GNSS for Policy and Decision Makers

Introduction to GNSS

Dinesh Manandhar

Center for Spatial Information Science

The University of Tokyo

Contact Information: dinesh@csis.u-tokyo.ac.jp

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Objectives

- Give an overview of
  - GNSS Technology and Applications
- Exploring New Applications
  - Early Warning Systems,
  - Illegal Fishing Control and Vessel Monitoring
  - Dynamic Road Pricing, Traffic Congestion Management, Toll Charging
- Introduction of Low-Cost Receiver Systems
  - For Capacity Development, GNSS/GIS Data Collection, Conducting Pilot Projects
- GNSS Security Issues
  - Jamming, Interference and Spoofing
- Interpreting GNSS Specifications
  - How to interpret technical terms?

Disclaimer

In this training, we will be referring to several GNSS receiver and related products, brands and company names for explanation and data collection and data processing purposes only. Neither ICG nor CSIS/The University of Tokyo has any intention to promote or prefer either commercially or non-commercially to any of the products in these presentations. Please refer them just as reference materials that we have gathered from different sources. Interested participants are requested to contact the company's homepage directly.

Navigation Types

- Landmark-based Navigation
  - Stones, Trees, Monuments
    - Limited Local use
- Celestial-based Navigation
  - Stars, Moon
    - Complicated, Works only at Clear Night
- Sensors-based Navigation
  - Dead Reckoning
    - Gyroscope, Accelerometer, Compass, Odometer
    - Complicated, Errors accumulate quickly
- Radio-based Navigation
  - LORAN, OMEGA
    - Subject to Radio Interference, Jamming, Limited Coverage
- Satellite-based Navigation or GNSS
  - TRANSIT, GPS, GLONASS, GALILEO, QZSS, BEIDOU (COMPASS), IRNSS
    - Global, Difficult to Interfere or Jam, High Accuracy & Reliability

What is GNSS?

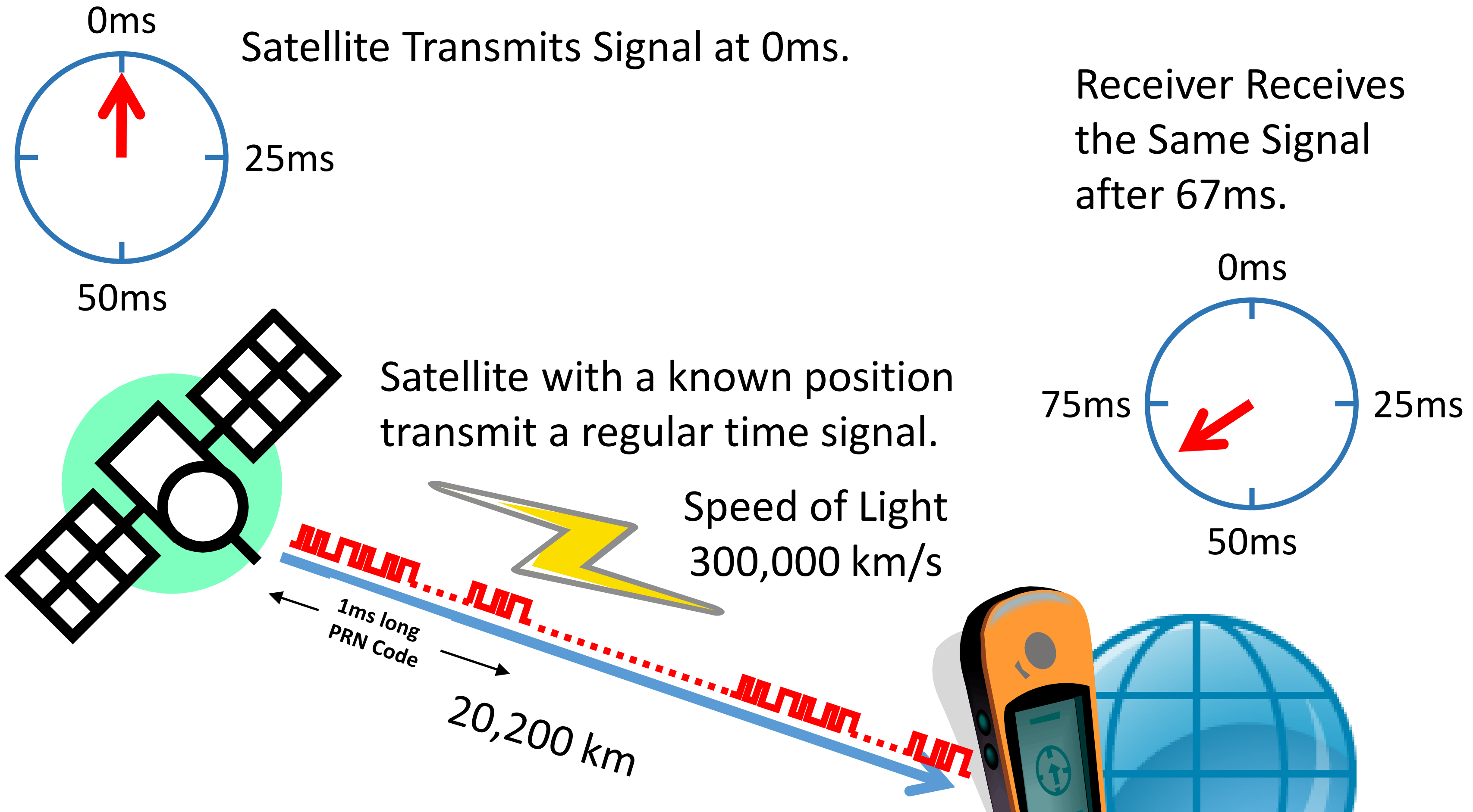
Global Navigation Satellite System (GNSS) is the standard generic term for all navigation satellites systems like GPS, GLONASS, GALILEO, BeiDou, QZSS, NAVIC.

- Global Constellation
  - GPS USA
  - GLONASS, Russia
  - Galileo, Europe
  - BeiDou (COMPASS) / BDS, China
- Regional Constellation
  - QZSS, Japan
  - NAVIC (IRNSS), India

Satellite Based Augmentation System (SBAS)

- Satellite Based Augmentation System (SBAS) are used to augment GNSS Data
  - Provide Higher Accuracy and Integrity
  - Correction data for satellite orbit errors, satellite clock errors, atmospheric correction data and satellite health status are broadcasted from Geo-stationary satellites
  - Used by ICAO for Aviation
- SBAS Service Providers
  - WAAS, USA
  - MSAS, Japan
  - EGNOS, Europe
  - GAGAN, India
  - SDCM, Russia
  - Nigeria
  - Korea (Also navigation system)
  - Australia

GNSS: How does it work?
Determine the Distance using Radio Wave



Distance = (Transmission time – Reception time)
× Speed of light

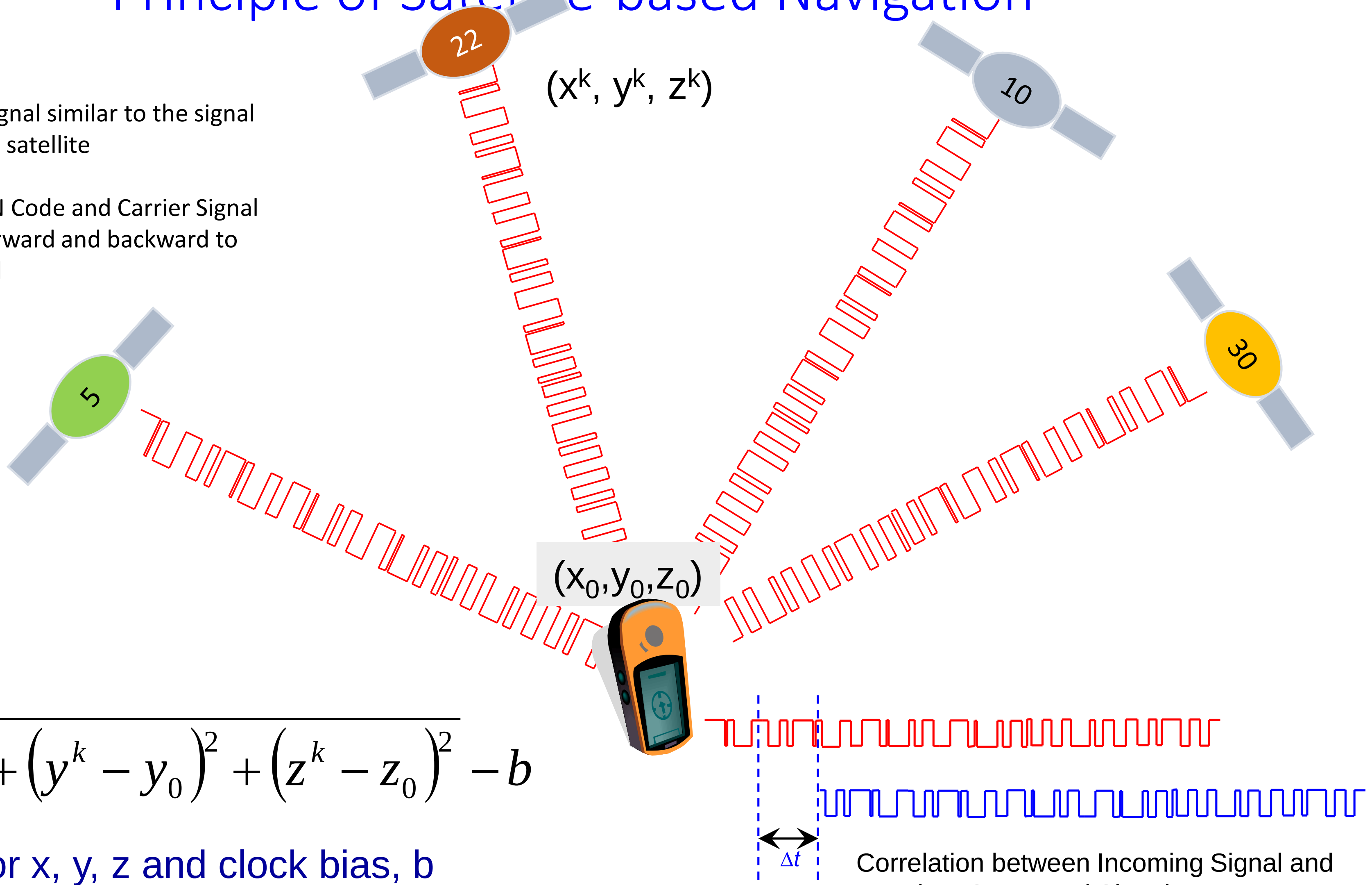
GNSS: How does it work?
Principle of Satellite-based Navigation

Receiver generates its own GPS signal similar to the signal coming from the satellite for each satellite

➔ Its called Replica Signal

➔ The Replica Signal includes PRN Code and Carrier Signal

➔ This Replica Signal is moved forward and backward to match with the incoming signal



Correlation between Incoming Signal and Receiver Generated Signal

$$\rho^k = \sqrt{(x^k - x_0)^2 + (y^k - y_0)^2 + (z^k - z_0)^2} - b$$

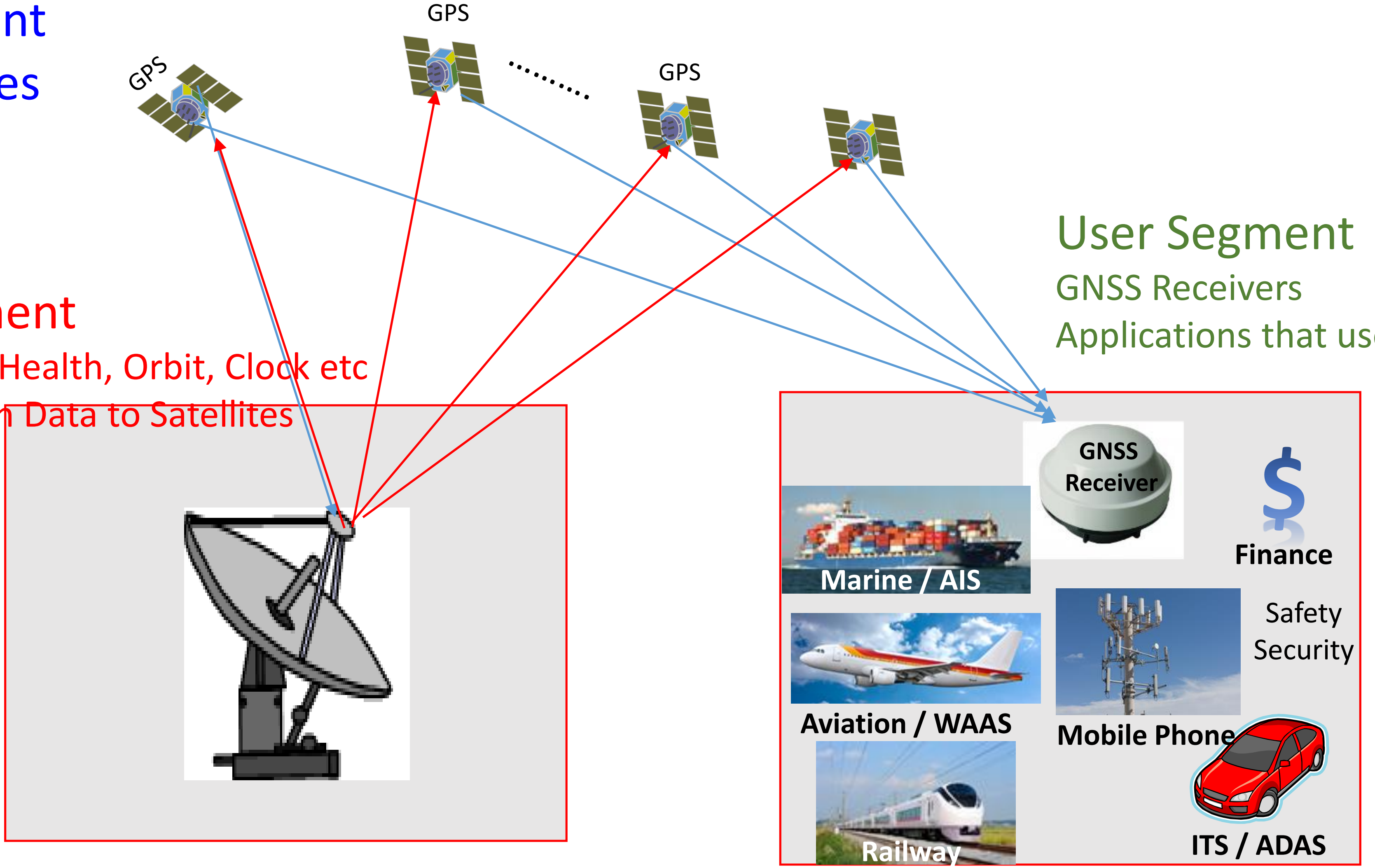
If k ≥ 4, solve for x, y, z and clock bias, b

GNSS Architecture

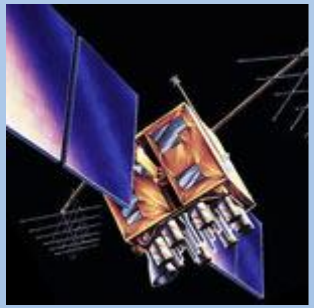
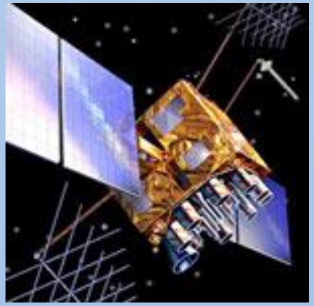
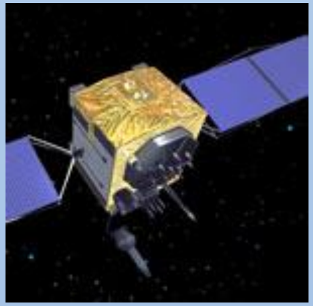
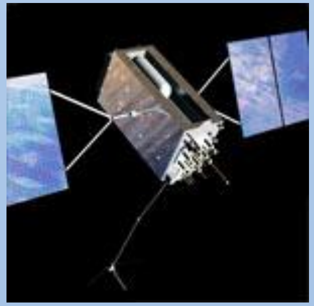
Space Segment
GNSS Satellites

Control Segment
Monitor Satellite Health, Orbit, Clock etc
Upload Navigation Data to Satellites

User Segment
GNSS Receivers
Applications that use GNSS



GPS Space Segment: Current & Future Constellation

Legacy Satellites		Modernized Satellites		
				
Block IIA	**Block IIR**	**Block IIR(M)**	**Block IIF**	**GPS III**
0 operational	**9 operational**	**7 operational**	**12 operational**	**2 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

Source: http://www.gps.gov/systems/gps/space/#IIF
https://www.unoosa.org/oosa/en/ourwork/icg/annual-meetings

Information in this slide may not be the latest information.
Please check the Source HP link and UNOOSA documents

GPS Signals

Band	Frequency, MHz	Signal Type	Code Length msec	Chip Rate, MHz	Modulation Type	Data / Symbol Rate, bps/sps	Notes
L1	1575.42	C/A	1	1.023	BPSK	50	Legacy Signal
		C_{Data}	10	1.023	BOC(1,1)	50 / 100	From 2014
		C_{Pilot}	10	1.023	TMBOC	No Data	BOC(1,1) & BOC(6,1)
		P(Y)	7 days	10.23	BPSK		Restricted
L2	1227.60	CM	20	0.5115	BPSK	25 / 50	Modulated by TDM of (L2CM xor Data) and L2CL
		CL	1500	0.5115		No Data	
		P(Y)	7days	10.23	BPSK		
L5	1176.45	I	1	10.23	BPSK	50 / 100	Provides Higher Accuracy
		Q	1			No Data	

GLONASS (Russia)

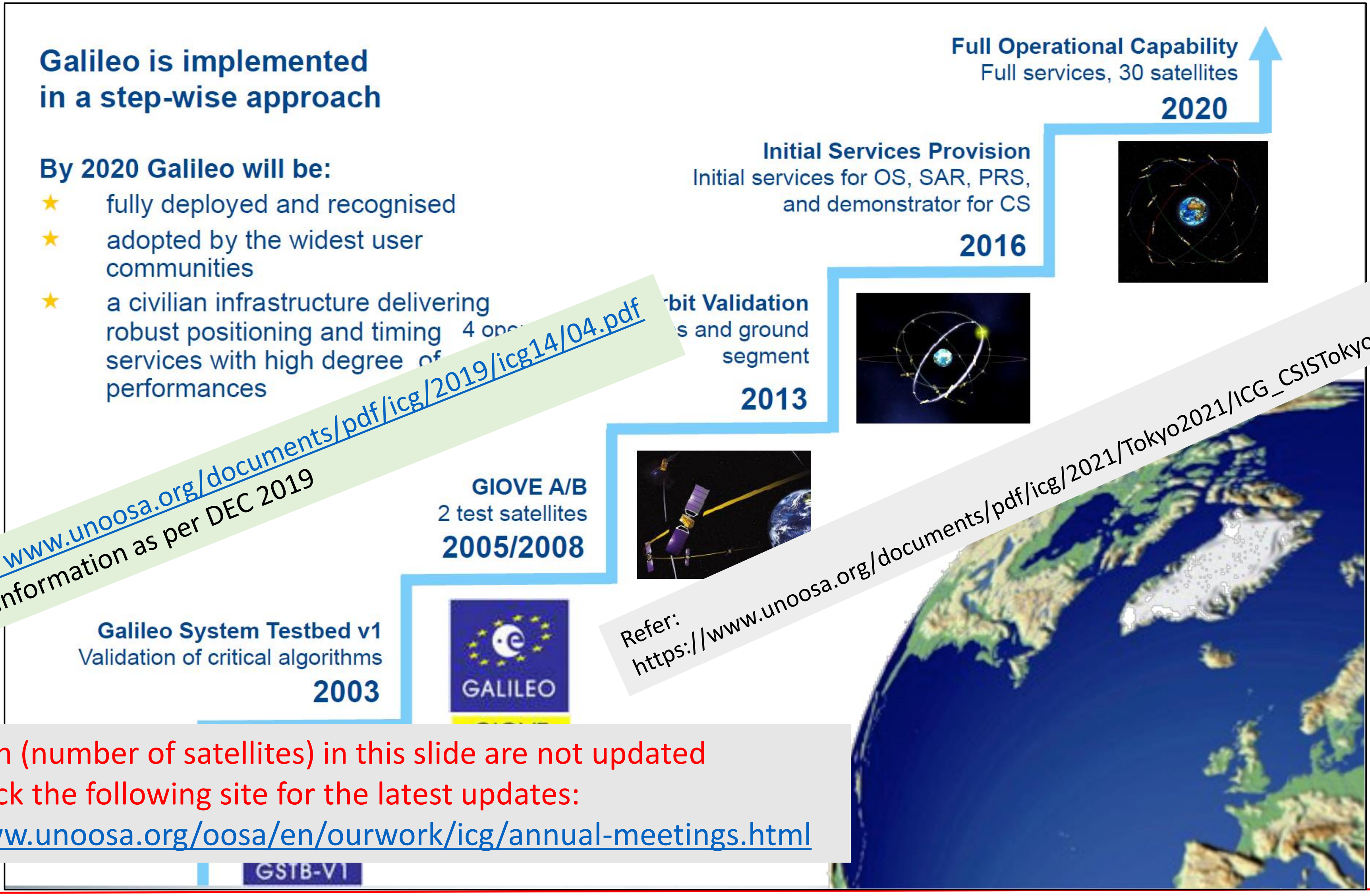
1982 First Launch	2003	2011	Planned Launch
			
GLONASS	**GLONASS-M**	**GLONASS-K1**	**GLONASS-K2**
DECOMMISSIONED **87 Launched** **0 Operational** **81 Retired** **6 Lost**	**Under Normal Operation** **45 Launched** **27 Operational** **12 Retired** **6 Lost**	**Under Production / Operation** **2 Launched** **2 Operational** **First launch**	**...d 2018**
•L1OF, L1SF • L2SF	•L1OF, L1SF •L2OF, L2S... •L3OC		•L1OF, L1SF •L2OF, L2SF •L1OC, L1SC •L2OC, L2SC •L3OC

See File
https://www.unoosa.org/documents/pdf/icg/2019/icg14/03.pdf
for the latest information as per DEC 2019

Information (Number of Satellites) in this slide are not updated
Please check the following site for the latest updates:
https://www.unoosa.org/oosa/en/ourwork/icg/annual-meetings.html

GLONASS space segment STATUS & MODERNIZATION, Joint - Stock Company «Academician M.F. Reshetnev» Information Satellite Systems» ICG-7, November 04-09, 2012 , Beijing, China, https://en.wikipedia.org/wiki/GLONASS-K2

Galileo (Europe)



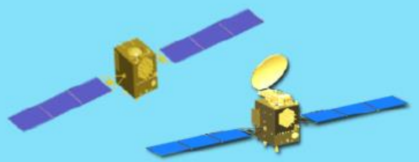
See file https://www.unoosa.org/documents/pdf/icg/2019/icg14/04.pdf for the latest information as per DEC 2019

Refer: https://www.unoosa.org/documents/pdf/icg/2021/Tokyo2021/ICG_CSISTokyo_2021_01.pdf

Information (number of satellites) in this slide are not updated
Please check the following site for the latest updates:
https://www.unoosa.org/oosa/en/ourwork/icg/annual-meetings.html

BeiDou Space Segment

Space Segment



- 5 GEO satellites
- 3 IGSO satellites
- 27 MEO satellites

Ground Segment

- Master Control Stations (MCS)
- Uplink Stations (US)
- Monitoring Stations (MS)

User Segment

- BeiDou terminals
- Terminals compatible with other navigation satellite systems

Four types of services:

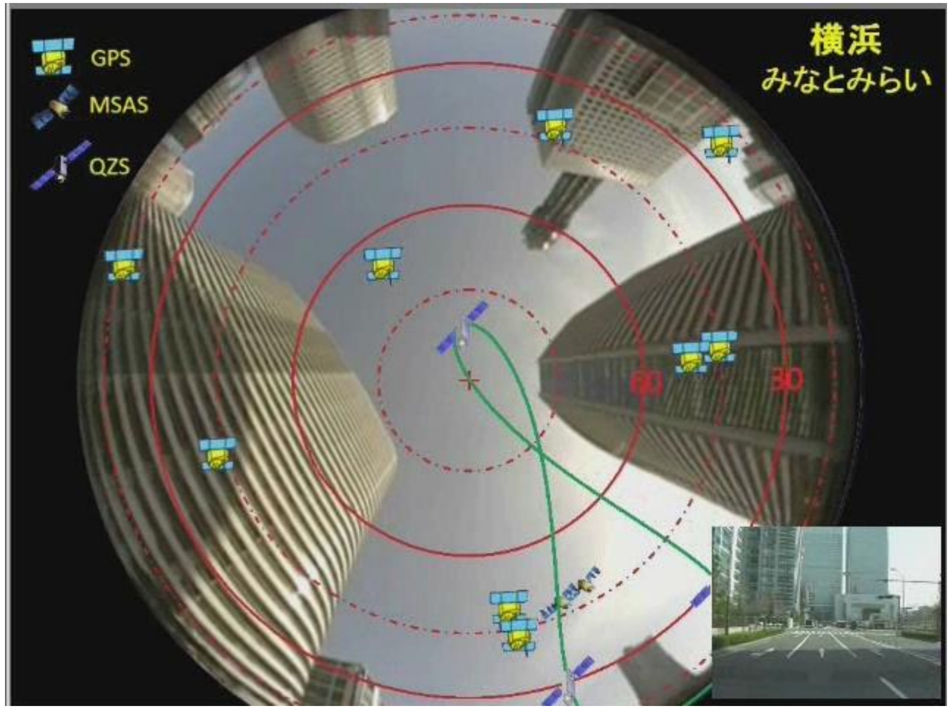
open, authorized, differential augmentation, and short message services.

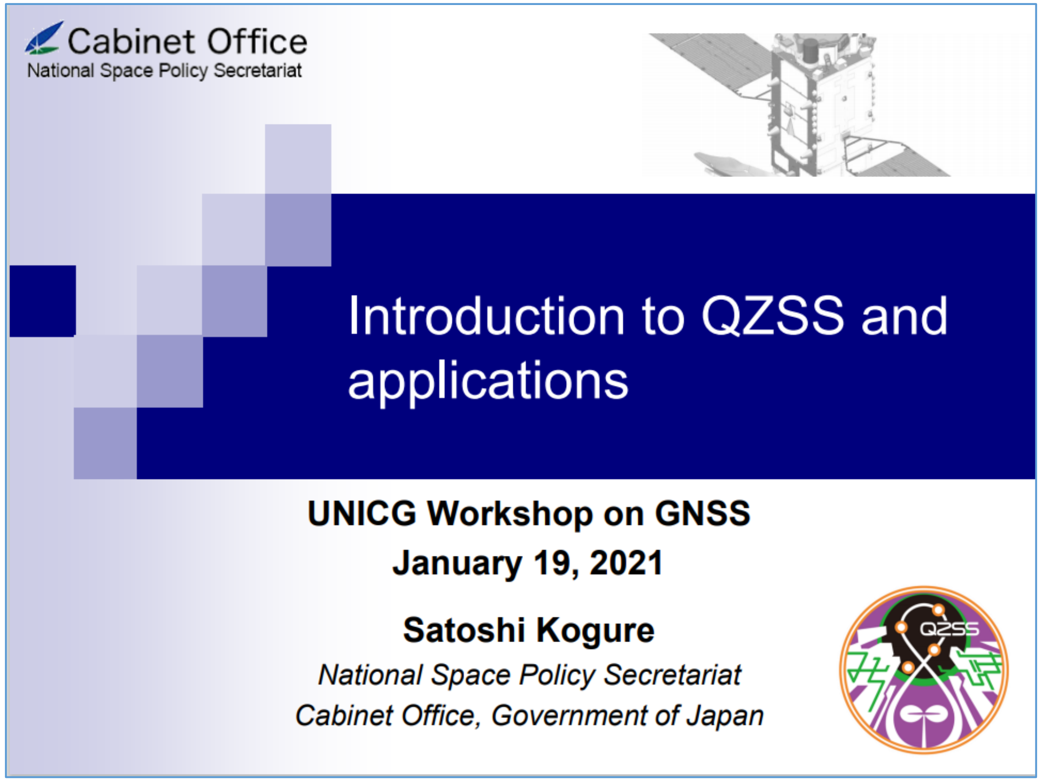
The nominal positioning accuracy is better than 10 m, timing and velocity accuracy is better than 20 ns and 0.2 m/s respectively.

Information (number of satellites) in this slide are not updated
Please check the following site for the latest updates:
https://www.unoosa.org/documents/pdf/icg/2019/icg14/05.pdf

Source: Update on BeiDou Navigation Satellite System, Chengqi Ran, China Satellite Navigation Office
Tenth Meeting of ICG, NOV 2015

QZSS (Quasi-Zenith Satellite System)
Nickname: MICHIBIKI





Please check the document for the latest updates:
https://www.unoosa.org/documents/pdf/icg/2019/icg14/06.pdf

Refer:
https://www.unoosa.org/documents/pdf/icg/2021/Tokyo2021/ICG_CSISTokyo_2021_04.pdf

NavIC Signal Types

Signal	Carrier Frequency	Bandwidth
L5	1176.45MHz	24MHz
S	2492.028MHz	16.5MHz

https://www.unoosa.org/documents/pdf/icg/2021/Tokyo2021/ICG_CSISTokyo_2021_03.pdf
presentations (unoosa.org)

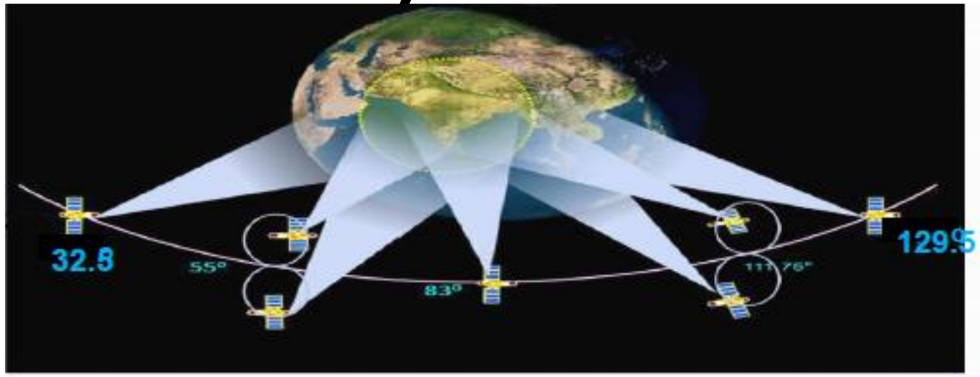
Please check the following document for the latest information
https://www.unoosa.org/documents/pdf/icg/2019/icg14/01.pdf

See file 01_NAVIC_ICG_2019.pdf for the latest information as per DEC 2019

NavIC (Navigation with Indian Constellation)

- **Consists of 7 Satellites**
- **4 Geo Synchronous Orbit (GSO) satellites**
  - **at 55ºE and 111.75ºE at an inclination of 27º**
- **3 Geo Stationary Satellites (GEO)**
  - **at 32.5ºE, 83ºE and 129.5º E at an inclination of 5º**
- **Transmits signals in L5 band (1176.45MHz) and S band (2492.028MHz)**

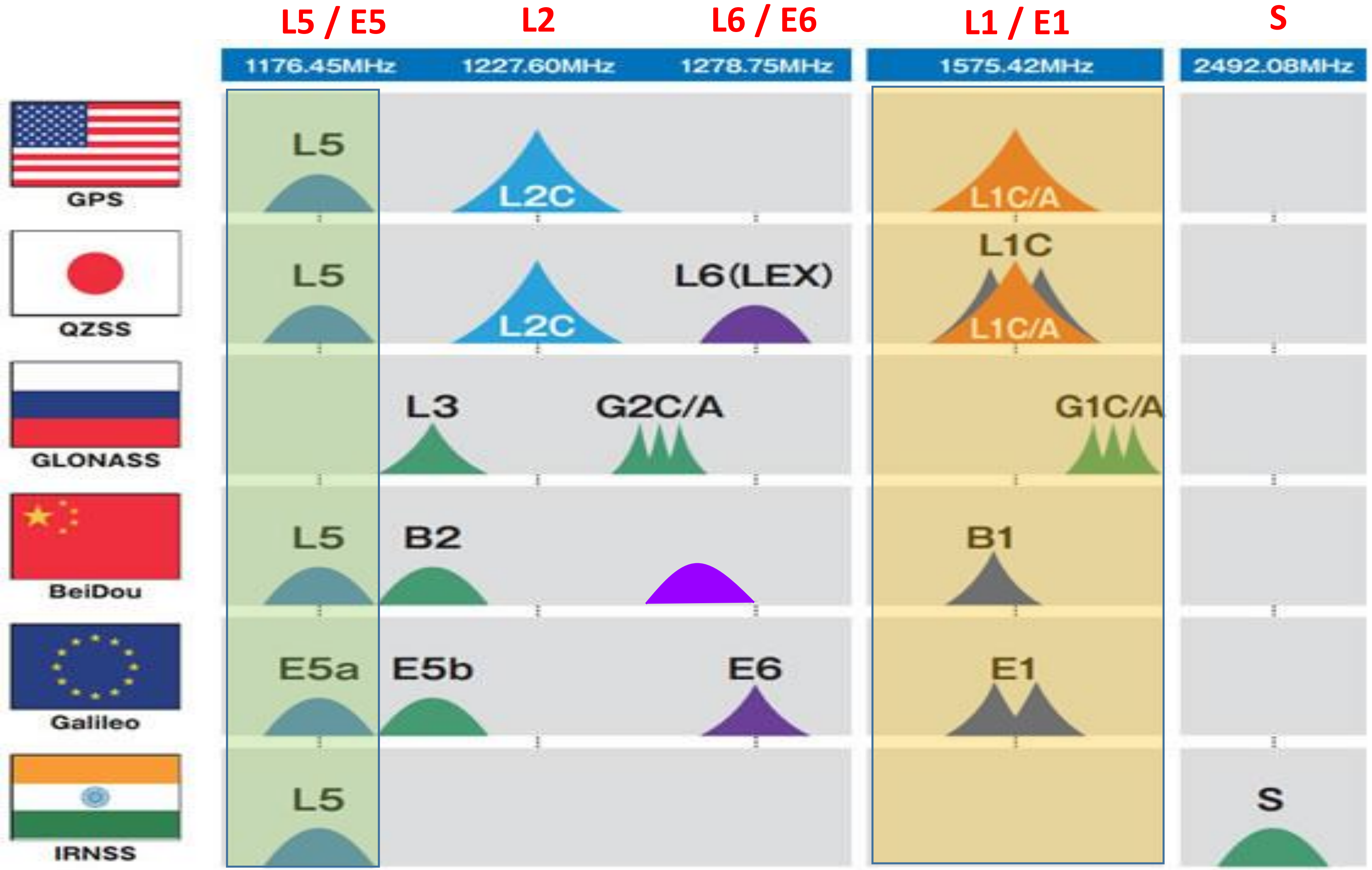
Please check the following site for the latest updates:
https://www.unoosa.org/oosa/en/ourwork/icg/annual-meetings.html



Multi GNSS Issues

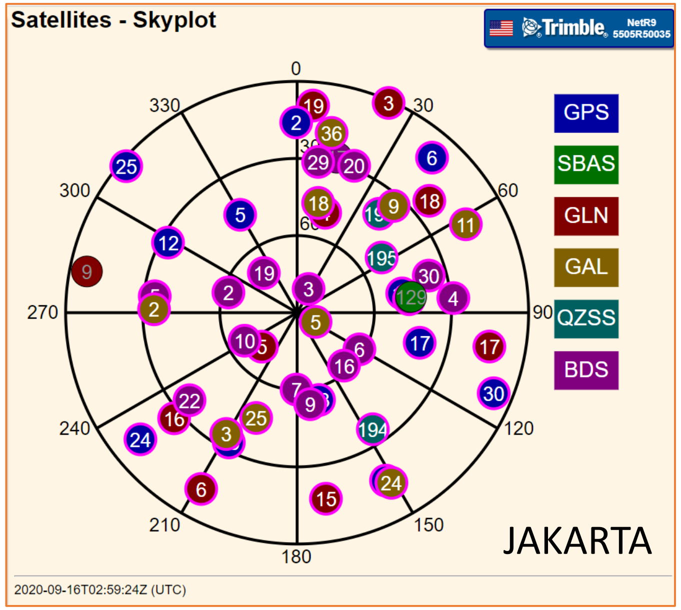
- In the past we had only GPS & GLONASS, now we have Galileo, BeiDou, QZSS, NAVIC
- Compatibility
  - Lets not hurt each other
    - Interference issues
- Interoperable
  - I'll use yours, you can use mine
    - Use of the same receiver and antenna to receive different signals
- Interchangeable
  - Any four will do
    - Can ONE GPS, ONE GLONASS, ONE Galileo and ONE BeiDou provide 3D Position?

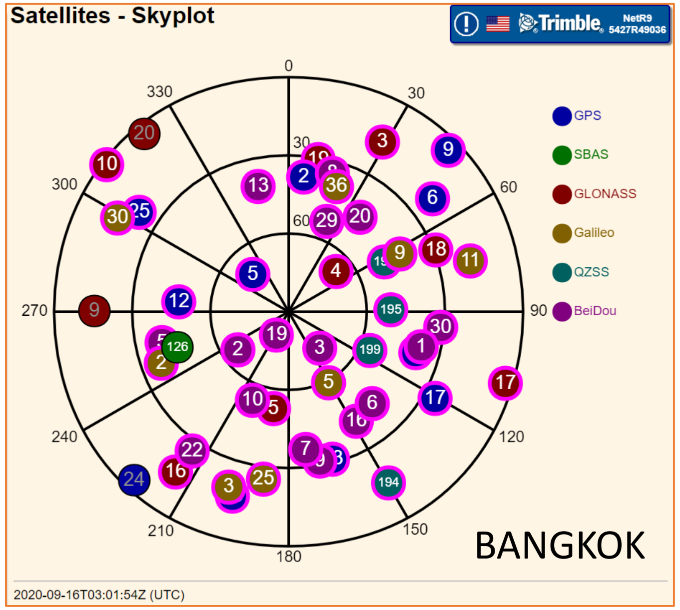
Multi-GNSS Signals

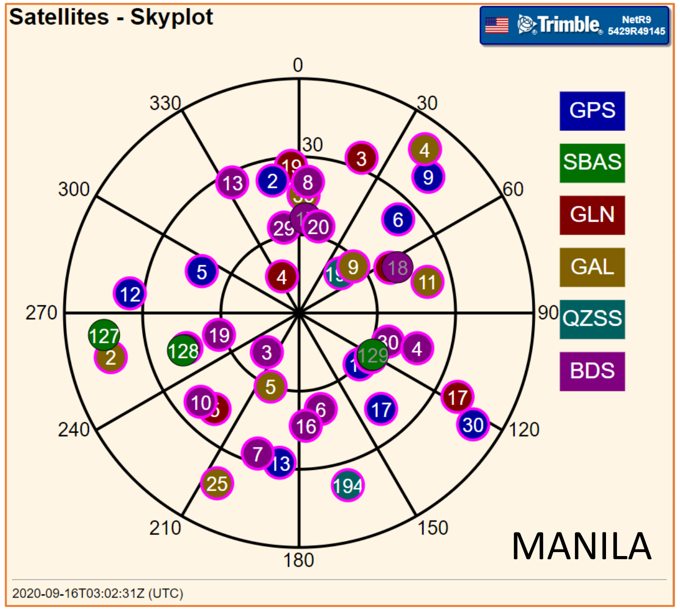


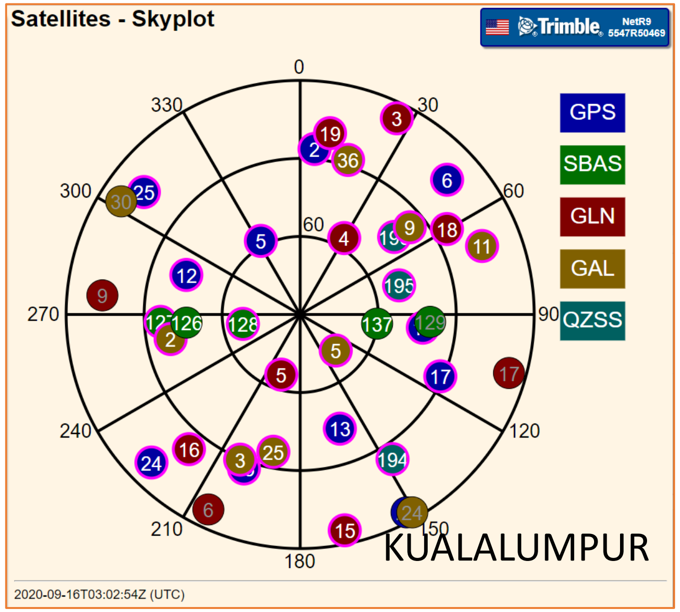
Multi GNSS Signals: Benefits to Users

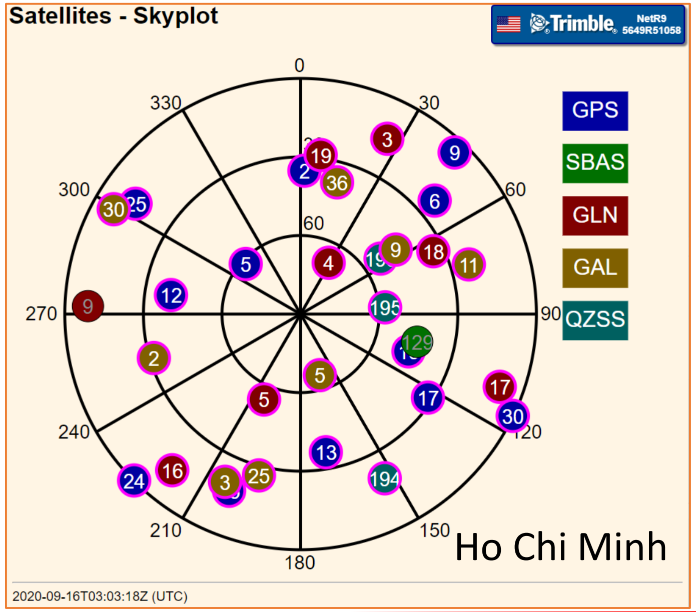
- Increase in usable SVs, signals and frequencies
  - Increase in availability and coverage
  - More robust and reliable services
  - Higher accuracy in bad conditions
  - Less expensive high-end services
  - Better atmospheric correction
- Emerging new and expanding existing applications are to be expected
    - Atmosphere related applications
    - Short Message Broadcasting
    - SAR (Search And Rescue Applications)
    - Bi-static Remote Sensing
      - Compute Soil Moisture, Wind Velocity, Sea Wave Height etc…

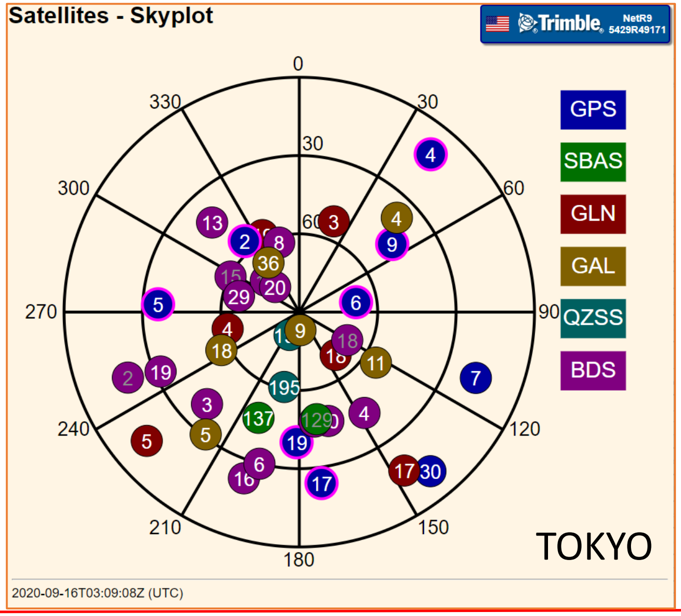

Satellites - Skyplot
GPS
SBAS
GLN
GAL
QZSS
BDS
JAKARTA
2020-09-16T02:59:24Z (UTC)


Satellites - Skyplot
GPS
SBAS
GLONASS
Galileo
QZSS
BeiDou
BANGKOK
2020-09-16T03:01:54Z (UTC)


Satellites - Skyplot
GPS
SBAS
GLN
GAL
QZSS
BDS
MANILA
2020-09-16T03:02:31Z (UTC)

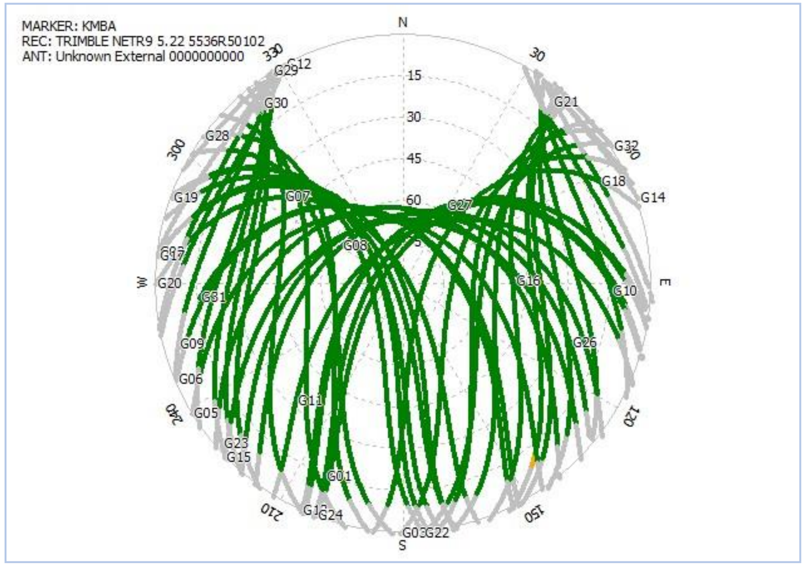

Satellites - Skyplot
GPS
SBAS
GLN
GAL
QZSS
KUALALUMPUR
2020-09-16T03:02:54Z (UTC)

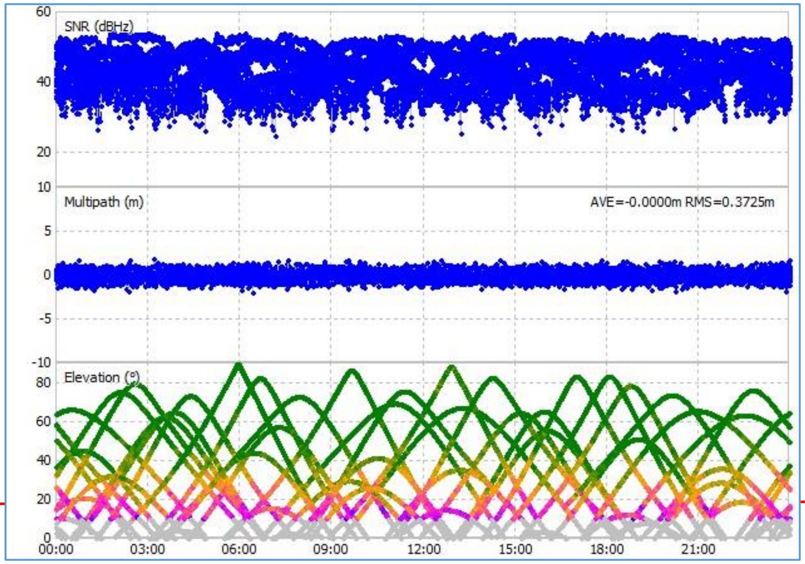

Satellites - Skyplot
GPS
SBAS
GLN
GAL
QZSS
Ho Chi Minh
2020-09-16T03:03:18Z (UTC)


Satellites - Skyplot
GPS
SBAS
GLN
GAL
QZSS
BDS
TOKYO
2020-09-16T03:09:08Z (UTC)

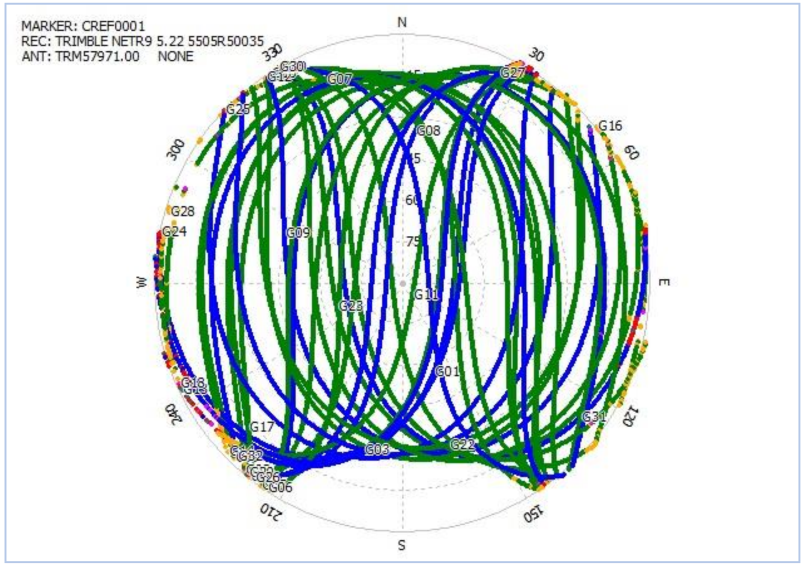
GPS Skyplots: Tokyo, Jakarta and Maputo

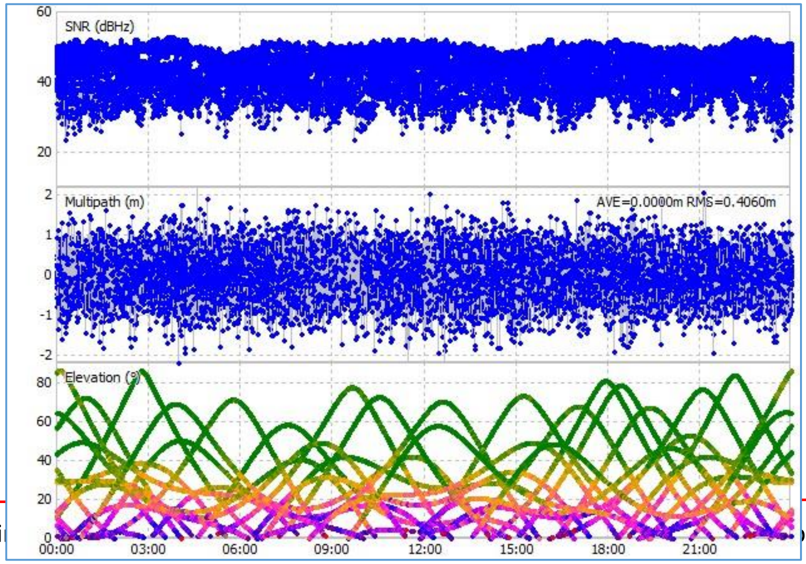
Tokyo-A Base-Station



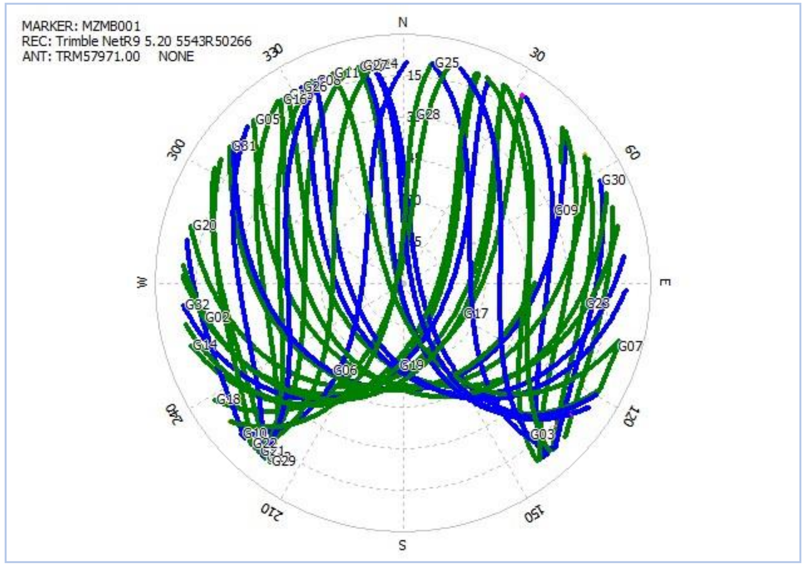


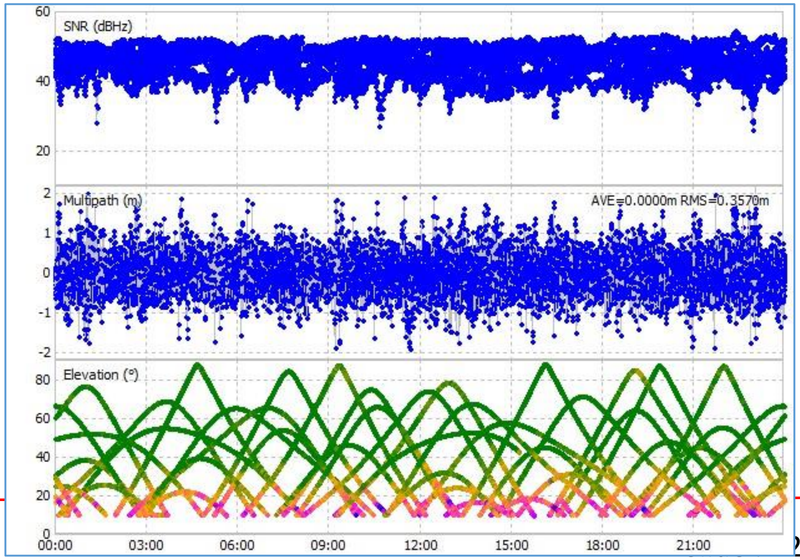
Jakarta Base-Station





Maputo Base-Station





Data Formats: NMEA, RINEX, RTCM

References: https://www.nmea.org/
http://freenmea.net/docs

National Marine Electronics Association (NMEA) Format

- NMEA is format to output measurement data from a sensor in a pre-defined format in ASCII
- In the case of GPS, It outputs GPS position, velocity, time and satellite related data
- NMEA sentences (output) begins with a "Talker ID" and "Message Description"
  - Example: $GPGGA,123519,4807.038,N,01131.000,E,1,08,0.9,545.4,M,46.9,M,,*47
  - "$GP" is Talker ID
  - "GGA" is Message Description to indicate for Position Data

NMEA Data Format

GGA - Fix data which provide 3D location and accuracy data.

$GPGGA,123519,4807.038,N,01131.000,E,1,08,0.9,545.4,M,46.9,M,,*47

Where: GGA Global Positioning System Fix Data

123519	Fix taken at 12:35:19 UTC
4807.038, N	Latitude 48 deg 07.038' N
01131.000, E	Longitude 11 deg 31.000' E
1 Fix quality:	
	0 = invalid ,
	1 = GPS fix (SPS),
	2 = DGPS fix,
	3 = PPS fix,
	4 = Real Time Kinematic
	5 = Float RTK
	6 = estimated (dead reckoning) (2.3 feature)
	7 = Manual input mode
	8 = Simulation mode
08	Number of satellites being tracked
0.9	Horizontal dilution of position
545.4,M	Altitude, Meters, above mean sea level
46.9,M	Height of geoid (mean sea level) above WGS84 ellipsoid
(empty field)	time in seconds since last DGPS update (empty field) DGPS station ID number
*47	the checksum data, always begins with *

RINEX Data Format

- RINEX: Receiver Independent Exchange Format is a data exchange format for raw satellite data among different types of receivers.
  - Different types of receivers may output position and raw data in proprietary formats
  - For post-processing of data using DGPS or RTK it is necessary to use data from different types of receivers. A common data format is necessary for this purpose.
  - Example: How to post process data from Trimble, Novatel and Septenrtio receivers to compute a position?
- RINEX only provides Raw Data. It does not provide position output.
  - User has to post-process RINEX data to compute position
  - Raw data consists of Pseudorage, Carrierphase, Doppler, SNR
- RINEX basically consists of two data types
  - "*.*N" file for Satellite and Ephemeris Related data.
    - Also called Navigation Data
  - "*.*O" file for Signal Observation Data like Pseudorange, Carrier Phase, Doppler, SNR
    - Also called Observation Data
- The latest RINEX version is 3.04, 23 NOV 2018
  - Note: Not all the software and receivers are yet compatible with the latest version
  - Make sure which version of RINEX works the best with your software

RINEX “N” File for GPS

```
     2.11           NAVIGATION DATA     GPS(GPS)            RINEX VERSION / TYPE
cnvtToRINEX 2.90.0  convertToRINEX OPR  05-Jul-17 03:38 UTC PGM / RUN BY / DATE
----------------------------------------------------------- COMMENT
    0.8382D-08  0.2235D-07 -0.5960D-07 -0.1192D-06          ION ALPHA
    0.8602D+05  0.6554D+05 -0.1311D+06 -0.4588D+06          ION BETA
   -0.931322574615D-09-0.355271367880D-14   405504     1947 DELTA-UTC: A0,A1,T,W
    18                                                      LEAP SECONDS
                                                            END OF HEADER
32 17 05 01 00 00  0.0-0.400723423809D-03-0.110276232590D-10 0.000000000000D+00
    0.370000000000D+02-0.806250000000D+01 0.455840416154D-08-0.192420920137D+01
   -0.353902578354D-06 0.111064908560D-02 0.826455652714D-05 0.515371503258D+04
    0.864000000000D+05-0.782310962677D-07 0.675647076441D-01-0.838190317154D-07
    0.958529124300D+00 0.221156250000D+03-0.265074890978D+01-0.796390315710D-08
   -0.389659088008D-09 0.100000000000D+01 0.194700000000D+04 0.000000000000D+00
    0.240000000000D+01 0.000000000000D+00 0.465661287308D-09 0.370000000000D+02
    0.795120000000D+05 0.400000000000D+01 0.000000000000D+00 0.000000000000D+00
24 17 05 01 00 00  0.0-0.341213308275D-04-0.454747350886D-12 0.000000000000D+00
    0.100000000000D+02 0.787812500000D+02 0.459340561950D-08 0.167267059468D+01
    0.404566526413D-05 0.564297637902D-02 0.102464109659D-04 0.515370226479D+04
    0.864000000000D+05-0.782310962677D-07 0.108986675687D+01 0.484287738800D-07
    0.945651423640D+00 0.170906250000D+03 0.490563049326D+00-0.815641117584D-08
   -0.128933942045D-09 0.100000000000D+01 0.194700000000D+04 0.000000000000D+00
    0.240000000000D+01 0.000000000000D+00 0.279396772385D-08 0.100000000000D+02
    0.792180000000D+05 0.400000000000D+01 0.000000000000D+00 0.000000000000D+00
```

RINEX “O” File GPS, GLONASS, GALILEO, QZSS, SBAS

```
     2.11           OBSERVATION DATA    Mixed(MIXED)        RINEX VERSION / TYPE
cnvtToRINEX 2.90.0  convertToRINEX OPR  05-Jul-17 03:38 UTC PGM / RUN BY / DATE
------------------------------------------------------------COMMENT
KMBA                                                        MARKER NAME
KMBA                                                        MARKER NUMBER
DM                  UT                                      OBSERVER / AGENCY
5536R50102          TRIMBLE NETR9       5.20                REC # / TYPE / VERS
                    UNKNOWN EXT                             ANT # / TYPE
 -3955510.8982  3357111.6791  3697796.5495                  APPROX POSITION XYZ
        0.0000        0.0000        0.0000                  ANTENNA: DELTA H/E/N
     1     1     0                                          WAVELENGTH FACT L1/2
     8    C1    C2    C3    L1    L2    L3    P1    P2      # / TYPES OF OBSERV
     1.000                                                  INTERVAL
  2017     5     1     0     0    0.0000000     GPS         TIME OF FIRST OBS
  2017     5     1    23    59   59.0000000     GPS         TIME OF LAST OBS
     0                                                      RCV CLOCK OFFS APPL
    18                                                      LEAP SECONDS
    59                                                      # OF SATELLITES
   G01 23351 23350     0 23350 46694     0     0 23344      PRN / # OF OBS
   G02 22293     0     0 22293 22286     0     0 22286      PRN / # OF OBS
   G03 19633 19632     0 19632 39259     0     0 19627      PRN / # OF OBS
   G05 25303 25302     0 25299 50599     0     0 25297      PRN / # OF OBS
   G06 24709 24708     0 24709 49411     0     0 24703      PRN / # OF OBS
   G07 27766 27764     0 27764 55505     0     0 27741      PRN / # OF OBS
```

RINEX "O" File, Continued from previous slide

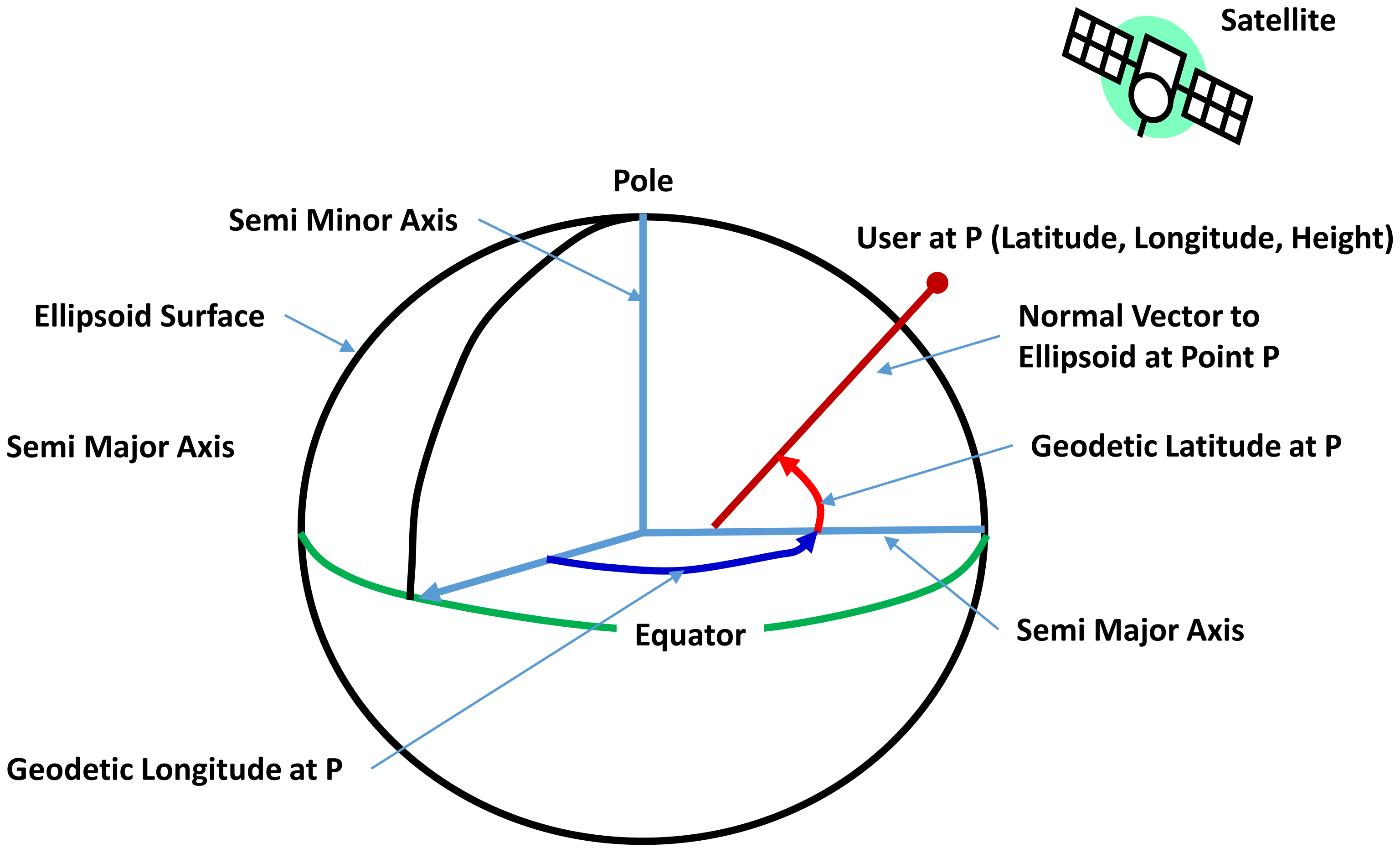
```
   S37 86400       0       0 86400       0       0       0       0       PRN / # OF OBS
   S40 56700       0       0 56700       0       0       0       0       PRN / # OF OBS
CARRIER PHASE MEASUREMENTS: PHASE SHIFTS REMOVED                         COMMENT
                                                                         END OF HEADER
 17  5  1  0  0  0.0000000  0 19G10G12G14G15G18G24G25G31G32R01R02R03
                                R11R12R13S28S29S37S40
  21375379.406 7  21375388.078 9                112328384.475 7  87528640.180 9
                                21375388.41448
  20991588.469 7  20991594.418 9                110311559.942 7  85957091.970 9
                                20991594.71548
  23097788.500 6                                121379711.146 6  94581624.25147
                                23097793.85247
  24539464.648 6  24539473.480 8                128955722.954 6 100484989.893 8
                                24539473.66046
  21890081.000 6                                115033147.870 6  89636240.02147
                                21890086.53547
  22760846.398 6  22760855.313 9                119609048.681 6  93201876.319 9
                                22760854.86347
  20303284.266 7  20303294.227 9                106694510.219 7  83138615.317 9
                                20303294.01248
  23440741.258 6  23440748.211 8                123181935.734 6  95985961.100 8
                                23440748.62147
  21395760.742 7  21395769.145 9                112435502.496 7  87612113.685 9
                                21395769.30548
```

RTCM

- RTCM : Radio Technical Commission for Maritime Services
  - An internationally accepted data transmission standard for base-station data transmission to a rover defined. The standards are defined and maintained by RTCM SC-104
- RTCM SC-104 (Special Committee 104)
  - Defines data formats for Differential GPS and
  - RTK (Real-Time Kinematic Operations)
- The Current Version is RTCM-3 (10403.3)
- Refer https://www.rtcm.org/ for detail information and document
  - Documents are not free
  - A normal user does not need RTCM document.
  - GNSS receivers with base-station capabilities will setup necessary messages for RTK
  - If you are developing a system or application you may need it

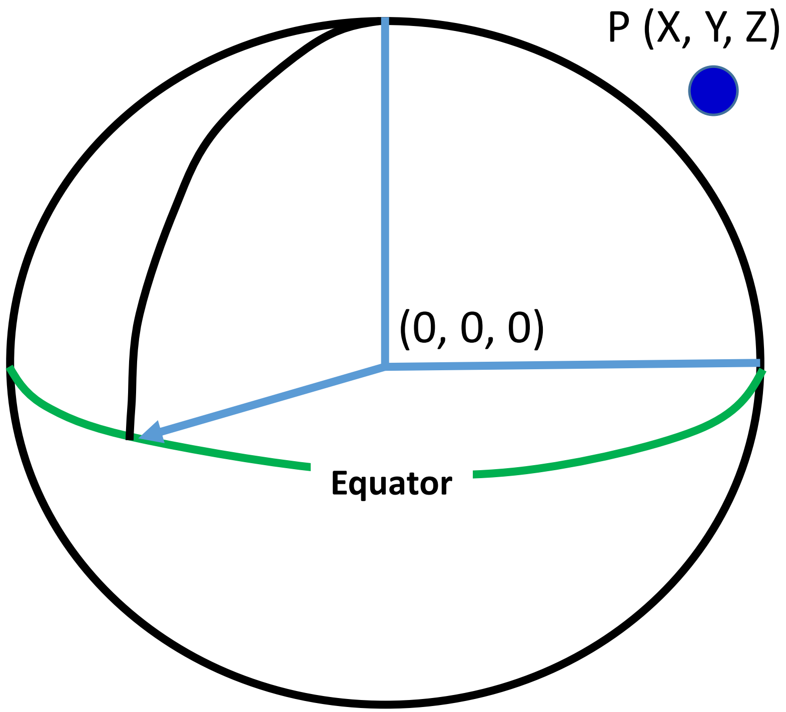
Coordinate Systems

Geodetic Coordinate System



ECEF (Earth Centered, Earth Fixed)

ECEF Coordinate System is expressed by assuming the center of the earth coordinate as (0, 0, 0)



Coordinate Conversion from ECEF to Geodetic and vice versa

Geodetic Latitude, Longitude & Height to ECEF (X, Y, Z)

$$X = (N + h)\cos\varphi\cos\lambda$$

$$Y = (N + h)\cos\varphi\sin\lambda$$

$$Z = [N(1 - e^2) + h]\sin\varphi$$

$$\varphi = Latitude$$
$$\lambda = Longitude$$
h = Height above Ellipsoid

ECEF (X, Y, Z) to Geodetic Latitude, Longitude & Height

$$\varphi = \text{atan}\left(\frac{Z + e^2 b\, sin^3\theta}{p - e^2 a cos^3\theta}\right)$$

$$\lambda = \text{atan2}(y, x)$$

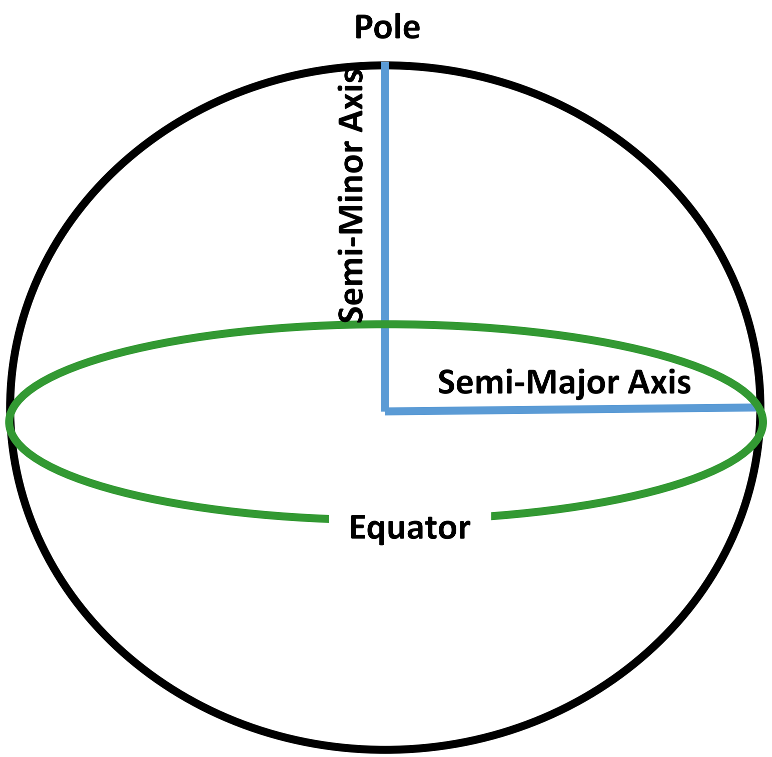
$$h = \frac{P}{\cos\varphi} - \mathrm{N}(\varphi)$$

$$P = \sqrt{x^2 + y^2}$$

$$\theta = atan\left(\frac{Za}{Pb}\right)$$

$$N(\varphi) = \frac{a}{\sqrt{1 - e^2 sin^2\varphi}}$$

Geodetic Datum: Geometric Earth Model



GPS uses WGS-84 Datum

But, topographic maps and many other maps use different datum. Before using GPS data on these maps, its necessary to convert GPS coordinates from WGS-84 to local coordinate system and datum. Many GPS software have this tool. Also, GPS receivers have built-in datum selection capabilities.

Check your receiver settings before using.

WGS-84 Geodetic Datum Ellipsoidal Parameters

Semi-Minor Axis, b = 6356752.3142m

Semi-Major Axis, a = 6378137.0m

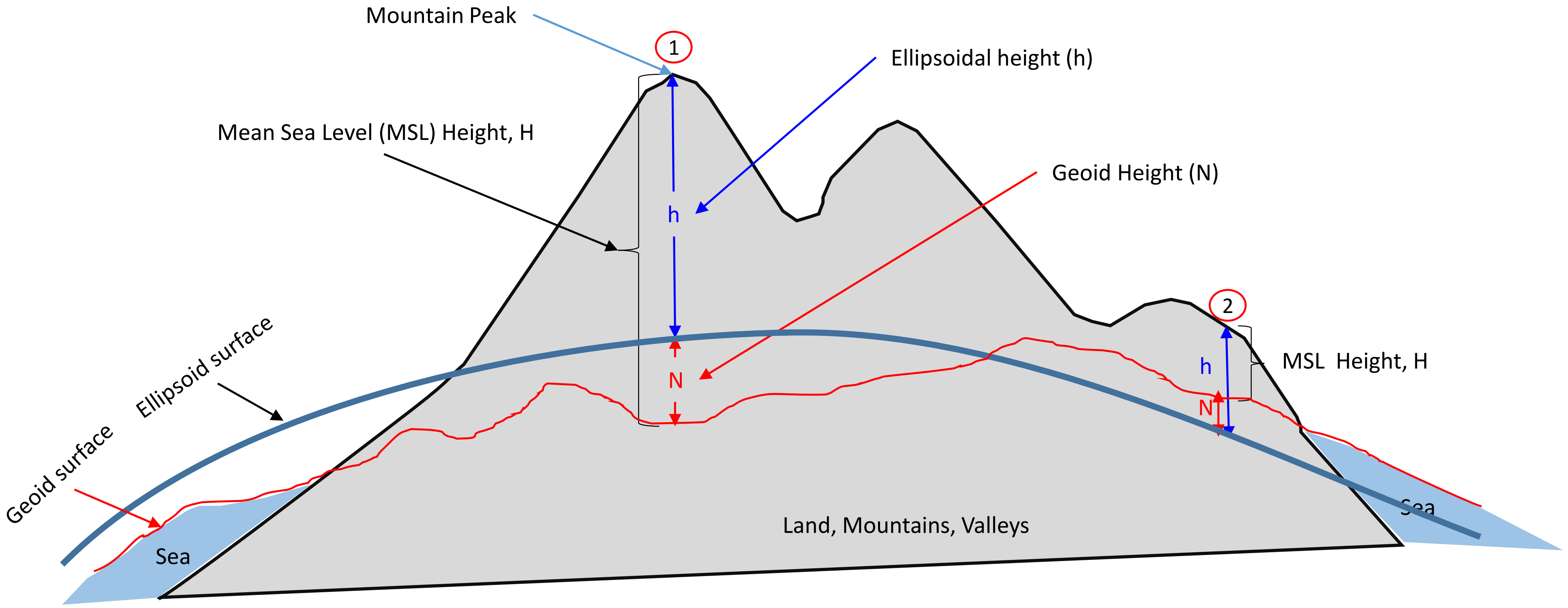
Flattening, f = (a-b)/a

= 1/298.257223563

First Eccentricity Square = e^2 = 2f-f^2

= 0.00669437999013

Ellipsoid, Geoid and Mean Sea Level (MSL)



MSL Height (H) = Ellipsoidal height (h) – Geoid height (N)
Geoid Height is negative if its below Ellipsoidal height

Example at point (1) : h = 1200m, N = -30m
H = h – N = 1200 – (-30) = 1200 + 30 = 1230m

Example at point (2) : h = 300m, N = +15m
H = h – N = 300 – 15 = 285m

Height Data Output in u-blox Receiver, NMEA Sentence, $GNGGA Sentence

MSL (Altitude)

Geoid Separation
Geoid Height

$GNVTG,,T,,M,0.010,N,0.018,K,D*30

$GNGGA,012039.00,3554.18235,N,13956.35867,E,2,12,0.48,54.4,M,39.6,M,0.0,0000*5D

$GNGSA,A,3,03,04,06,09,17,19,22,28,194,195,02,,0.92,0.48,0.78,1*06

$GNGSA,A,3,11,12,04,24,19,31,33,,,,,,0.92,0.48,0.78,3*00

$GNGSA,A,3,30,01,03,14,08,28,33,04,02,07,10,13,0.92,0.48,0.78,4*08

$GPGSV,5,1,17,01,18,076,,02,04,279,36,03,43,045,43,04,34,109,41,1*6C

$GPGSV,5,2,17,06,38,295,43,09,26,152,40,11,02,107,29,17,74,330,47,1*67

$GPGSV,5,3,17,19,53,320,45,22,22,048,39,28,36,213,43,41,18,249,39,1*6D

$GPGSV,5,4,17,50,46,201,40,193,52,172,43,194,16,193,40,195,85,163,46,1*5E

$GPGSV,5,5,17,199,46,201,37,1*66

$GAGSV,2,1,07,04,25,175,40,11,28,299,37,12,65,007,43,19,50,105,40,7*72

$GAGSV,2,2,07,24,27,245,41,31,09,198,36,33,33,082,42,7*43

$GBGSV,4,1,15,01,48,172,43,02,19,248,36,03,39,225,43,04,44,148,42,1*7C

$GBGSV,4,2,15,06,00,185,29,07,39,214,41,08,53,305,43,10,44,248,42,1*7C

$GBGSV,4,3,15,13,33,283,42,14,23,043,38,27,55,323,48,28,61,092,48,1*71

$GBGSV,4,4,15,30,05,306,36,32,17,206,42,33,48,055,46,1*4F

$GNGLL,3554.18235,N,13956.35867,E,012039.00,A,D*76

NMEA - GxGGA (Global Positioning System Fix Data)

Parameter	Value	Unit	Description
UTC	012040.00	hhmmss.sss	Universal time coordinated
Lat	3554.18235	ddmm.mmmm	Latitude
Northing Indicator	N		N=North, S=South
Lon	13956.35868	dddmm.mmmm	Longitude
Easting Indicator	E		E=East, W=West
Status	2		0=Invalid, 1=2D/3D, 2=DGNSS, 4=Fixed RTK, 5=Float RTK, 6=Dead Reckoning
SVs Used	12		Number of SVs used for Navigation
HDOP	0.48		Horizontal Dilution of Precision
Alt (MSL)	54.4	m	Altitude (above means sea level)
Unit	M		M=Meters
Geoid Sep.	39.6	m	Geoid Separation = Alt(HAE) - Alt(MSL)
Unit	M		M=Meters
Age of DGNSS Corr	0.0	s	Age of Differential Corrections
DGNSS Ref Station	0000		ID of DGNSS Reference Station

The NMEA sentences in this figure are from u-blox receiver.
NMEA format uses "Mean Sea Level" for height data (shown in blue texts).
Also it provides Geoid Height (Geoid Separation) value.
GPS by default is Ellipsoidal height and this height is converted to Mean Sea Level height using the geoid Height (shown in red texts) .
This means, u-blox receiver uses a built-in database of Geoid Height.

U-blox also outputs Ellipsoidal height in proprietary message $PUBX,00 (marked as altRef)
$PUBX,00,time,lat,NS,long,EW,**altRef**,navStat,hAcc,vAcc,SOG,COG,vVel,diffAge,HDOP,VDOP,TDOP,numSvs,reserved,DR,*cs<CR><LF>
altRef ➔ Altitude above user datum ellipsoid

Height Data Output in u-blox Receiver, NMEA Sentence, $GNGGA Sentence

MSL (Altitude)

Geoid Separation
Geoid Height

$GNVTG,,T,,M,0.010,N,0.018,K,D*30

$GNGGA,012039.00,3554.18235,N,13956.35867,E,2,12,0.48,54.4,M,39.6,M,0.0,0000*5D

$GNGSA,A,3,03,04,06,09,17,19,22,28,194,195,02,,0.92,0.48,0.78,1*06

$GNGSA,A,3,11,12,04,24,19,31,33,,,,,,0.92,0.48,0.78,3*00

$GNGSA,A,3,30,01,03,14,08,28,33,04,02,07,10,13,0.92,0.48,0.78,4*08

$GPGSV,5,1,17,01,18,076,,02,04,279,36,03,43,045,43,04,34,109,41,1*6C

$GPGSV,5,2,17,06,38,295,43,09,26,152,40,11,02,107,29,17,74,330,47,1*67

$GPGSV,5,3,17,19,53,320,45,22,22,048,39,28,36,213,43,41,18,249,39,1*6D

$GPGSV,5,4,17,50,46,201,40,193,52,172,43,194,16,193,40,195,85,163,46,1*5E

$GPGSV,5,5,17,199,46,201,37,1*66

$GAGSV,2,1,07,04,25,175,40,11,28,299,37,12,65,007,43,19,50,105,40,7*72

$GAGSV,2,2,07,24,27,245,41,31,09,198,36,33,33,082,42,7*43

$GBGSV,4,1,15,01,48,172,43,02,19,248,36,03,39,225,43,04,44,148,42,1*7C

$GBGSV,4,2,15,06,00,185,29,07,39,214,41,08,53,305,43,10,44,248,42,1*7C

$GBGSV,4,3,15,13,33,283,42,14,23,043,38,27,55,323,48,28,61,092,48,1*71

$GBGSV,4,4,15,30,05,306,36,32,17,206,42,33,48,055,46,1*4F

$GNLLL,3554.18235,N,13956.35867,E,012039.00,A,D*76

NMEA - GxGGA (Global Positioning System Fix Data)

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UTC	012040.00	hhmmss.sss	Universal time coordinated
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Status	2		0=Invalid, 1=2D/3D, 2=DGNSS, 4=Fixed RTK, 5=Float RTK, 6=Dead Reckoning
SVs Used	12		Number of SVs used for Navigation
HDOP	0.48		Horizontal Dilution of Precision
Alt (MSL)	54.4	m	Altitude (above means sea level)
Unit	M		M=Meters
Geoid Sep.	39.6	m	Geoid Separation = Alt(HAE) - Alt(MSL)
Unit	M		M=Meters
Age of DGNSS Corr	0.0	s	Age of Differential Corrections
DGNSS Ref Station	0000		ID of DGNSS Reference Station

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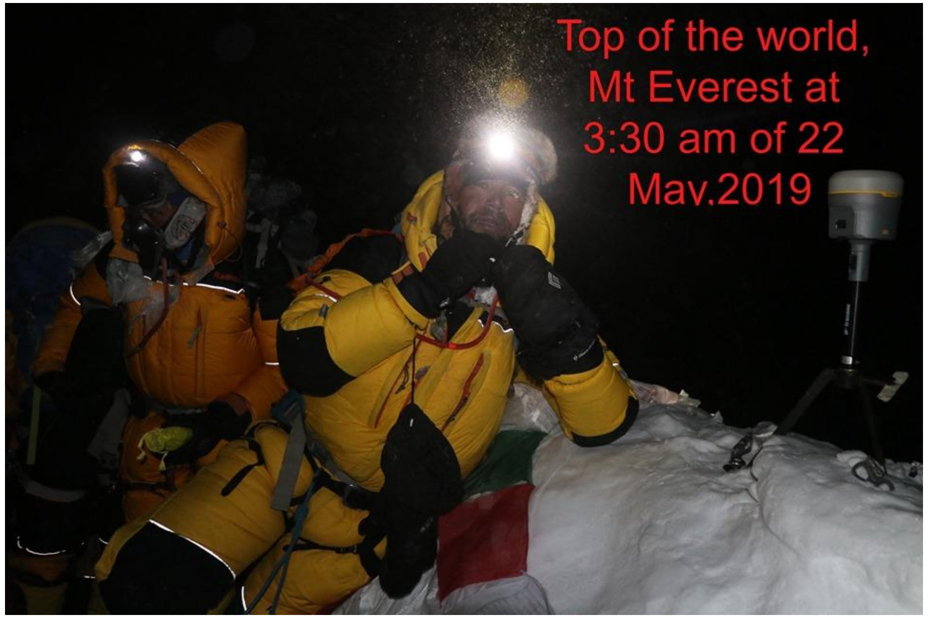
U-blox also outputs Ellipsoidal height in proprietary message $PUBX,00 (marked as altRef)
$PUBX,00,time,lat,NS,long,EW,**altRef**,navStat,hAcc,vAcc,SOG,COG,vVel,diffAge,HDOP,VDOP,TDOP,numSvs,reserved,DR,*cs<CR><LF>
altRef → Altitude above user datum ellipsoid

Points to Be Careful in GPS Survey

- Datum
    - Which Datum is used for GPS Survey?
    - By default, GPS uses WGS-84
    - But, your Map may be using different datum like Everest
        - Make Sure that Your Map and Your Coordinates from the GPS are in the same Datum, if not, datum conversion is necessary
        - You can get necessary transformation parameters from your country's survey department
- Height
    - Which Height is used?
    - By default GPS uses Ellipsoidal Height
    - But, your Map may be using Mean Sea Level (MSL or Topographic) Height
        - You need to convert from Ellipsoidal Height into MSL Height
        - Use Ellipsoidal and Geoid height Difference Data for your survey region
            - You can get it from your country's survey office

How to Measure the Height of Everest?

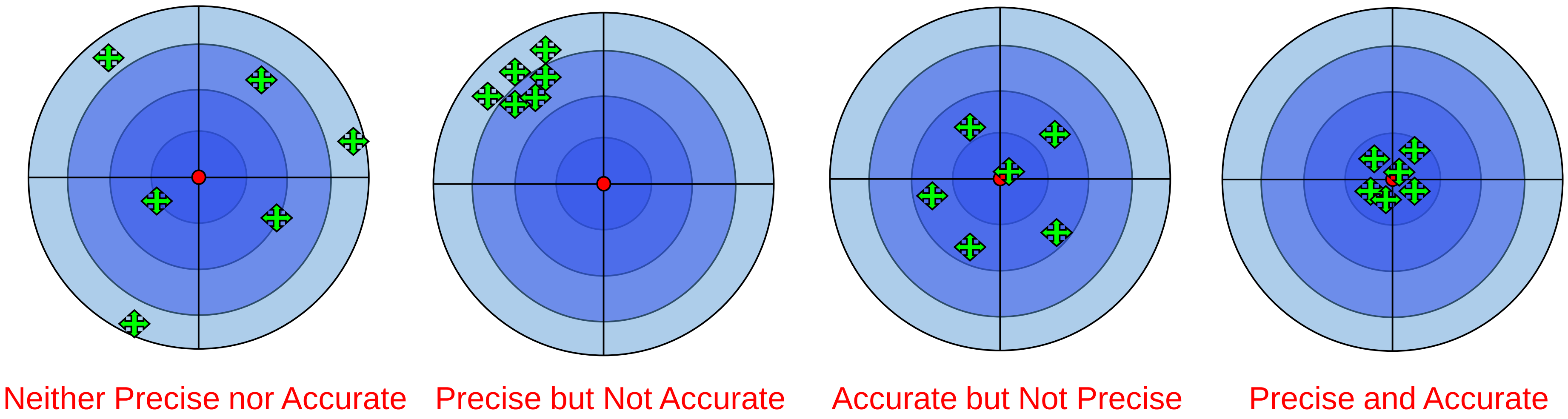
- Measure by GNSS receiver at the peak of the mountain
  - But it gives Ellipsoidal height, how to get Mean Sea Level height?
  - The peak is covered by snow and ice, how to get the true rock height?
  - High-accuracy requires long-time data observation but summiteers can stay for short duration only (about 30 minutes in average)



GNSS Errors

Background Information: Accuracy vs. Precision

- Accuracy
  - Capable of providing a correct measurement
  - Measurement is compared with true value
  - Affected by systematic error
- Precision
  - Capable of providing repeatable and reliable measurement
  - Statistical analysis of measurement provides the precision
  - Measure of random error
  - Systematic error has no effect



GNSS Measurement Errors

Measure	Abbreviation	Definition
Root Mean Square	RMS	The square root of the average of the squared errors
Twice Distance RMS	2D RMS	Twice the RMS of the horizontal errors
Circular Error Probable	CEP	A circle's radius, centered at the true antenna position, containing 50% of the points in the horizontal scatter plot
Horizontal 95% Accuracy	R95	A circle's radius, centered at the true antenna position, containing 95% of the points in the horizontal scatter plot
Spherical Error Probable	SEP	A sphere's radius centered at the true antenna position, containing 50% of the points in the three dimensional scatter plot

Source: GPS Accuracy: Lies, Damn Lies, and Statistics, GPS World, JAN 1998
https://www.gpsworld.com/gps-accuracy-lies-damn-lies-and-statistics/

Commonly Used GNSS Performance Measurements

- TTFF
  - True Time to First Fix
  - Parameter: Cold Start, Warm Start, Hot Start
- Standard Accuracy
  - Accuracy attainable without any correction techniques
- DGPS Accuracy
  - Accuracy attainable by differential correction data
  - Code-phase correction
- RTK Accuracy
  - Accuracy attainable by differential correction data
  - Use both Code-Phase and Carrier Phase correction

TTFF and Typical Example Values

- TTFF
  - Cold Start : < 36 seconds
    - Time required to output first position data since the receiver power is on
    - No reference data like time or almanac are available
  - Warm Start : < 6 seconds
    - Time required to output first position data since the receiver power is on with the latest satellite almanac data in the receiver's memory
    - Time and almanac related reference data are already known
  - Hot Start : < 1 second
    - Receiver has already output position data
    - Time to reacquire an already tracked satellite due to temporary blockage by buildings or trees

Contact and Additional Information

- Homepage
  - Main Page : https://home.csis.u-tokyo.ac.jp/~dinesh/
  - Webinar Page : https://home.csis.u-tokyo.ac.jp/~dinesh/WEBINAR.htm
    https://gnss.peatix.com/
  - Training Data Etc : https://home.csis.u-tokyo.ac.jp/~dinesh/GNSS_Train.htm
  - Low-Cost Receiver : https://home.csis.u-tokyo.ac.jp/~dinesh/LCHAR.htm
  - Facebook : https://www.facebook.com/gnss.lab/
- Contact
  - E-mail : dinesh@csis.u-tokyo.ac.jp
  - Skype : mobilemap