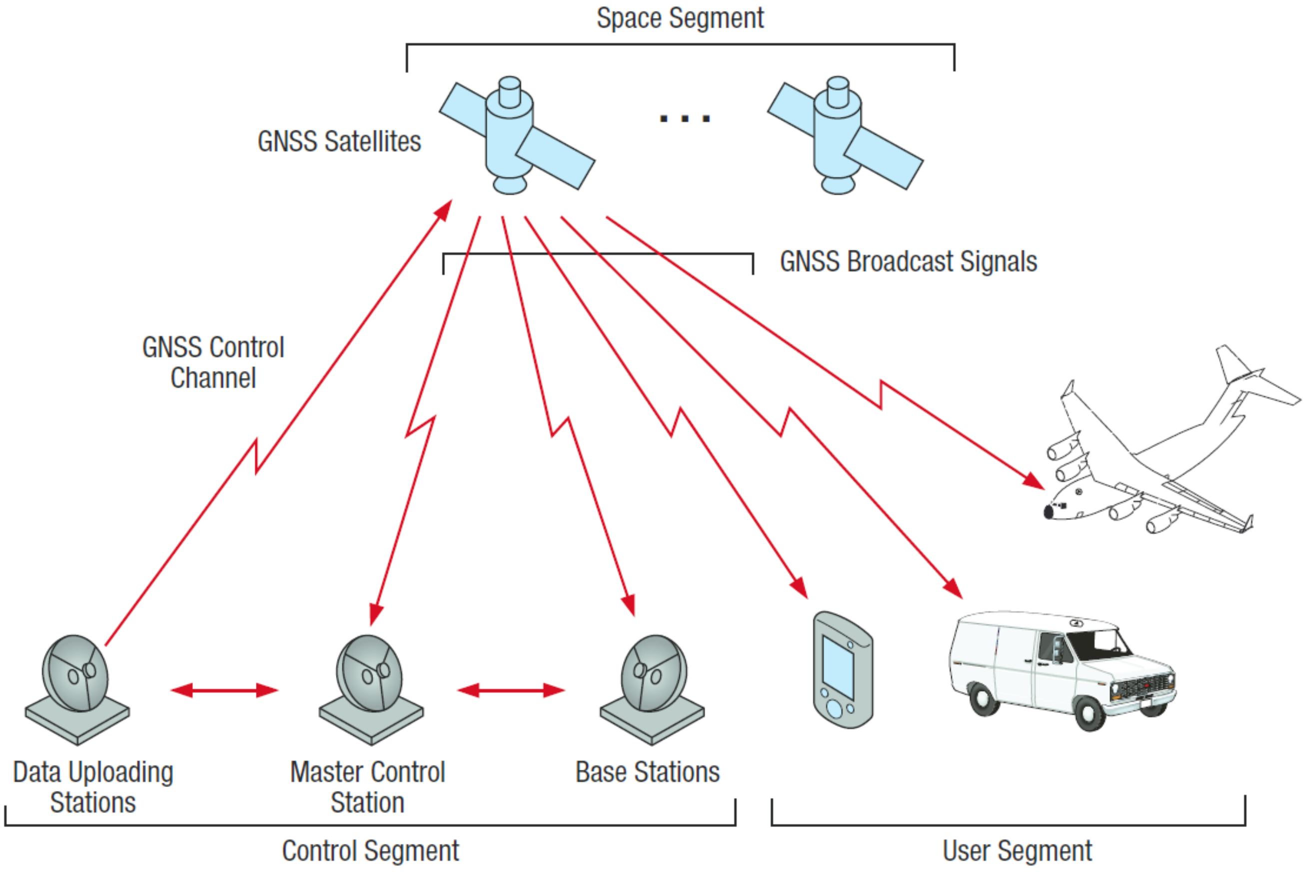
Highly Elliptical – Geosynchronous Orbits





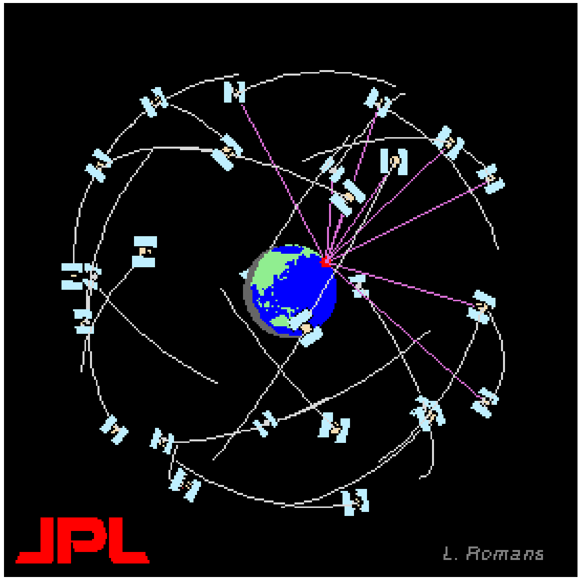
GNSS Architecture

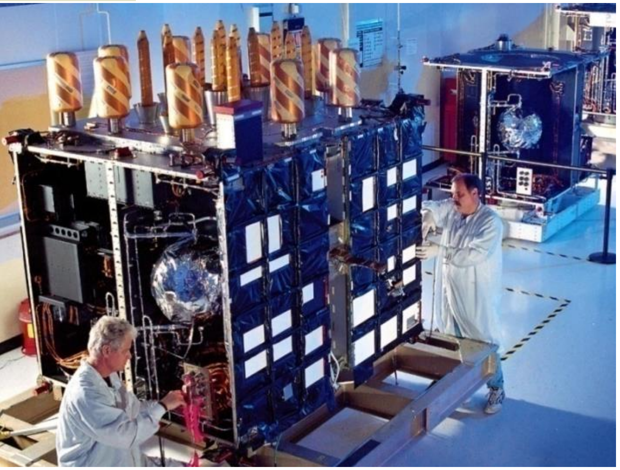
- Space Segment
- Control Segmen
- User Segment



Space Segment

- All GNSS have their own constellation of MEO **satellites** with Orbiting Altitude: 20,000~24,000km
- Have VERY accurate **clocks** on board Rubidium Clock (±5 parts in 10^{-11})
- Transmit radio signals.
- Satellite ephemerides & time is known and controlled by ground-based control





Clocks on the satellites run *38 μs faster per day* than the clocks on the Earth.

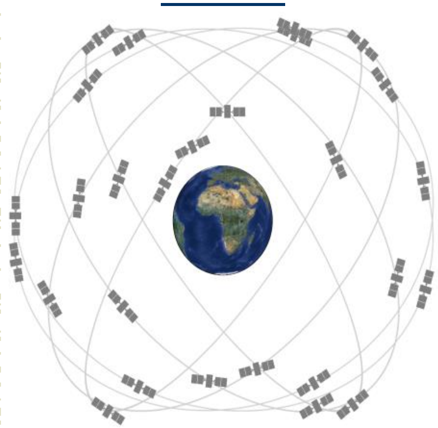
Satellites

Approx Weight : 1500 Kg

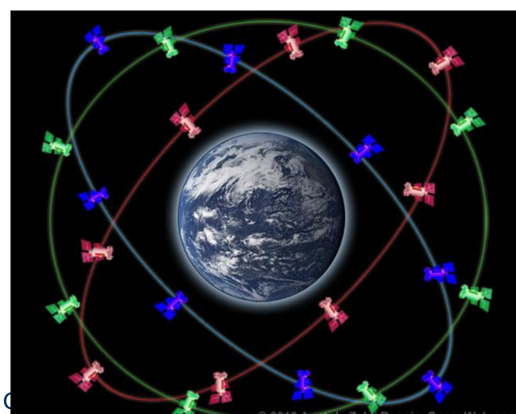
- The time taken by GNSS signal to travel from satellites to receiver is used to determine distances
  - Error of 1 µS will cause 300m error in position
  - Error of 1 nS will cause 30 cm error in position

- By Collecting Distance information from multiple ground stations, the coordinates of any satellite at any time can be calculated

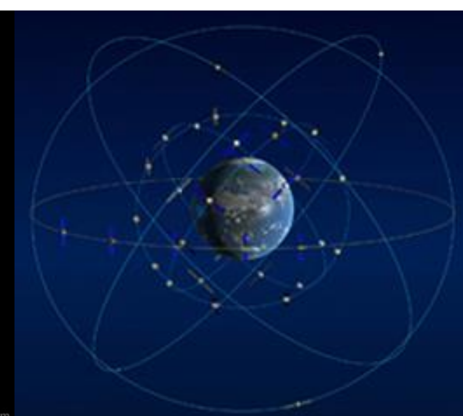
GPS



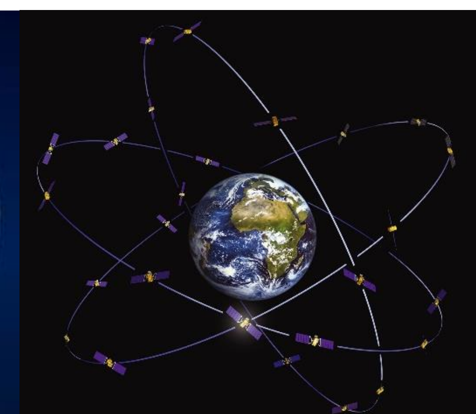
GLONASS



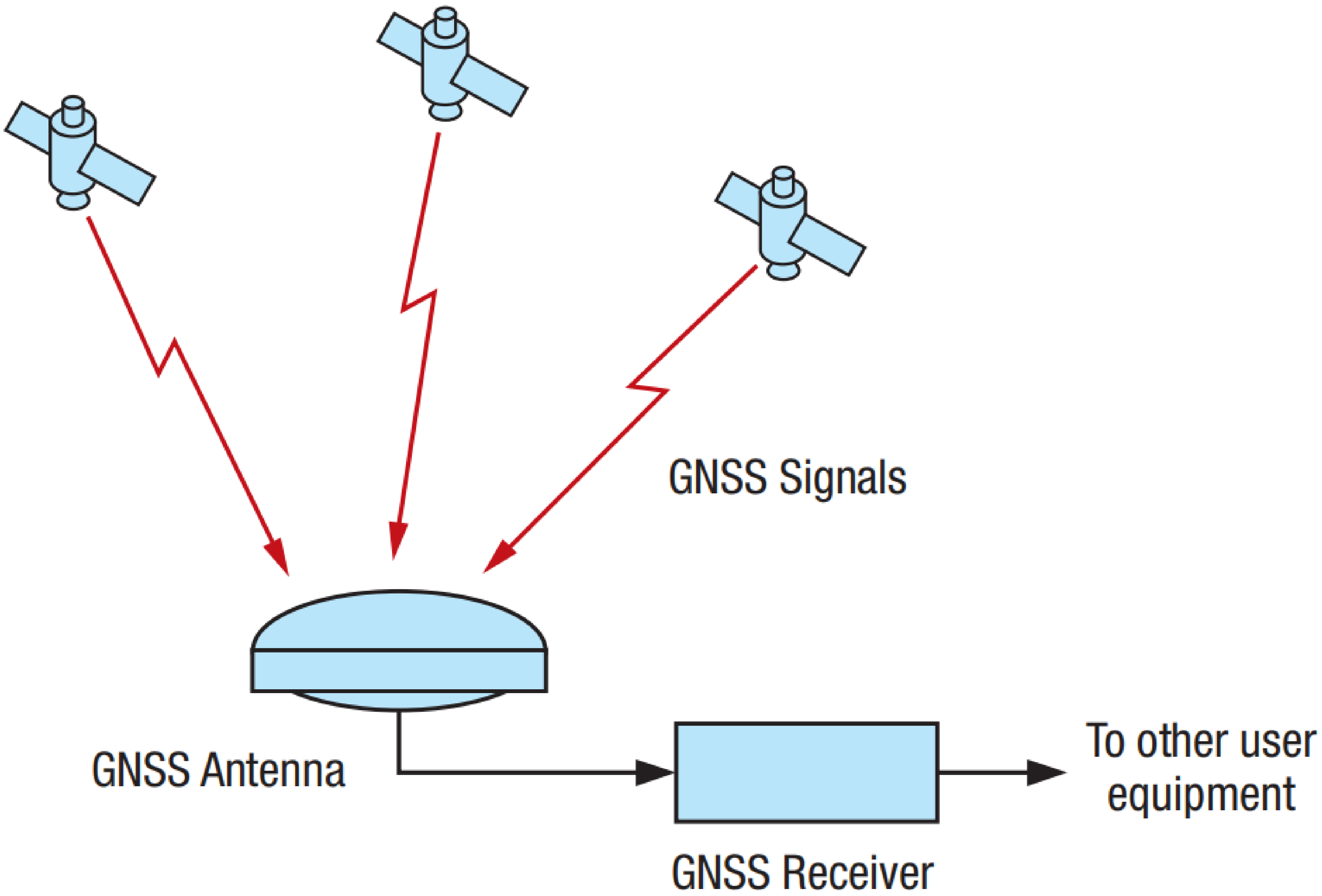
BEIDOU



GLILEO



Satellites


GNSS Signals
GNSS Antenna
GNSS Receiver
To other user equipment

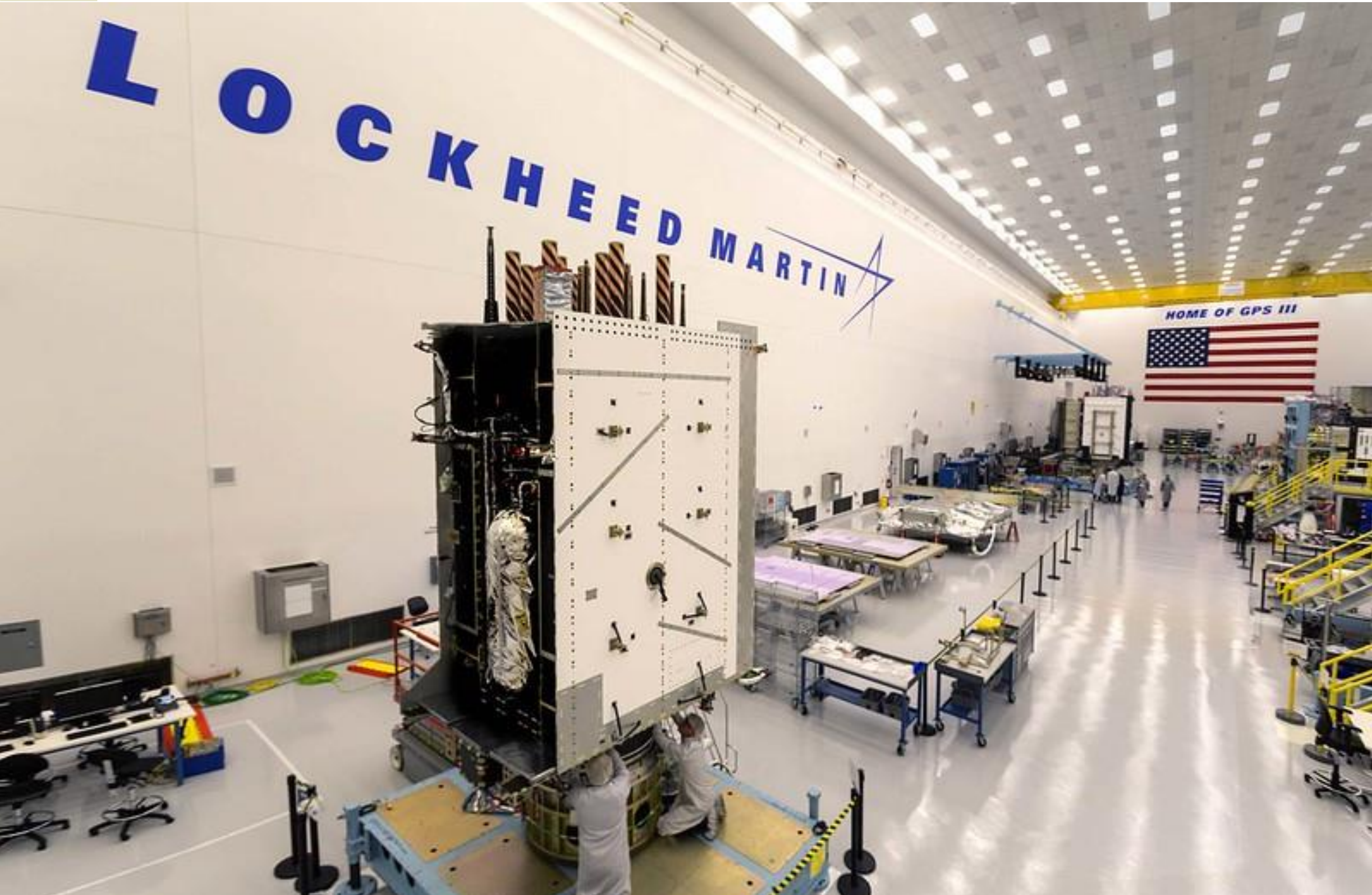
GPS-III Satellites

GPS-III Satellites

GPS-III Satellites

GPS-III Satellites

GPS-III Satellites



GPS-III Satellites

GPS-III Satellites

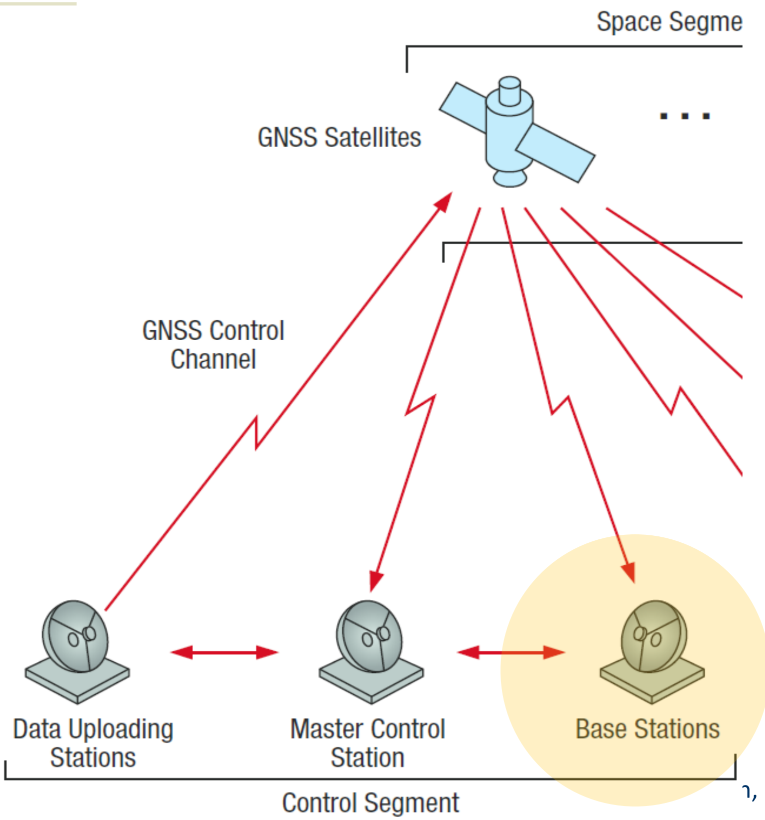
GPS-III Satellites

GPS-III Satellites

Control Segment

Base Stations / Monitor Stations

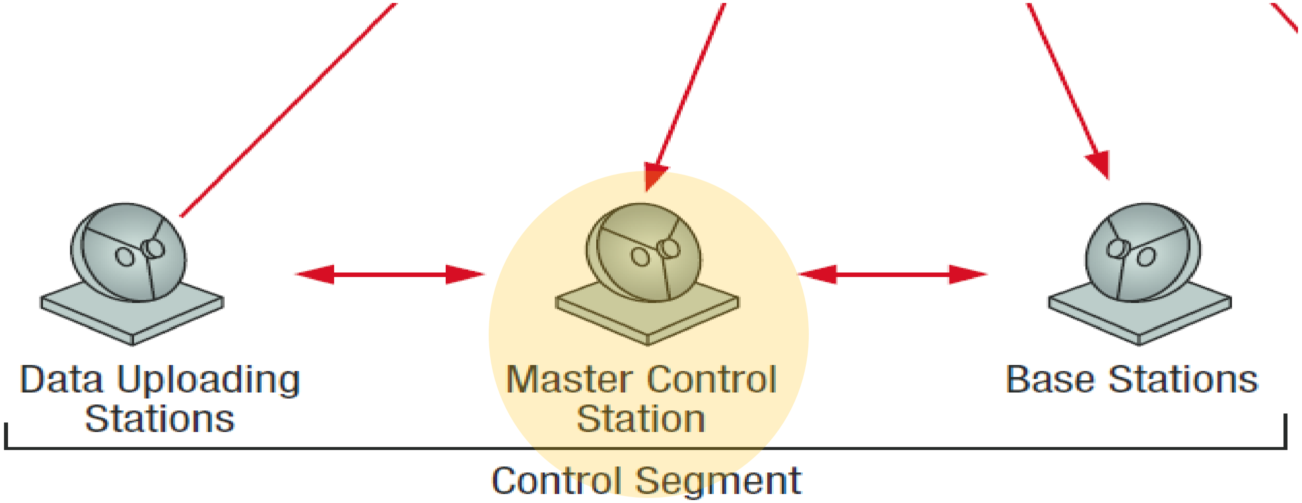
- Have precise receivers installed over a broad geographic area (16 Sites)
- Track satellites & Collect Nav signals, and atmospheric data
- Feed observations to the master control station



Control Segment

Master Control Station

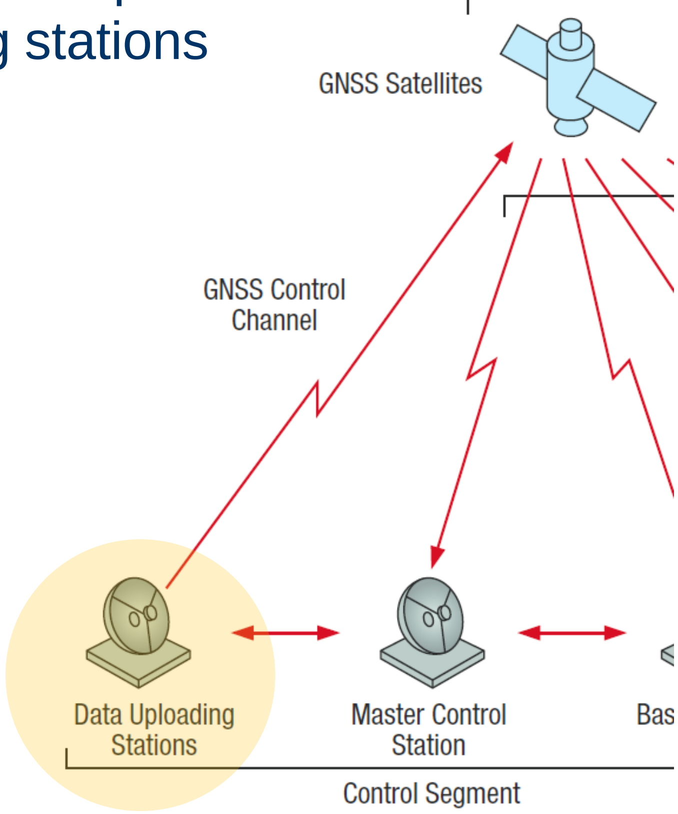
- Using data from monitor stations computes satellites' ephemerides, generates Nav Messages incl orbit and time corrections) for upload to the satellites
- Monitors *satellite broadcasts accuracy* and *system integrity*
- Performs Satellite maintenance, anomaly resolution, repositioning
- Backed up by a fully operational alternate master control station



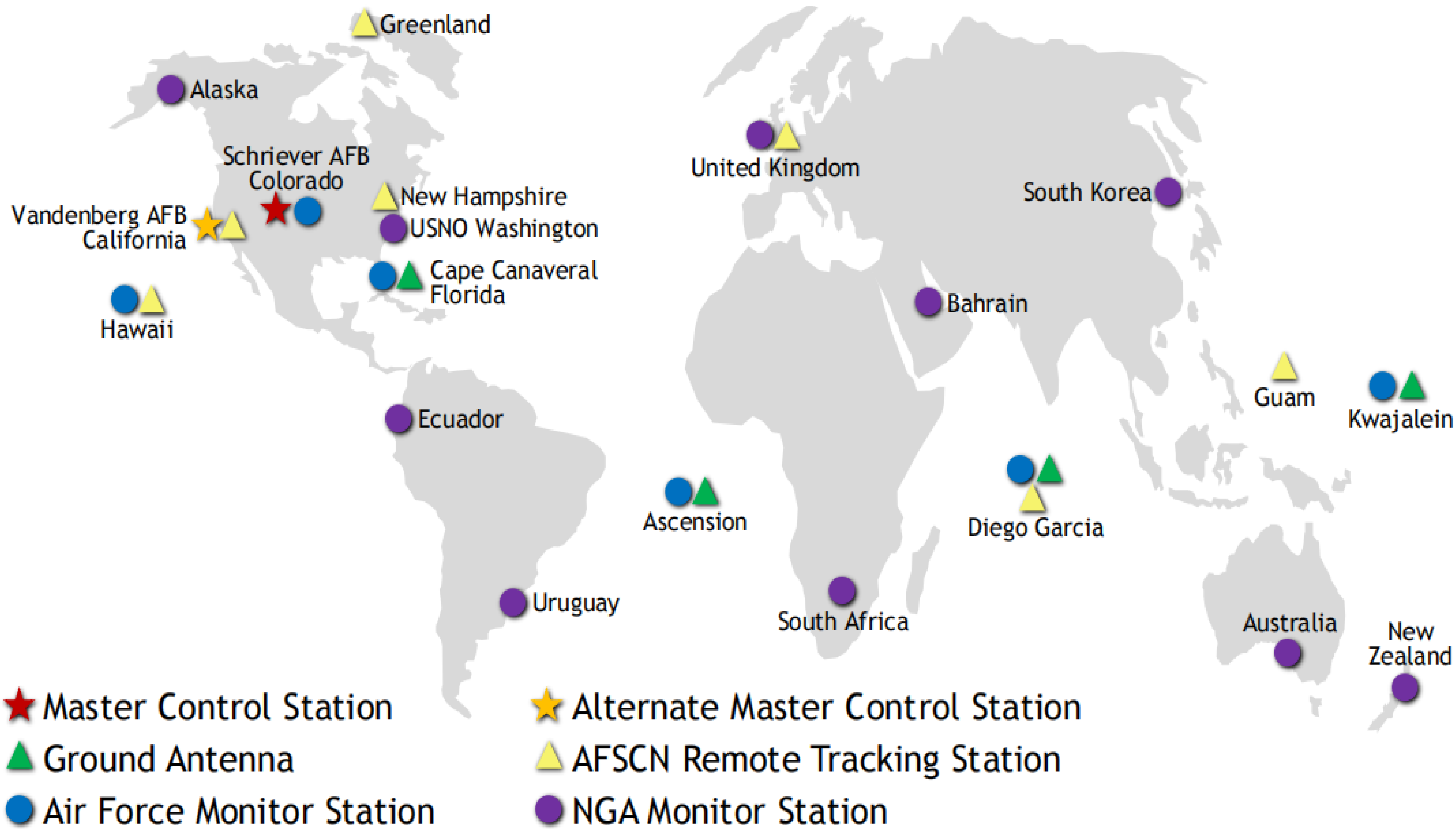
Control Segment

Ground Antennas / Uploading Stations

- Send commands and navigation data to the satellites
- Perform ranging to provide anomaly resolution
- Consist of 4 dedicated GPS ground antennas plus 7 Air Force Satellite Control Network (AFSCN) remote tracking stations



Control Segment



User Segment

- GNSS **antennas** receive signals from satellites and send to the **receivers** to determine information (position, velocity, and time)
- The GPS receiver knows how long signal from each satellite is taking to reach the receiver.
- Select optimally positioned satellites and measures pseudoranges and pseudorange rates corresponding to each satellite.
- A receiver is often described by its number of channels (No of satellites it can monitor simultaneously)

User Segment

The U.S. government controls the export of some civilian receivers.

- GPS receivers capable of functioning above 18 km altitude
- Speed > 515 m/s
- Designed or modified for use with unmanned vehicles like, ballistic or cruise missile systems, are classified as munitions (weapons)

Require State Department export licenses.



GNSS Receivers Modernization

Continue to get better and better

- Better antennae,
- Efficient power consumption,
- Smaller size
- Increasingly more **"bells & whistles"** (maps, hard drives, cameras, etc.)
- New bells + whistles keeps prices fairly stable...

Tracker Enhanced Receivers

A *tracker combines sets of satellite measurements collected at different times*

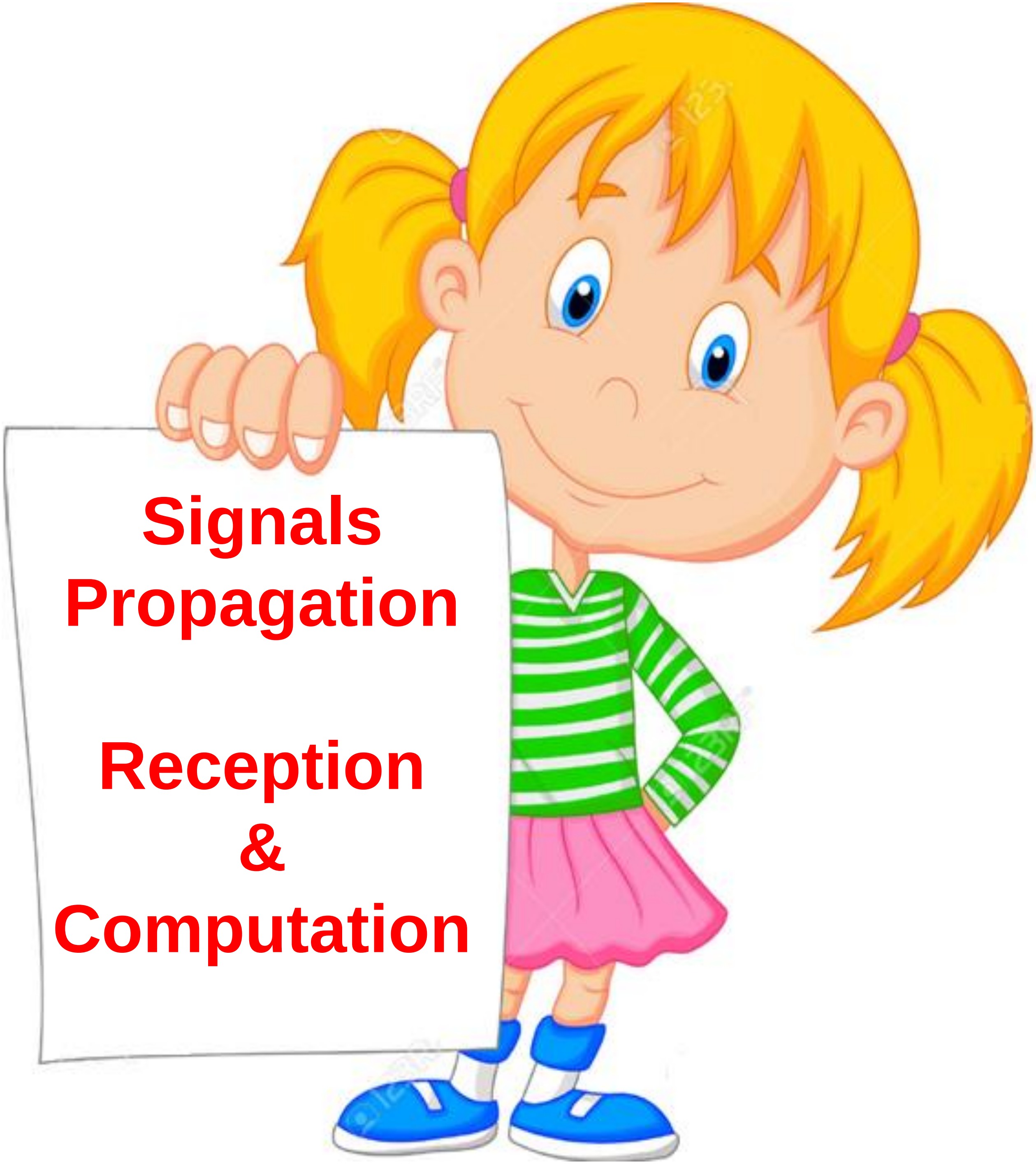
Successive receiver positions are usually close to each other.

Tracker predicts the receiver location corresponding to the next set of satellite measurements.

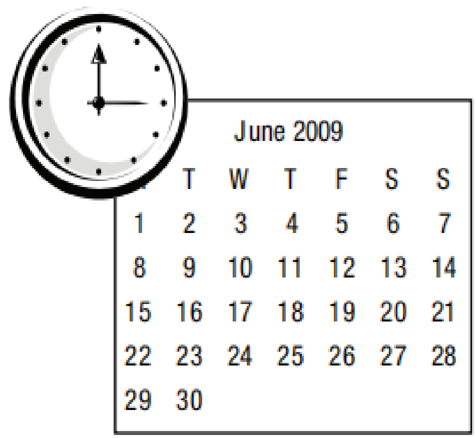
Receiver uses a weighting scheme to combine the new measurements with the tracker prediction.

A tracker can:

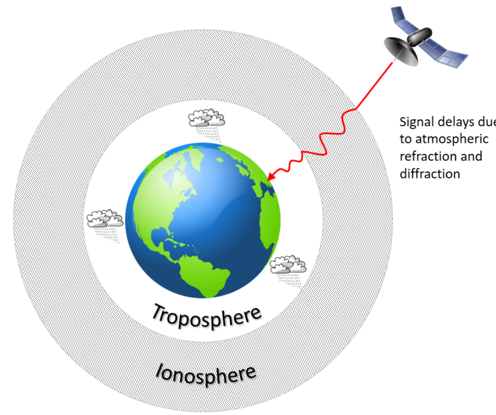
- improve receiver position and time accuracy
- reject bad measurements
- estimate receiver speed and direction.

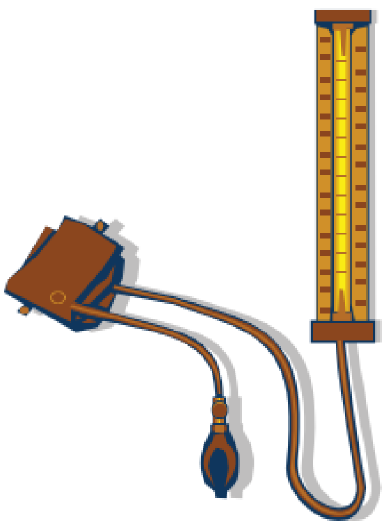

Signals
Propagation
Reception
&
Computation

Navigation Message from Satellites

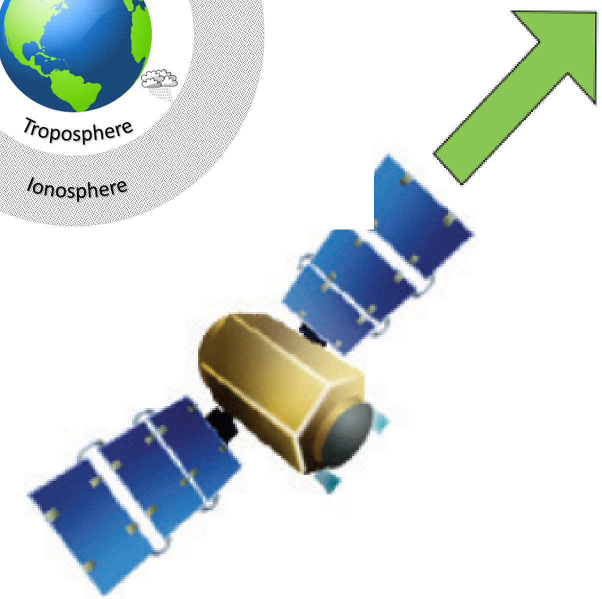


GPS Date and Time





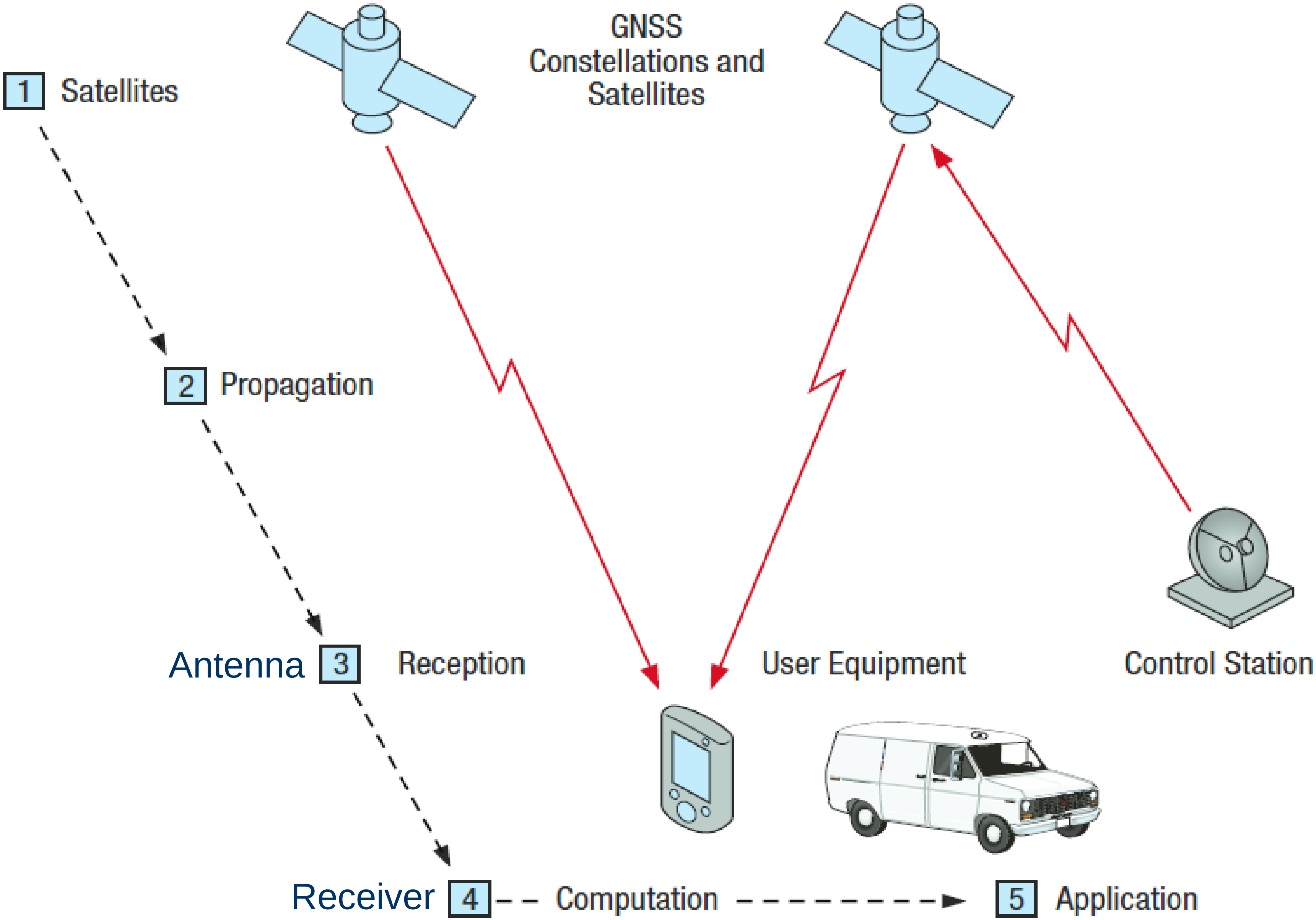
Satellite Status and Health



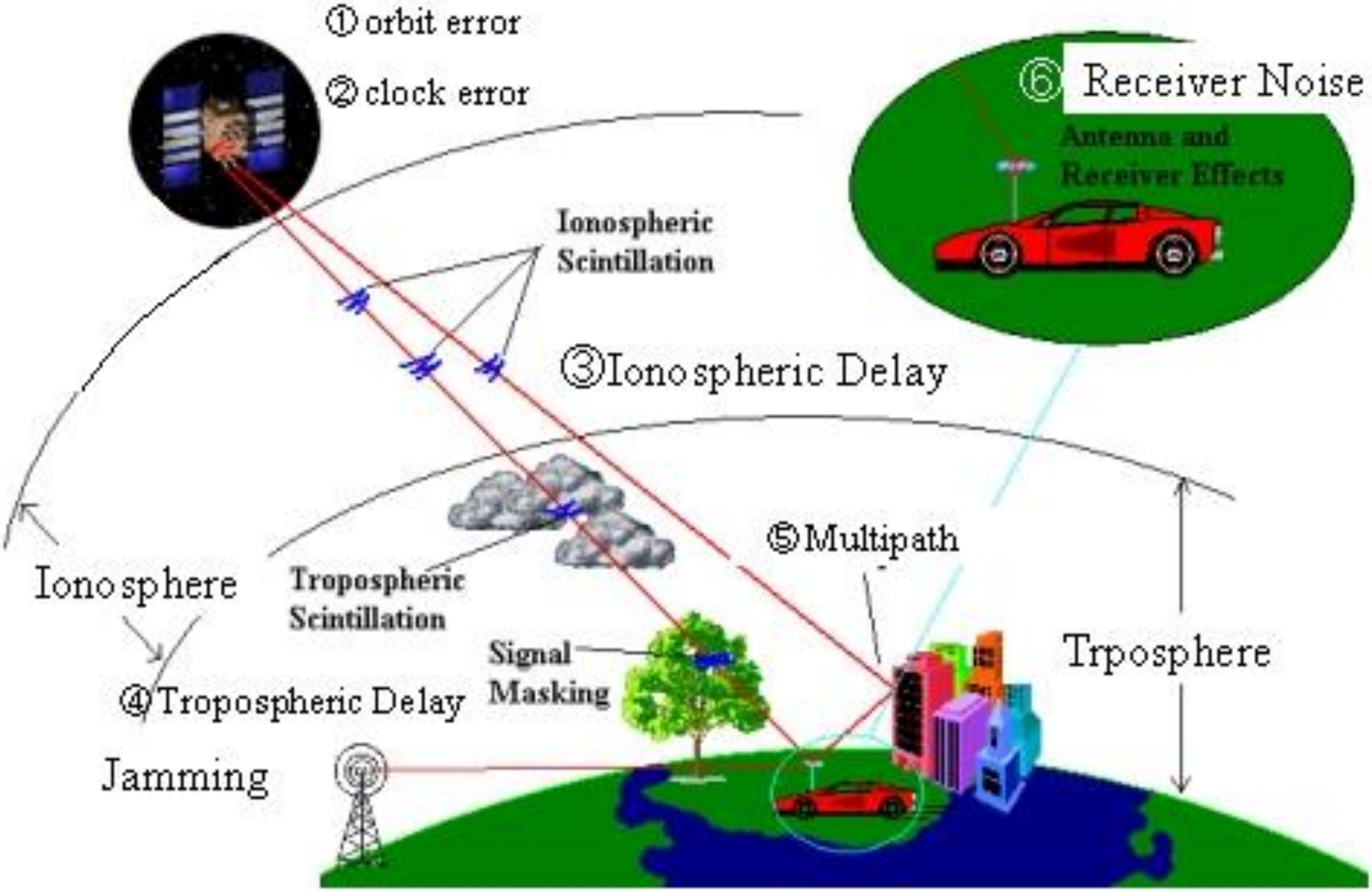
Satellite Ephemeris Information

Almanac (information about other satellites in the constellation)

Transmission to Application

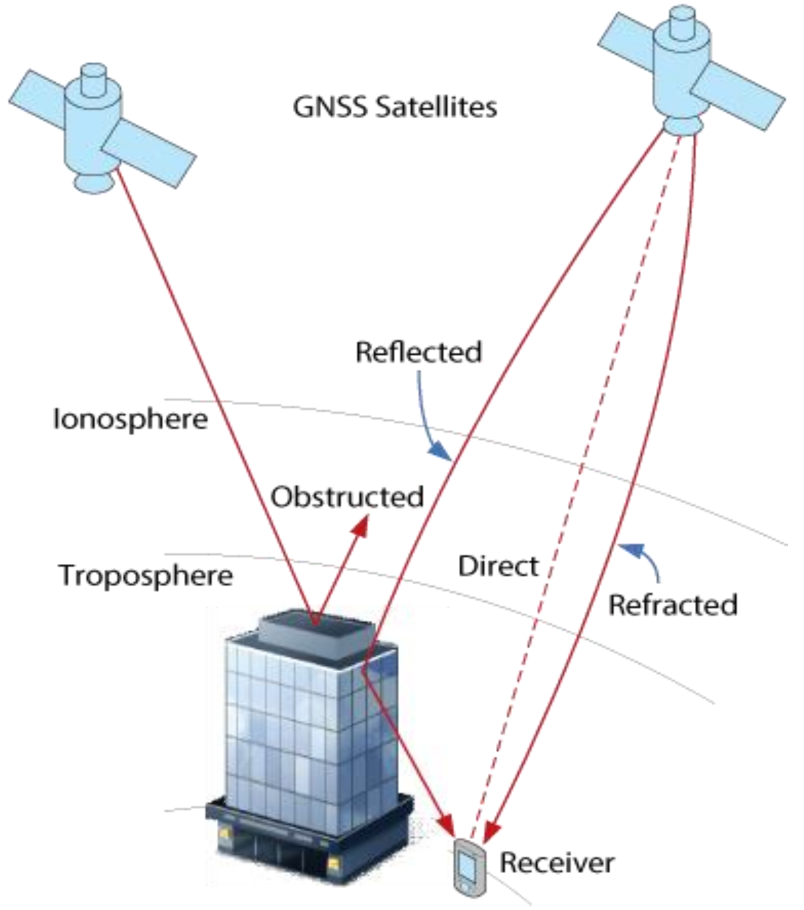


Signals Propagation and Errors



Signals Propagation and Errors

- Receiver needs to know the range to the satellite.
- The signal will bend while traveling through the earth's atmosphere
- Bending increases the time signal takes to travel from the satellite to the receiver
- Computed range contains errors and is not exactly equal to the actual range, therefore called as "pseudorange"

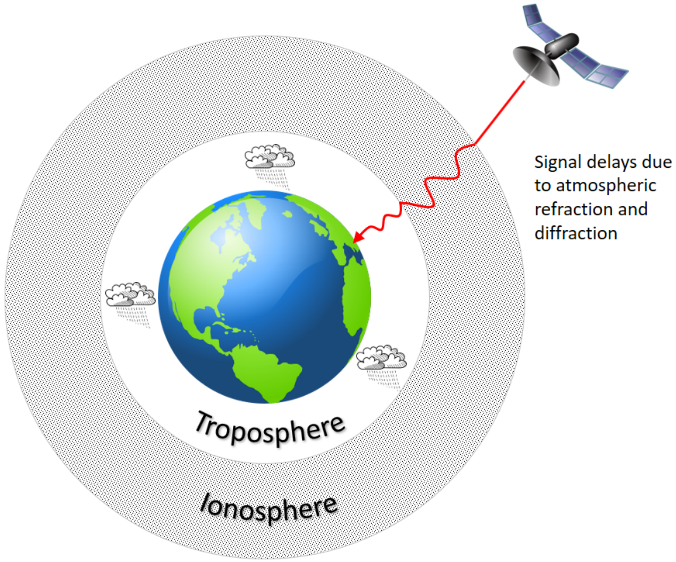


Positional Errors

Contributing Source	Error Range
Satellite clocks	±2 m
Orbit errors	±2.5 m
Ionospheric delays	±5 m
Tropospheric delays	±0.5 m
Receiver noise	±0.3 m
Multipath	±1 m

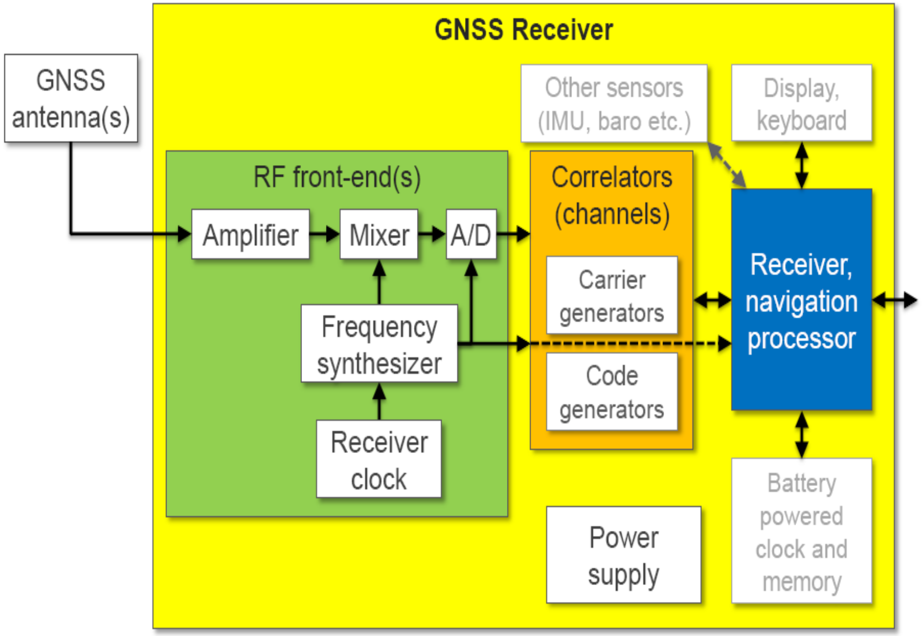
Signals Propagation and Errors

- The ionosphere contributes to most of errors, where free electrons effect electromagnetic wave propagation
- Ionospheric delays being frequency dependent, are significantly eliminated by using both **L1 and L2**
- The troposphere contributes to delays due to variations in local temperature, pressure and relative humidity



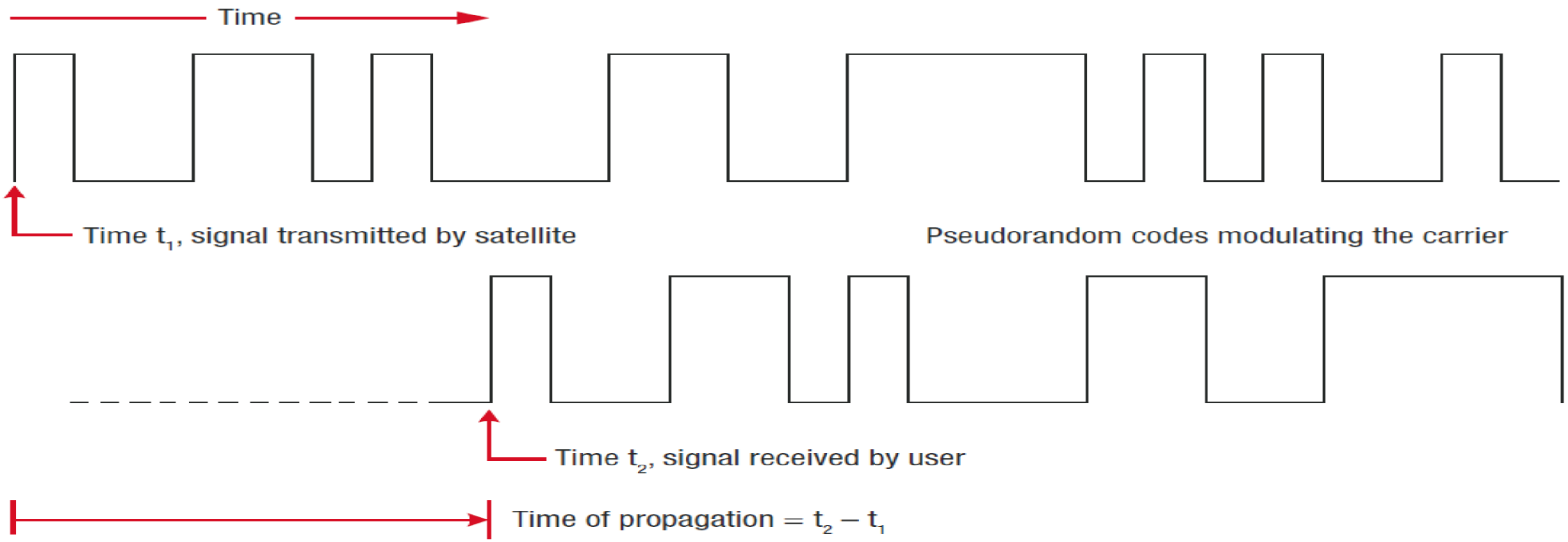
Reception

- 4 satellites req to compute position. If more are in view solution is improved
- GNSS signals from each satellite are modulated by a unique ***Pseudo-Random Number*** (PRN).
- Receivers can recognize PRN code and **CORRELATE** the signal to a particular satellite
- Through code correlation, the receiver recover the signal and the information

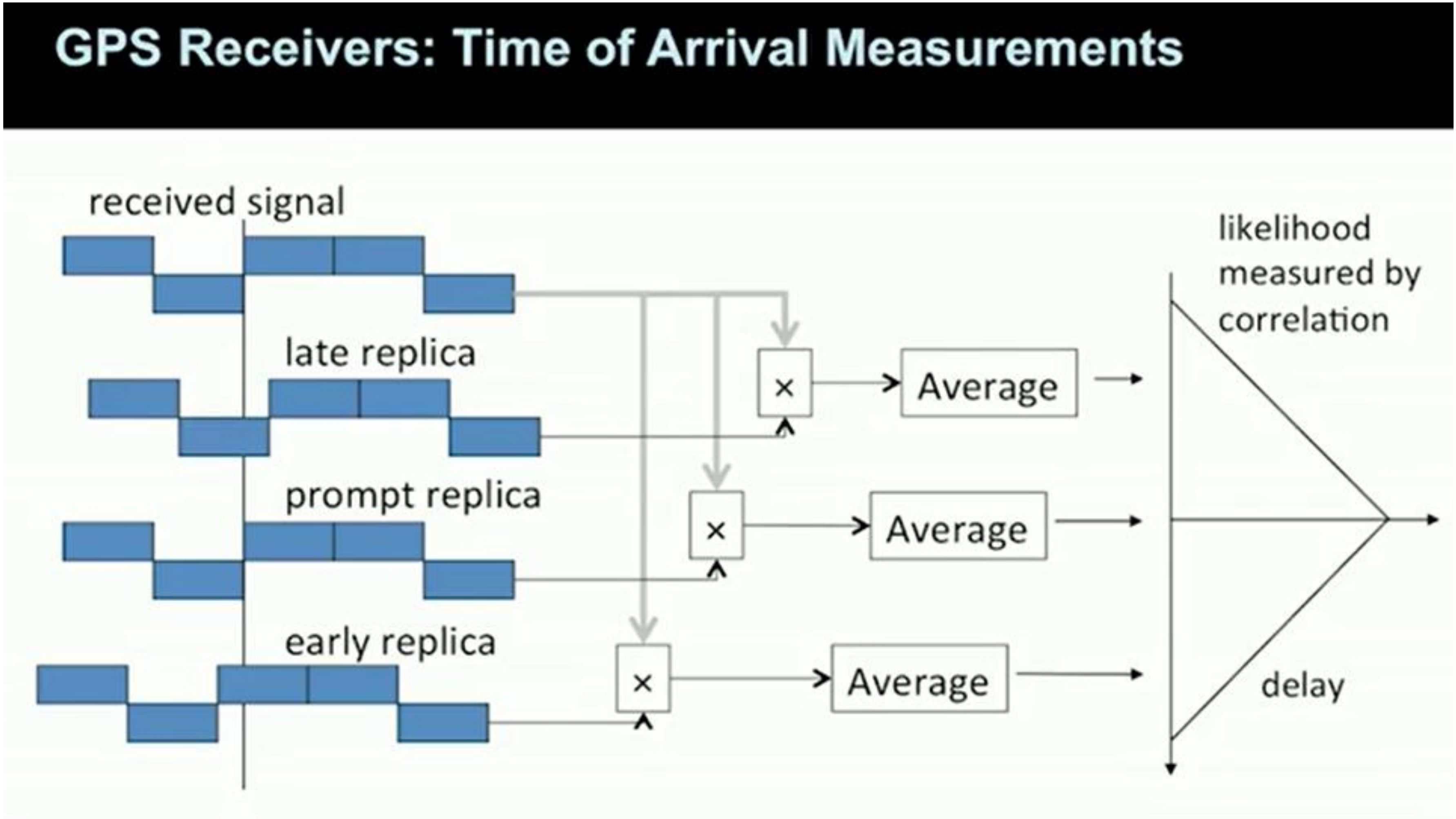


Reception

- For each satellite tracked, receiver determine the time of propagation by differencing the **transmit time** to the **receive time**



Reception


GPS Receivers: Time of Arrival Measurements
received signal
late replica
prompt replica
early replica
×
×
×
Average
Average
Average
likelihood
measured by
correlation
delay

Computation

- Ranges from 4 satellites are needed to determine position
  - Propagation Time = Time Signal Reached Receiver (Tr) – Time Signal Left Satellite ($\boldsymbol{T_T}$)
  - Propagation Time =$\Delta \boldsymbol{T}$= $\boldsymbol{T_R - T_T}$
  - Distance to Satellite = C ***x*** $\Delta \boldsymbol{T}$
- Receiver knows where the satellite *was at the time of transmission* through orbit ephemerides sent by the Satellite
- **Trilateration:-** the receiver calculates its position with respect ECEF.

Pseudorange and Position Computation

$$\rho = r + c\Delta t_u$$

$$\rho_i = \sqrt{(x - x_{si})^2 + (y - y_{si})^2 + (z - z_{si})^2} + c\Delta t_u$$

$$r = \begin{bmatrix} x & y & z \end{bmatrix}^T$$ Is the true position of the receiver to be computed

$$\rho_1 = \sqrt{(x - x_{s1})^2 + (y - y_{s1})^2 + (z - z_{s1})^2} + c\Delta t_u$$

$$\rho_2 = \sqrt{(x - x_{s2})^2 + (y - y_{s2})^2 + (z - z_{s2})^2} + c\Delta t_u$$

$$\rho_1 = \sqrt{(x - x_{s3})^2 + (y - y_{s3})^2 + (z - z_{s3})^2} + c\Delta t_u$$

$$\rho_1 = \sqrt{(x - x_{s4})^2 + (y - y_{s4})^2 + (z - z_{s4})^2} + c\Delta t_u$$

Pseudorange and Position Computation

ρ = pseudorange; r =true range; c= speed of light;

T_r=time of signal reception; T_t=time of signal transmission

ρ_i= Measurement of the Pseudoranges to the ith satellite

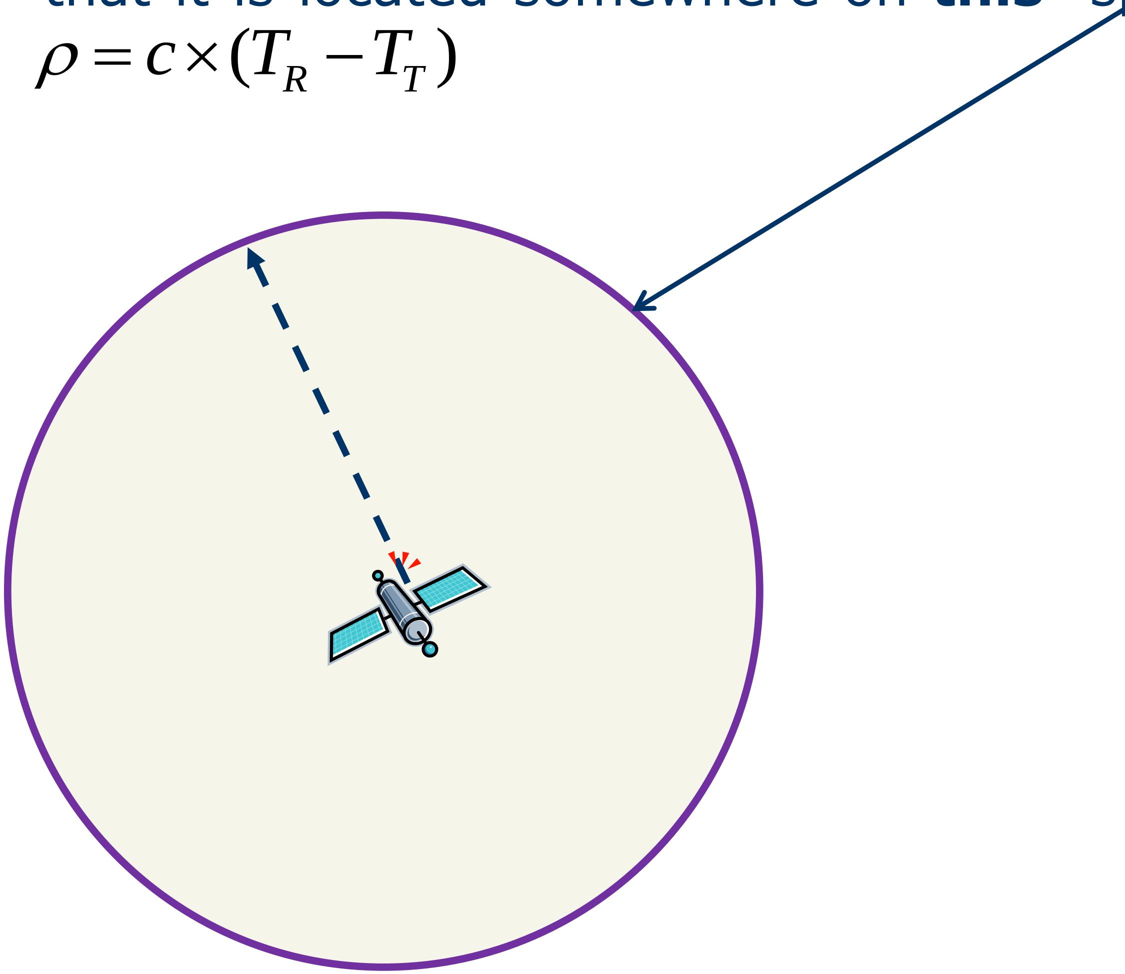
$(x_{si} \quad y_{si} \quad z_{si})$=Position of the satellite (known)

Δt_u = Clock offset (unknown)

x, y, z,Δt can be solved from Navigation Equation (Simultaneous Sol of 4 equation of Pseudoranges)

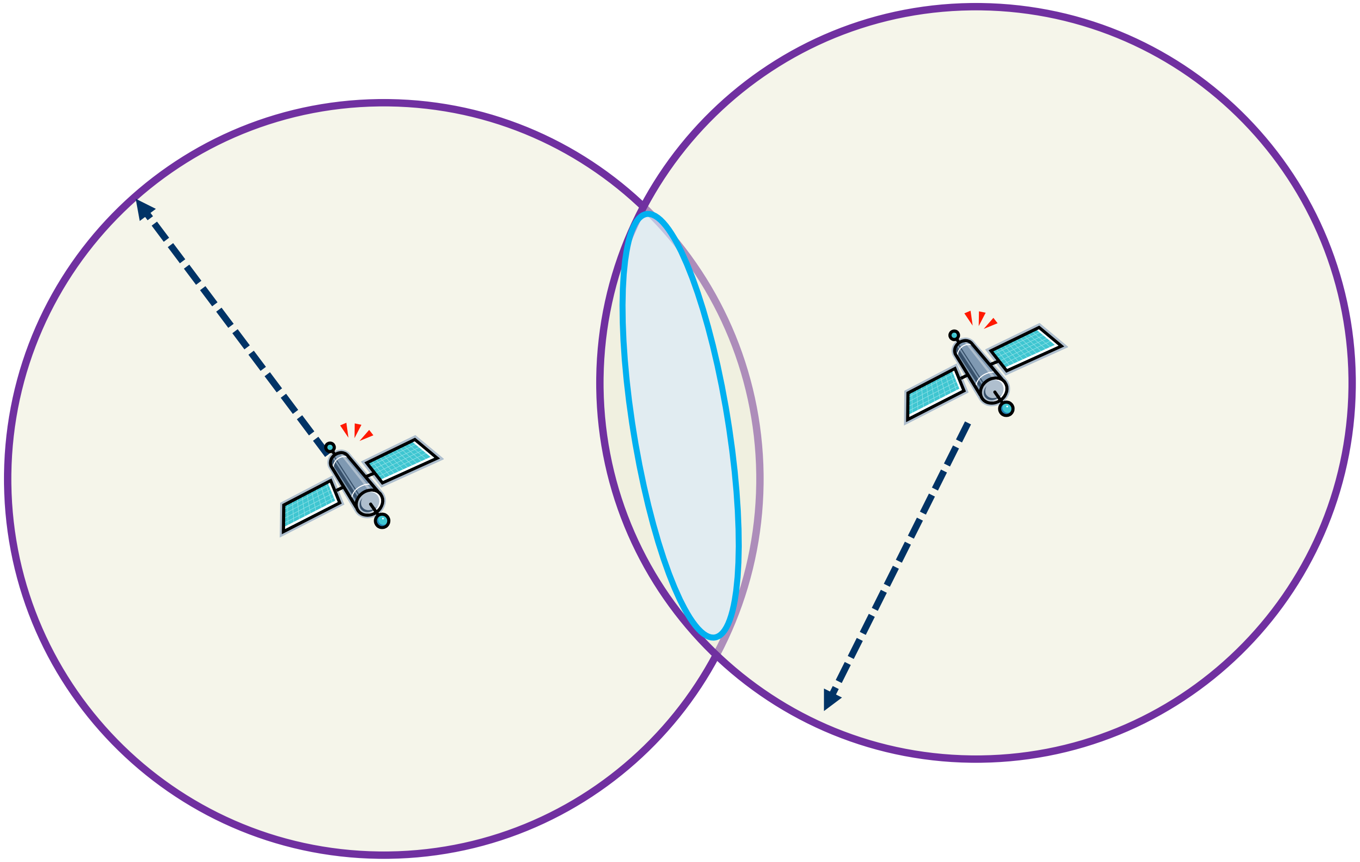
Computation - Trilateration in 3D

If the GNSS receiver acquire signals only from 1 Satellite, it "knows" that it is located somewhere on **this** sphere with a radius $\rho = c \times (T_R - T_T)$



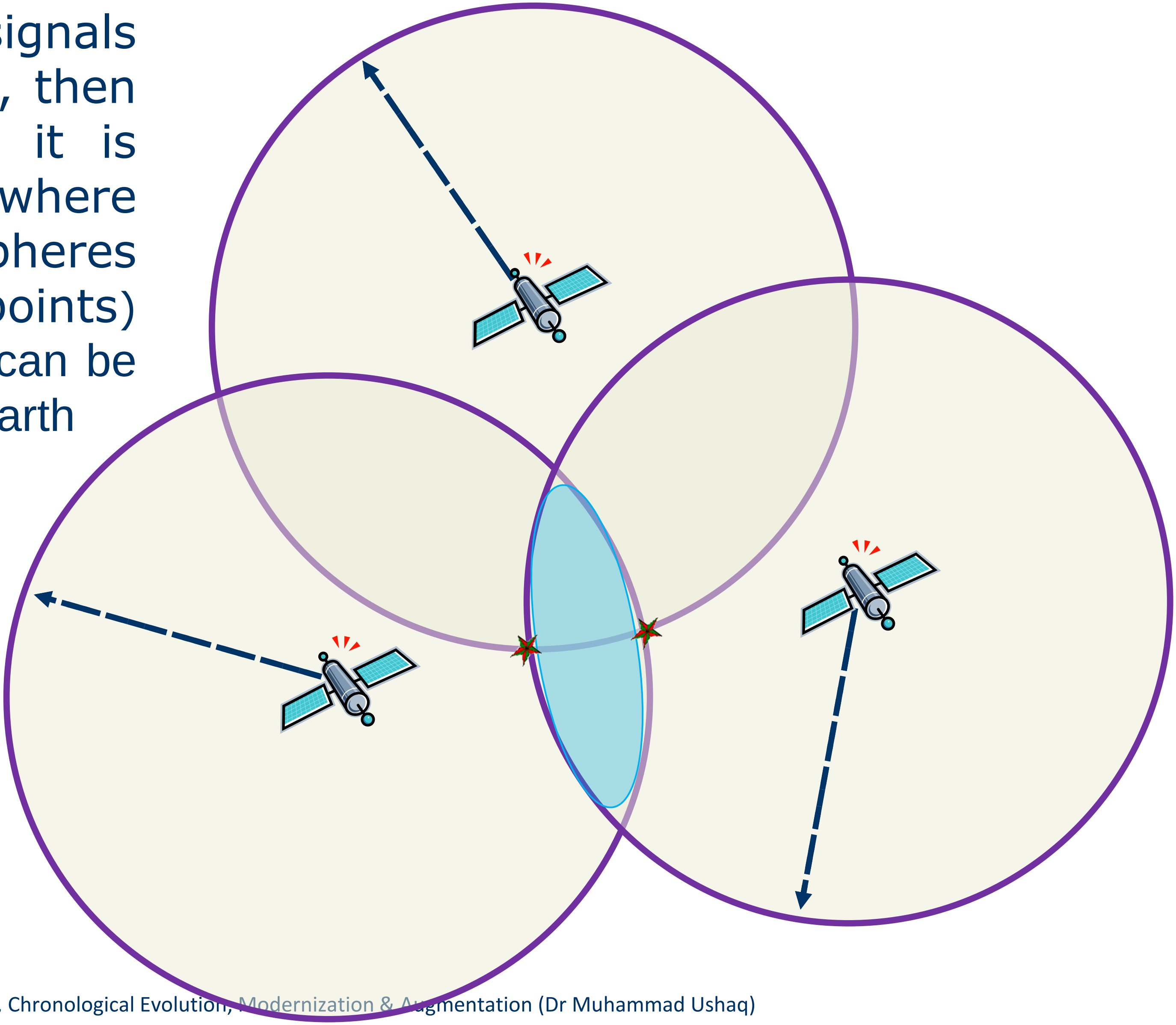
Computation - Trilateration in 3D

If receiver obtains signals from 2 satellites, then it **knows** that it is located somewhere these 2 spheres intersect (Circle)



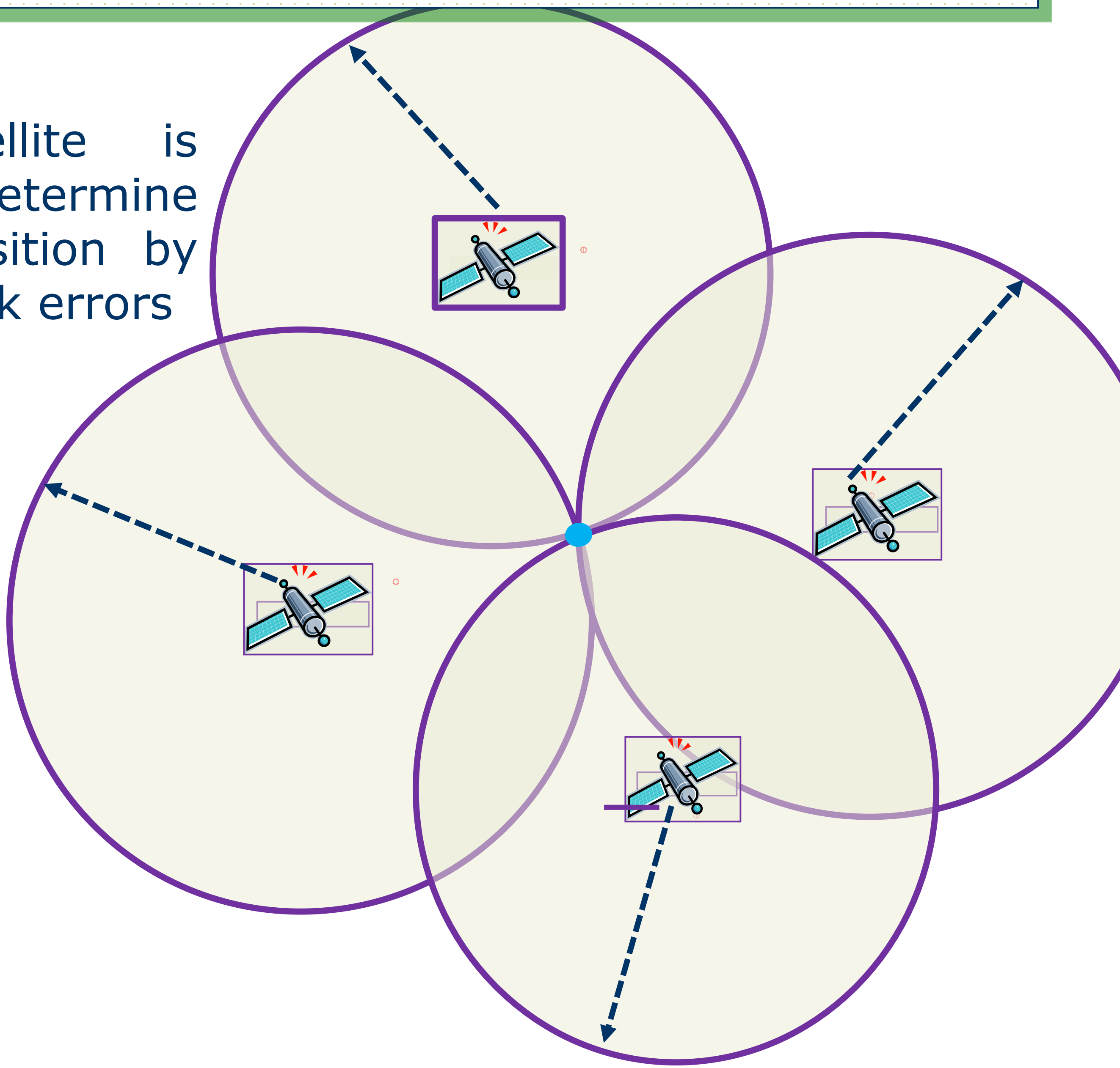
Computation - Trilateration in 3D

If receiver gets signals from 3 satellites, then it "knows" that it is located somewhere these 3 spheres intersect (2 points) only one of these can be on surface of the Earth



Computation - Trilateration in 3D

A fourth satellite is required to determine nearly exact position by adjusting the clock errors



Components of Ephemeris Data

Term	Description	Unit
t_{0e}	Reference time of ephemeris	Second
$\sqrt{a}$	Square root of semimajor axis	$\sqrt{\text{meter}}$
e	Eccentricity	Dimensionless
i_0	Inclination angle (at time t_{0e})	Semicircle
Ω_0	Longitude of the ascending node (at weekly epoch)	Semicircle
ω	Argument of perigee (at time t_{0e})	Semicircle
M_0	Mean anomaly (at time t_{0e})	Semicircle
$IDOT$	Rate of change of inclination angle (i.e., di/dt)	Semicircle/s
$\dot{\Omega}$	Rate of change of longitude of the ascending node	Semicircle/s
Δn	Mean motion correction	Semicircle/s
C_{uc}	Amplitude of cosine correction to argument of latitude	Radian
C_{us}	Amplitude of sine correction to argument of latitude	Radian
C_{rc}	Amplitude of cosine correction to orbital radius	Meter
C_{rs}	Amplitude of sine correction to orbital radius	Meter
C_{ic}	Amplitude of cosine correction to inclination angle	Radian
C_{is}	Amplitude of sine correction to inclination angle	Radian

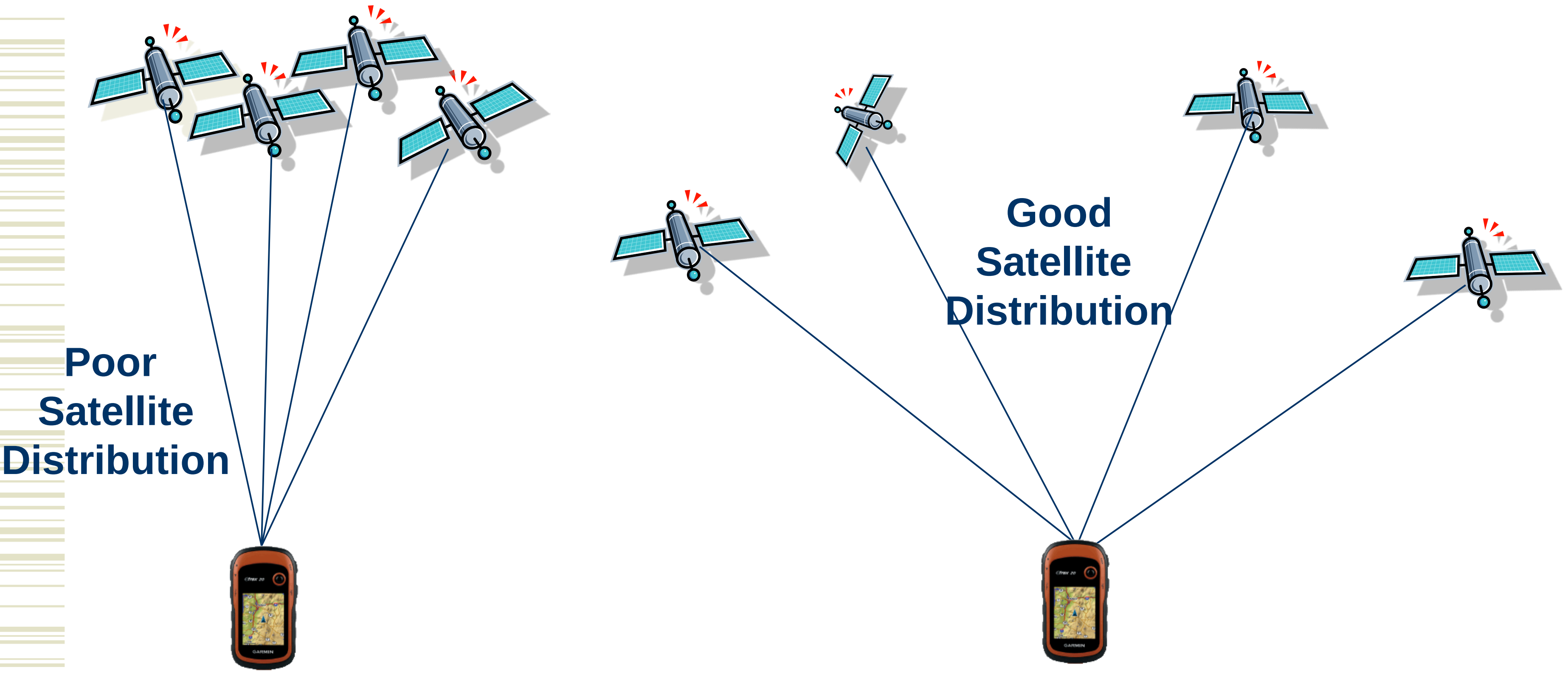
Algorithm for Computing Satellite Position

	$\mu = 3.986005 \times 10^{14}\ \text{m}^3/\text{s}^2$	WGS84 value of Earth's universal gravitational parameter
	$c = 2.99792458 \times 10^{8}\ \text{m/s}$	GPS value for speed of light
	$\dot{\Omega}_e = 7.2921151467 \times 10^{-5}\ \text{rad / s}$	WGS84 value of Earth's rotation rate
	$\pi = 3.1415926535898$	GPS value for ratio of circumference to radius of circle
1	$a = \left(\sqrt{a}\right)^2$	Semimajor axis
2	$n = \sqrt{\dfrac{\mu}{a^3}} + \Delta n$	Corrected mean motion (rad/s)
3	$t_k = t - t_{0e}$	Time from ephemeris epoch
4	$M_k = M_0 + (n)(t_k)$	Mean anomaly
5	$M_k = E_k - e\sin\ E_k$	Eccentric anomaly (must be solved iteratively for E_k)
6	$\sin v_k = \dfrac{\sqrt{1-e^2}\sin E_k}{1-e\cos E_k}$ $\cos v_k = \dfrac{\cos E_k - e}{1-e\cos E_k}$ $v_k = \text{atan2}\left[\dfrac{\sin v_k}{\cos v_k}\right]$	True anomaly (solve for in each quadrant)

7	$\phi_k = v_k + \omega$	Argument of latitude
8	$\delta\phi_k = C_{us} \sin(2\phi_k) + C_{uc} \cos(2\phi_k)$	Argument of latitude correction
9	$\delta r_k = C_{rs} \sin(2\phi_k) + C_{rc} \cos(2\phi_k)$	Radius correction
10	$\delta i_k = C_{is} \sin(2\phi_k) + C_{ic} \cos(2\phi_k)$	Inclination correction
11	$u_k = \phi_k + \delta\phi_k$	Corrected argument of latitude
12	$r_k = a(1 - e\cos E_k) + \delta r_k$	Corrected radius
13	$i_k = i_0 + (\mathrm{di/dt})t_k + \delta i_k$	Corrected inclination
14	$\Omega_k = \Omega_0 + \left(\dot{\Omega} - \dot{\Omega}_e\right)(t_k) - \dot{\Omega}_e t_{0e}$	Corrected longitude of ascending node
15	$x'_k = r_k \cos u_k$	In-plane x position (ECI frame)
16	$y'_k = r_k \sin u_k$	In-plane y position (ECI frame)
17	$x_k = x'_k \cos\Omega_k - y'_k \cos i_k \sin\Omega_k$	ECEF x coordinate
18	$y_k = x'_k \sin\Omega_k + y'_k \cos i_k \cos\Omega_k$	ECEF y coordinate
19	$z_k = y'_k \sin i_k$	ECEF z coordinate

Dilution of Precision - DOP

- It is better for your receiver to get a fix from “distributed” satellites, then poorly distributed satellites.
- DOP is a numerical representation of satellite geometry, and it is dependent on the locations of satellites visible to the receiver.



GNSS Jamming & Interference

- Jamming devices are radio frequency transmitters which block, jam, or interfere with lawful communications, such as cell phone calls, text messages, GPS systems, and Wi-Fi networks.
- Jammers are illegal to market, sell, or use in the USA and EU
- GPS interference can come from a variety of sources, including radio emissions in nearby bands
- Jamming/Interference can be intentional or unintentional , and naturally occurring space weather.

Location Spoofing
A Serious Vulnerability for GNSS

Spoofing	Jamming & Interference
Intentional	Intentional and Non-Intentional
Difficult to detect	Can be detected
Service available but Lead to False Position solution	Denial of Service
Lesser solution for Existing Signals	Many Solutions Exist

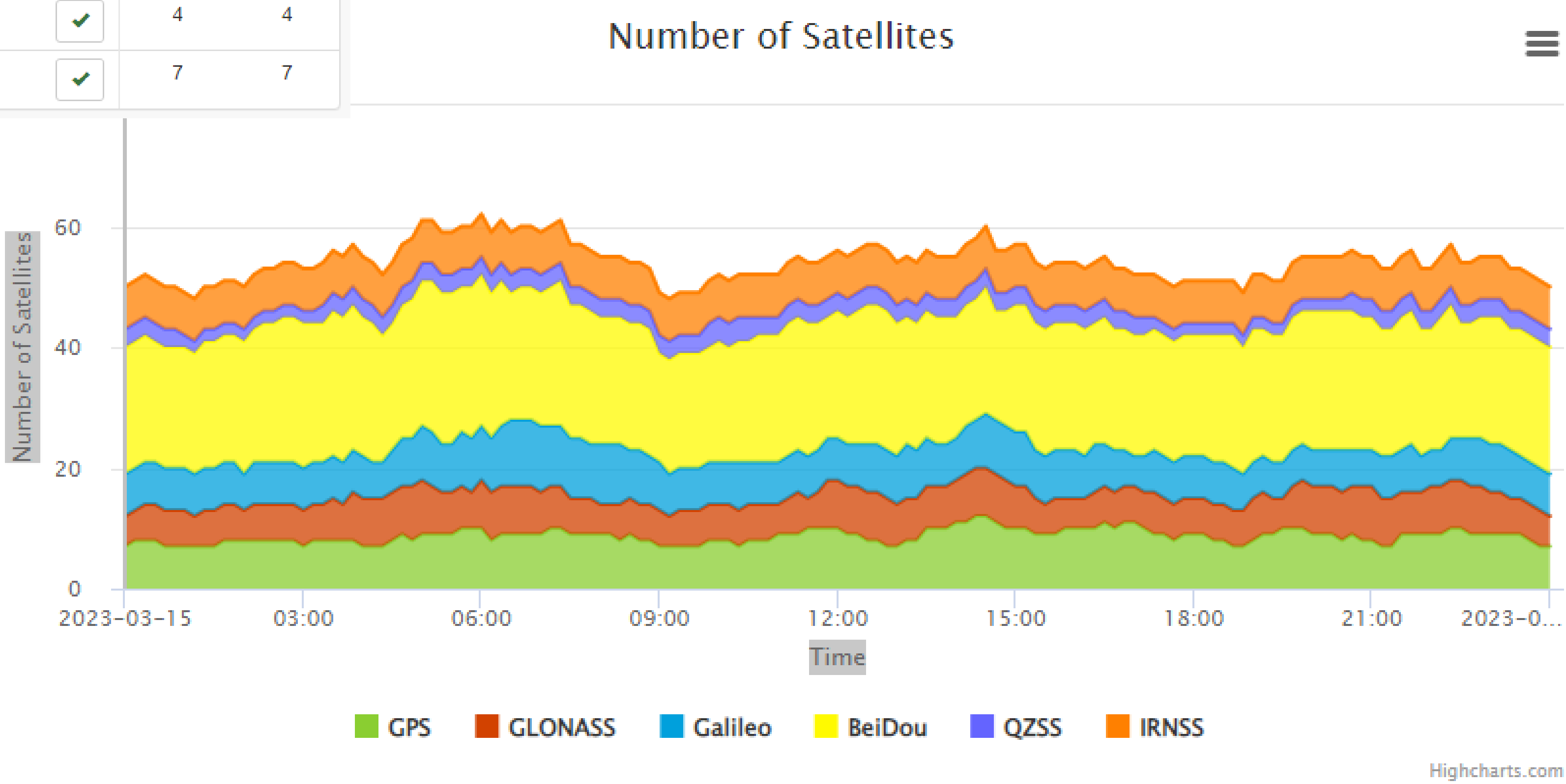
GNSS Planning

https://www.gnssplanning.com/#/charts

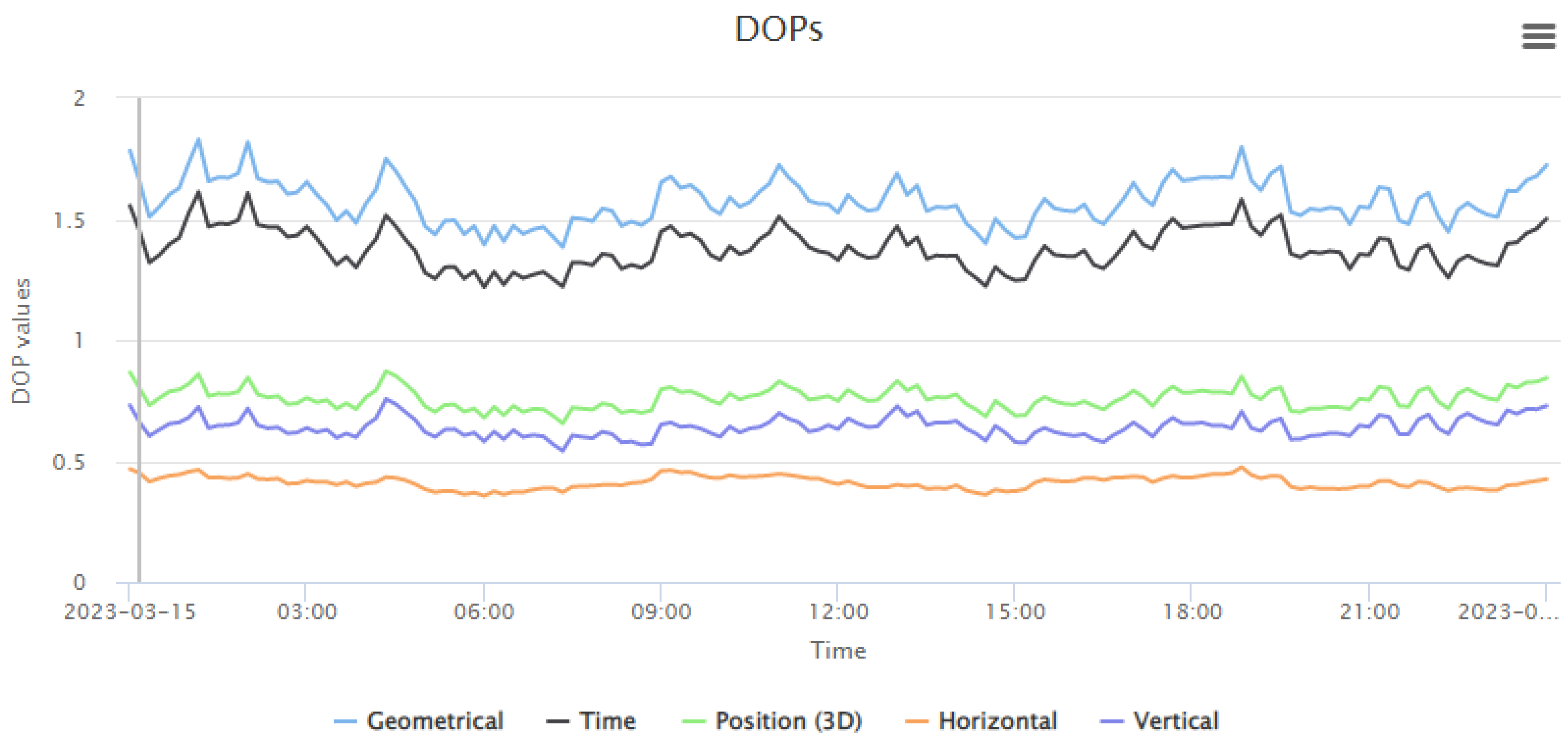
System: active		Satellites	
		Selected	Healthy
GPS	✔	31	31
GLONASS	✔	24	24
Galileo	✔	26	26
BeiDou	✔	47	47
QZSS	✔	4	4
IRNSS	✔	7	7

GNSS Satellite Visibility

Mar 15, 2023



GNSS – Activity Planning



http://gnssmissionplanning.com/App/DOPs

https://www.gnssplanning.com/#/charts

GNSS Planning

Latitude: N 33° 46' 46.4313" °

Longitude: E 72° 53' 18.8979" °

Height: 500 m

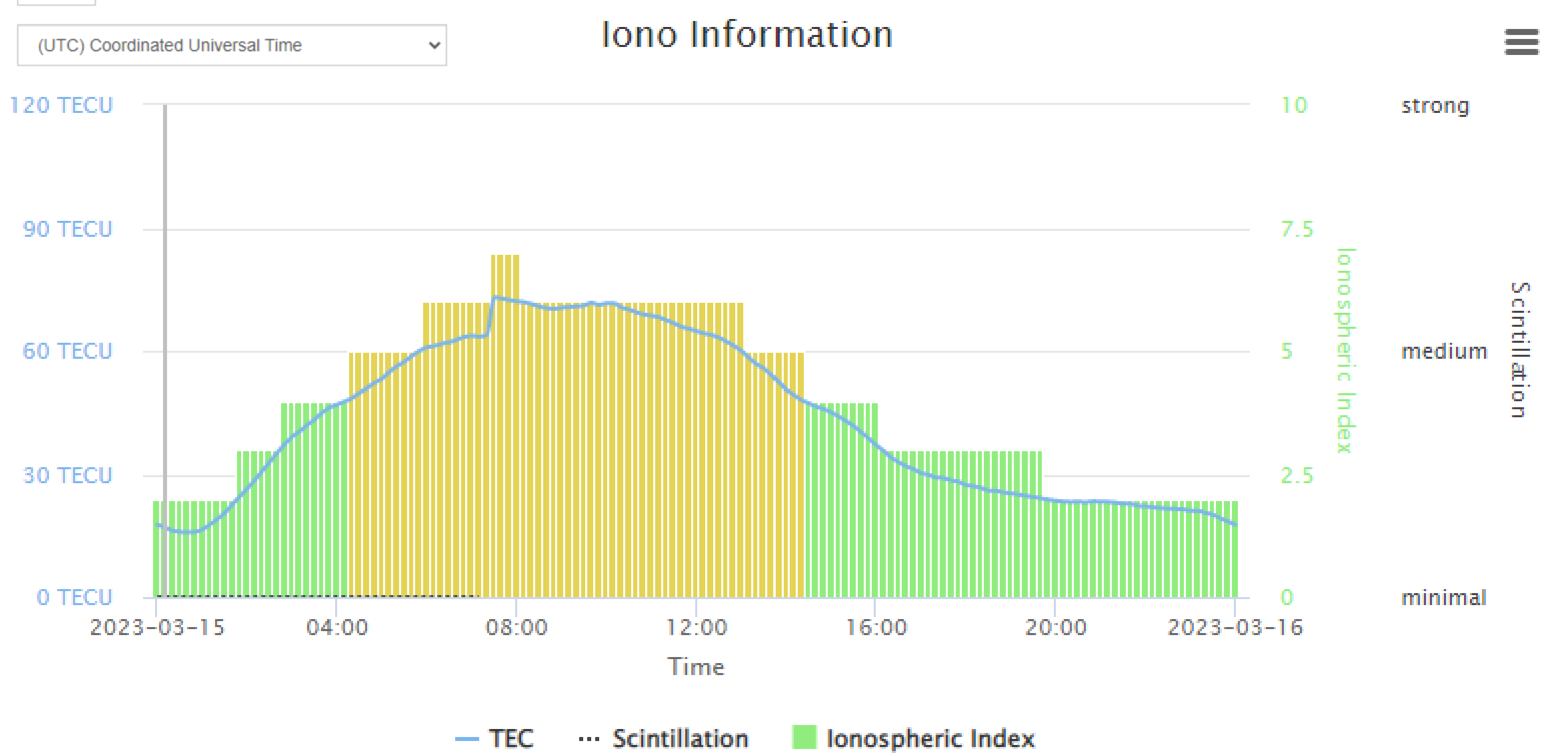
Elevation cutoff: 10 °

Day: 15-Mar-2023 Today

Start time: 00:00 UTC +00:00

Period [hours]: 24

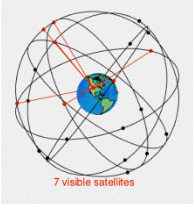
Time zone: (UTC) Coordinated Universal Time



Operational GNSS

- GPS
- GLONASS
- BeiDou
- Galileo

GPS



Country/Organization	United States of America
Operator	Air Force Space Command (AFSPC)
Service Type	Military, Civilian
Present Status	Fully operational since 1994
Coverage	Global
Precision	5 m (public), <1 cm (encrypted)
Constellation	31 (24 + 7) Satellites in Orbits, in 6 MEO Planes, at 55^o with Equator (30, 105, 120, and 105 deg apart)
First Satellite Launch	1978
Orbital Altitude	20,180 km (Orbital Radius = 26, 560km)
Rev Period, Rev/SD	11 h, 58 min , 2
Approx Project Cost	US$8B

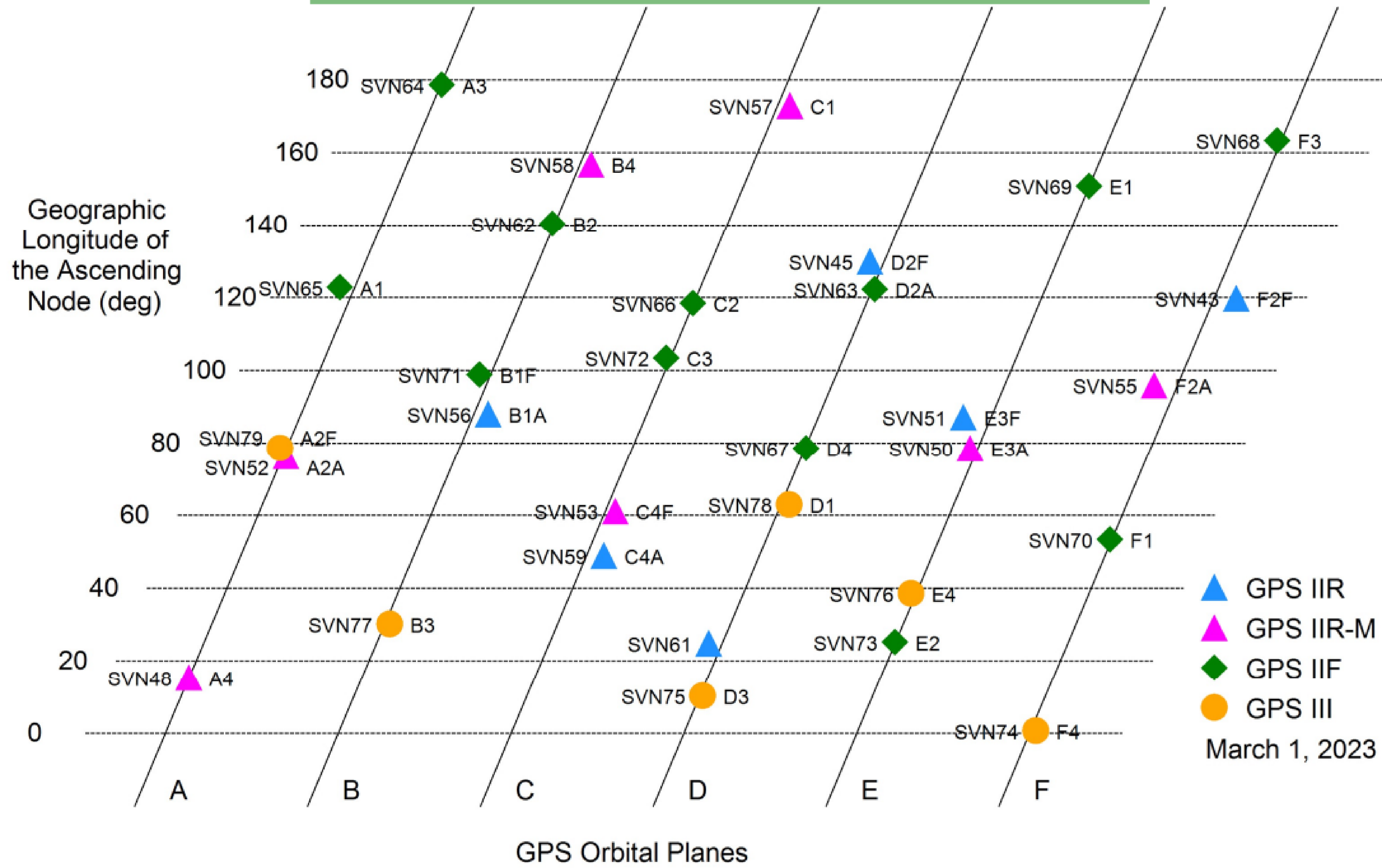
GPS Satellites – Launch History

Block	Launch Period	Satellite launches				Currently in orbit & healthy
		Success	Failure	In Preparation	Retired	
I	1978–1985	10	1	0	0	0
II	1989–1990	9	0	0	0	0
IIA	1990–1997	19	0	0	0	0
IIR	1997–2004	12	1	0	0	7
IIR-M	2005–2009	8	0	0	0	7
IIF	2010–2016	12	0	0	0	12
IIIA	2018-	5	0	5	0	5
IIIF	—	0	0	0	22	0
Total		75	2	5	39	31

GPS CONSTELLATION STATUS FOR Sat Jun 17 2023

Ser	Plane	SVN	PRN	Block-Type	Clock	Outage Start
1	B	56	16	IIR	RB	
2	C	57	29	IIR-M	RB	
3	D	61	2	IIR	RB	08 JUN 2023
4	A	65	24	IIF	CS	
5	E	69	3	IIF	RB	
6	F	70	32	IIF	RB	14 OCT 2022
7	D	63	1	IIF	RB	
8	A	52	31	IIR-M	RB	02 JUN 2023
9	F	55	15	IIR-M	RB	
10	B	62	25	IIF	RB	
11	C	66	27	IIF	RB	
12	E	73	10	IIF	RB	
13	D	45	21	IIR	RB	
14	E	50	5	IIR-M	RB	
15	A	64	30	IIF	RB	
16	F	68	9	IIF	RB	
17	C	72	8	IIF	CS	
18	A	48	7	IIR-M	RB	
19	E	51	20	IIR	RB	
20	C	53	17	IIR-M	RB	
21	B	58	12	IIR-M	RB	
22	D	67	6	IIF	RB	
23	F	74	4	III	RB	
24	C	59	19	IIR	RB	
25	B	71	26	IIF	RB	
26	E	76	23	III	RB	
27	D	78	11	III	RB	
28	F	43	13	IIR	RB	
29	D	75	18	III	RB	
30	B	77	14	III	RB	
31	A	79	28	III	RB	

GPS Constellation



GLONASS

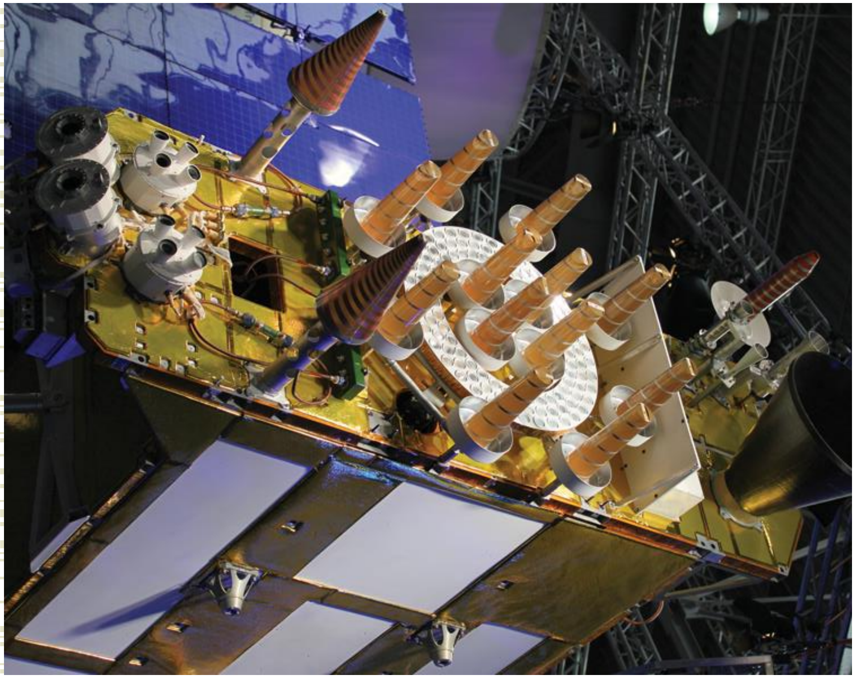
Country/Organization	Russian Federation
Operator	Russian Aerospace Defense Forces
Service Type	Civilian, Commercial, Military
Present Status	Operational 1994 to 98…decline...revival in 2000 Fully Operational since 2011
Coverage	Global
Precision	5-10 m (public), < 5cm encrypted
Constellation Size	29 (24 +5) in 3 MEO Planes inclined at 64.8º, Latest launch Feb 2016
First Satellite Launch	1982
Orbital Altitude	19,130 km , (Orbital Radius 25,510 km)
Rev Period, R/SD	11h 15 min 36 sec , 17/8 day
Approx Project Cost	US$6B

GLONASS

- First satellite was launched in 1983, and fully operational in 1993
- Period of decline (1994 ~ 2000)
- System got back to fully operational mode in 2011
- Satellites transmit the same code at different frequencies, a technique known as FDMA (Frequency Division Multiple Access)

GLONASS - Signal

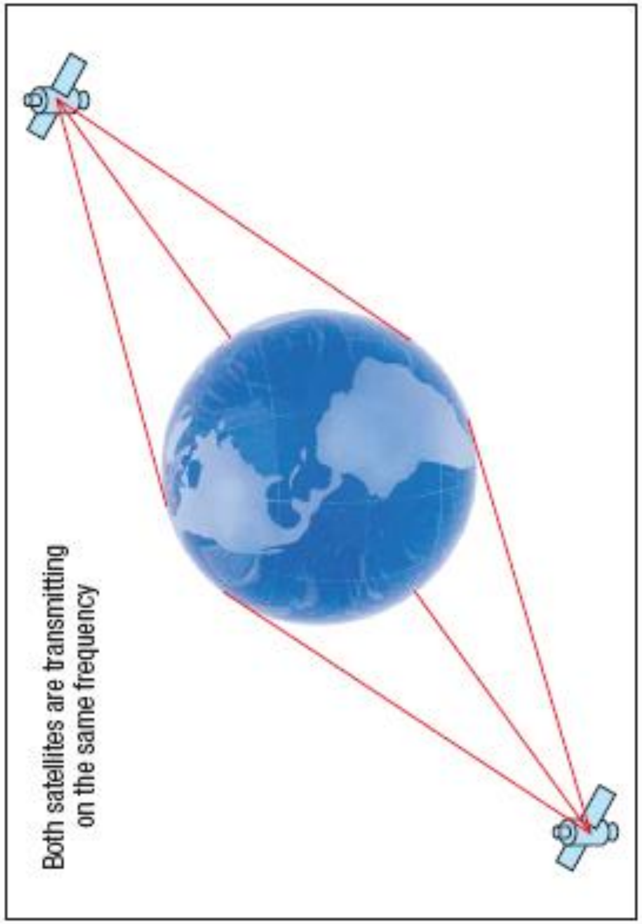
- Positioning, velocity and acceleration information for computing satellite locations.
- Satellite health information.
- Offset of GLONASS time from UTC
- Almanac of all other GLONASS satellites.



GLONASS-M Satellite

GLONASS - Signal

- 24 satellites use 12 frequencies
- The antipodal satellites transmitting on the same frequency
- Antipodal satellites are in the same orbital plane 180º apart.
- The antipodal satellites will never appear simultaneously in view of a receiver
- Lately GLONASS is being changed to CDMA hence improving the interoperability.



Accuracy	2 m (public) 20 cm (on-demand)

GLONASS – Control Segment

- The GLONASS control segment consists of the system control center and a network of command tracking stations across Russia
- GLONASS control segment monitors the status of satellites, determines the ephemerides corrections, and satellite clock offsets with respect to GLONASS time and UTC time
- Uploads corrections to the satellites, twice a day

Designation	Frequency	Description
L1	1598.0625 - 1609.3125 MHz	L1 is modulated by the HP (high precision) and the SP (standard precision) signals.
L2	1242.9375 - 1251.6875 MHz	L2 is modulated by the HP and SP signals. The SP code is identical to that transmitted on L1.

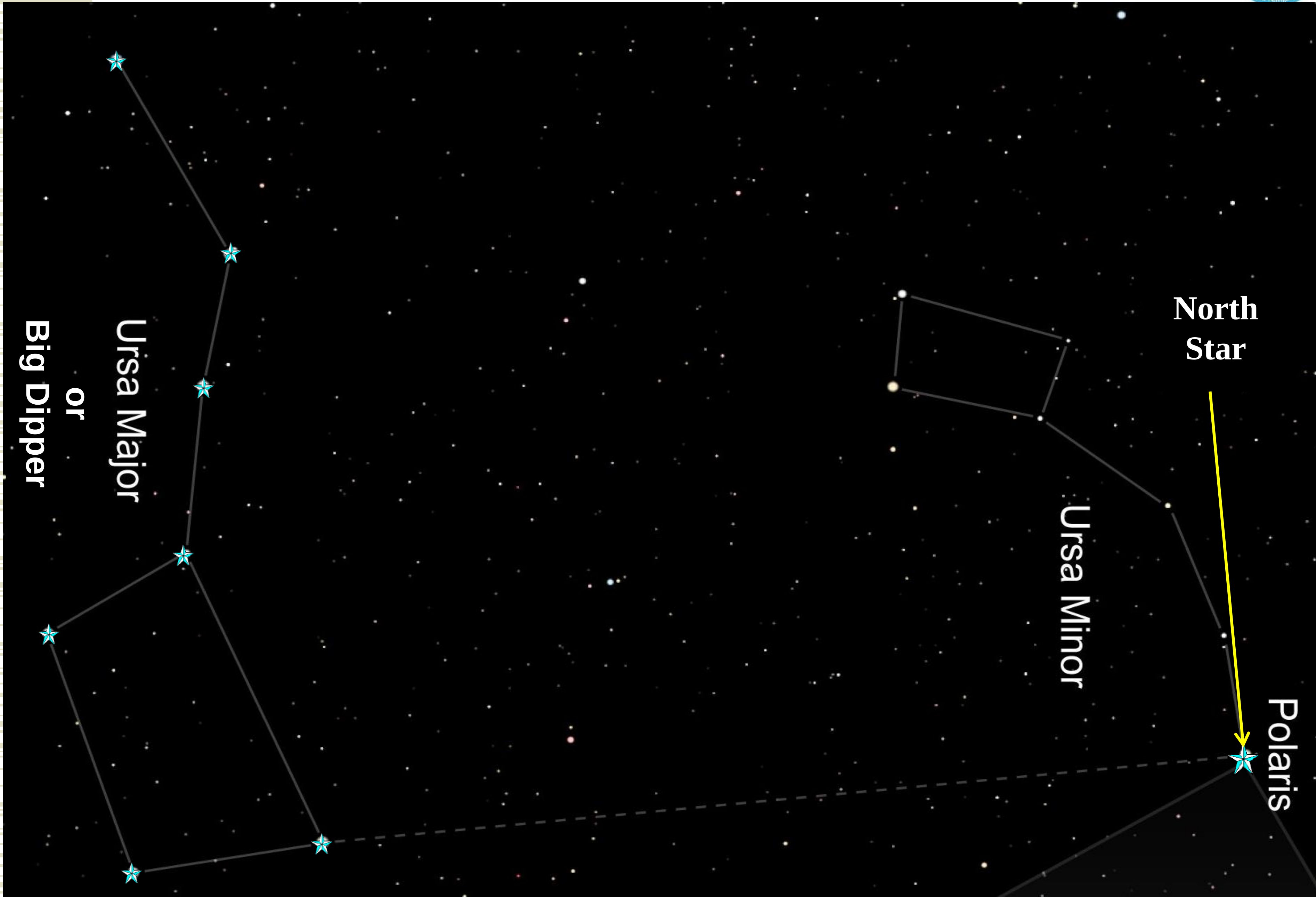
Roadmap of GLONASS modernization

Satellite series	Launch	Current status	Clock error
GLONASS	1982–2005	Out of service	5×10^{-13}
GLONASS-M	2003–2022	In service	1×10^{-13}
GLONASS-K1	2011–	In service	$5\times10^{-14}...1\times10^{-13}$
GLONASS-K2	2023–	Test satellite manufacturing	$5\times10^{-15}...5\times10^{-14}$
GLONASS-V	2025–	Design phase	
GLONASS-KM	2030–	Research phase	

BeiDou-2

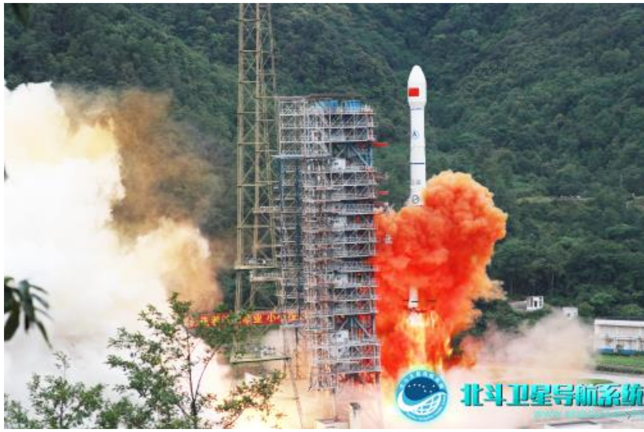
Country/Organization	People's Republic of China
Operator	China National Space Administration
Service Type	Military, civilian
Present Status	Regional (Asia Pacific since 2012) Global 2019
Coverage	Global
Precision	10 m (public), <1 cm (encrypted)
Constellation Size	49 (8GEO, 12 GS, 29MEO, 5 other), at 55^o,
First Satellite Launch	Oct 2000
Orbital Altitude	21,150km, (orbital radius 27,528km)
Rev Period, R/SD	12 h, 38 min , 17/9
Country/Organization	People's Republic of China

BeiDou-3



Summary of BeiDou-3 Satellites

Block	Launch Period	Satellite launches			Currently in orbit and healthy
		Success	Failure	Planned	
1	2000–2006	4	0	0	0
2	2007-2019	20	0	0	12
3	From 2015-Present	35	0	0	30
Total		59	0	0	42



Beidou Constellation

GEO Satellites are positioned at:

58.75° E

80.00° E

110.5° E

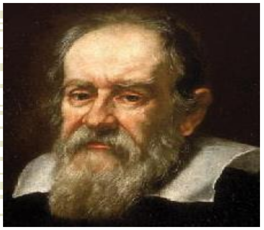
140.0° E

160.0° E

BeiDou Services

Service	Description
Public Service	For civilian use, and free in China. The public service will provide location accuracy of 5 m, velocity accuracy within 0.1 m/s and timing accuracy of 50 ns
Licensed Military Service	More accurate than the public service, and also providing system status information and military communications capability.

Accuracy	3.6 m (global, public) 2.6 m (Asia Pacific, public) 10 cm (encrypted)

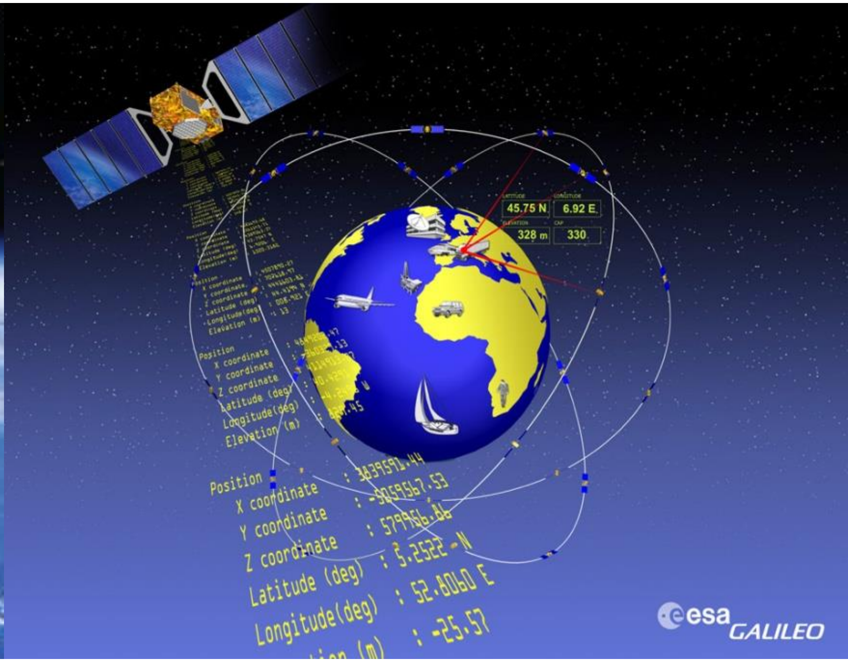


Galileo

Country/Organization	European Union
Operator	European Space Agency
Service Type	Civilian
Present Status	In developmental phase since 2003, Partially Operational
Coverage	Global
Precision	1 m (public), 1 cm (encrypted)
Constellation Size	30, in 3 Med Earth Orbits, at 56^o (Presently 28 launched, 22 Available)
First Satellite Launch	2005 (Experimental) , 2011 (In Orbit Validation)
Orbital Altitude	Orbital Radius 23,2616 km
Rev Period, R/SD	14 h, 05 min , 17/10
Approx Project Cost	€5B

Galileo

- Civilian Control and guaranteed availability of service under all but the most extreme circumstances
- Two Galileo Control Centers (GCC) will be located in Europe
- Data recovered by a global network of 20 Galileo Sensor Stations (GSS) will be sent to the GCC
- Galileo will provide global Search and Rescue (SAR) function



Galileo Services

Service	Description
Free Open Service (OS)	Positioning, Navigation and Precise Timing service. Available for all having a Galileo receiver. No authorization required.
Safety-of-Life Service (SOL)	Improves on OS by providing timely warnings to users when it fails to meet certain margins of accuracy. A service guarantee will likely be provided for this service.
Commercial Service (CS)	Service providers to provide added-value services, for which they will charge the end customer. The CS signal will contain data relating to these additional commercial services.
Encrypted Public Regulated Service (PRS)	Highly encrypted restricted-access service offered to government agencies that require a high availability navigation signal.
Search and Rescue Service (SAR)	Public service designed to support search and rescue operations, which will make it possible to locate people and vehicles in distress.

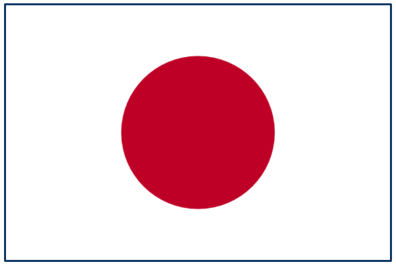
Summary of Galileo Satellites

Block	Launch Period	Satellite launches			Currently in operational orbit and healthy
		Full success	Failure	Planned	
GIOVE	2005–2008	2	0	0	0
IOV	2011–2012	4	0	0	3
FOC	From 2014	22	2	10	21
G2G	From 2024	0	0	12	
Total		**28**	**2**	**22**	**24**

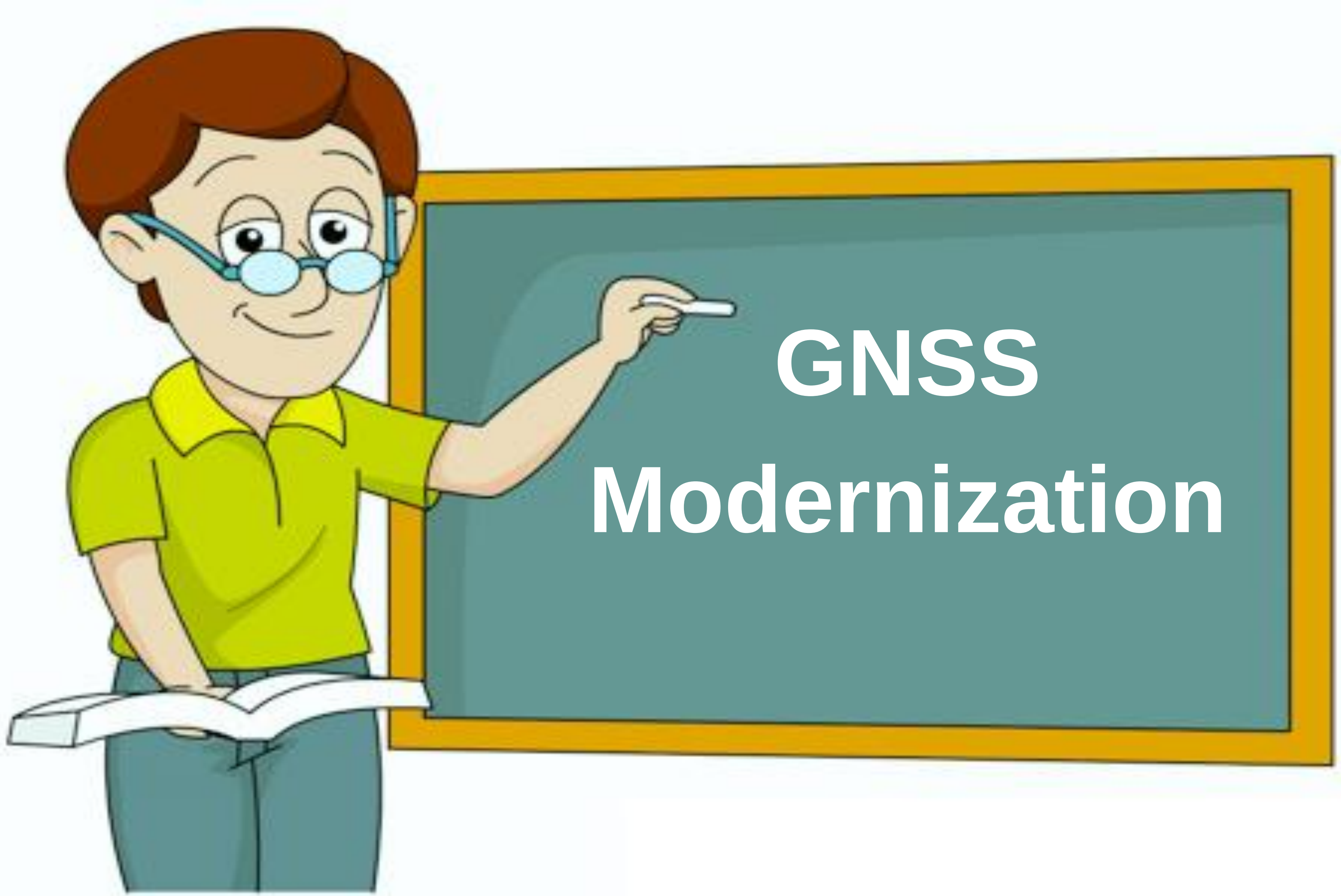
Regional Satellite Navigation Systems

- **IRNSS** (Indian Regional Navigation Satellite System)
  - Satellite system to provide regional coverage
  - 7 Geostationary Satellites
  - Operational since 2013

- **QZSS** (Quasi-Zenith Satellite System)
  - A 3 satellite system providing regional communication services and positioning information for the mobile environment
  - Highly Elliptical Orbit (HEO).



Each QZSS satellites "dwell" over Japan for more than **12 hours a day**, at elevation > 70° (almost overhead most of the time).


GNSS
Modernization

GPS Modernization

In 2000, a project was initiated to modernize the GPS to take advantage of new technologies and user requirements.

- Improvements in clock precision
- Satellite signal strength and reliability
- Improved ionospheric / tropospheric / Stratospheric modelling
- Orbital accuracy through Additional monitoring stations
- New civilian signal L2C to directly measure and remove the ionospheric error.
- L5 signal is added for safety-of-life applications
- New military signal and improved L1C to provide greater civilian interoperability with Galileo

GPS Modernization

In 2000, a modernization project was initiated to take advantage of emerging technologies and user requirements.

- **Space Segment Modernization**

Includes new signals, as well as improvements in atomic clock accuracy, satellite signal strength and reliability.

- GPS Block IIR-M and GPS Block IIF
- GPS III and GPS III Follow-On

- **Control Segment Modernization**

Includes improved ionospheric and tropospheric modelling and in-orbit accuracy, and additional monitoring stations.

- GPS III Contingency Operations (COps)
- M-Code Early Use (MCEU)
- Next Generation Operational Control System (OCX) programs

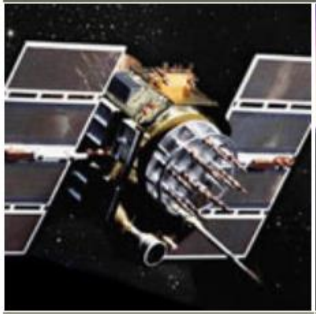
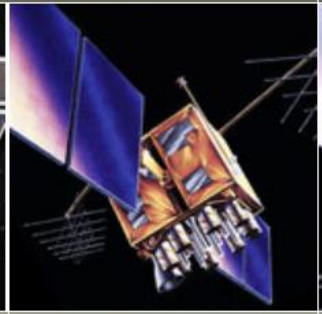
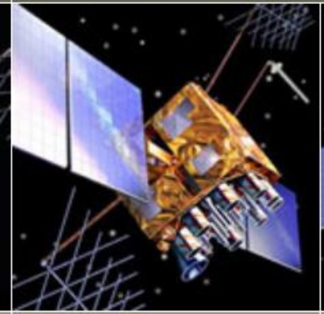
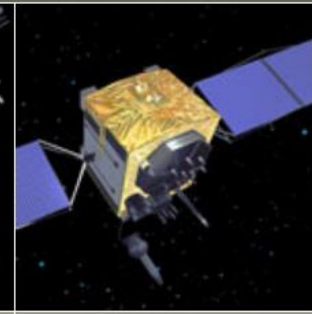
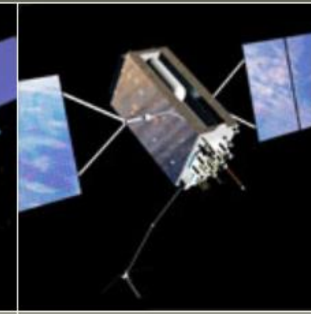
- **User Equipment** have also evolved, to take advantage of space and control segment improvements.

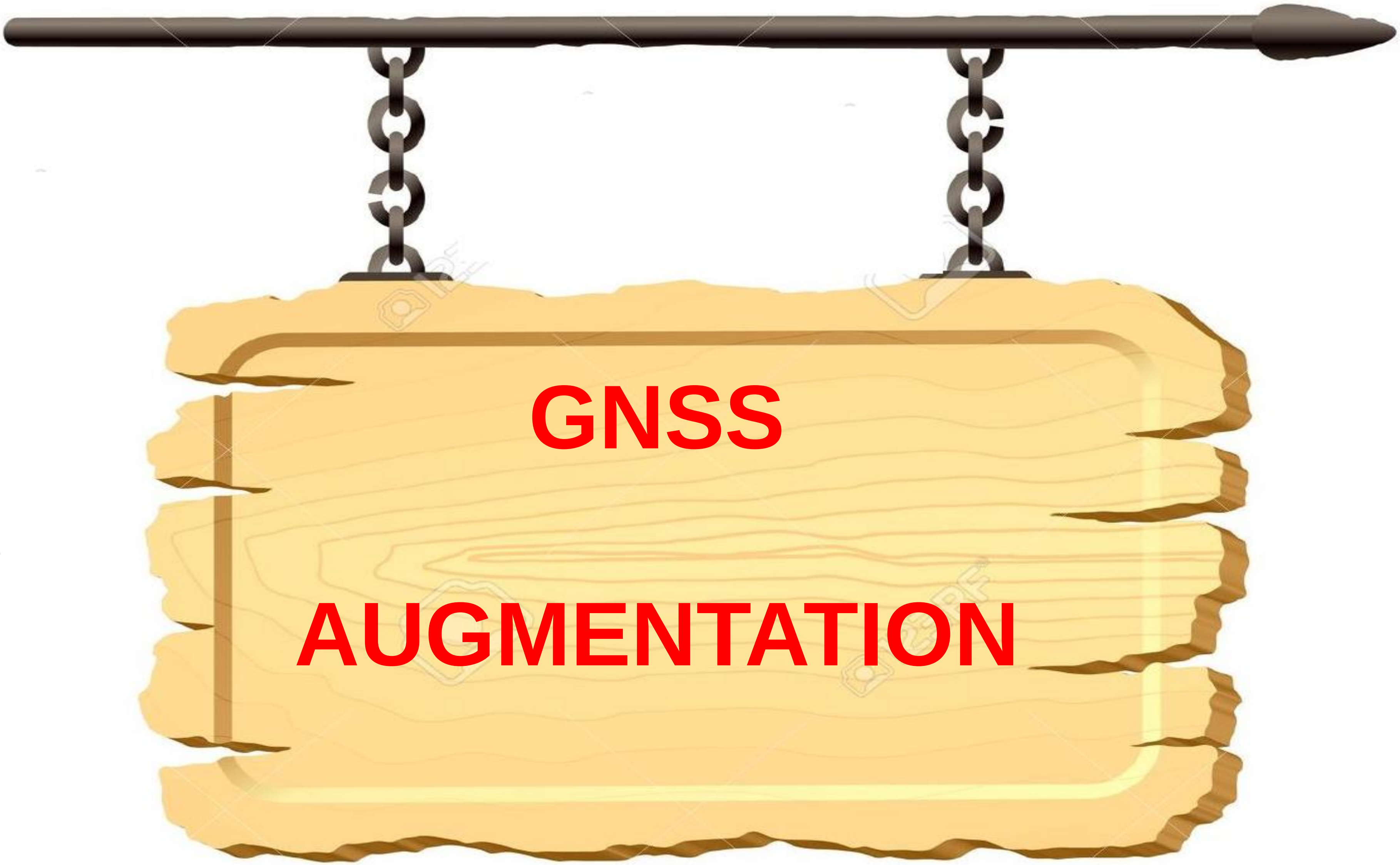
Modernization – Monitoring & Control Segment

- **The Next Generation Operational Control System (OCX)**
  - A master control station and alternate master control station
  - Dedicated monitor stations ad Ground antennas
  - GPS system simulator and Standardized space trainer
- **Next Gen OCX Functionalities**
  - Commands all modernized and legacy GPS satellites
  - Manage all civil and military navigation signals
  - Provide improved cybersecurity & resilience for the next gen of GPS operations

Receivers Modernization

- Efficient antennae
- Integration with INS and other Augment Systems
- Efficient Computation power and algorithms
- Efficient power consumption,
- Mminiaturization
- More **<u>“bells & whistles” </u>**(maps, hard drives, cameras, etc.)
- New bells + whistles keeps prices fairly stable...

LEGACY SATELLITES		MODERNIZED SATELLITES		
				
BLOCK IIA	BLOCK IIR	BLOCK IIR-M	BLOCK IIF	GPS III/IIIF
0 operational	7 operational	7 operational	12 operational	5 operational
▪ Coarse Acquisition (C/A) code on L1 frequency for civil users ▪ Precise P(Y) code on L1 & L2 frequencies for military users ▪ 7.5-year design lifespan ▪ Launched in 1990-1997 ▪ Last one decommissioned in 2019	▪ C/A code on L1 ▪ P(Y) code on L1 & L2 ▪ On-board clock monitoring ▪ 7.5-year design lifespan ▪ Launched in 1997-2004	▪ All legacy signals ▪ 2nd civil signal on L2 (L2C) ▪ New military M code signals for enhanced jam resistance ▪ Flexible power levels for military signals ▪ 7.5-year design lifespan ▪ Launched in 2005-2009	▪ All Block IIR-M signals ▪ 3rd civil signal on L5 frequency (L5) ▪ Advanced atomic clocks ▪ Improved accuracy, signal strength, and quality ▪ 12-year design lifespan ▪ Launched in 2010-2016	▪ All Block IIF signals ▪ 4th civil signal on L1 (L1C) ▪ Enhanced signal reliability, accuracy, and integrity ▪ No Selective Availability ▪ 15-year design lifespan ▪ IIIF: laser reflectors; search & rescue payload ▪ First launch in 2018


GNSS
AUGMENTATION

Augmented GNSS

Combining solutions from fol systems improves GNSS performance

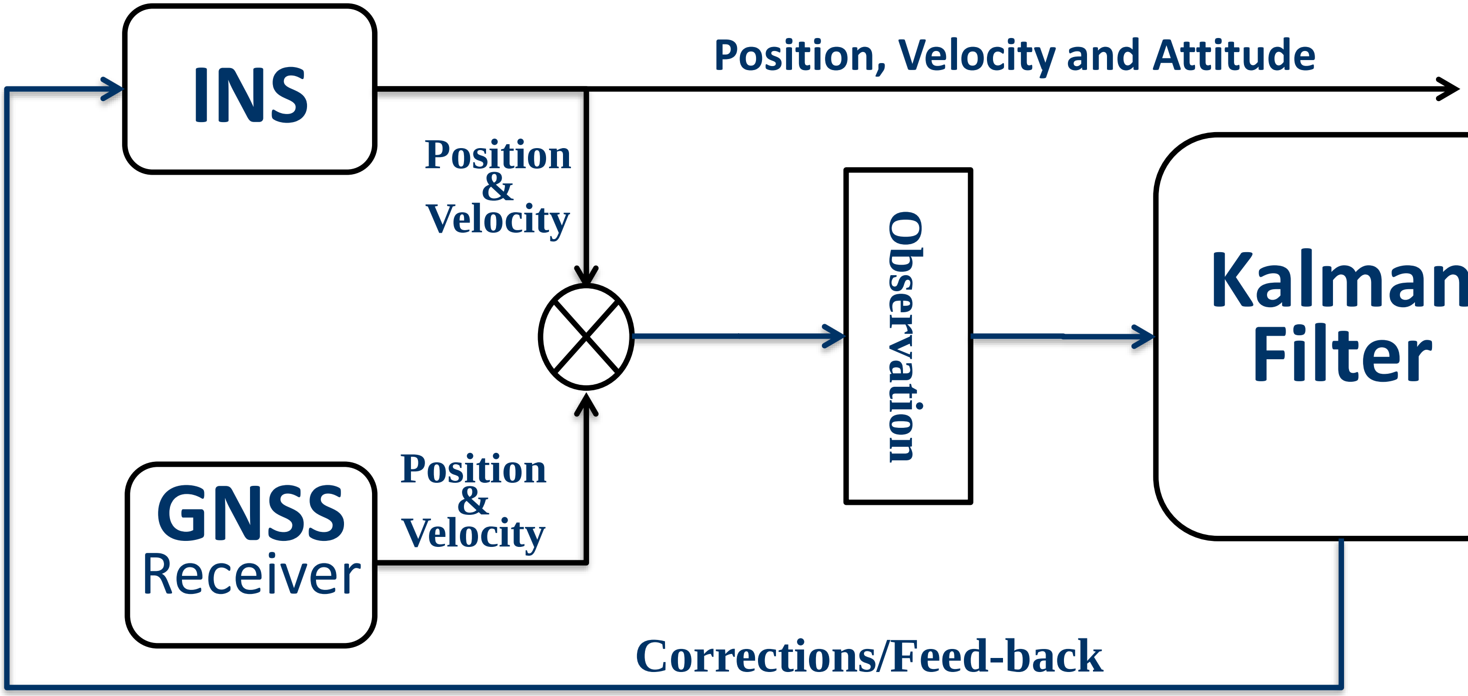
- Inertial Navigation Systems
- GBAS and SBAS
- Cellular network based positioning
- Bluetooth beacons and localization
- Wi-Fi base stations

Advantages

- Supplementary coverage in challenging environments
- Prompt **First Position Fix**
- Enhanced availability, accuracy, continuity, integrity and Redundancy

GNSS/INS Augmentation

- INS Errors grow UNBOUNDEDLY with time
- GNSS solution are not available when signals obstructed
- **GNSS / INS Augmentation is the solution**



Kalman Filter

Kalman Filter

Prior estimate:

$$\hat{x}_k^-, P_k^-$$

Compute Kalman Gain :

$$K_k = P_k^- H_k^T (H_k P_k^- H_k^T + R_k)^{-1}$$

Measurement

z_k

Estimated Measurement

Update estimate with measurement

$$\hat{x}_k = \hat{x}_k^- + K_k (z_k - H_k \hat{x}_k^-)$$

Output

$\hat{x}_k$

Compute error covariance for update estimate

$$P_k = (I - K_k H_k) P_k^-$$

Project Ahead:

$$\hat{x}_{k+1}^- = \Phi_k \hat{x}_k$$

$$P_{k+1}^- = \Phi_k P_k \Phi_k^T + Q_k$$

GNSS Vs INS

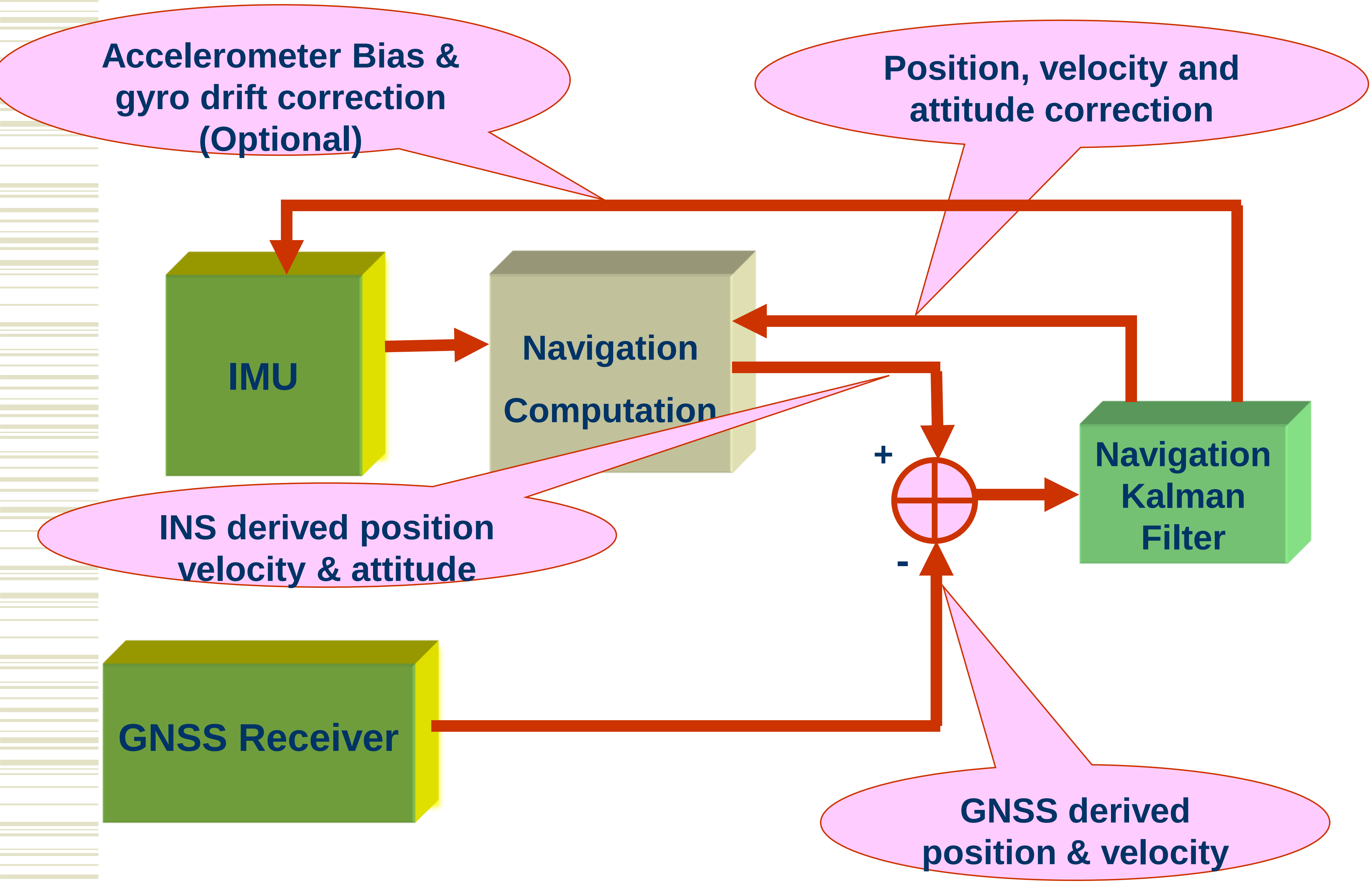
GNSS

- Low data rate
- Errors are bounded
- No precise attitude information
- Susceptible to jamming (intentional and unintentional)

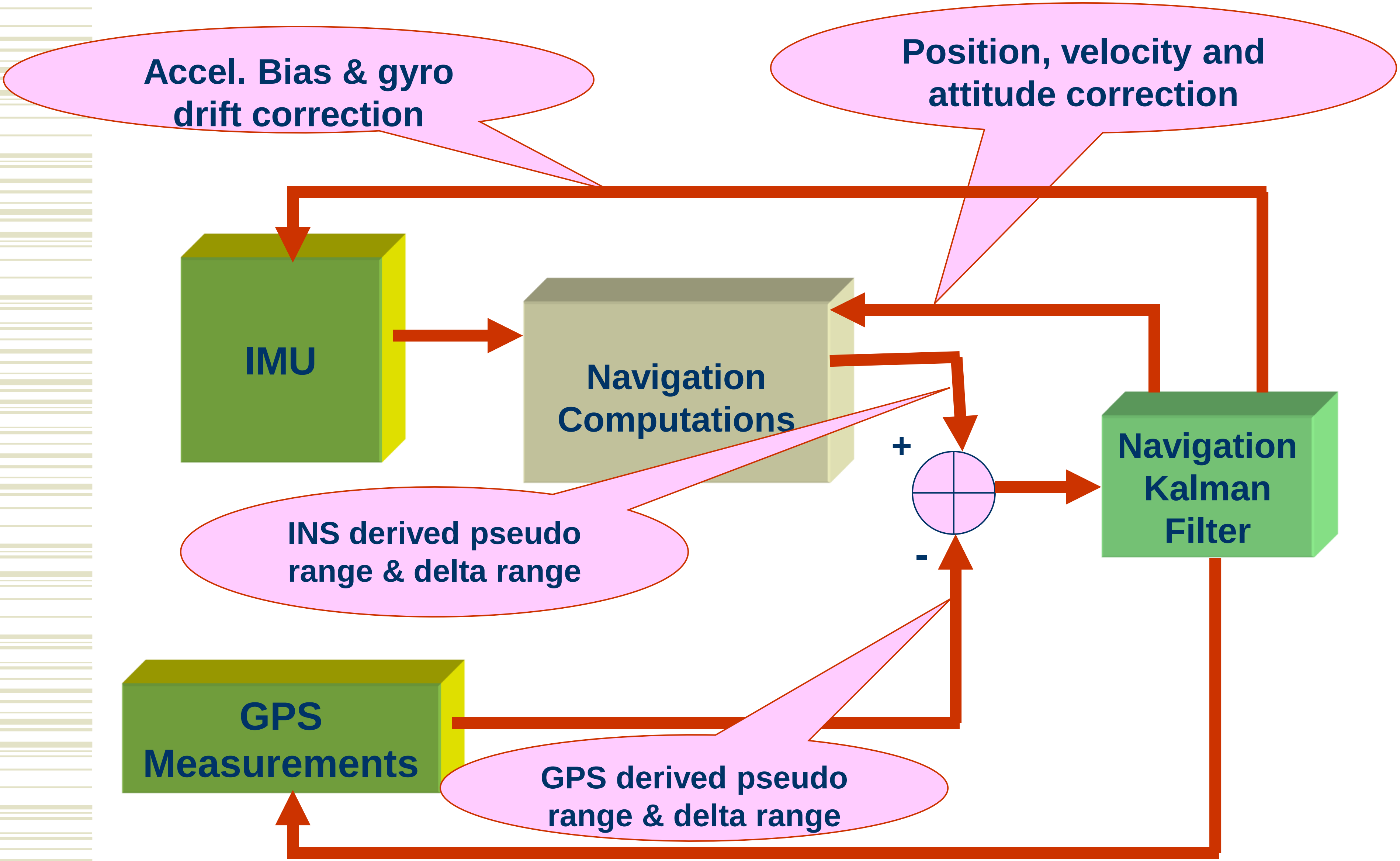
INS

- High data rate
- Unbounded Errors
- High precision attitude information aval
- Self-contained (un-susceptible to jamming)

Loosely Coupled Integration



Tightly/Deeply Coupled Integration



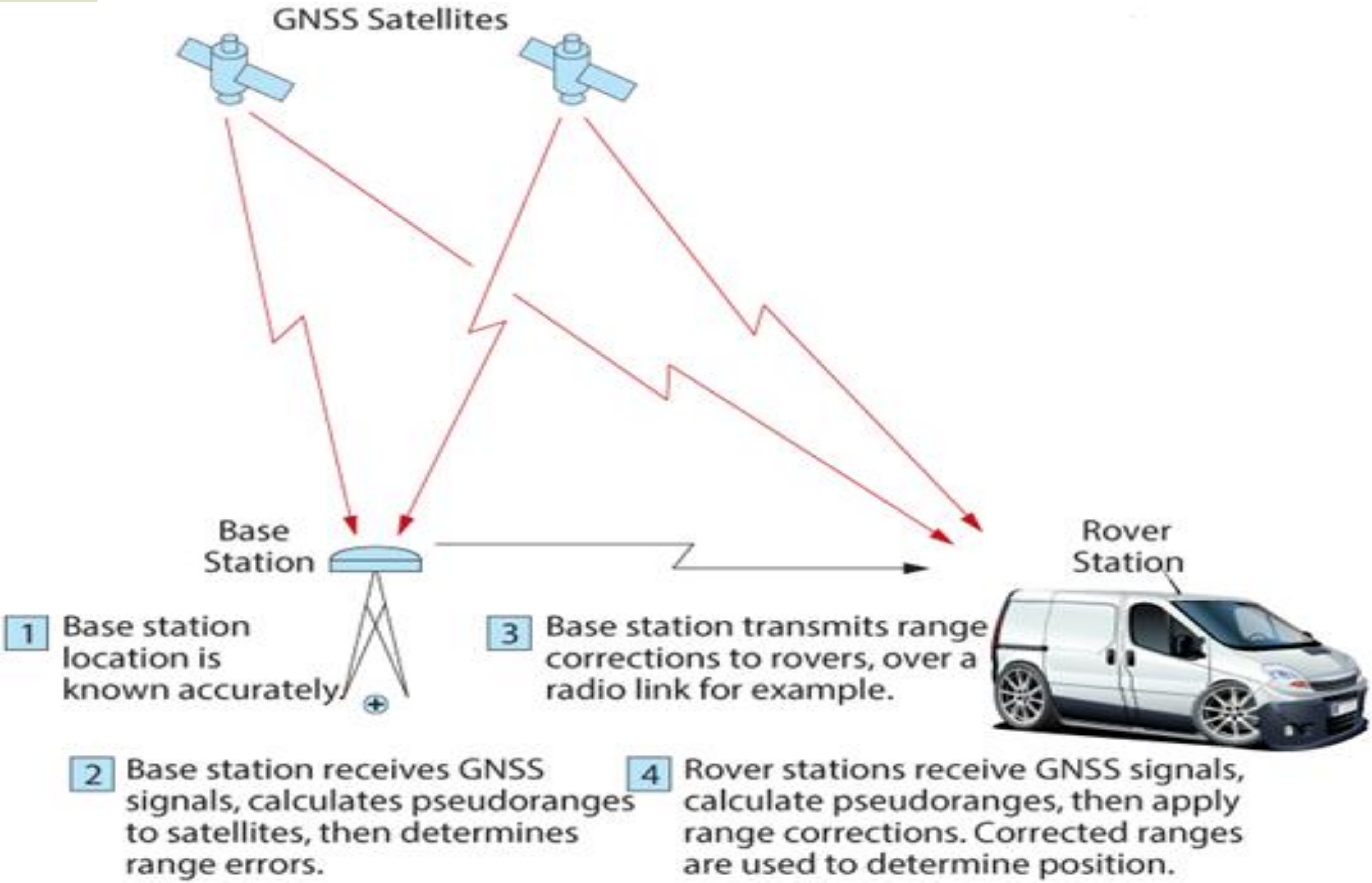
Kalman Filter

- A linear quadratic state estimator.
- Operates recursively on streams of noisy measurements to produce a optimal estimate of the state.
- **Prediction:** Prediction of the current state based on previous state
- **Correction:** After availability of measurement correction is made using a weighted average, with more weight being given to estimates with higher certainty

Kalman Filter –The Work Horse for Integrated Navigation

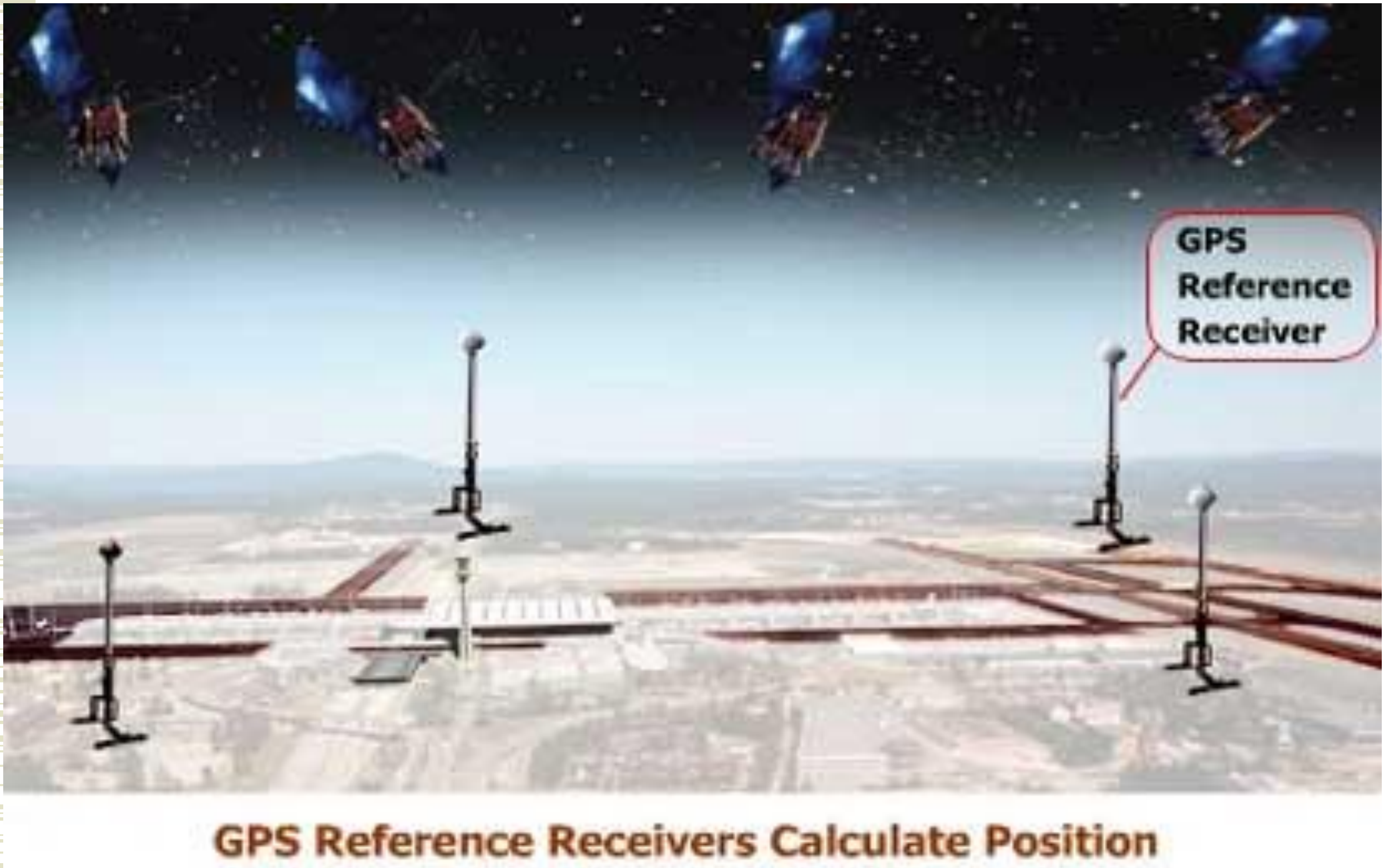
A key function performed by the Kalman filter is the statistical combination of external (non-inertial) information and INS information to track or contain drifting parameters of the sensors in the INS.

Differential GNSS

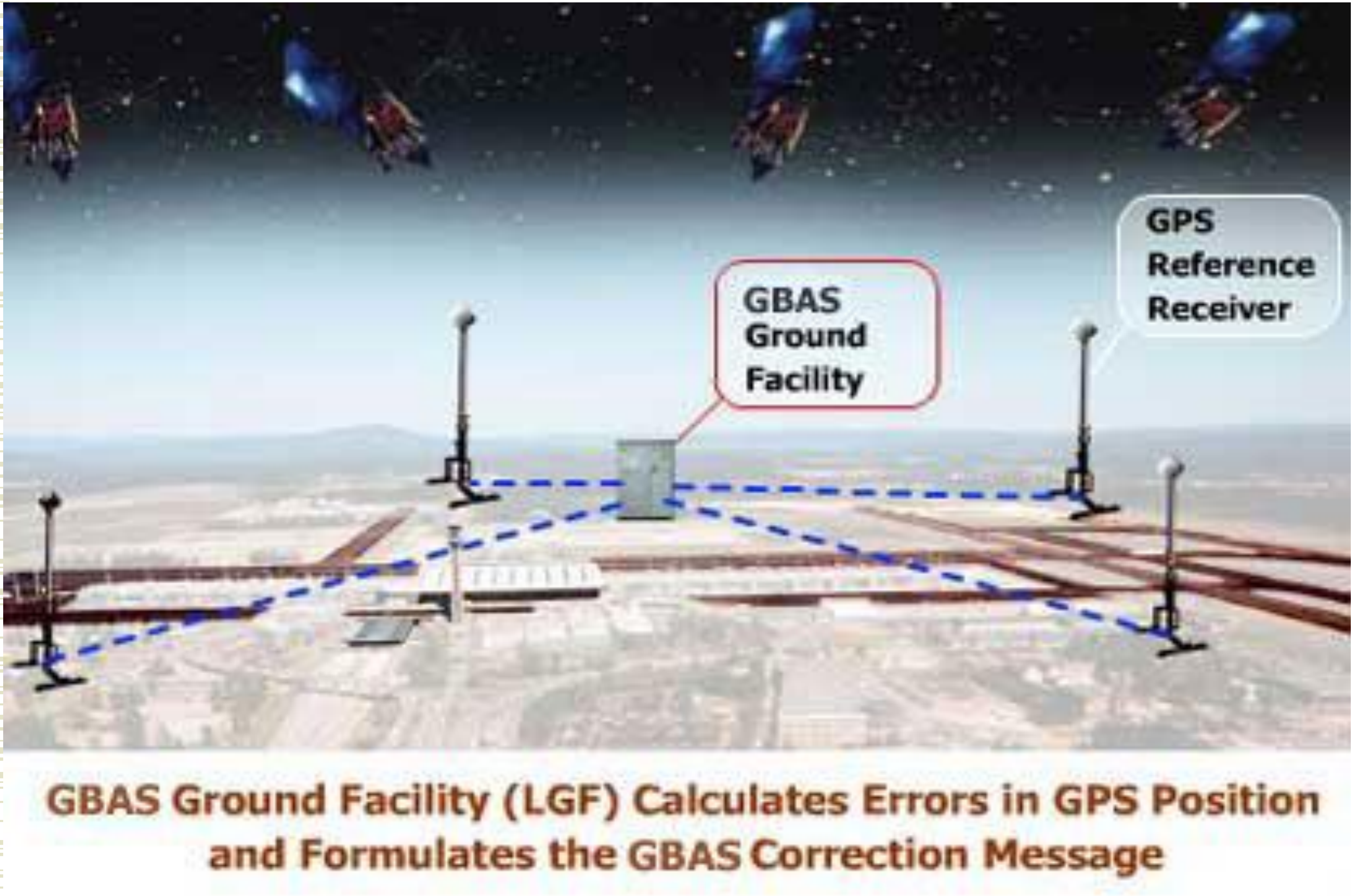


Differential GNSS- Ground Base Augmentation

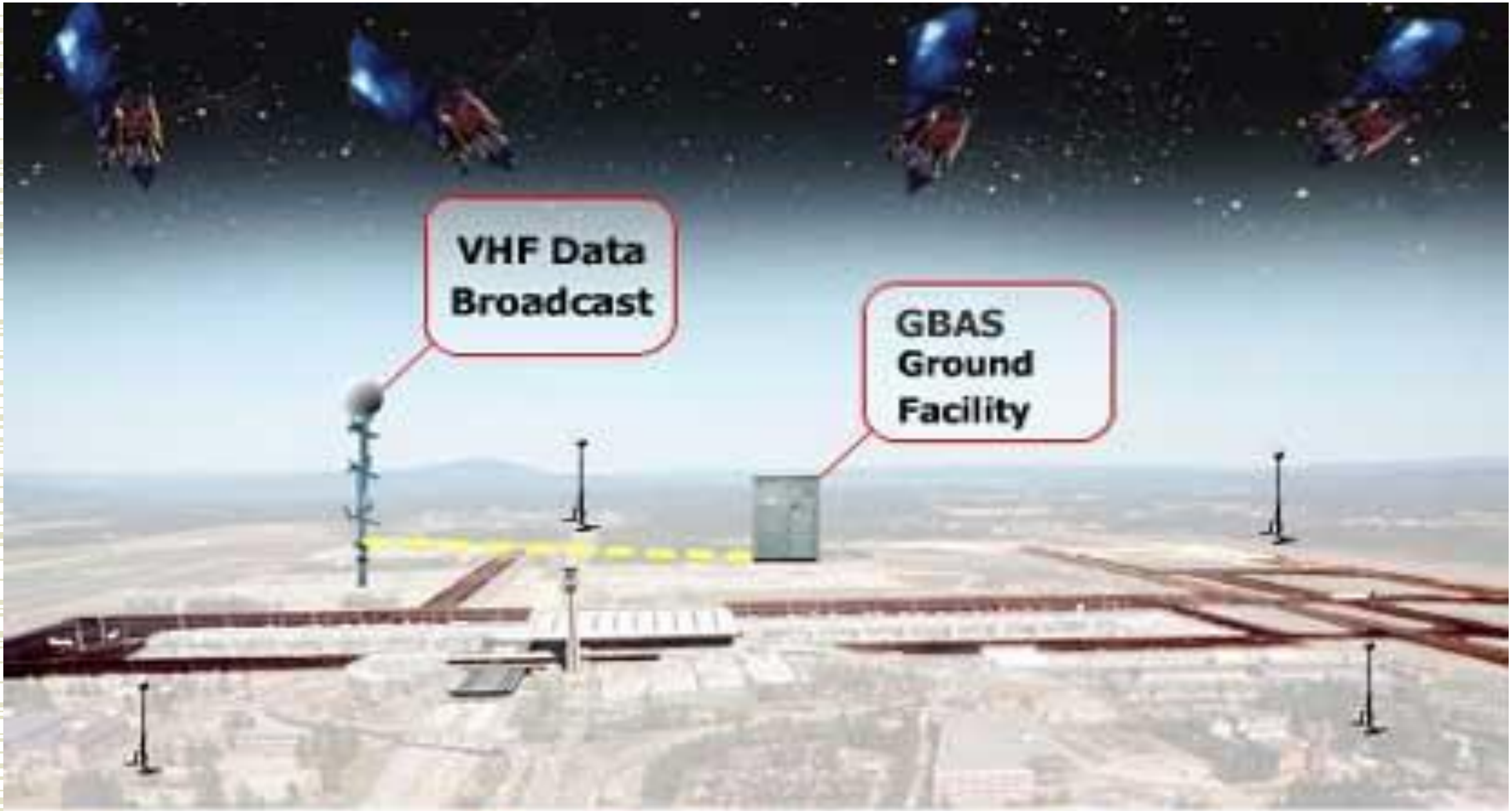
Joint Precision Approach and Landing System (JPALS)



Differential GNSS- Ground Base Augmentation



Differential GNSS- Ground Base Augmentation

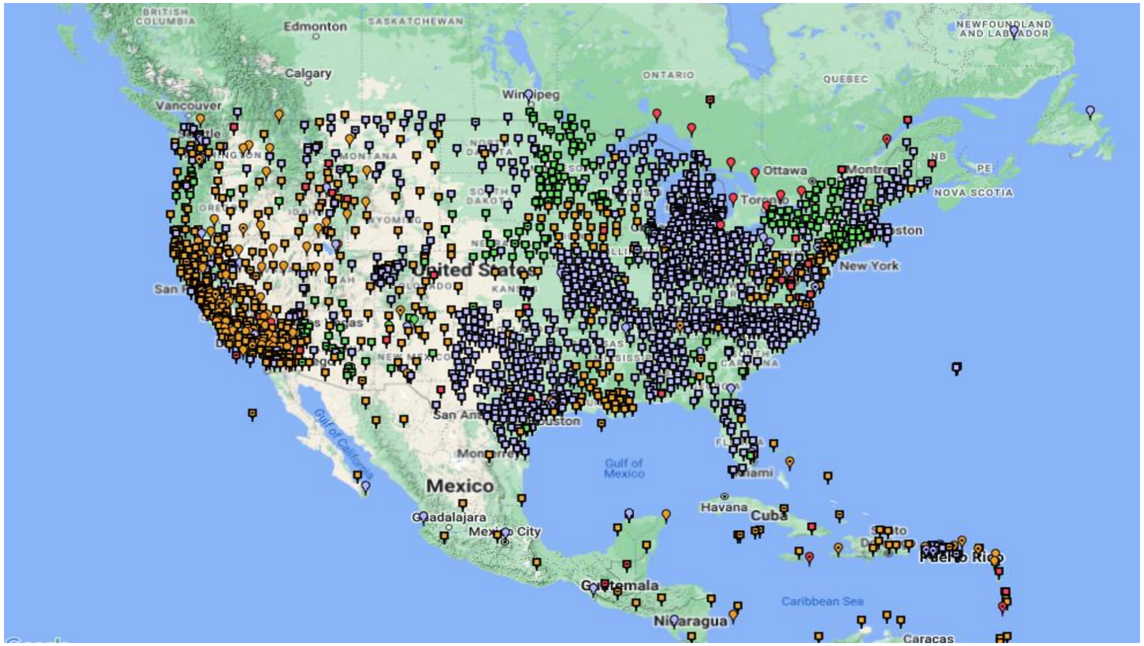


The GBAS Ground Facility Sends the Correction Message to the VHF Data Broadast (VDB) Transmitter

Differential GNSS- Ground Base Augmentation

Continuously Operating Reference Stations (CORS)

- Archives and distributes GPS data for precise positioning tied to the National Spatial Reference System.
- Over 200 private, public, and academic organizations contribute data from almost 2,000 GPS tracking stations to CORS.
- The Online Positioning User Service (OPUS) offers free post-processing of GPS data sets to the centimeter level using CORS information. CORS is also being modernized to support real-time users.



The Online Positioning User Service (OPUS)

- OPUS users submit their GPS data files to the NGS Internet site.
- The NGS computers determine a position by using reference receivers from three CORS sites.
- The position is reported back to the user by email within few minutes
- For use in the United States
- Does not publish geodetic coordinates outside the United States without the agreement of the affected countries.

Global Differential GPS (GDGPS)

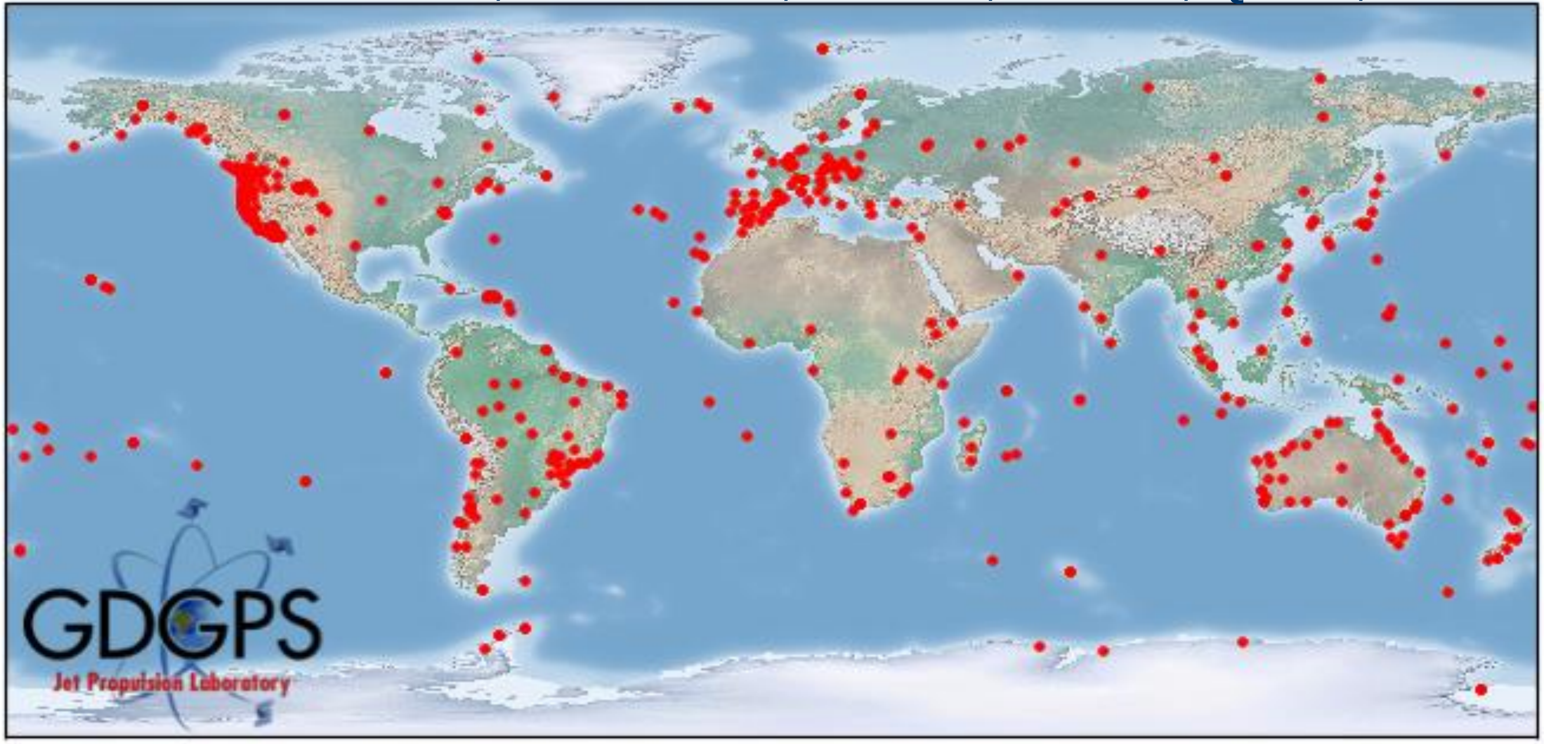
An accurate, and robust real-time GNSS monitoring and augmentation system consisting of:

- large ground network of real-time reference receivers
- innovative network architecture
- real-time data processing software

❖ sub-decimeter (<10 cm) positioning accuracy

❖ sub-nanosecond ($<10^{-9}$) time transfer accuracy

Services available for GPS, GLONASS, BeiDou, Galileo, QZSS, and NAVIC.

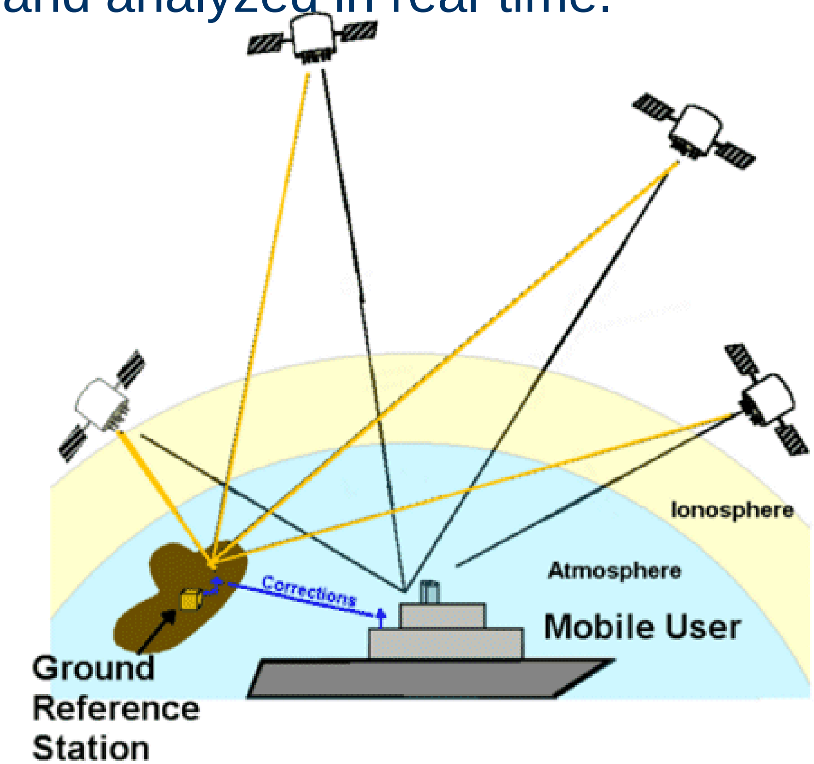


Global Differential GPS (GDGPS)

NASA-owned and JPL-operated network of ***<u>75+ geodetic-quality, triple frequency receivers</u>***, distributed globally.

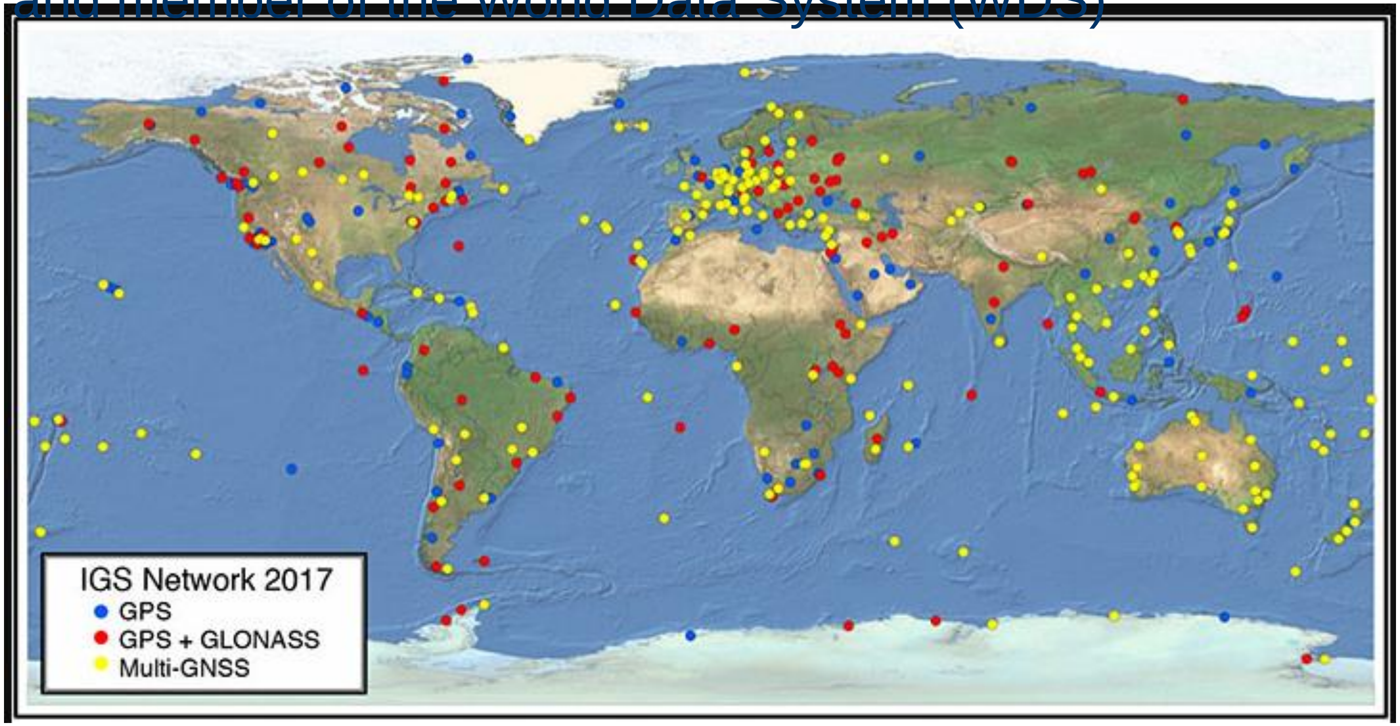
Additional real-time sites are contributed by a variety of U.S. and international agencies and partner organizations: > ***<u>200 global sites</u>***

All these sites stream their GNSS measurements at 1 Hz to the GDGPS Operation Centers, where it is processed and analyzed in real-time.



International GNSS Service (IGS)

- Federation of over 200 self-funding orgs, universities, and research institutions in more than 100 countries
- Free access to the highest precision products available for scientific advancement and public benefit
- Providing access to tracking data from over ***400 worldwide Ref Stations***
- Functioning as a component of the Global Geodetic Observing System (GGOS) and member of the World Data System (WDS)



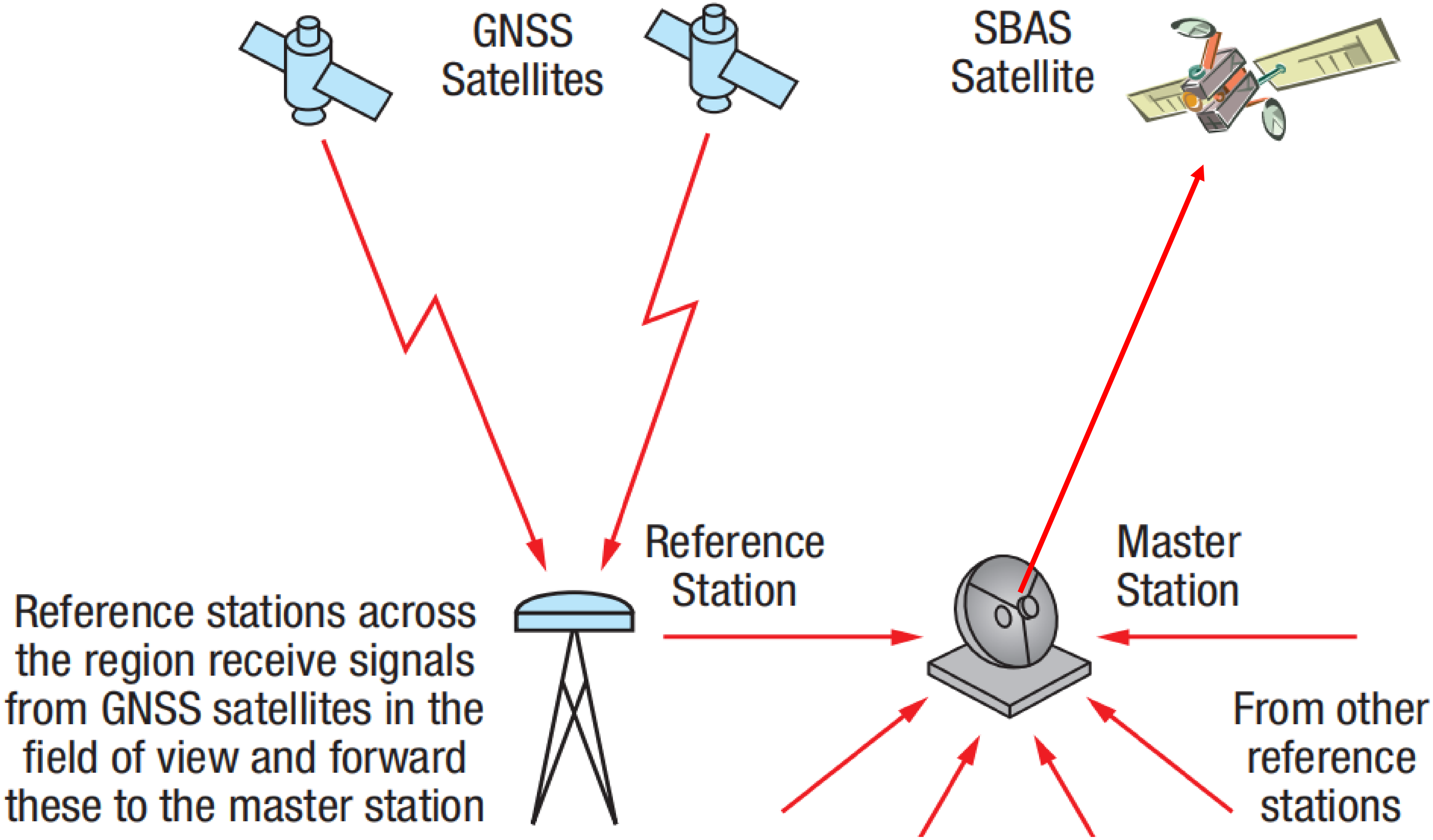
Australia's Online GPS Processing System (AUPOS)

- Submit via the Internet dual frequency geodetic quality GPS RINEX data observed in a "static" mode
- Receive rapid-turnaround precise position coordinates.
- The service is free
- Provides both International Terrestrial Reference Frame (ITRF) and Geocentric Datum of Australia (GDA94) coordinates.
- This Internet service takes advantage of both IGS products and the IGS GPS network and can handle GPS data collected anywhere on earth.

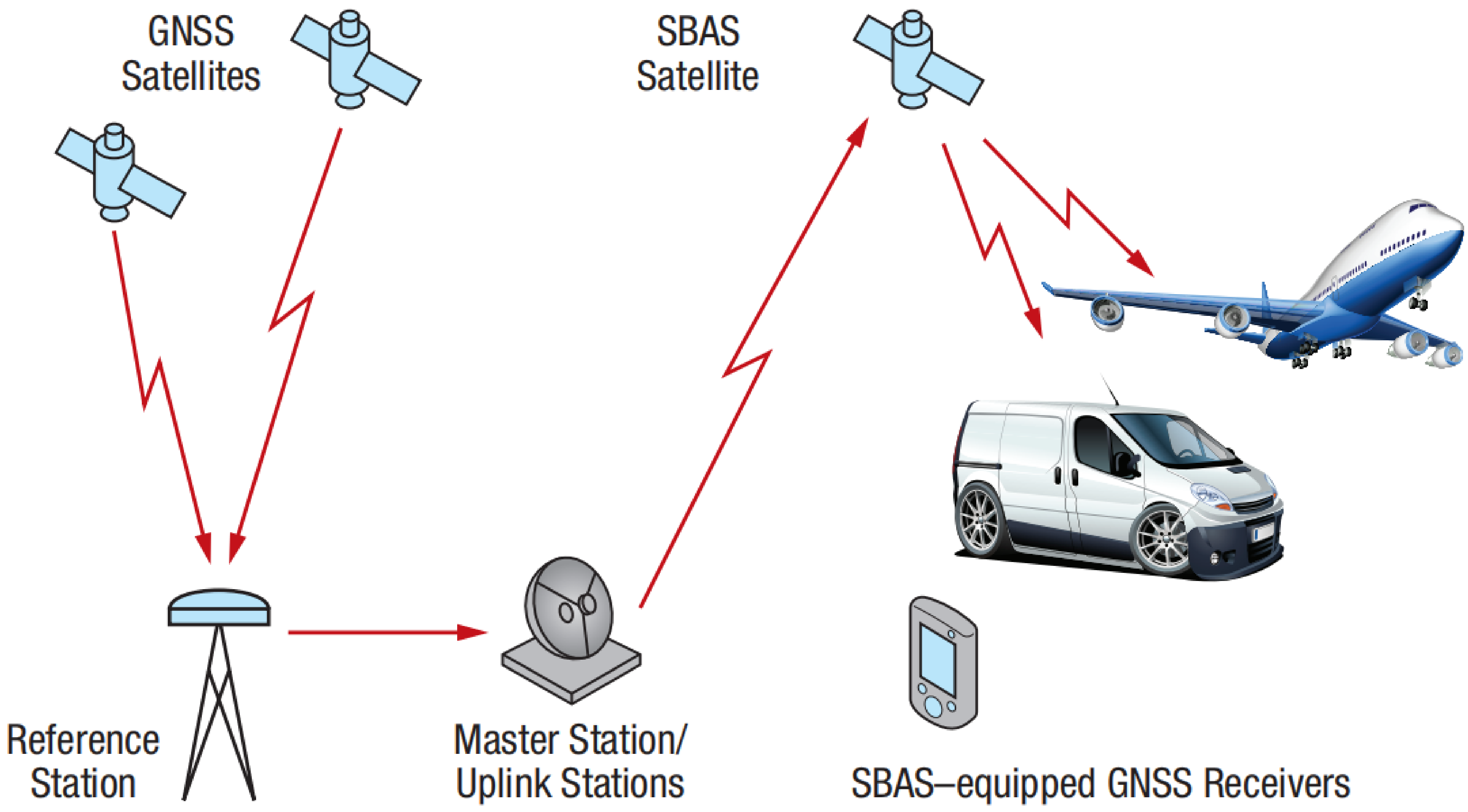
Scripps Coordinate Update Tool (SCOUT)

- Managed by the Scripps Institute of Oceanography
- Provides precise positioning for users who submit GPS RINEX data from their receiver via the Internet.
- The reference stations are by default the three nearest sites for which data have been collected
- When SCOUT has finished determining a DGPS position solution, it sends a report of the results to the user via the Internet.

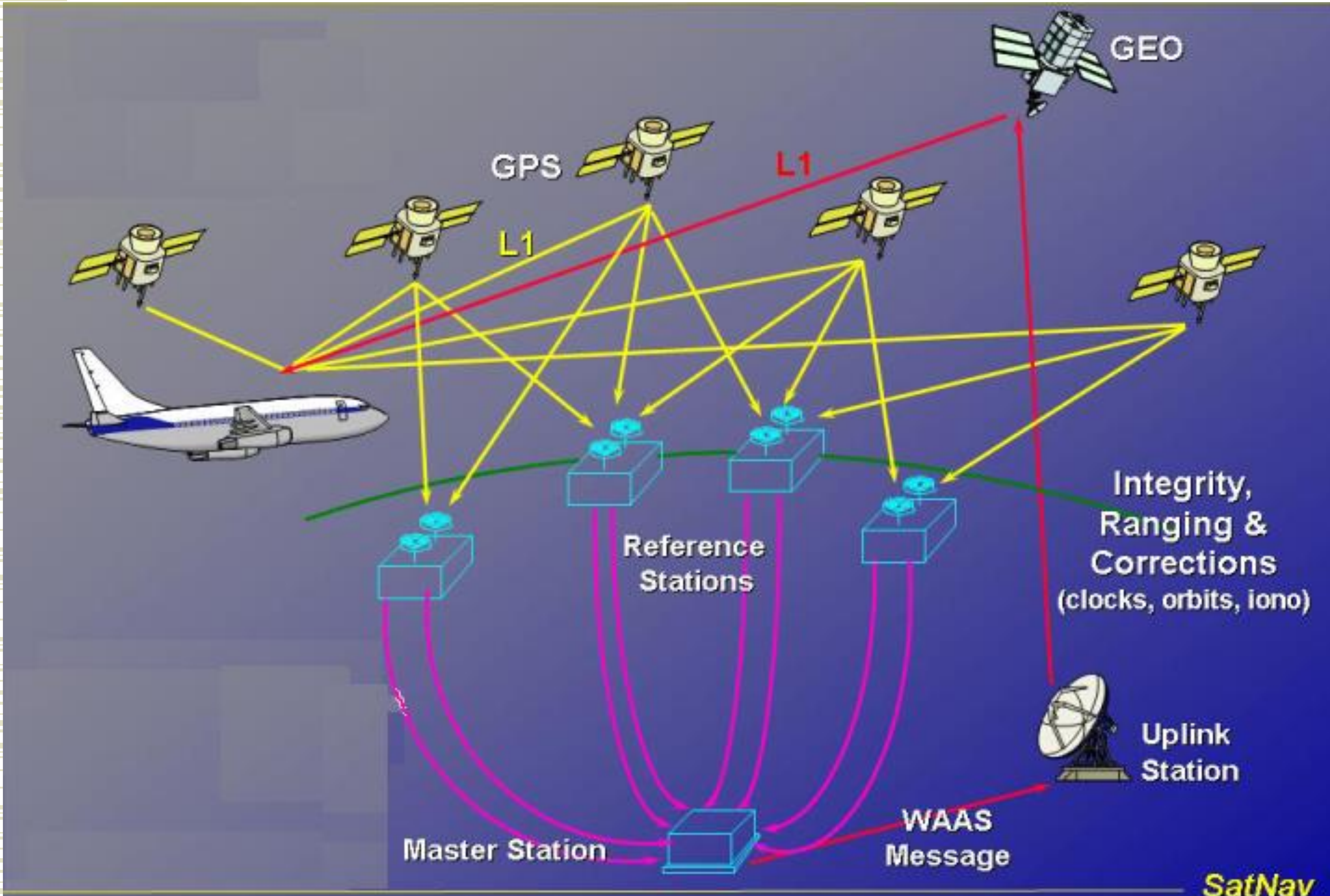
Satellite Based Augmentation System



Satellite Based Augmentation System



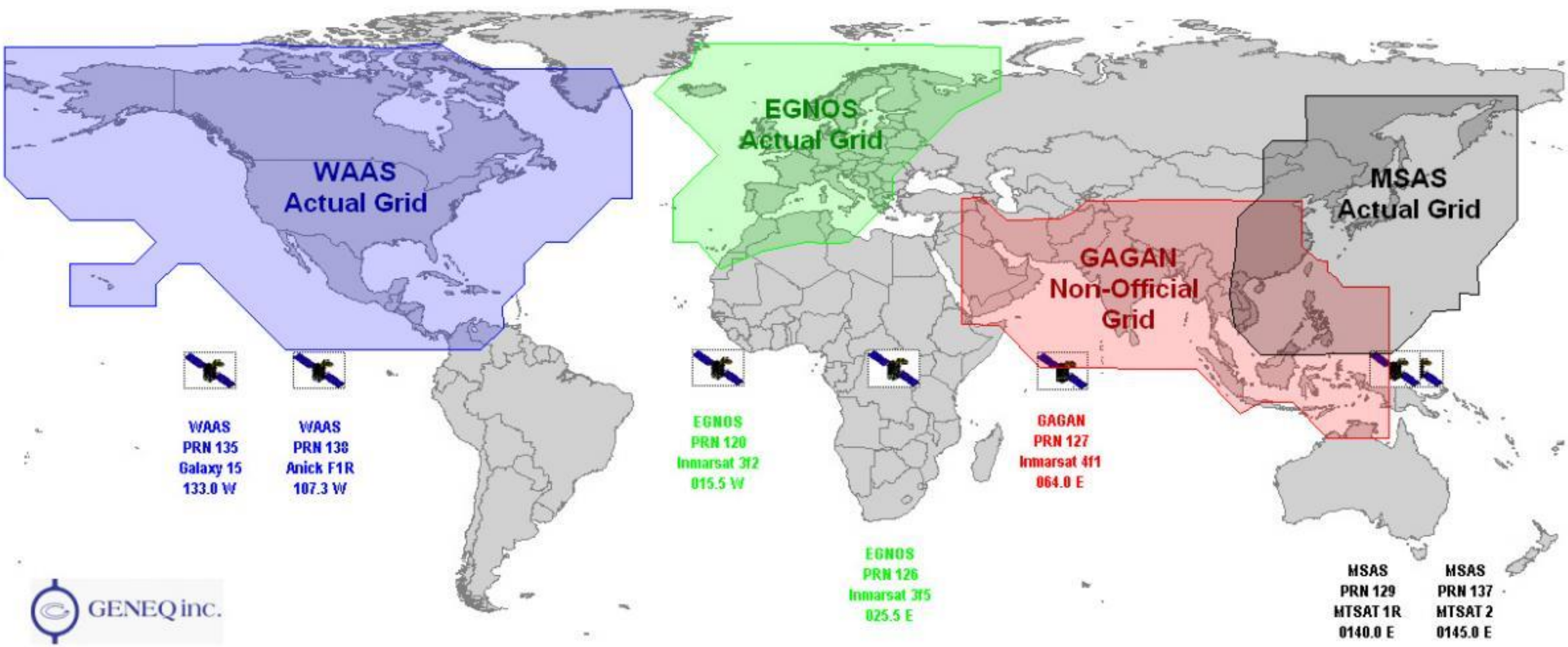
Satellite Based Augmentation System



SBAS Worldover

SBAS	Country
Wide Area Augmentation System (WAAS)	USA
European Geostationary Navigation Overlay Service (EGNOS)	EU
Multi-functional Satellite Augmentation System (MSAS)	Japan
GPS Aided Geo Augmented Navigation (GAGAN)	India
System for Differential Correction and Monitoring (SDCM)	Russia
Satellite Navigation Augmentation System (SNAS)	China
Canada-Wide Differential GPS (CDGPS)	Canada
Southern Positioning Augmentation Network (SouthPAN)	Aus/NZ

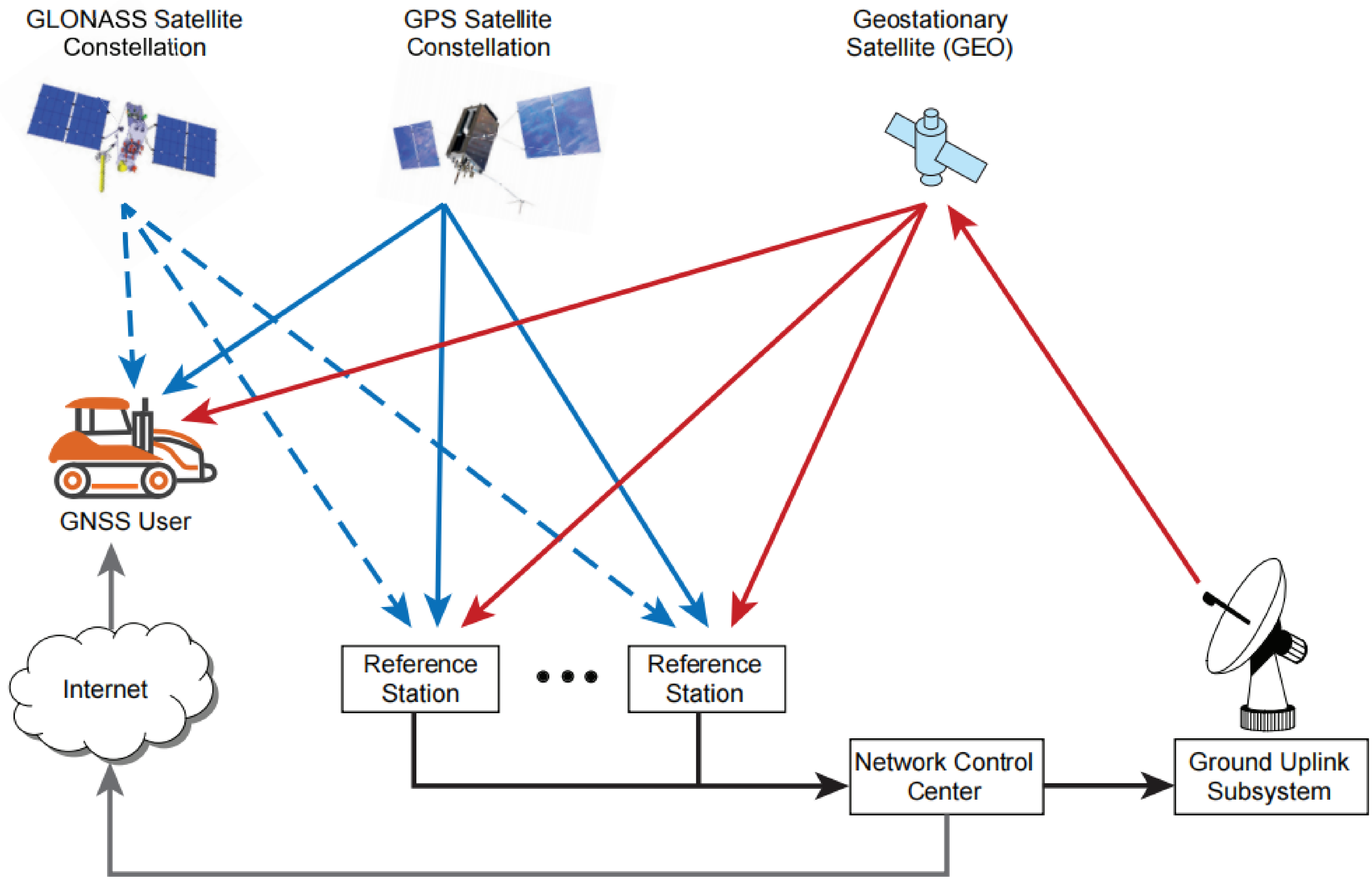
Available SBAS & Coverage



Carrier Phase Measurement

- Distance from the satellite to the user's antenna can be expressed in terms of the number of wavelengths of the carrier signal.
- Wavelength of GPS L1 carrier = 19 cm
- Fractional part ("phase") of a given wavelength, can be measured to 1/100 of a wavelength ~ resolution of 2mm
- Enables position relative to a known point with cm accuracy
- Dual frequency measurements most reliable but accessing L2 carrier signal require expensive receivers
- Full L2C signal availability is the solution

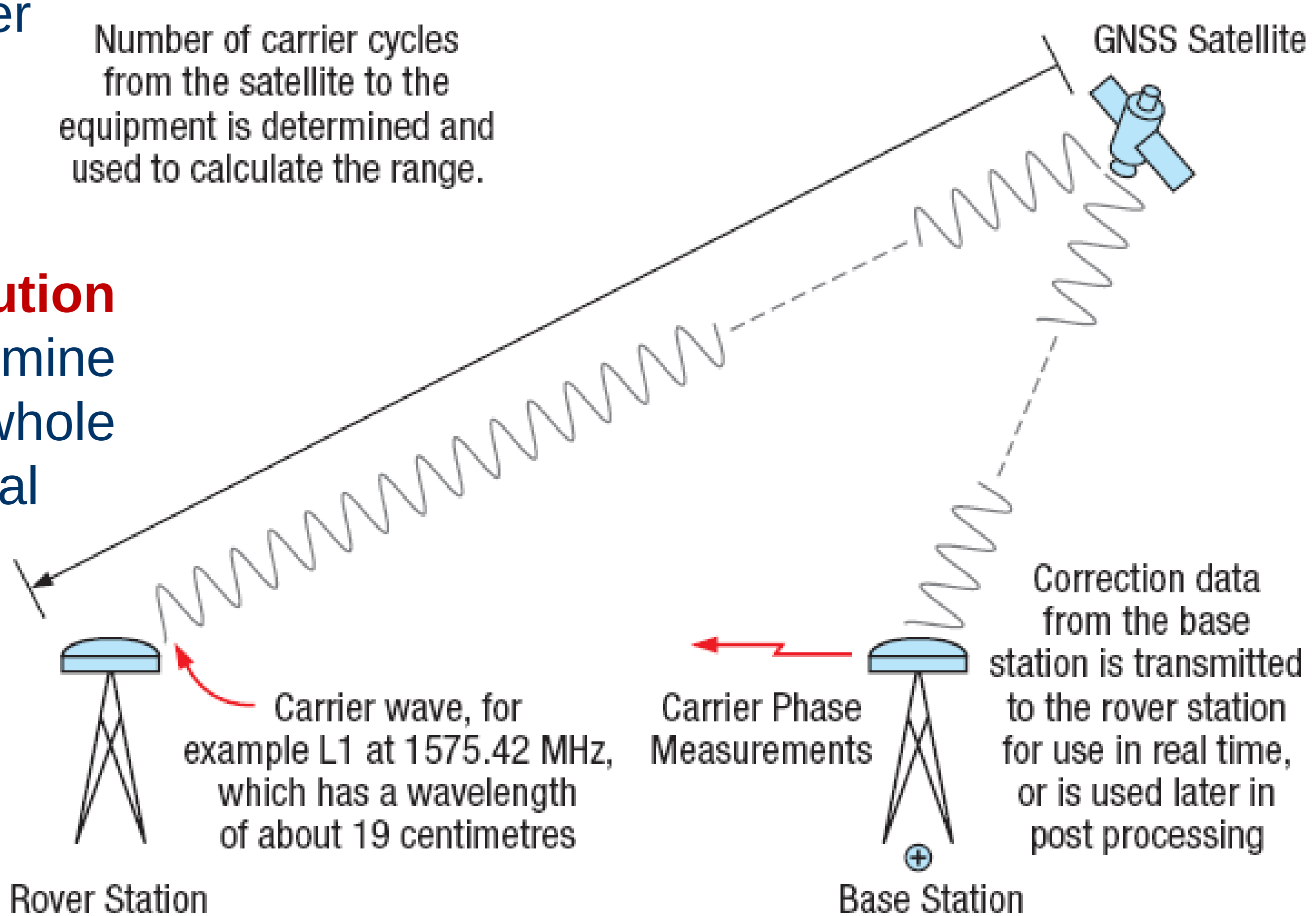
Precise Point Positioning (PPP) System



Real Time Kinematic (RTK)

- Carrier-based ranging that provides more accurate positioning than through code-base positioning
- Idea is to reduce and remove errors from satellites common to both the base and rover

Ambiguity Resolution is required to determine the number of whole cycles in carrier signal



Network RTK

- Based on the use of several widely spaced permanent stations.
- Positioning data from the permanent stations is regularly communicated to a central processing station.
- On demand from RTK user terminals, which transmit their approximate location to the central station, the central station calculates and transmits correction information or corrected position to the RTK user terminal.
- The benefit of this approach is an overall reduction in the number of RTK base stations required. Depending on the implementation, data may be transmitted over cellular radio links or other wireless medium.

Precision by Averaging

- **Averaging:** A GNSS receiver can collect points continuously for 15-30 seconds. The receiver can then average all these locations together
- Works only for stationary receiver
- All GNSS receivers DO NOT have an averaging capability

GNSS Data Post-Processing

- For applications where real-time solution is not necessary, raw GNSS data can be collected and stored for post mission processing
- Post-processing does not require a real-time transmission of differential corrections, simplifying hardware configuration
- Users can load data from multiple base stations, or download freely available base station data
- Users can also download PPP data (precise ephemeris and clock data) to process without a base station
- Post-processing can be done on both **static** or **kinematic** data

GNSS Equipment & Applications

Equipment & Applications

MEASURE WHAT IS MEASURABLE,

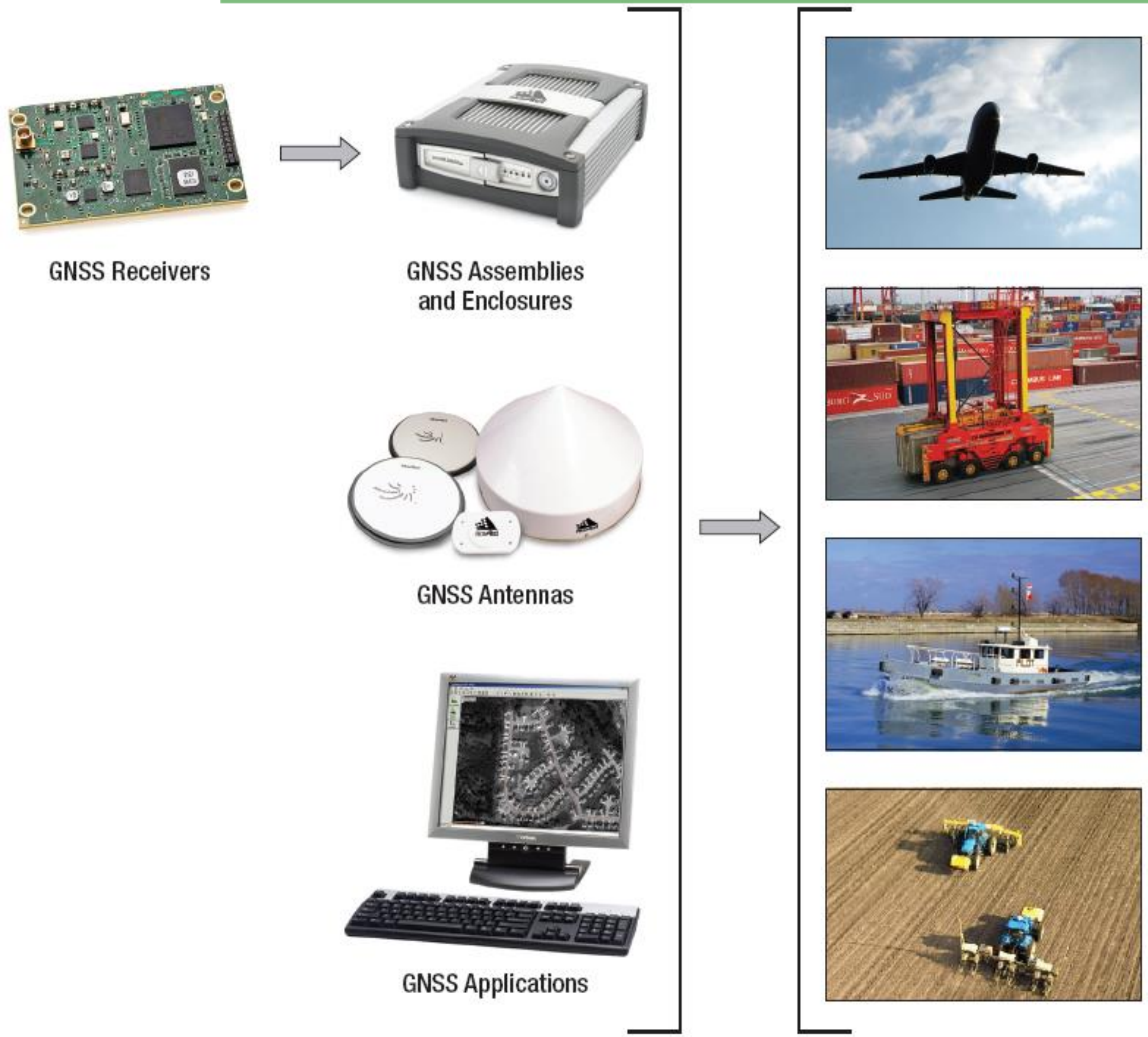
AND

MAKE MEASURABLE

WHAT IS NOT SO

Galileo

GNSS Application Aspects



Acquisition Time

Reliability

Availability

Environmental

Shock and Vibration

Portability

Regulatory

Data Storage

Power Consumption

User Interface

Computational Requirements

Communications

Future-Proof

Different Grades of Receivers

- **Recreational Grade**
  - Accurate to within 5 meters
  - Low cost: $5-$800


- **Mapping Grade**
  - Accurate to within 0.5 meter
  - $1000-$4,000

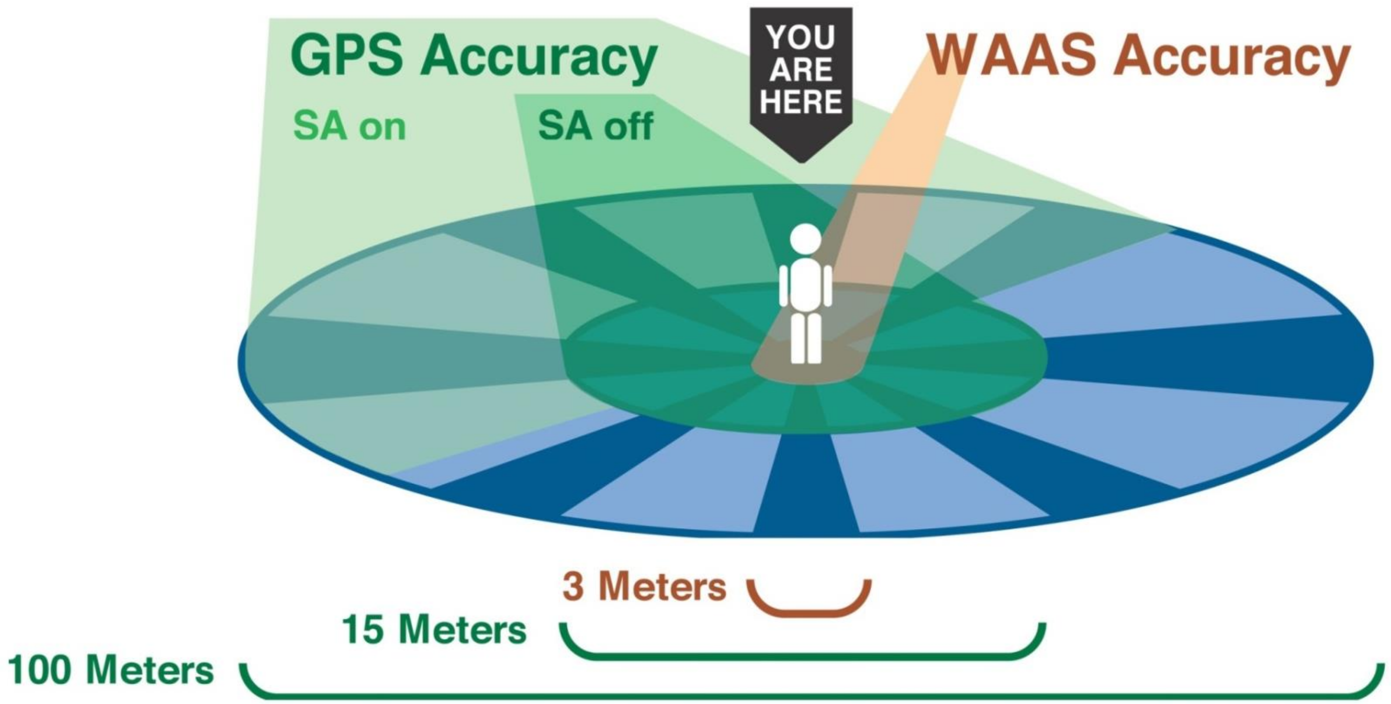

- **Survey Grade**
  - Accurate to within few mm
  - $4,000 -$30,000

Total Stations



Factors Affecting Accuracy of Receiver

- The make and model
- The satellite constellation at that particular point in time
- Buildings, tree canopy coverage, and other factors
- GBAS, SBAS, WAAS etc availability



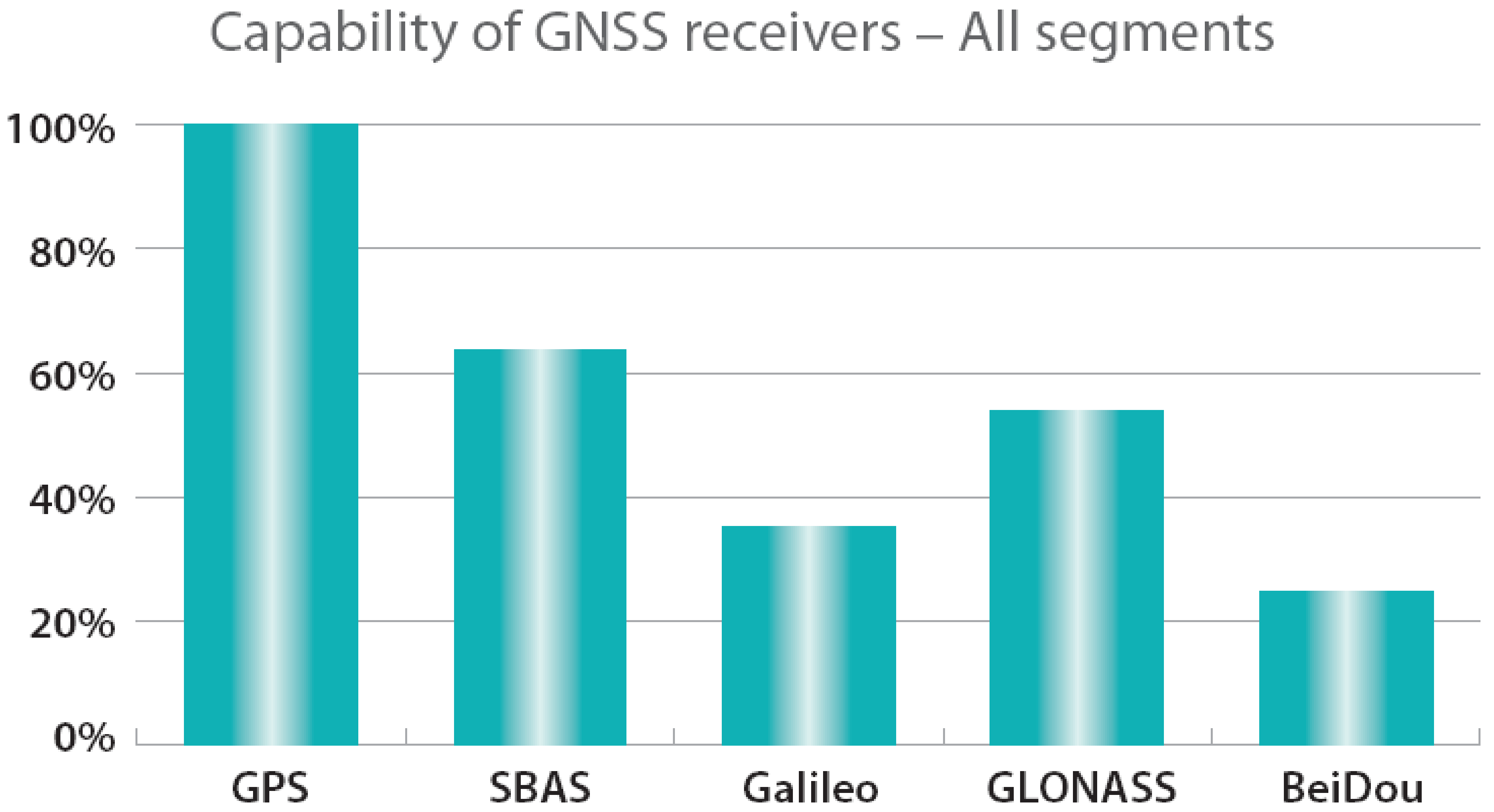
Development of GNSS Receiver

- **GPS L1**
- **GPS L1 & L2**
- **GPS + GLONASS + SBAS**
- **GPS + L5 + GLONASS + GALILEO + BeiDou**
- **GPS + L5 + GLONASS + GALILEO + SBAS + GBAS**
- **GPS + L5 + GLONASS + GALILEO + SBAS + GBAS + IRNS**
- **…**
- **…**

Position with dm and even sub-cm accuracy is available

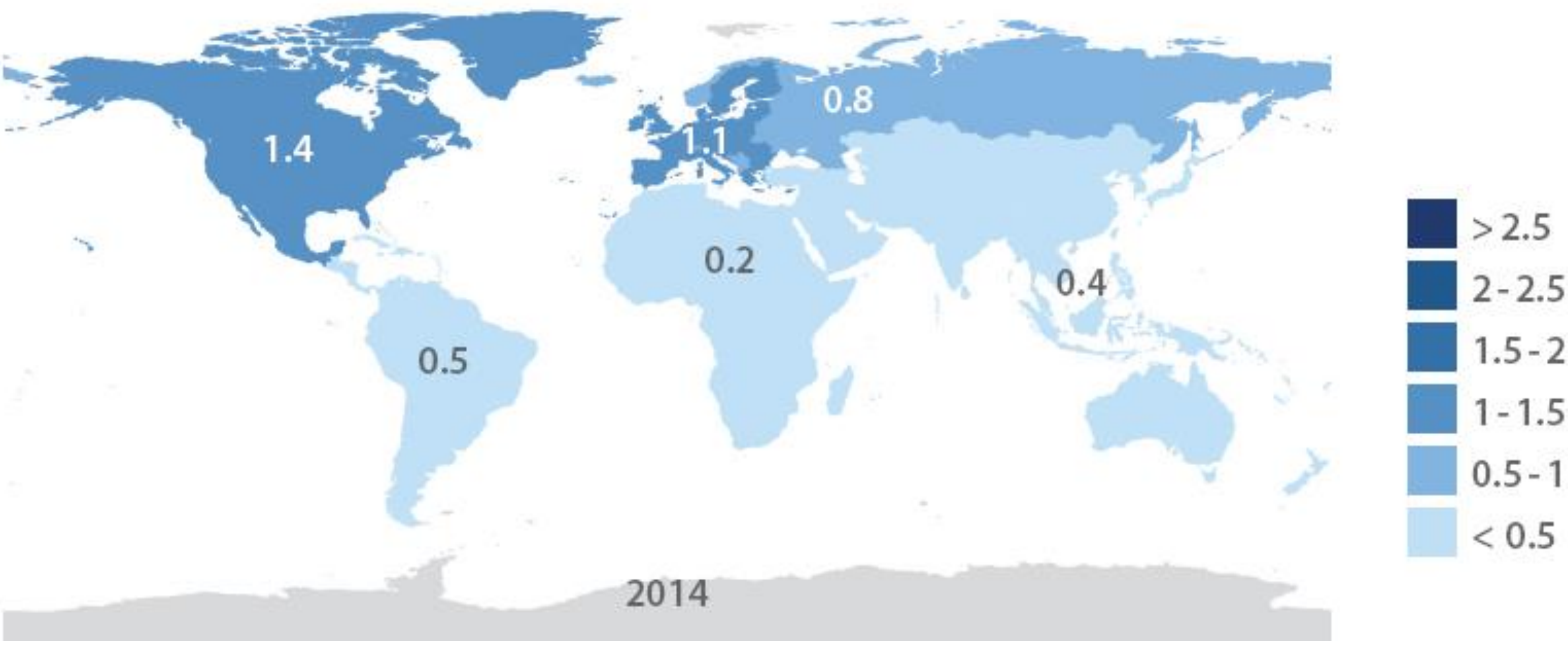
Analysed manufacturers: CSR, Furuno, Hemisphere GNSS, Japan Radio Co., Leica Geosystems AG, Mediatek, NavCom Technology, Nottingham Scientific Ltd, NovAtel, Orolia, Septentrio, STMicroelectronics, Topcon, Trimble, U-blox, Avidyne, Broadcom, Esterline, Garmin, Honeywell, Infineon, Intel, John Deere, Kongsberg, Omnicom, Qualcomm, Rockwell Collins, SkyTraq Technology, Texas Instruments, THALES Avionics, Universal Aviation.

Development of GNSS Receiver

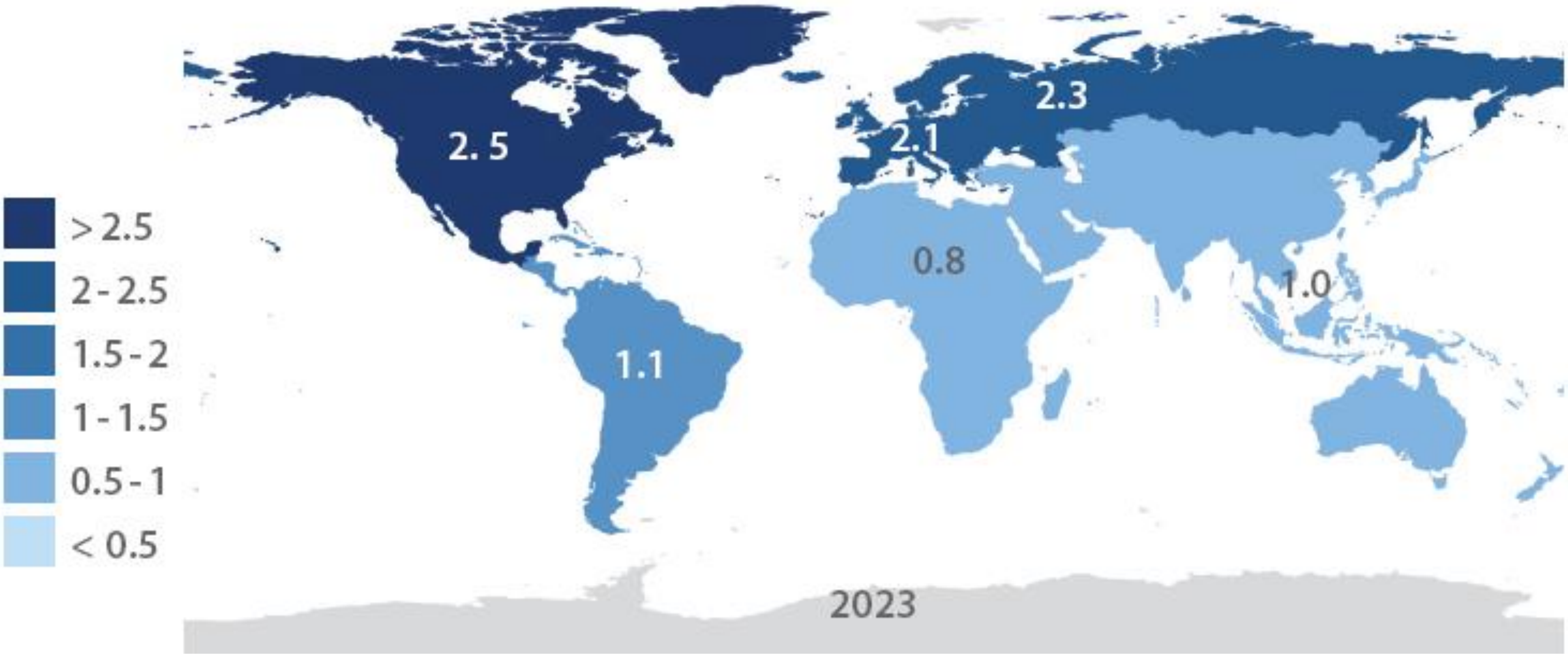


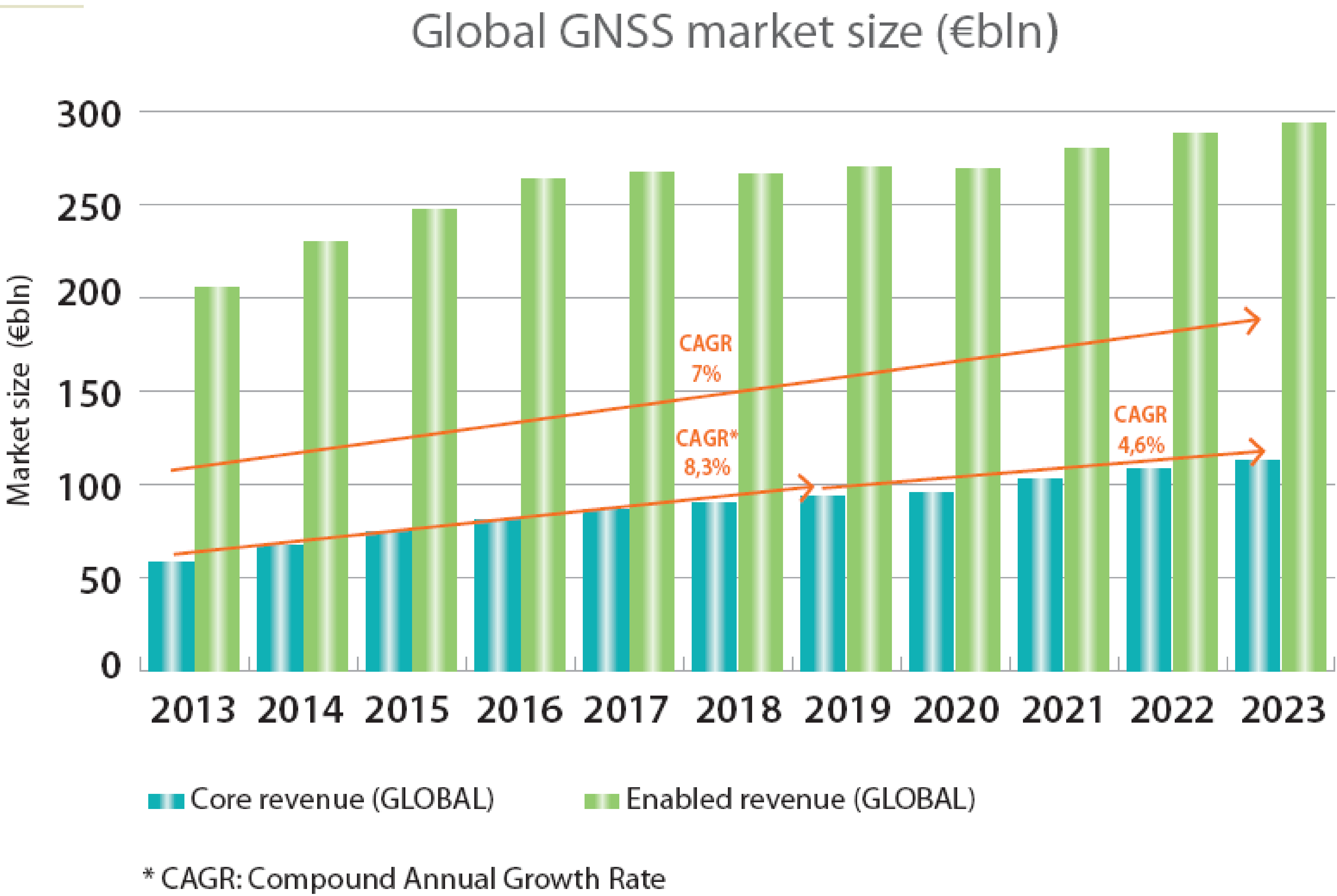
GNSS Devices – World Over

- Approx 4 billion GNSS devices being used worldwide (85% in Smartphones)
- All regions experiencing growth

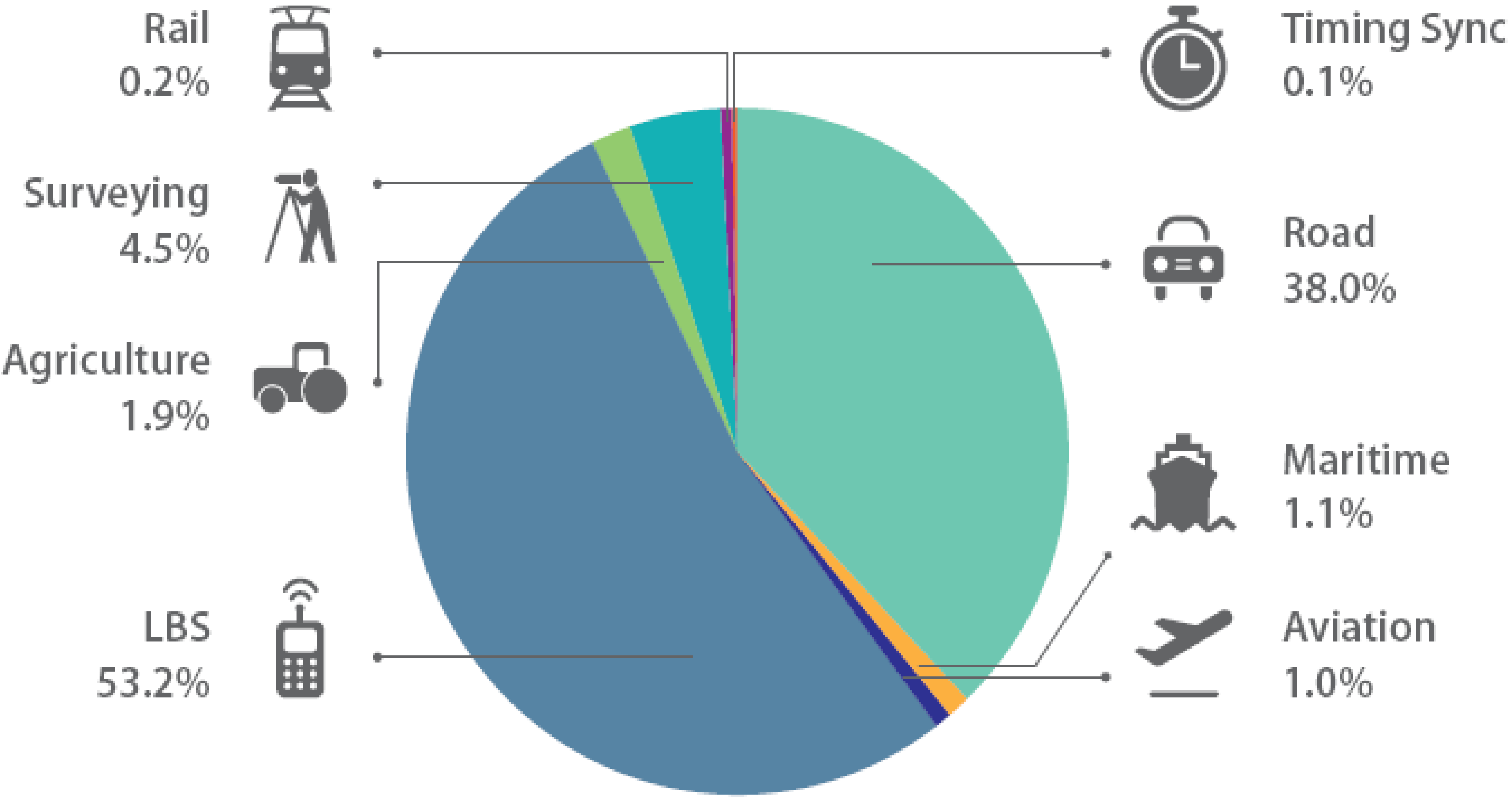


GNSS Devices – World Over

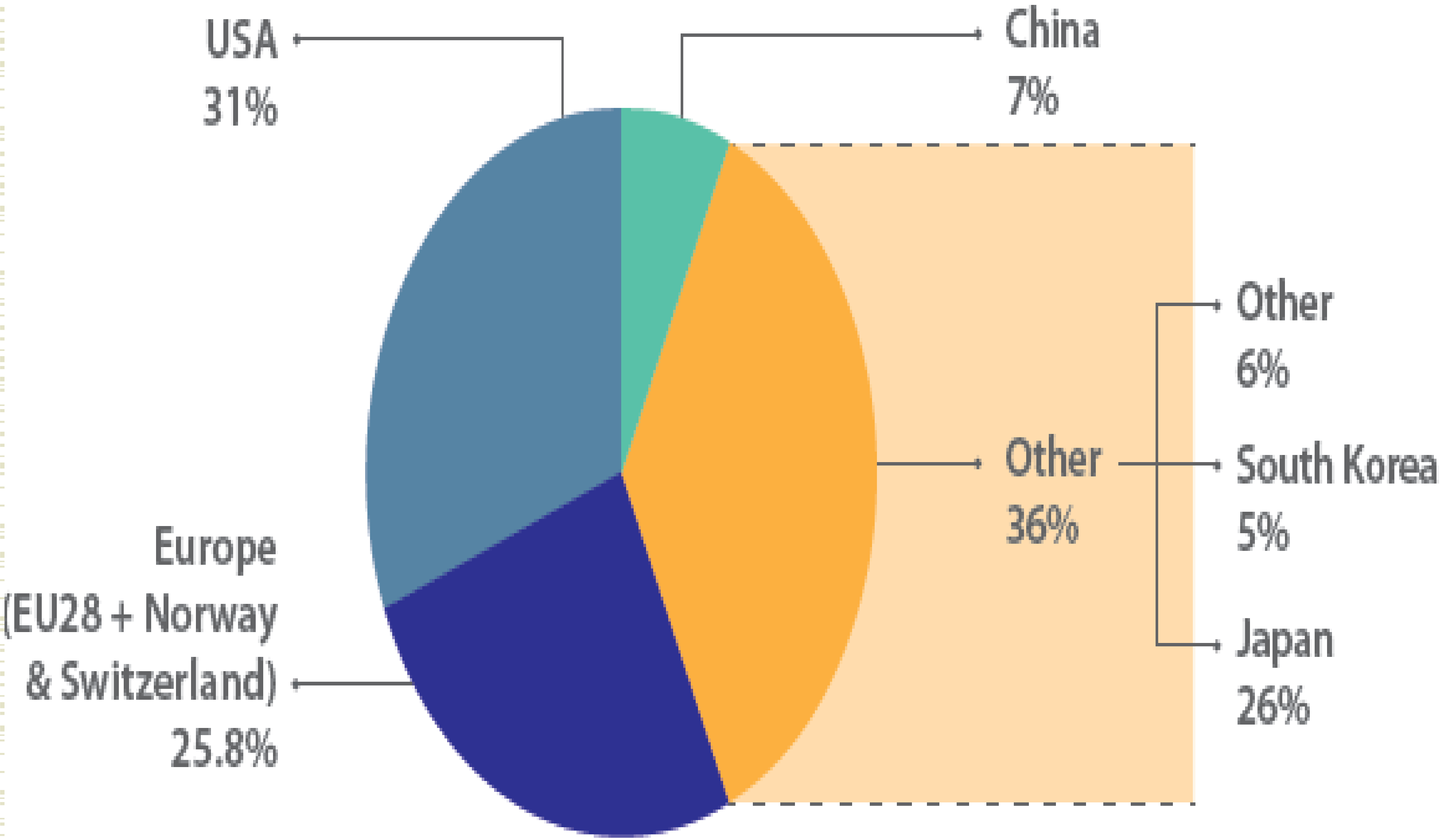



Global GNSS market size (€bln)
Market size (€bln)
300
250
200
150
100
50
0
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
CAGR
7%
CAGR*
8,3%
CAGR
4,6%
Core revenue (GLOBAL)
Enabled revenue (GLOBAL)
* CAGR: Compound Annual Growth Rate

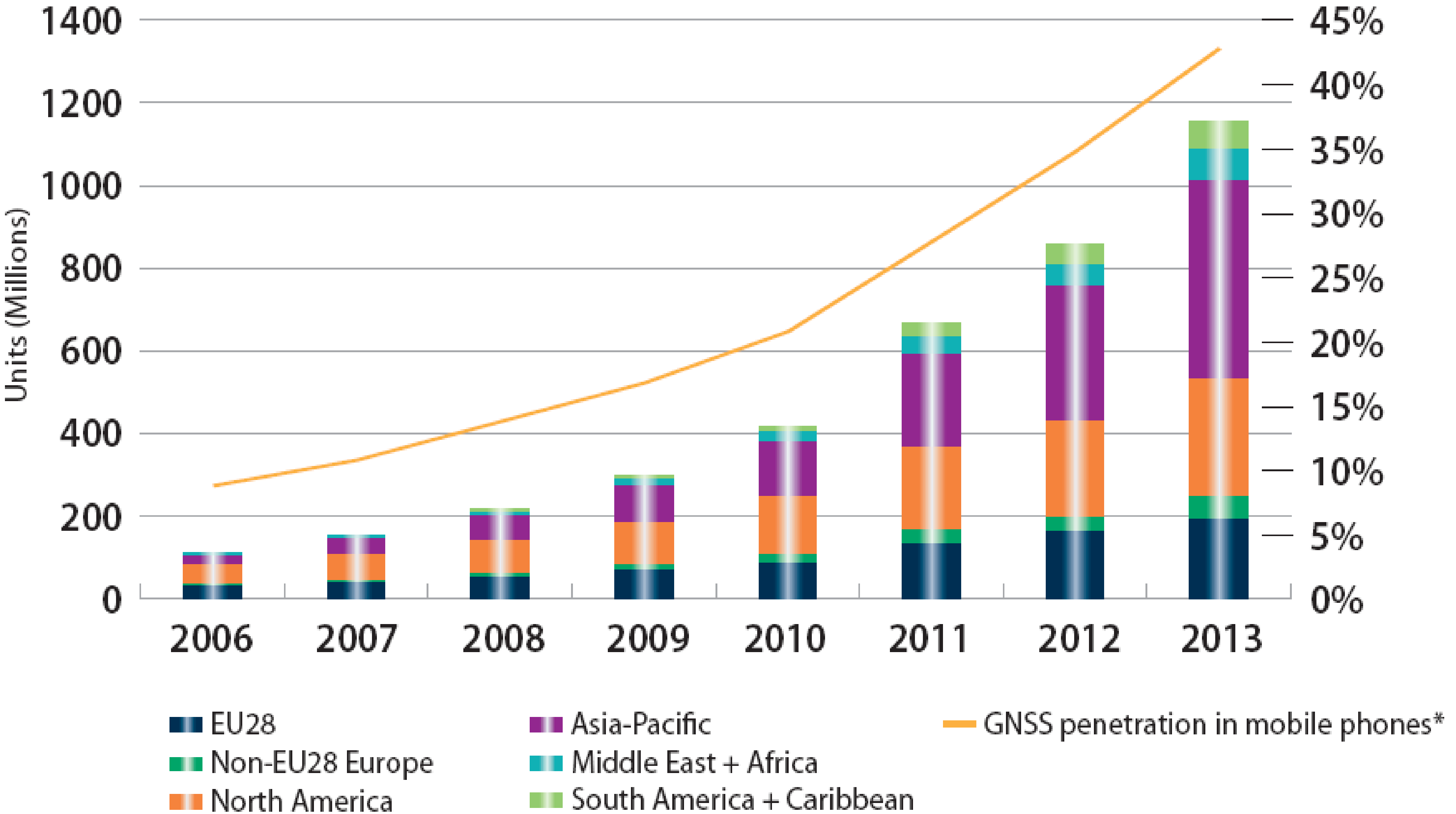
Cumulative core revenue 2013-2023



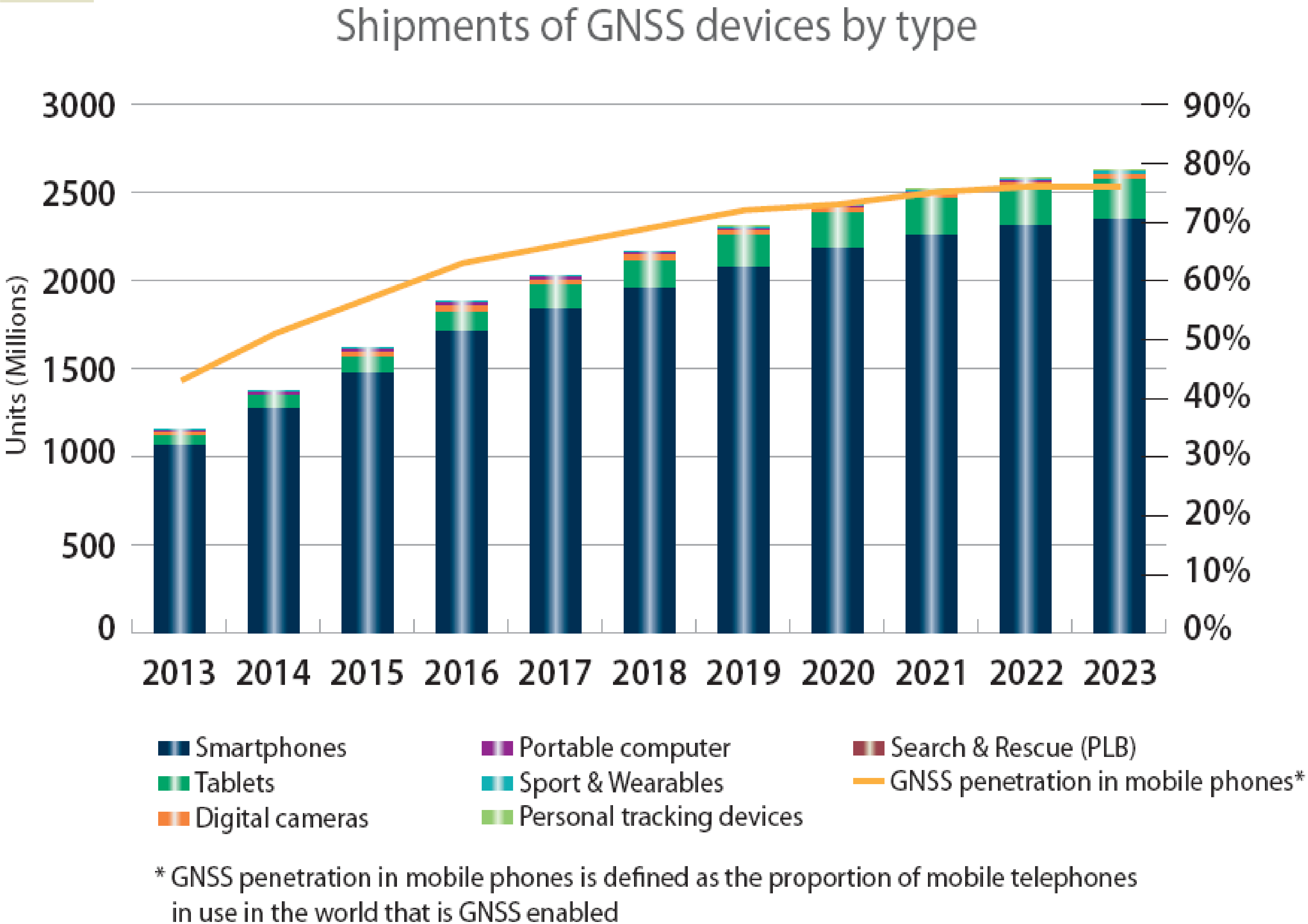
GNSS Industry Share by Region (% split of revenues; 2012)



Shipments of GNSS devices by region



* GNSS penetration in mobile phones is defined as the proportion of mobile telephones in use in the world that is GNSS enabled


Shipments of GNSS devices by type
3000
2500
2000
1500
1000
500
0
Units (Millions)
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
Smartphones
Tablets
Digital cameras
Portable computer
Sport & Wearables
Personal tracking devices
Search & Rescue (PLB)
GNSS penetration in mobile phones*
* GNSS penetration in mobile phones is defined as the proportion of mobile telephones in use in the world that is GNSS enabled

Users

Applications

- Defense
- Transportation
- Timing/Synchronization
- Machine Control
- Marine
- Surveying
- Port Automation
- Job-Site Mgmt

Defense

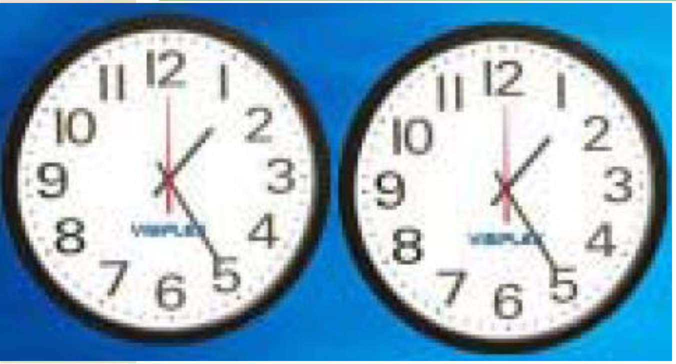

EX 18 Payload Safe/Arm
• Payload Base Eject
• Gas-Expanded Metal Bladder Submunition Dispense
XM 234 Submunition Self-Destruct Fuze (Arming)
TC5 - Pyrotechnic Delay Igniter
Selectable Home-on-GPS-Jam Guidance
TC6 - Inertial Measuring Unit
Flight Thermal Battery (Not Shown)
TC4 - Four-Fin Tail Assembly
Tightly Coupled, Fast Acquisition, High Anti-Jam GPS
TC3 - Ram Brake (Not Shown)
Low-Drag Boat Tail Taper
Breech Pressure Equalizing Rocket Motor
TC2 - Forward Located Slip Obturator
Low-Drag Fineness Ratio
TC1 - System Software
Canard Control Electro Mechanical Actuators
72 EX-1 Submunitions (Lethality)

Defense

- Navigation (Men and Machines)
- Reconnaissance and Map Creation
- Search and Rescue
- UAV

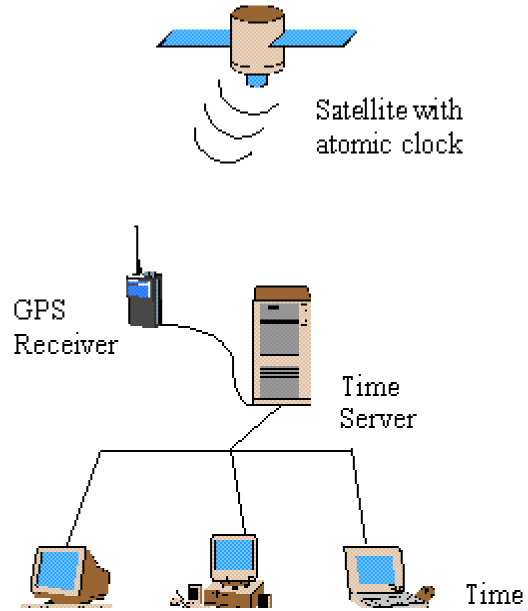
Smart Munition Dispensation

Timing/Synchronization

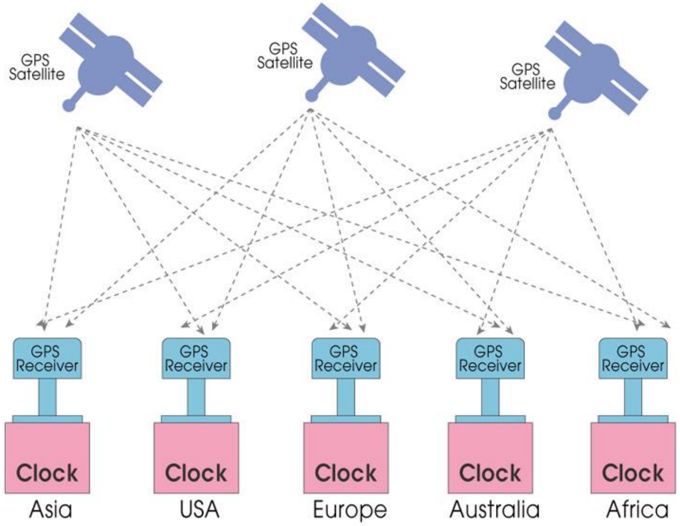


Systems Synchronization

- Power grids
- Cellular systems
- Internet
- Financial networks



GNSS derived time works well for any application where **precise timing** is required by devices dispersed over a wide area.

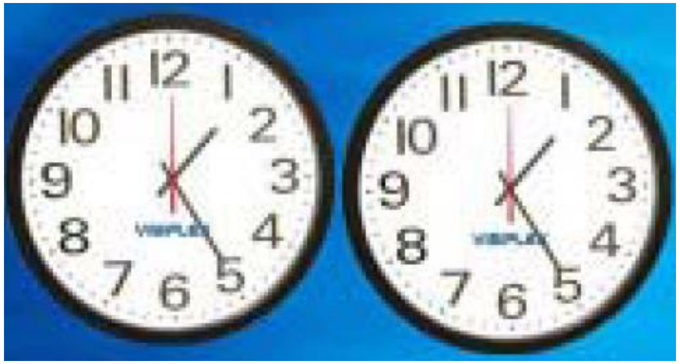


Grid station Synchronization

Timing/Synchronization

Seismic monitors that are **synchronized** with GNSS satellite clocks can be used to determine the epicenter of an earthquake by triangulation based on the exact time the earthquake was detected by each monitor.

Mobile Satellite Communications — Satellite communications systems use a directional antenna (usually a "dish") pointed at a satellite. The **antenna on a moving ship** or train, must be pointed based on its current location (provide by GNSS).



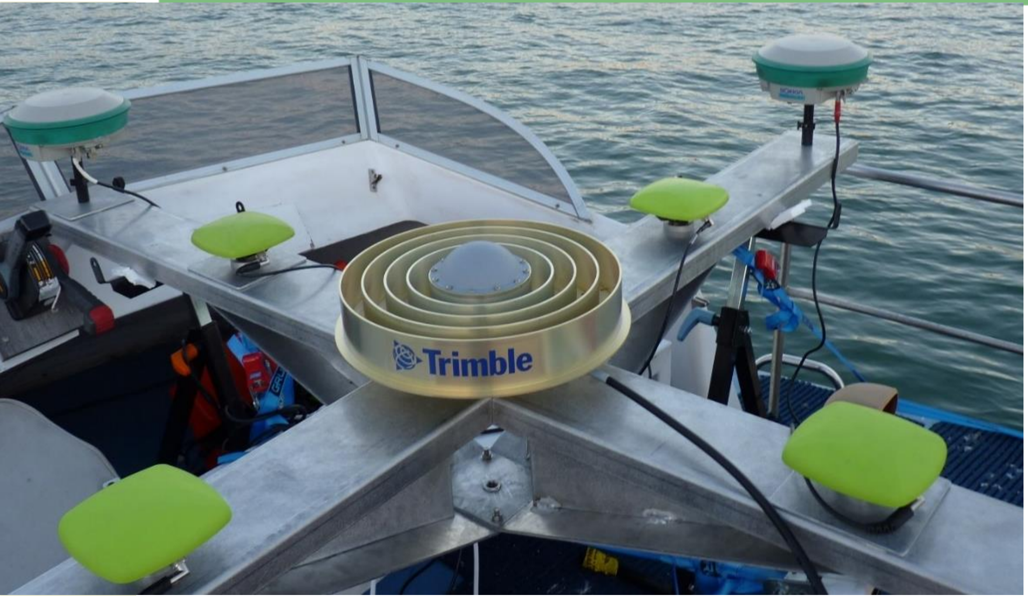
Machine Control

GNSS-based steering devices for determining the crane's position

Dozer productivity and accuracy

No need to stop work while survey crew evaluate the grade

Marine



Seafloor Mapping

Bathymetry

GNSS may be connected to the ships self-steering system

- Navigation
- Oilrig positioning
- Underwater cable and pipeline installation
- Rescue and recovery
- Dredging of ports and waterways

Surveying

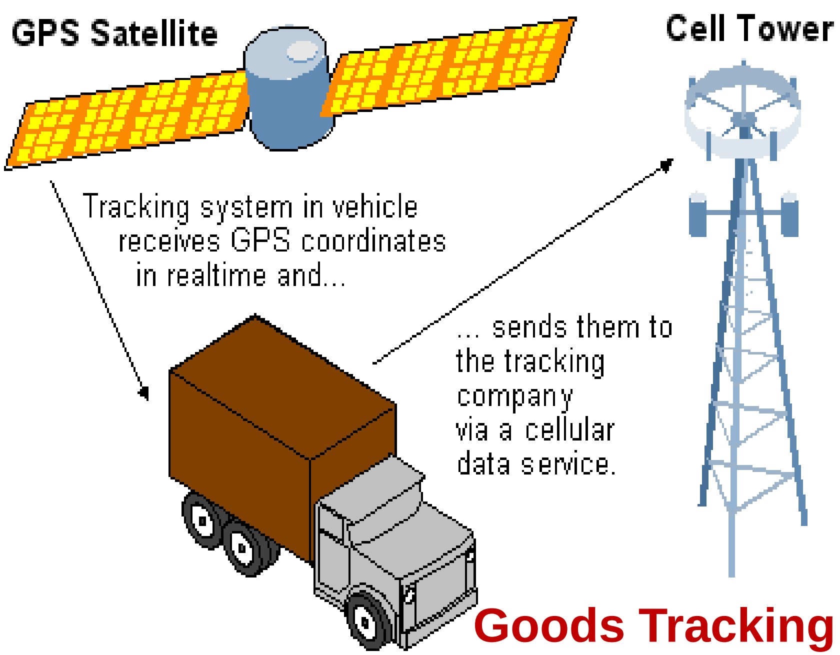
GNSS-based surveying reduces the amount of equipment, labor
&
Time

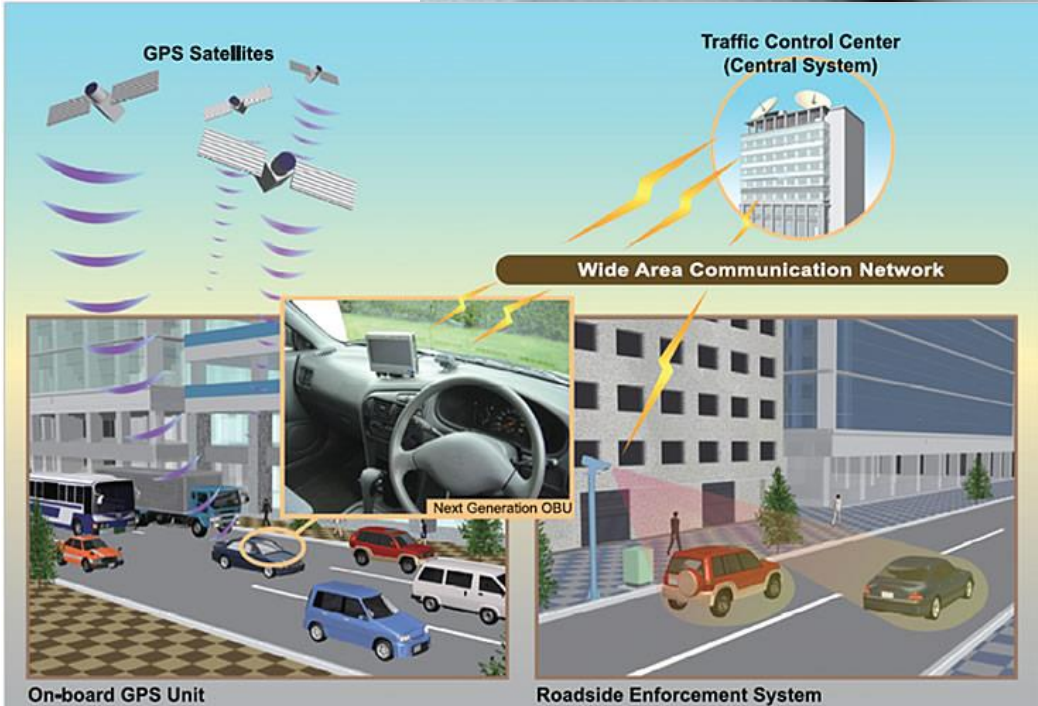
Agriculture

- Farm planning
- Field mapping
- Tractor guidance
- Crop assessment
- Precise application of fertilizers /pesticides /herbicides

Transportation

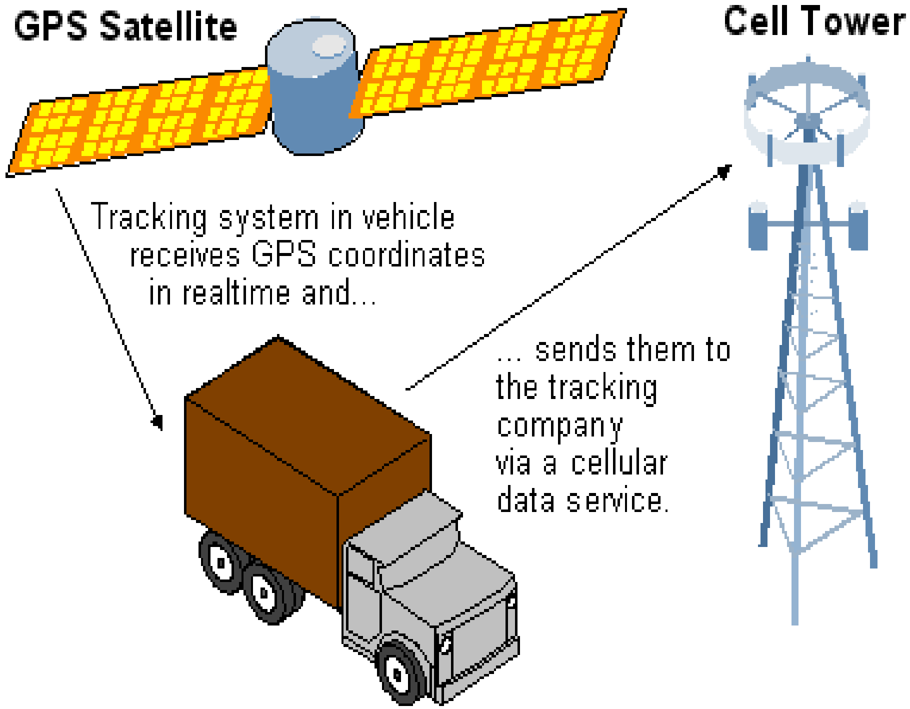
- Departure
- En route
- Landing





Multimodal Logistics

- Monitoring goods and assets during transport
- Positioning and timing is combined, informing the status of the container and the cargo
- Information is transmitted to logistic operators and their clients



Internet-of-Things & Machine-to-Machine communication

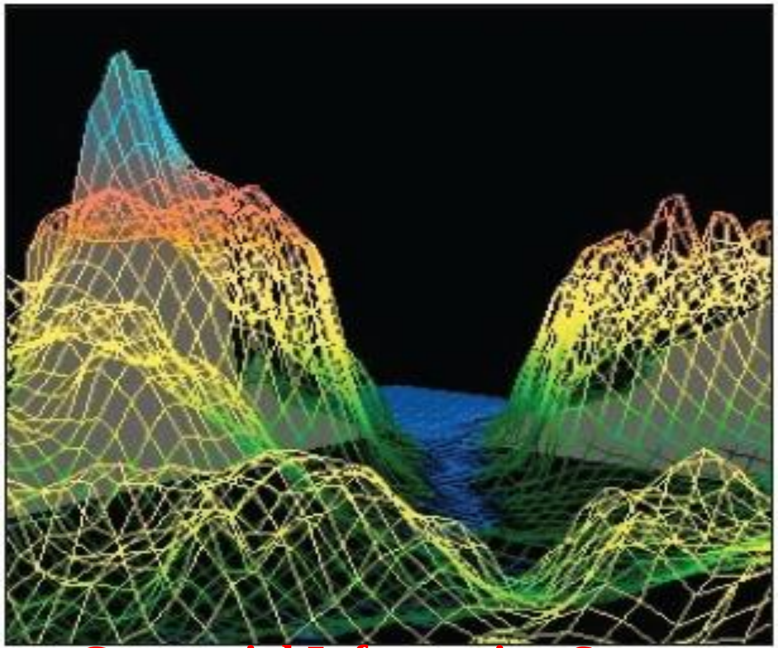
Major development in the role of the Internet & GNSS

The interconnectivity of uniquely identifiable devices

Thanks to IPV6, all physical objects can be assigned unique address and, thus, communicate.

IoT market expected to hit $1 trillion in 2023

Miscellaneous Applications



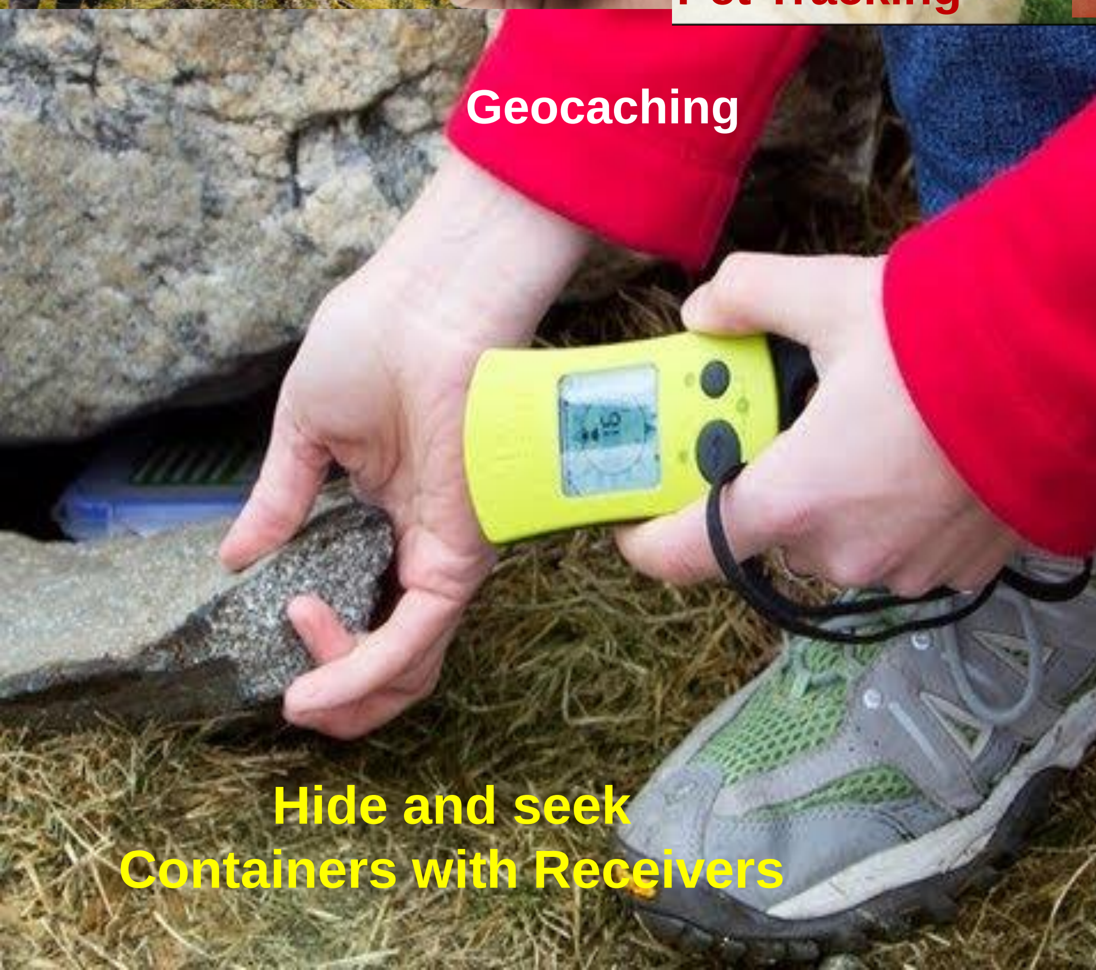
Geospatial Information Systems

Implantable Tracking Chip


Trekking
etrex
GARMIN


Pet Tracking


Rowing

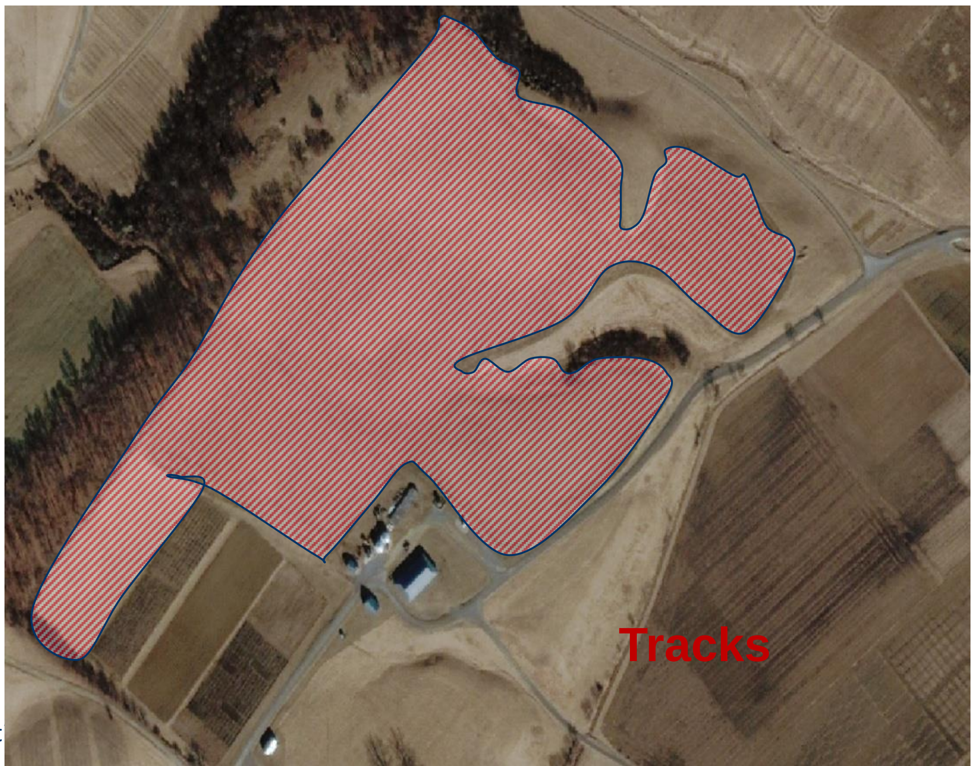

Geocaching
Hide and seek
Containers with Receivers


Cycling
GPS 60
GARMIN


GNSS for
Visually Impaired Person

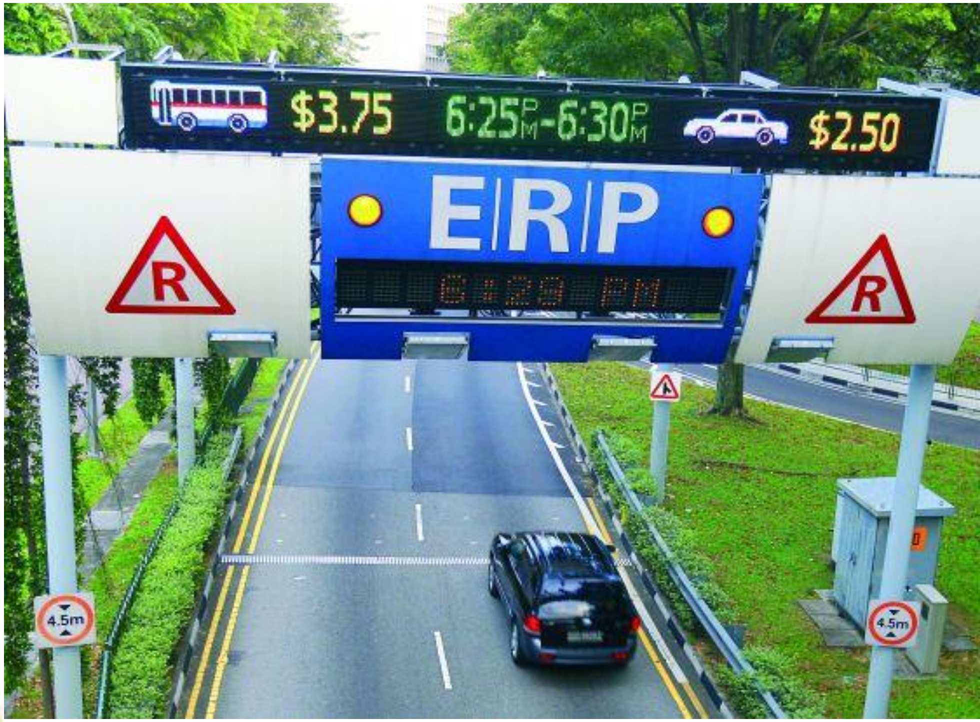

Archelogy


POSITION
S28°45.876
E30°24.658
HEADING
305°
Heading Information


Tracks

Electronic Road Pricing (ERP)

Floating Veh Data, for Traffic Modeling & Management.



Geo-Fence: Define geographic boundary.

Virtual administrative barrier

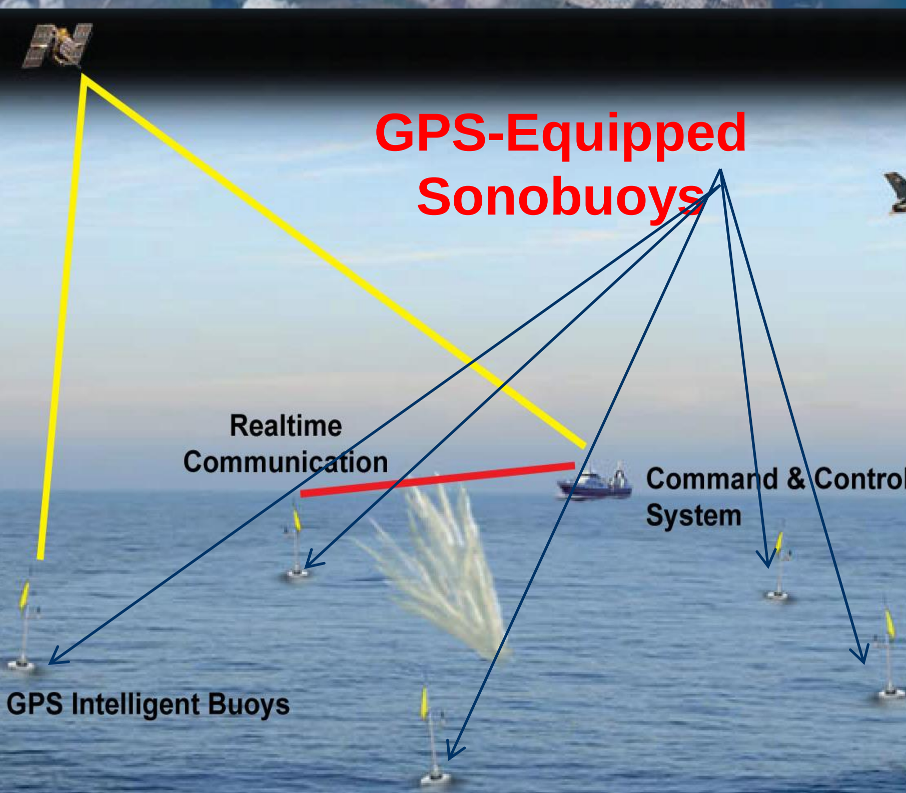
Triggers message, when a mobile GNSS enabled device enters/exits barrier

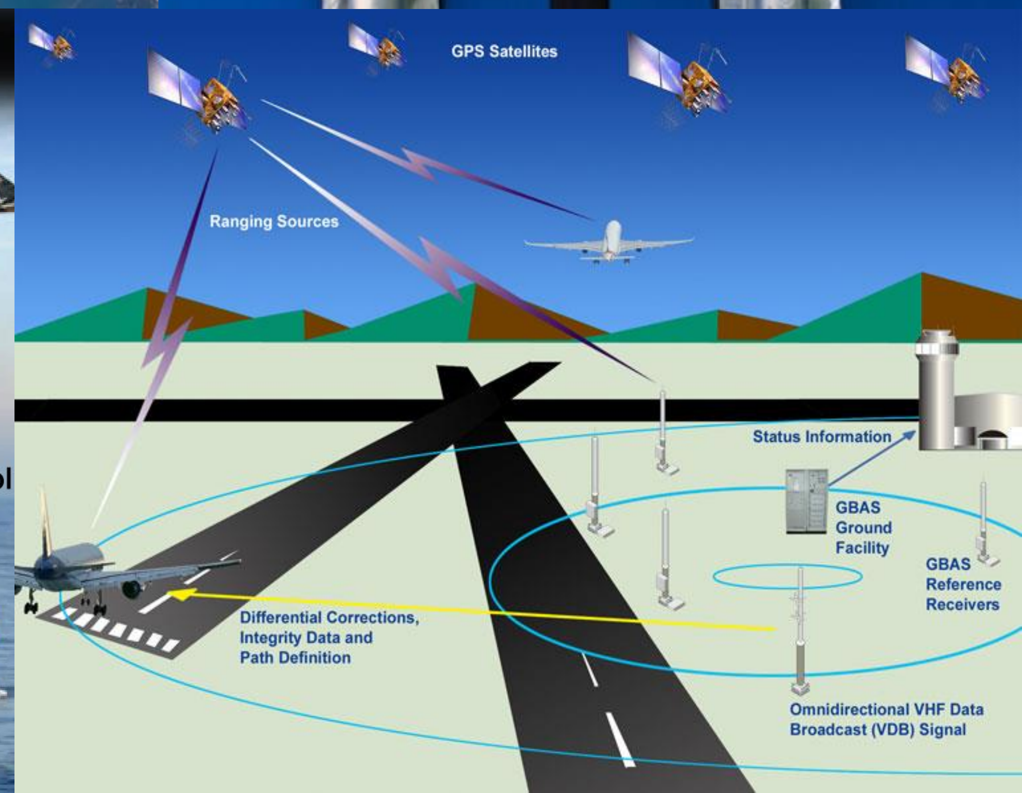
Automatic transactions for a car park etc

Theft detection


Skydiving


GPS Container Tracking Lock
TRAKLOK
www.traklok.com
1-865-927-4911
WARNING
GPS MONITORED


GPS-Equipped Sonobuoys
Realtime Communication
Command & Control System
GPS Intelligent Buoys


GPS Satellites
Ranging Sources
Status Information
GBAS Ground Facility
GBAS Reference Receivers
Differential Corrections, Integrity Data and Path Definition
Omnidirectional VHF Data Broadcast (VDB) Signal


Thank You