Navigation Satellite Systems
architectures

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Navigation satellite systems

- Regional systems
  - QZSS / JRNSS
  - NavIC / IRNSS
- Global systems
  - GPS
  - GLONASS
  - BEIDOU
  - GALILEO
- Augmentation systems
  - EGNOS
  - WAAS
  - MSAS
  - GAGAN

Augmentation systems

- GNSS augmentation is a method of improving a navigation system's attributes, such as accuracy, reliability, and availability, through the integration of external information into the calculation process, for example:
  - Satellite Based Augmentation System
    - the Wide Area Augmentation System,
    - the European Geostationary Navigation Overlay Service,
    - the Multi-functional Satellite Augmentation System,
    - GPS Aided GEO Augmented Navigation (GAGAN)
  - Differential GPS
  - inertial navigation systems.

GNSS - architecture

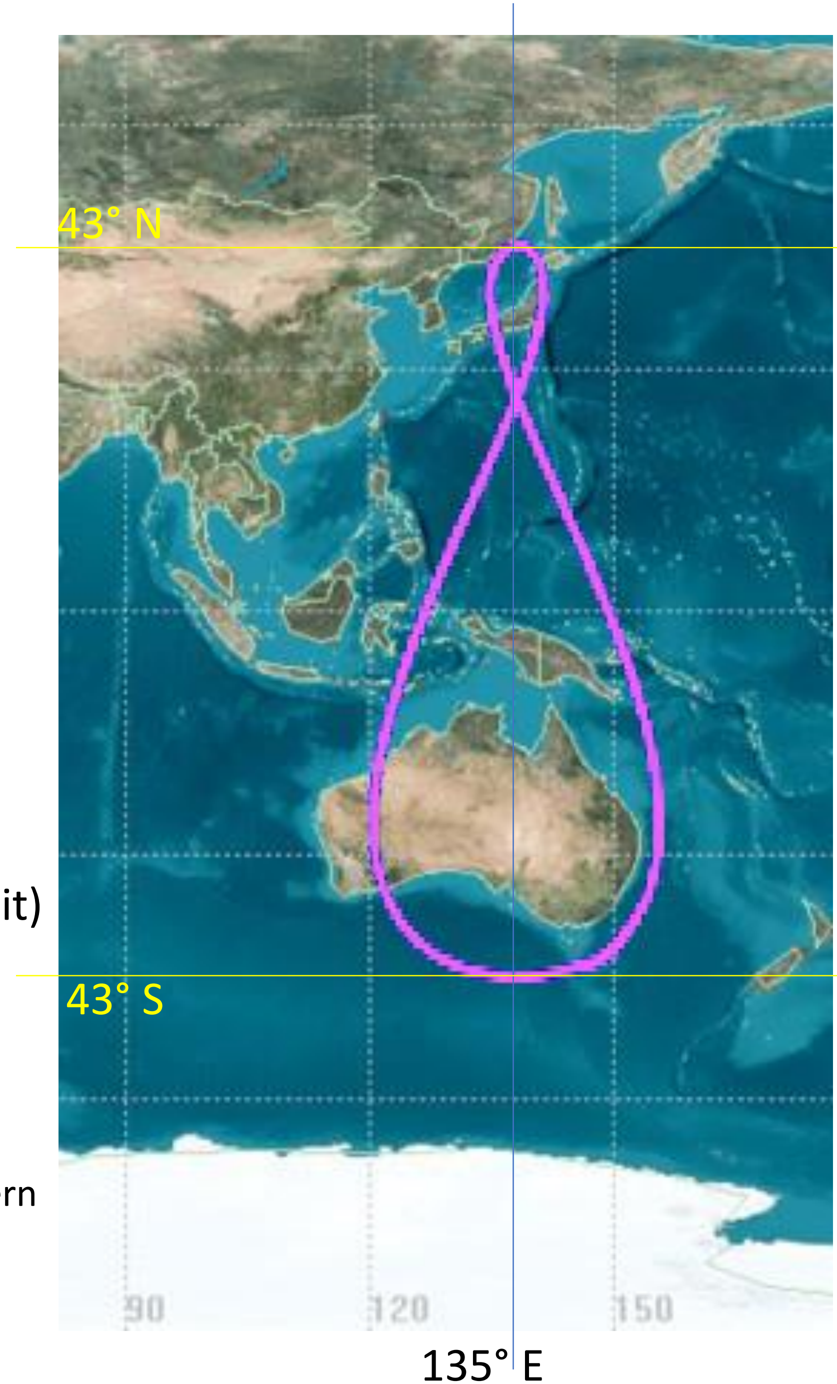
Each navigation satellite system consists of 3 main components (segments):

- Space segment – constellation of satellites transmitting radiosignals
- Ground segment – facilities, infrastructure located on the Earth surface, responsible for monitoring and controlling the space segment: positions on orbits and quality of radiosignals
- User segment – every receiver which can utilizes signals transmitted by satellites

QZSS - constellation

Quasi –Zenith Satellite System

- Regional satellite system
- To enhance for GPS covering Japan
- the first demonstration satellite was launched in September 2010
- Full constellation
  - 3 GEO satellites
    - Central longitude 123° E
  - 4 GSO satellites (HEO Highly Elliptical Orbit)
    - Inclination (i)43° ± 4 °
    - Semimajor axis (a)) 42.3 kkm
    - Eccentricity (e) 0.075 ± 0.015 – altitudes: perigee 32 kkm, apogee 40 kkm
    - Central longitude 135° E ± 5°
    - 13h northern hemisphere and 11h on southern hemisphere



QZSS - constelation

PRN	SVN	Satellite	Launch Date (UTC)	Orbit (*1)	Positioning Signals	Clock(*2)
193	J001	QZS-1	2010/9/11	QZO	L1C/A, L1C, L2C, L5	RB
183					L1S	
193					L6	
194	J002	QZS-2	2017/6/1	QZO	L1C/A, L1C, L2C, L5	RB
184					L1S	
196					L5S	
194					L6	
199	J003	QZS-3	2017/8/19	GEO	L1C/A, L1C, L2C, L5	RB
189					L1S	
197					L5S	
187					L1Sb	
199					L6	
-					Sr/Sf	
195	J004	QZS-4	2017/10/9	QZO	L1C/A, L1C, L2C, L5	RB
185					L1S	
200					L5S	
195					L6	

http://qzss.go.jp/en/technical/satellites/index.html#QZSS

QZSS – ground segment

- The ground segment is composed of:
  - a master control station (MCS),
  - tracking control stations (TT&C),
  - laser ranging stations and monitoring stations.
- The network of monitoring stations covers East Asia and Oceania region, with stations:
  - in Japan (Okinawa, Sarobetsu, Koganei, Ogasawara) and
  - abroad: Bangalore (India), Guam, Canberra (Australia), Bangkok (Thailand) and Hawaii (USA).
- The MSC is the responsible of the navigation message generation that are uplinked to the quasi-zenith satellite via a TT&C station placed in Okinawa.

QZSS - signals

There are 6 signals planned for the QZSS system:[3][5]

- L1-C/A (1575.42 MHz):
  Used by combining with GNSS; increase availability of PNT services.
- L1C (1575.42 MHz):
  Used by combining with GNSS; increase availability of PNT services.
- L2C (1227.6 MHz):
  Used by combining with GNSS; increase availability of PNT services.
- L5 (1176.45 MHz):
  Used by combining with GNSS; increase availability of PNT services.
- L1-SAIF (1575.42 MHz):
  Submeter-class Augmentation; interoperable with GPS-SBAS.
- LEX (1278.75 MHz):
  QZSS Experimental Signal for High precision (3 cm level) service; compatible with Galileo E6 signal

QZSS - services

Finally, QZSS will provide positioning-related services and a messaging service, as follows:

- Positioning-related services:
  - Satellite Positioning Service - the same as GPS satellites (in spite of urban and mountain areas) level of accuracy
  - Sub-Meter Level Augmentation Service: will provide accurate positioning around 2-3 meters
  - Centimeter Level Augmentation Service: will provide highly accurate positioning around 10 centimeters (not free of charge)
  - Position Technology Verification Services: will provide an application demonstration for new positioning technology
- Messaging service:
  - Short Message Delivery Service: will provide users in the field with disaster management and rescue

NAVIC - Navigation with Indian Constellation

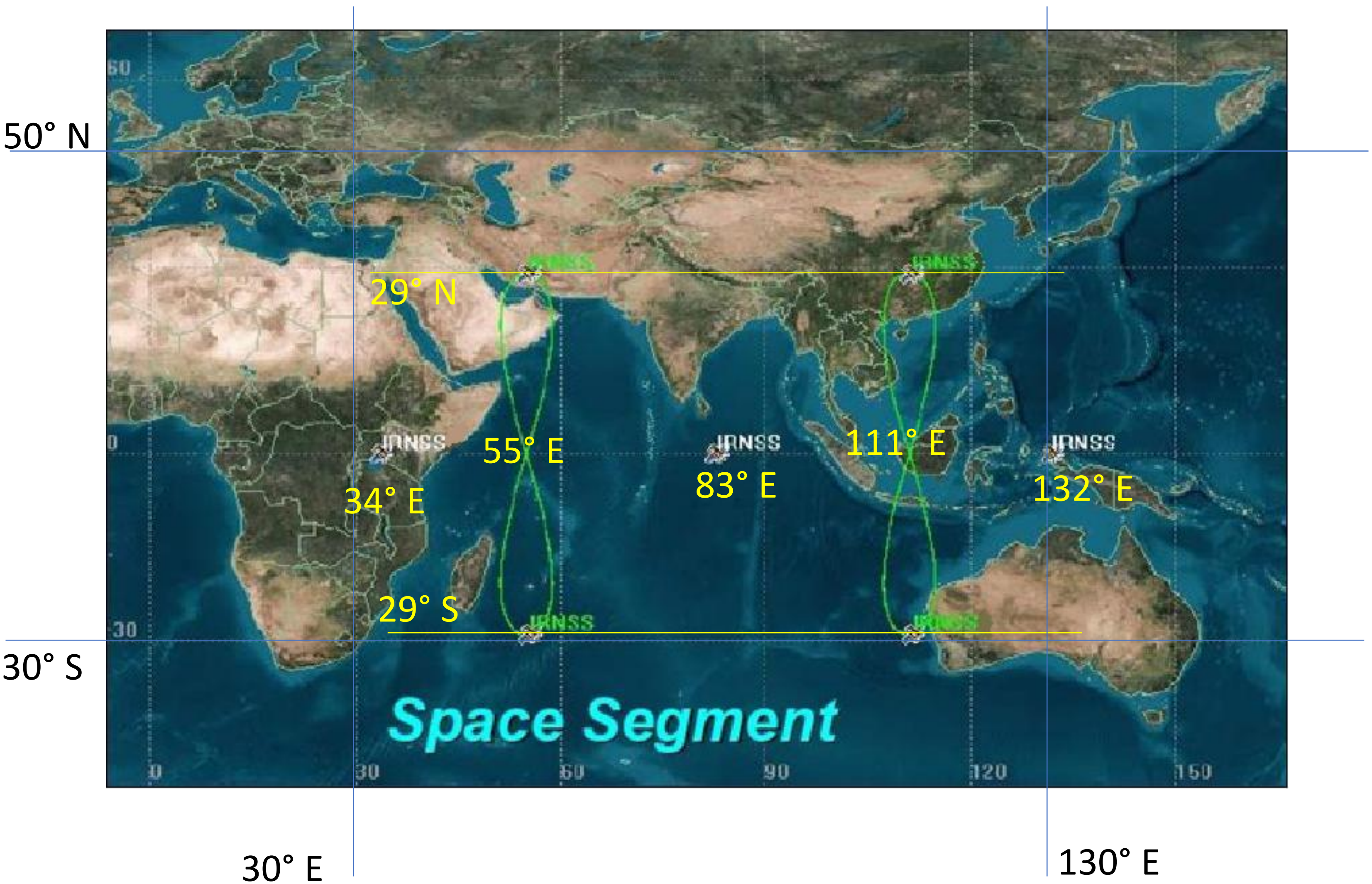
Indian Regional Navigation Satellite System NavIC

- is an autonomous regional satellite navigation system, that provides accurate real-time positioning and timing services.
- It covers India and a region extending 1,500 km around it, with plans for further extension (Latitude 30° S to 50° N, Longitude 30° E to 130° E)
- The system at-present consist of a constellation of 7 satellites with two additional satellites on ground as stand-by
  - 3 GEO satellites at longitudes: 34 °E, 83 °E, 132 °E
  - 4 GSO satellites with inclination 29° and longitudes: 55 °E, 111 °E

NavIC – constellation

IRNSS spacecraft	Longitude (E)	Inclination	RAAN	Launch Date
1A	55.0º	29º (±2)	135º	July 1, 2013
1B	55.0º	29º (±2)	310º	April 4, 2014
1C	83.0º		274º	October 15, 2014
1D	111.75º	29º (±2)	135º	March 27, 2015
1E	111.75º	29º (±2)	310º	January 20, 2016
1F	32.5º	± 5º	270º	March 10, 2016
1G	129.5º	± 5º	270º	April 28, 2016
1H				Aug. 31 2017 **(launch failure)**
1I	55.0º	29º		April 11, 2018

NavIC - constellation

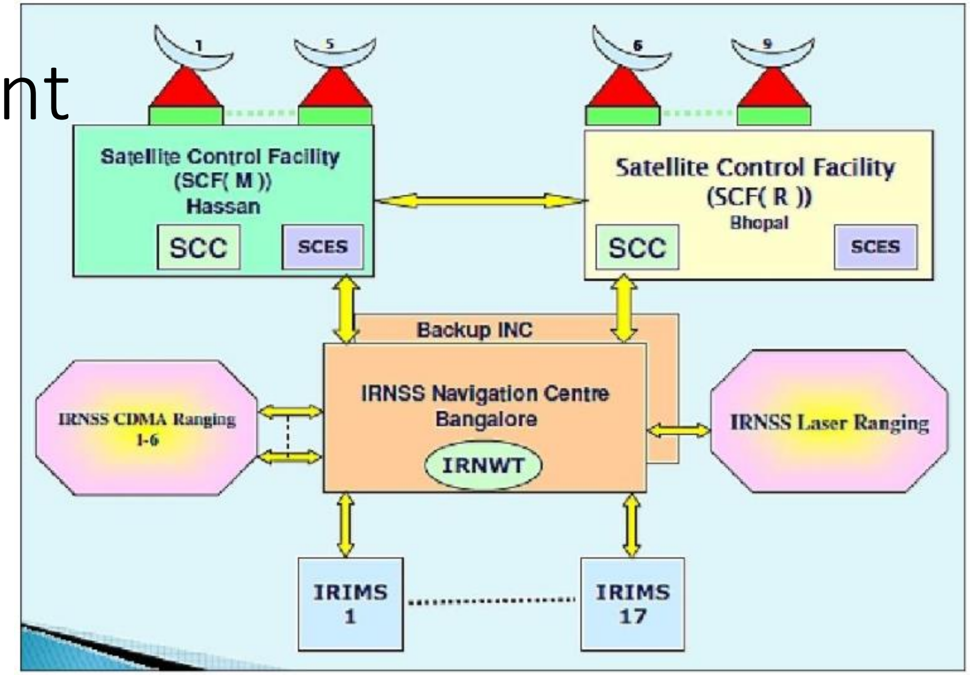


NavIC – ground segment

IRNSS Ground Segment Elements:

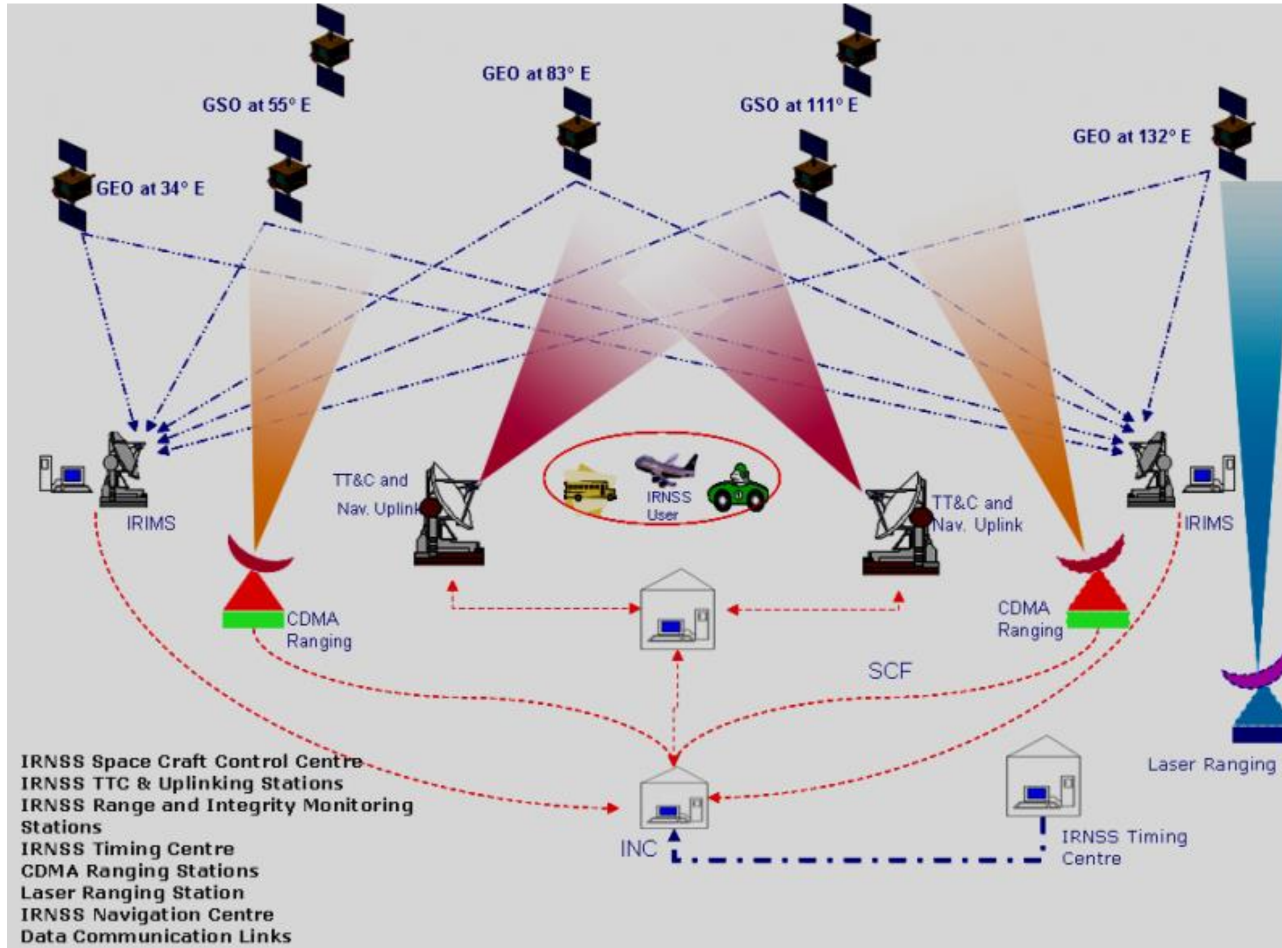
- IRSCF (IRNSS Satellite Control Facility)
  IRSCF controls the space segment through Telemetry Tracking & Command network. In addition to the regular TT&C operations, IRSCF also uplinks the navigation parameters generated by the INC.
- IRTTC (IRNSS TTC and Land Uplink Stations)
- IRSCC (IRNSS Satellite Control Center)
- IRIMS (IRNSS Range and Integrity Monitoring Stations)
  IRIMS perform continuous one way ranging of the IRNSS satellites and are also used for integrity determination of the IRNSS constellation
- INC (ISRO Navigation Center), located at Byalalu. INC is the nerve center of the IRNSS Ground Segment. INC primarily generates navigation parameters
- IRDCN (IRNSS Data Communication Network). IRDCN provides the required digital communication backbone to IRNSS network

NavIC – ground segment



- Seventeen IRIMS sites will be distributed across the country for orbit determination and ionospheric modeling.
- Four ranging stations, separated by wide and long baselines, will provide two-way CDMA (Code Division Multiple Access) ranging.
- The IRNSS timing center will consist of highly stable clocks. The navigation center will receive all this data through communication links, then process and transmit the information to the satellites.

NAVIC - architecture



ISRO Navigation Centre
IRNSS Spacecraft Control Facility
IRNSS Range and Integrity Monitoring Stations
IRNSS Network Timing Centre

IRNSS CDMA Ranging Stations
Laser Ranging Stations
Data Communication Network

NavIC - signals

The IRNSS constellation is expected to provide a position accuracy (2σ) of better than 20 m over India and a region extending outside the Indian land mass to about 1,500 km.

The system will provide two types of services:

- SPS (Standard Positioning Service)
- RS (Restricted/Authorized Service)

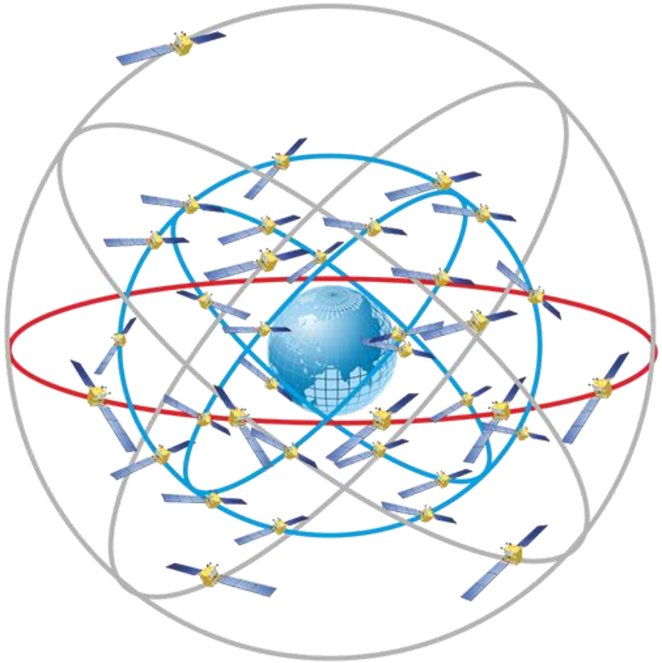
Both of these services will be provided at two frequencies:

- one in the L5 band, and
- the other in S-band

BEIDOU

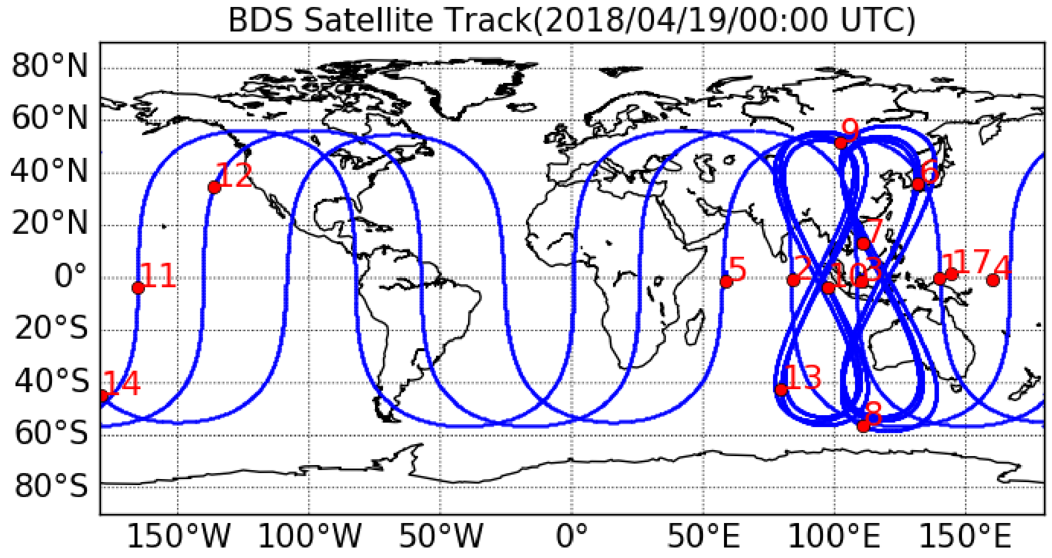
China Global Navigation Satellite System

- The system will consist of a constellation of 35 satellites
  - 5 GEO satellites at longitudes: 58.75° E, 80° E, 110.5° E, 140° E and 160° E
  - 3 GSO satellites with inclination 55° and longitudes: 118 °E
  - 27 MEO
    - Hight 21500 km
    - Inclination 55 °
    - T = 7/13 (12 h 53 min 24 s)



https://www.glonass-iac.ru/en/guide/beidou.php

BeiDou - covereage



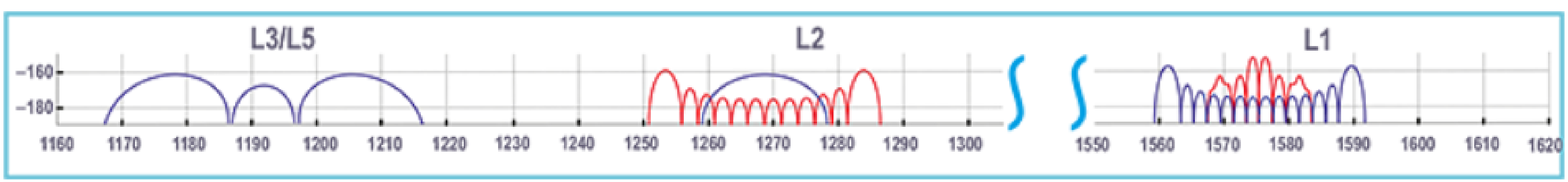
GROUND CONTROL SEGMENT

- The BeiDou Ground Control Segment is based on a classic centralized scheme including the **network of one-way measuring stations**
  - The network of one-way stations is located throughout China
  - monitor the navigation signals of all satellites on a continuous basis
  - transmit all the observations of all satellites for processing to **the system control center**
- The system control center generates the precise orbit and clock data for each satellite to be uploaded to satellites via up-link stations

Beidou - signals

- BeiDou transmits navigation signals in three frequency bands: B1, B2, and B3, which are in the same area of L-band as other GNSS signals.
- To benefit from the signal interoperability of BeiDou with Galileo and GPS China announced the migration of its civil B1 signal from 1561.098 MHz to a frequency centered at 1575.42 MHz — the same as the GPS L1 and Galileo E1 civil signals — and its transformation from a quadrature phase shift keying (QPSK) modulation to a multiplexed binary offset carrier (MBOC) modulation similar to the future GPS L1C and Galileo's E1.

BEIDOU SIGNALS



SPECTRAL CHARACTERISTICS OF BEIDOU NAVIGATION SIGNALS

GALILEO

- Galileo is Europe’s programme for a global navigation satellite system, providing a highly accurate, guaranteed global positioning service, interoperable with the US GPS and Russian Glonass systems.
- Galileo’s modern and efficient design will increase Europe's technological independence, and help to set international standards for Global Navigation Satellite Systems (GNSS).
- Galileo is developed in collaboration between the European Union and the European Space Agency (ESA)

- The first “civilian” GNSS

GALILEO – satellites constellation

- The complete Galileo constellation will consist of 24 (30) satellites plus spares
- The satellites will be positioned
  - along three orbital planes
  - at an angle of 56° to the equator (inclination),
  - at altitudes of 23 222 km,
  - taking about 14 hours to orbit Earth; orbital period equals 10/17 of sidereal day
- GALILEO will provide coverage worldwide, right up to the polar regions
- There will always be at least four satellites visible anywhere in the world

GALILEO
- constellation

In operation

Outage

In commissioning

Mainenance

In testing

Spares

Time problem

http://qzss.go.jp/en/technical/satellites/index.html#Galileo

PRN	SVN	Satellite	Launch Date (UTC)	Orbit (*1)	Positioning Signals	Clock(*2)
E11	E101	IOV-1,Galileo PFM	2011/10/21	MEO	E1, E5a, E5b, E6	PHM
E12	E102	IOV-2,Galileo FM2	2011/10/21	MEO	E1, E5a, E5b, E6	RAFS
E19	E103	IOV-3,Galileo FM3	2012/10/12	MEO	E1, E5a, E5b, E6	PHM
E20	E104	IOV-4,Galileo FM4	2012/10/12	MEO	E1, E5a, E5b, E6	RAFS
E18	E201	FOC-1	2014/8/22	MEO	E1, E5a, E5b, E6	RAFS & PHM
E14	E202	FOC-2	2014/8/22	MEO	E1, E5a, E5b, E6	RAFS & PHM
E26	E203	FOC-3	2015/3/27	MEO	E1, E5a, E5b, E6	RAFS & PHM
E22	E204	FOC-4	2015/3/27	MEO	E1, E5a, E5b, E6	RAFS & PHM
E24	E205	FOC-5	2015/9/11	MEO	E1, E5a, E5b, E6	RAFS & PHM
E30	E206	FOC-6	2015/9/11	MEO	E1, E5a, E5b, E6	RAFS & PHM
E08	E208	FOC-8	2015/12/17	MEO	E1, E5a, E5b, E6	RAFS & PHM
E09	E209	FOC-9	2015/12/17	MEO	E1, E5a, E5b, E6	RAFS & PHM
E01	E210	FOC-10	2016/5/24	MEO	E1, E5a, E5b, E6	RAFS & PHM
E02	E211	FOC-11	2016/5/24	MEO	E1, E5a, E5b, E6	RAFS & PHM
E07	E207	FOC-7	2016/11/17	MEO	E1, E5a, E5b, E6	RAFS & PHM
E03	E212	FOC-12	2016/11/17	MEO	E1, E5a, E5b, E6	RAFS & PHM
E04	E213	FOC-13	2016/11/17	MEO	E1, E5a, E5b, E6	RAFS & PHM
E05	E214	FOC-14	2016/11/17	MEO	E1, E5a, E5b, E6	RAFS & PHM
E21	E215	FOC-15	2017/12/12	MEO	E1, E5a, E5b, E6	RAFS & PHM
E25	E216	FOC-16	2017/12/12	MEO	E1, E5a, E5b, E6	RAFS & PHM
E27	E217	FOC-17	2017/12/12	MEO	E1, E5a, E5b, E6	RAFS & PHM
E31	E218	FOC-18	2017/12/12	MEO	E1, E5a, E5b, E6	RAFS & PHM

Control segment

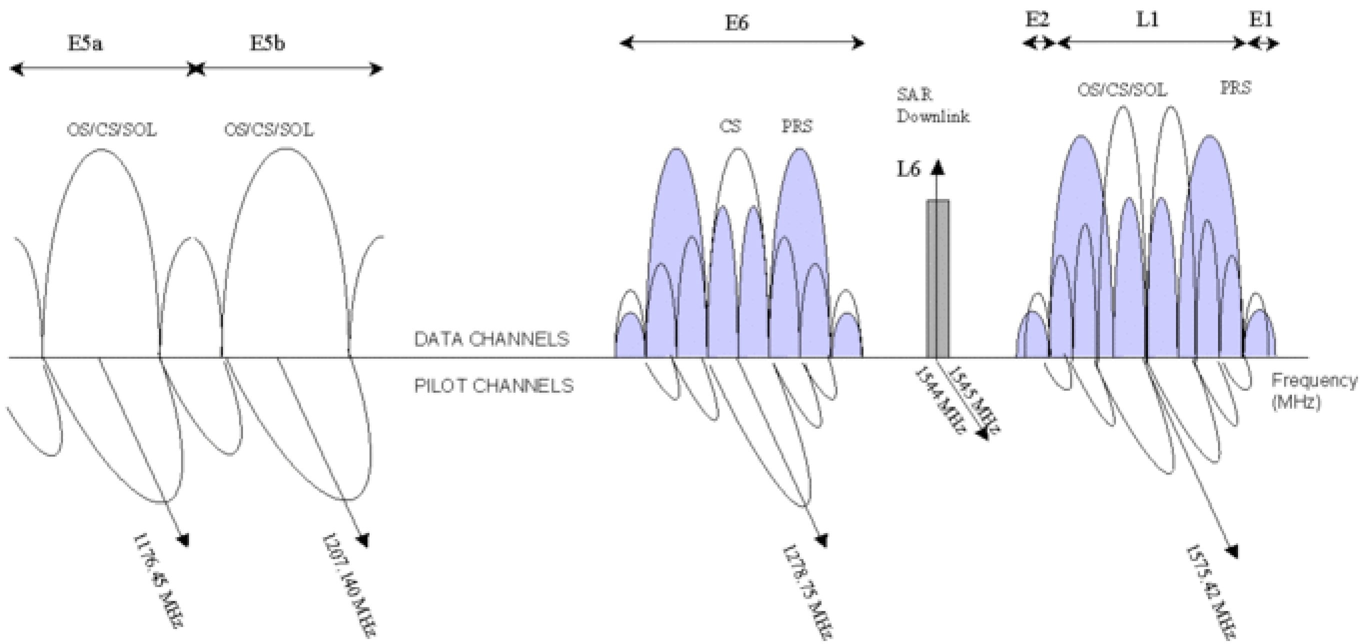
The Galileo Ground Segment necessary is one of the most complicated developments undertaken by Europe, having to fulfil strict levels of performance, security and safety:

- Ground Mission Segment (GMS) - it must provide cutting-edge navigation performance at high speed around the clock, processing data from a worldwide network of stations. GMS has two million lines of software code, 500 internal functions, 400 messages and 600 signals circulating through 14 different elements.
- Ground Control Segment (GCS) - it monitors and controls the constellation with a high degree of automation.

(For now the GMS is located in the Fucino Control Centre in Italy and the GCS in the Oberpfaffenhofen Control Centre in Germany. In future the two centres will host equivalent facilities, working together as hot backups with realtime data synchronisation. In the event of the loss of one centre, the other will be able to continue operations in a seamless way.)

- Telemetry, Tracking and Command Stations two, at Kiruna in Sweden and Kourou in French Guiana.
- Uplink Stations a network of stations to uplink the navigation and integrity data.
- Sensor Stations a global network providing coverage for clock synchronisation and orbit measurements.
- Data Dissemination Network interconnecting all Galileo ground facilities.

Signals



Each Galileo satellite will broadcast 10 different navigation signals making it possible for Galileo to offer the open (OS), safety-of-life (SOL), commercial (CS) and public regulated services (PRS)

https://www.esa.int/spaceinimages/Images/2005/04/Each_Galileo_satellite_will_broadcast_10_different_navigation_signals

GLONASS

- Russian: ГЛОНАСС Глобальная навигационная спутниковая система; transliteration Globalnaya navigatsionnaya sputnikovaya sistema), or
- "Global Navigation Satellite System",
- the space-based satellite navigation system operating in the radionavigation-satellite service.
- It provides an alternative to GPS and is the second navigational system in operation with global coverage and of comparable precision

GLONASS -constellation

Consists of:

- 24 satellites on 3 orbital planes
- Orbits inclination 66°
- Altitude 19100 km
- Orbital period 8/17 of sidereal day

GLONASS – constellation

Orb. slot	Orb. pl.	RF chnl	# GC	Launched	Operation begins	Operation ends	Life-time (months)	Satellite health status		Comments
								In almanac	In ephemeris (UTC)	
1	1	01	730	14.12.09	30.01.10		100.3	+	+ 08:51 23.04.18	In operation
2	1	-4	747	26.04.13	04.07.13		59.9	+	+ 08:51 23.04.18	In operation
3	1	05	744	04.11.11	08.12.11		77.7	+	+ 08:51 23.04.18	In operation
4	1	06	742	02.10.11	25.10.11		78.7	+	+ 08:51 23.04.18	In operation
5	1	01	734	14.12.09	10.01.10	19.04.18	100.3	-	- 08:51 23.04.18	Maintenance
6	1	-4	733	14.12.09	24.01.10		100.3	+	+ 08:51 23.04.18	In operation
7	1	05	745	04.11.11	18.12.11		77.7	+	+ 08:51 23.04.18	In operation
8	1	06	743	04.11.11	20.09.12		77.7	+	+ 08:51 23.04.18	In operation
9	2	-2	702	01.12.14	15.02.16		40.7	+	+ 08:51 23.04.18	In operation
10	2	-7	717	25.12.06	03.04.07		136.0	+	+ 08:51 23.04.18	In operation
11	2	00	753	29.05.16	27.06.16		22.8	+	+ 08:51 23.04.18	In operation
12	2	-1	723	25.12.07	22.01.08		124.0	+	+ 08:51 23.04.18	In operation
13	2	-2	721	25.12.07	08.02.08		124.0	+	+ 08:51 23.04.18	In operation
14	2	-7	752	22.09.17	16.10.17		7.0	+	+ 08:51 23.04.18	In operation
15	2	00	716	25.12.06	12.10.07		136.0	+	+ 08:51 23.04.18	In operation
16	2	-1	736	02.09.10	04.10.10		91.7	+	+ 08:51 23.04.18	In operation
17	3	04	751	07.02.16	28.02.16		26.5	+	+ 08:51 23.04.18	In operation
18	3	-3	754	24.03.14	14.04.14		49.0	+	+ 08:51 23.04.18	In operation
19	3	03	720	26.10.07	25.11.07		126.0	+	+ 08:51 23.04.18	In operation
20	3	02	719	26.10.07	27.11.07		126.0	+	+ 08:51 23.04.18	In operation
21	3	04	755	14.06.14	03.08.14		46.3	+	+ 08:51 23.04.18	In operation
22	3	-3	731	02.03.10	28.03.10		97.8	+	+ 08:51 23.04.18	In operation
23	3	03	732	02.03.10	28.03.10		97.8	+	+ 08:51 23.04.18	In operation
24	3	02	735	02.03.10	28.03.10		97.8	+	+ 08:51 23.04.18	In operation
20	3	-5	701	26.02.11			85.9			Flight Tests

GLONASS CONSTELLATION STATUS, 23.04.2018

Total satellites in constellation	25 SC
Operational	23 SC
In commissioning phase	-
In maintenance	1 SC
Under check by the Satellite Prime Contractor	-
Spares	-
In flight tests phase	1 SC

https://www.glonass-iac.ru/en/GLONASS/

Ground segment

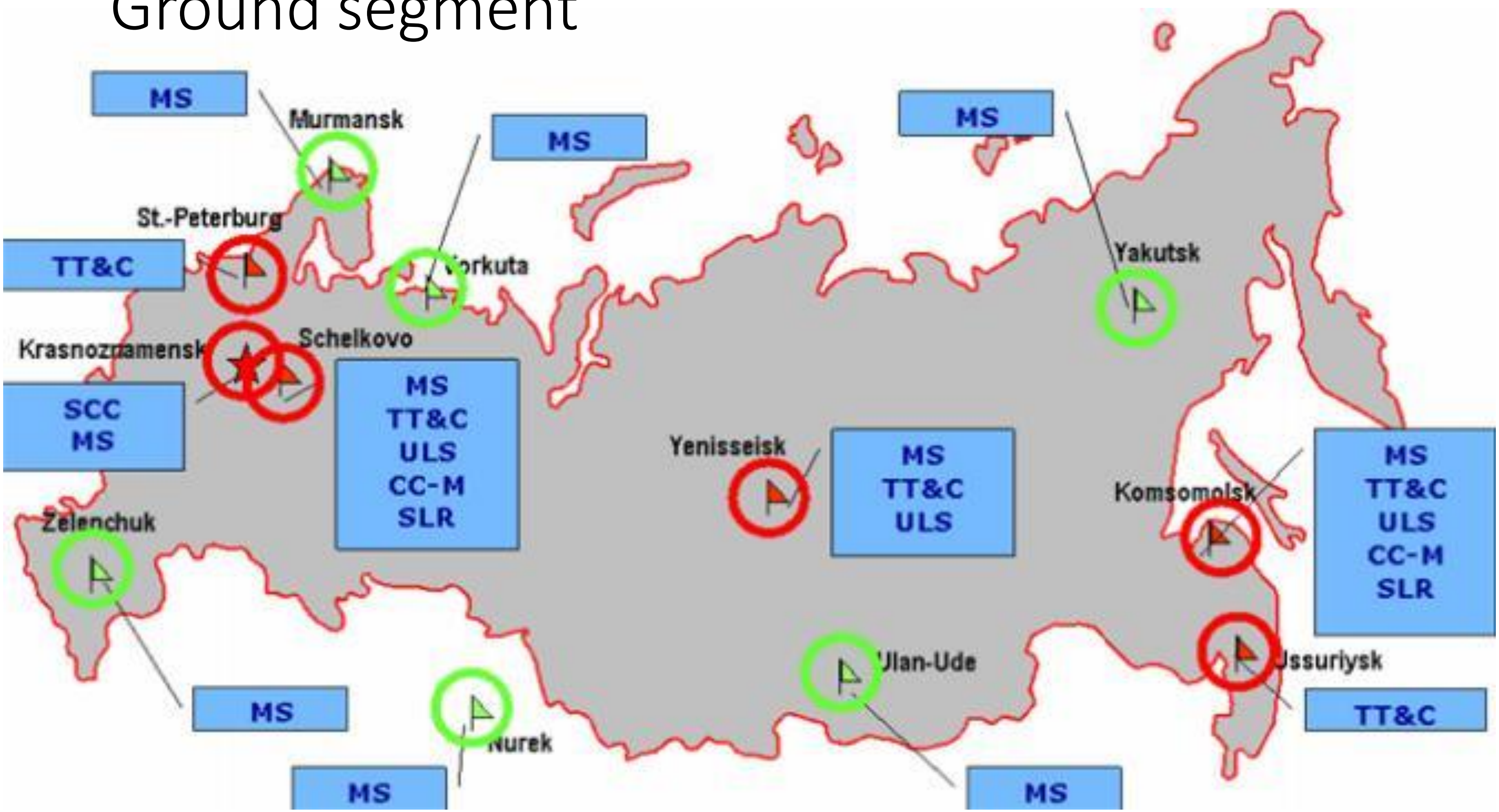
The ground control segment of GLONASS is almost entirely located within former Soviet Union territory, except for several in Brazil

- The GLONASS ground segment consists of:
  - a system control centre;
  - five Telemetry, Tracking and Command centers
  - two Laser Ranging Stations
  - ten Monitoring and Measuring Stations

Ground segment

	SCC	TT&C	CC-M	ULS	SLR	MS
Location	**System control**	**Telemetry, Tracking and Command**	**Central clock**	**Upload stations**	**Laser Ranging**	**Monitoring and Measuring**
Krasnoznamensk	x	-	-	-	-	x
Schelkovo	-	x	x	x	x	x
Komsomolsk	-	x	-	x	x	x
St-Peteburg	-	x	-	-	-	-
Ussuriysk	-	x	-	-	-	-
Yenisseisk	-	x	-	x	-	x
Yakutsk	-	-	-	-	-	x
Ulan-Ude	-	-	-	-	-	x
Nurek	-	-	-	-	-	x
Vorkuta	-	-	-	-	-	x
Murmansk	-	-	-	-	-	x
Zelenchuk	-	-	-	-	-	x

Ground segment



Signals

Roadmap of GLONASS modernization

Satellite series	Launch	Current status	Clock error	FDMA signals		CDMA signals			Interoperability CDMA signals		
				1602 + n×0.5625 MHz	1246 + n×0.4375 MHz	1600.995 MHz	1248.06 MHz	1202.025 MHz	1575.42 MHz	1207.14 MHz	1176.45 MHz
GLONASS	1982–2005	Out of service	5×10^{-13}	L1OF, L1SF	L2SF						
GLONASS-M	2003–2018	In service	1×10^{-13}	L1OF, L1SF	L2OF, L2SF			L3OC ‡			
GLONASS-K1	2011, 2014	In service	$5 \times 10^{-14} \ldots 1 \times 10^{-13}$	L1OF, L1SF	L2OF, L2SF			L3OC			
GLONASS-K2	2018–2024	Design phase	$5 \times 10^{-15} \ldots 5 \times 10^{-14}$	L1OF, L1SF	L2OF, L2SF	L1OC, L1SC	L2OC, L2SC	L3OC			
GLONASS-KM	2025–	Research phase		L1OF, L1SF	L2OF, L2SF	L1OC, L1SC	L2OC, L2SC	L3OC, L3SC	L1OCM	L3OCM	L5OCM

"O": open signal (standard precision), "S": obfuscated signal (high precision); "F":FDMA, "C":CDMA; n=−7,−6,−5,...,6

‡Glonass-M spacecraft produced since 2014 include L3OC signal

GPS

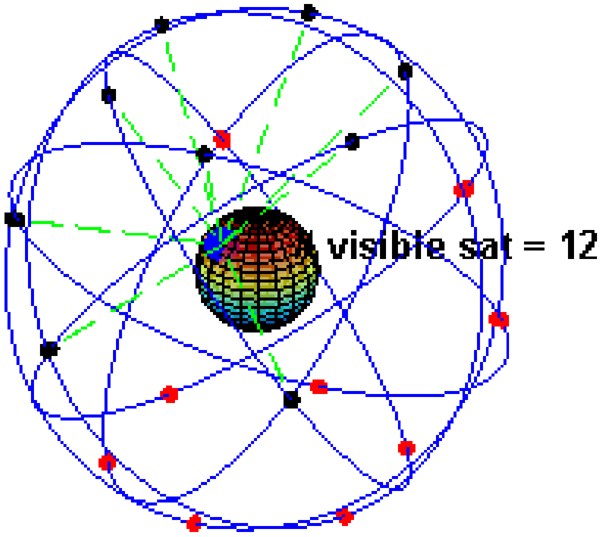
- Global Positioning System is a U.S.-owned utility that provides users with positioning, navigation, and timing (PNT) services.
- This system consists of three segments: the space segment, the control segment, and the user segment.
- The U.S. Air Force develops, maintains, and operates the space and control segments

GPS – constellation

- GPS satellites fly in medium Earth orbit (MEO) at an altitude of approximately 20,186 km
- Each satellite circles the Earth twice a sidereal day; orbital period equals ½ of sidereal day (11h 58m 2.05s)
- The satellites in the GPS constellation are arranged into six equally-spaced orbital planes surrounding the Earth.
- An inclinations of orbits equal 55°
- Each plane contains four "slots" occupied by baseline satellites.
- This 24-slot arrangement ensures users can view at least four satellites from virtually any point on the planet

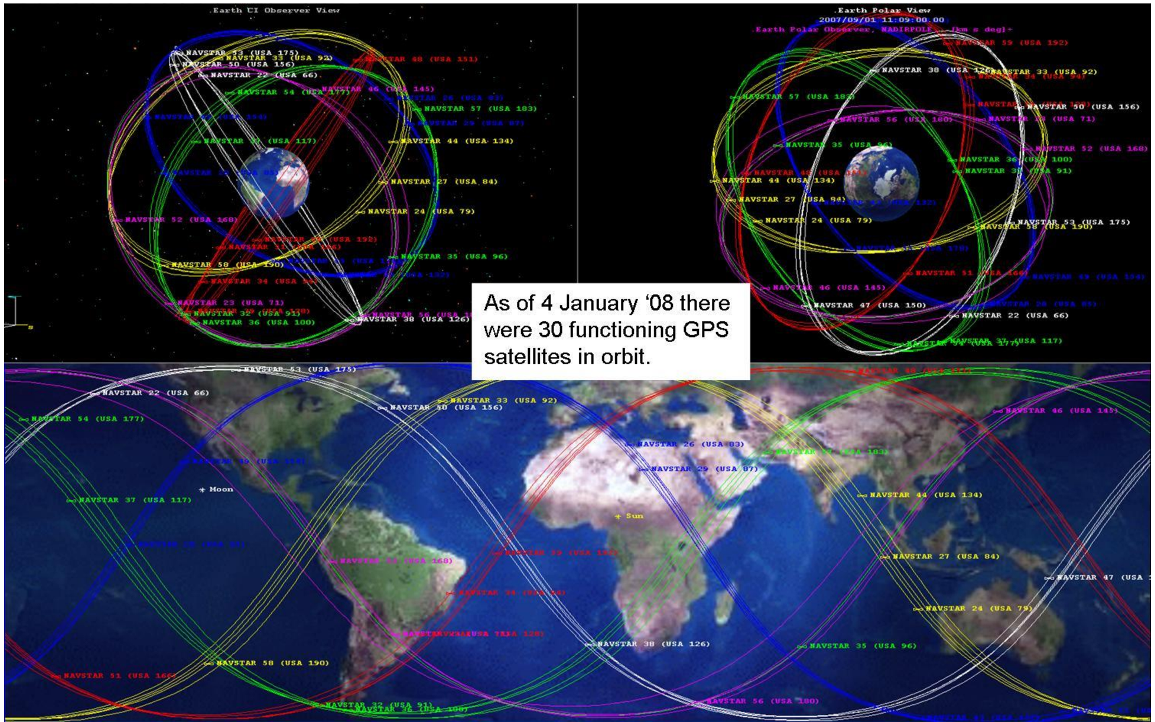
GPS – availability of 24 SV constellation

- Every 23h 56m 4.09s the same satellite configuration above a given point on the Earth surface
- Distribution of the satellites provide visibility of 4 up to 10 satellites all the time and almost on every place
- The number of visible satellites depends on a user latitude
- Probability of availability at least 5 satellites equals 0.9996
- there are places where for max 20 minutes/day cannot obtain 3D FIX (only 3 satellites available)
- The mean life time of satellites – 7.5 years



GPS – constellation 24+

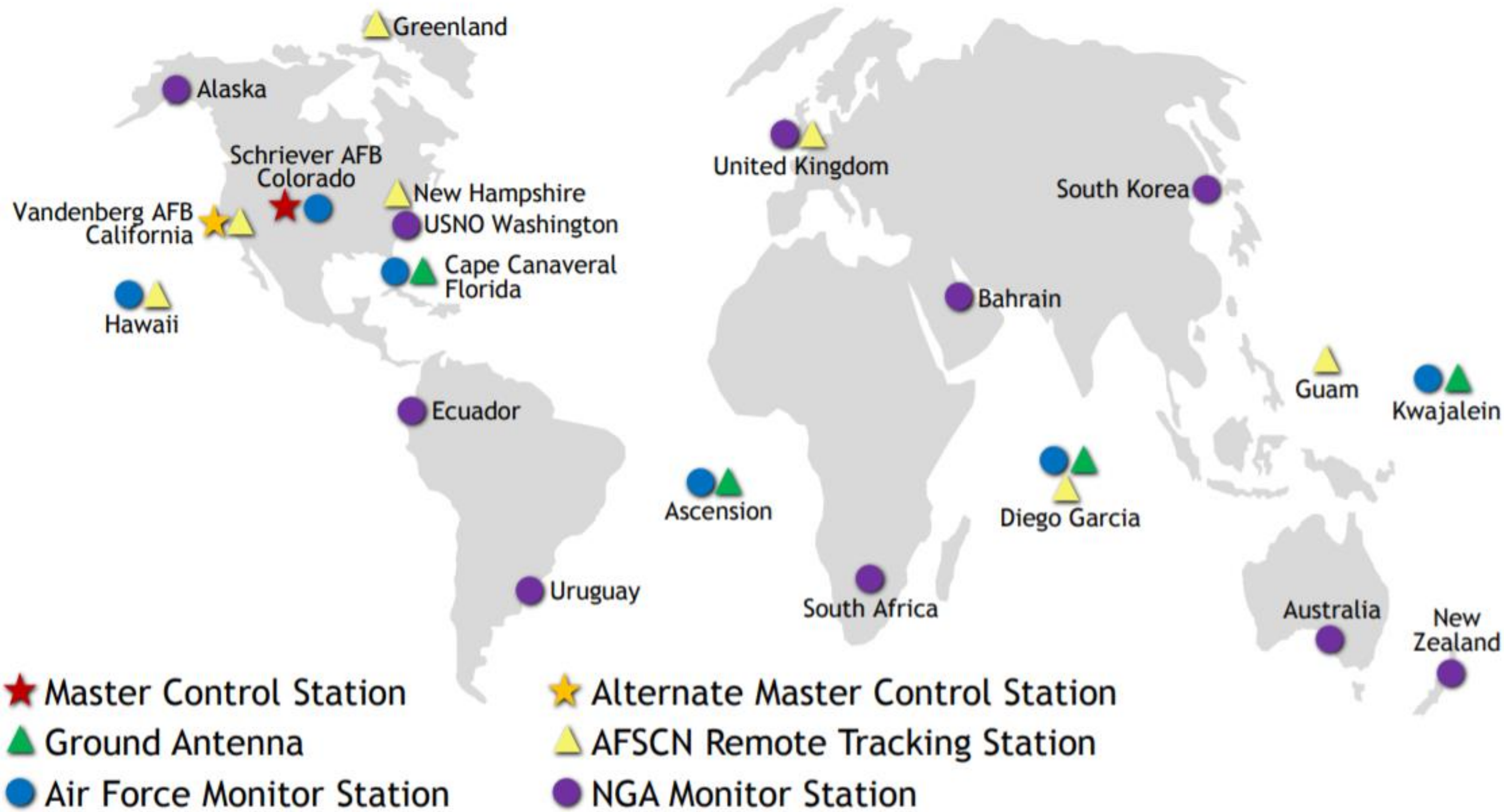
- Nowadays the GPS constellation is called 24+ (expandable 24), which means that minimum 24 satellites are enough to provide a required performance, but usually there are more up to 32 satellites.
- The extra satellites may increase GPS performance but are not considered part of the core constellation.



Control segment

- The GPS control segment consists of a global network of ground facilities that track the GPS satellites, monitor their transmissions, perform analyses, and send commands and data to the constellation
- The current Operational Control Segment (OCS) includes a master control station, an alternate master control station, 11 command and control antennas, and 16 monitoring sites.

Control segment



Master Control Station

- Provides command and control of the GPS constellation
- Uses global monitor station data to compute the precise locations of the satellites
- Generates navigation messages for upload to the satellites
- Monitors satellite broadcasts and system integrity to ensure constellation health and accuracy
- Performs satellite maintenance and anomaly resolution, including repositioning satellites to maintain optimal constellation
- Currently uses separate systems (AEP & LADO) to control operational and non-operational satellites
- Backed up by a fully operational alternate master control station

Master Control Station - AEP

Architecture Evolution Plan

The Air Force currently commands and controls the operational GPS constellation through a system called AEP. The system is capable of managing all of today's GPS satellites.

- AEP refers to the Architecture Evolution Plan implemented in 2007. Under this plan, the Air Force replaced its original, mainframe-based GPS master control station with an entirely new one built on modern IT technologies.

Master Control Station - AEP

- In 2014, AEP was upgraded to support modernized Civil Navigation (CNAV) capabilities, allowing GPS Block IIR-M and IIF satellites to broadcast pre-operational navigation messages on the L2C and L5 signals
- In 2016, the AEP COTS hardware and software baselines were upgraded with improved cyber security and improved supportability, to support operations into the 2020s.
- In 2019, AEP will be upgraded to command and control GPS III satellites with the GPS III Contingency Operations (COps) program
- In 2020, AEP will be upgraded to provide core capabilities of the modernized military GPS signal, known as M-Code, to the military GPS user community under the M-Code Early Use (MCEU) program

Master Control Station - LADO

the Launch/early orbit, Anomaly resolution, and Disposal Operations system to handle non-operational GPS (Block IIA/IIR/IIR-M, IIF) satellites. These operations include:

- Newly launched satellites undergoing checkout;
- Satellites taken out of service for anomaly resolution;
- Residual satellites stored in orbit; and
- Satellites requiring end-of-life disposal.

Serves three primary functions:

- Telemetry, tracking, and control;
- Planning and execution of satellite movements; and
- Simulation of different telemetry tasks for GPS payloads and subsystems

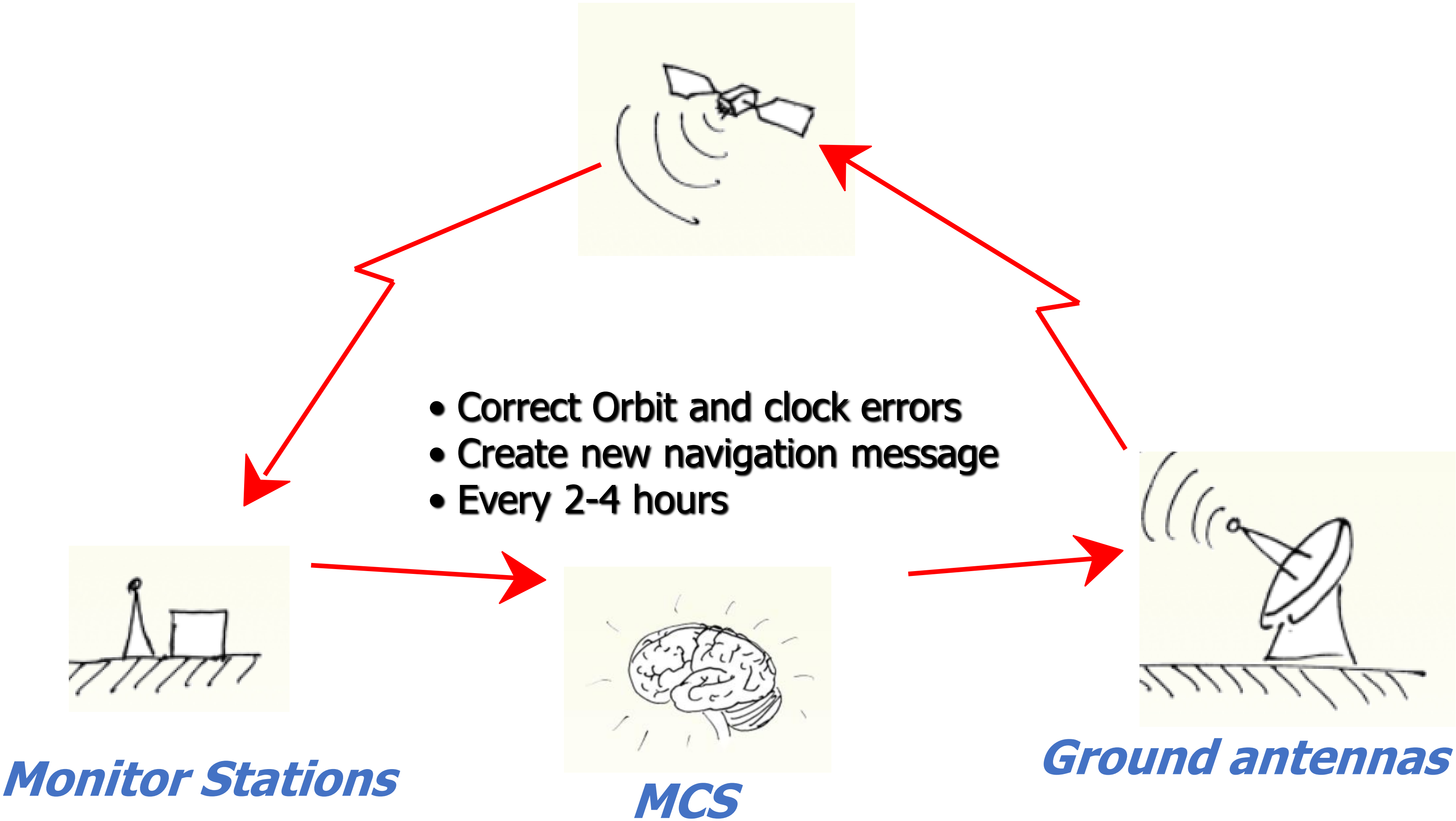
Monitor Stations

- Track GPS satellites as they pass overhead
- Collect navigation signals, range/carrier measurements, and atmospheric data
- Feed observations to the master control station
- Utilize sophisticated GPS receivers
- Provide global coverage via 16 sites: 6 from the Air Force plus 10 from NGA (National Geospatial-Intelligence Agency)
- The Legacy Accuracy Improvement Initiative, completed in 2008, expanded the number of monitoring stations in the GPS operational control segment from six to 16.
- This tripled the amount of data collected on GPS satellite orbits, enabling a 10% to 15% improvement in the accuracy of the information broadcast from the GPS constellation

Ground Antennas

- Send commands, navigation data uploads, and processor program loads to the satellites
- Collect telemetry
- Communicate via S-band and perform S-band ranging to provide anomaly resolution and early orbit support
- Consist of 4 dedicated GPS ground antennas plus 7 Air Force Satellite Control Network (AFSCN) remote tracking stations

Control segment



Ancillary institutions

- AFSCF – Air Force Satelite Control Facility
  - supervises the operation of satellites belong to USA
- USNO - US Naval Observatory
  - calculates the standard UTC time
- DMA – Defence Mapping Agency
  - calculates the data for determining the orbits of satellites
- Jet Propolution Laboratory
  - observes celestial bodies affecting the position of satellites (main Sun and Moon)

User segment

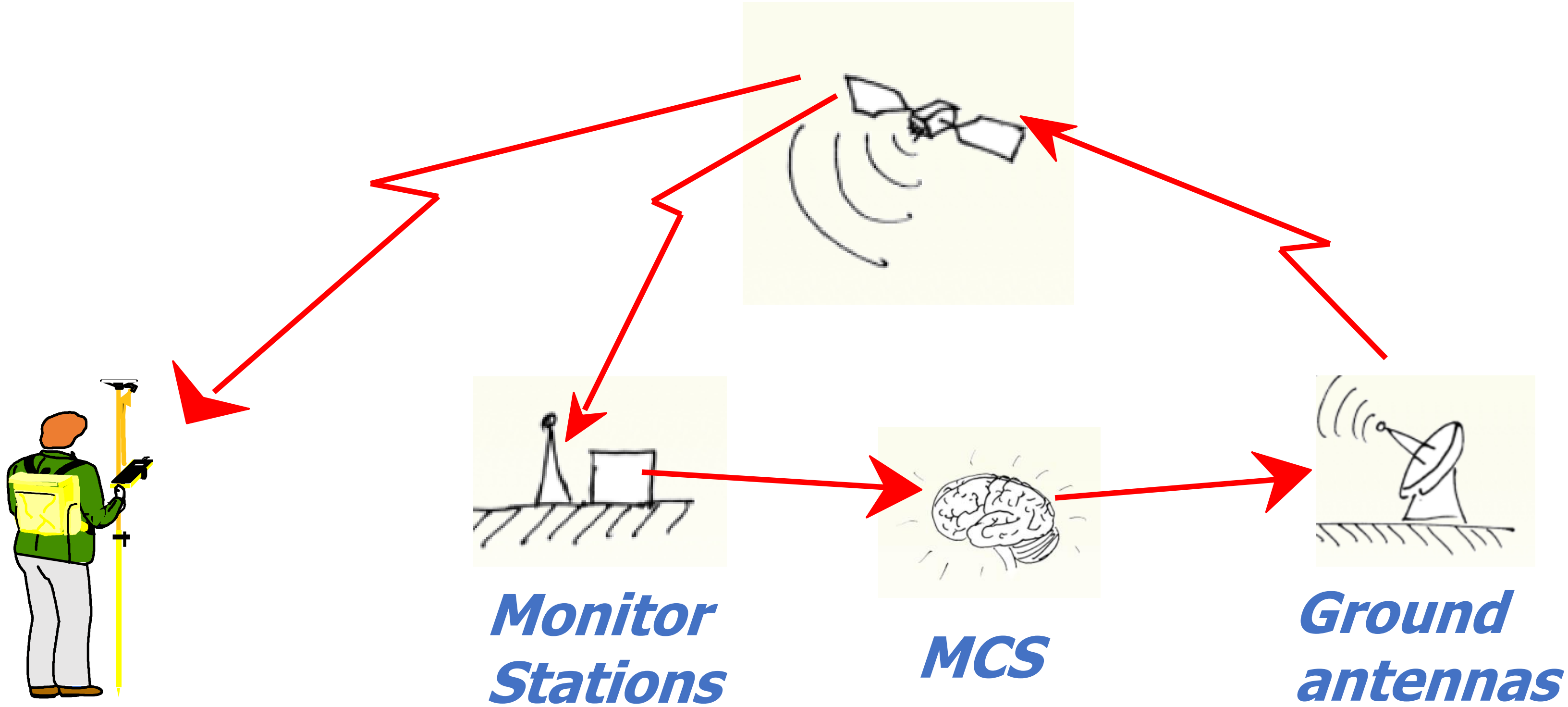
All receivers using signals transmitted by satellites.
They can be divided into following groups:

- Depending on signals receiving
  - Civil
  - Military / authorized
- Depending on receiver type
  - Standing alone
  - Integrated / built within other system
- Depending on the application
  - For positioning
  - For timing
  - For navigation: air, sea, land etc.
  - For geodesy surveys
  - Etc.

User segment

The GNSS receivers contain:

- Software for receiving, decoding satellites’ signals
- Software for obtaining position
- Software dependent on the receivers applications



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