Pushing Boundaries

Leica GNSS Modernization Strategy

GNSS Product Management

Leica Geosystems AG, Switzerland

September 10, 2020

- when it has to be right

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- Galileo
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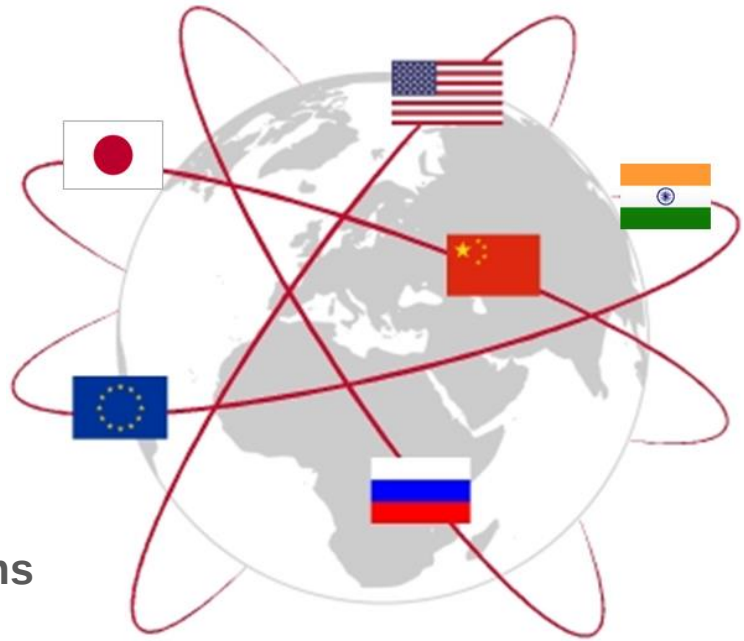
Regional systems



Leica GNSS Modernization Strategy

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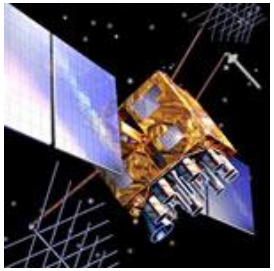
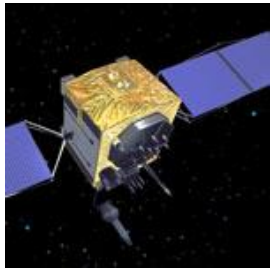
GPS
Space Segment

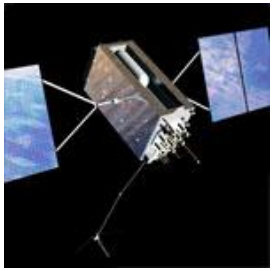
Block IIR



Block IIR-M



Block IIF



Block IIIA/IIIF

Number of satellites in the GPS constellation (September 8, 2020)

GPS satellite	Block IIR	Block IIR-M	Block IIF	Block IIIA/IIIF	Operational /Total
Now	9	7/8*	12	2/3**	30/32
2022	5	7	12	8	32

* IIR-M satellite launched on 24.03.09 in maintenance
** GPS IIIA SV 03 is currently in commissioning phase

- Launch of GPS IIIA SV04 planned on September 30/October 1, 2020
- GPS IIIA SV09 and 10 satellites expected to be ready for launch in 2022
- A total of 22 GPS IIIF satellites will be launched from 2026 to 2034

GPS
Space Segment

GPS
Space Segment

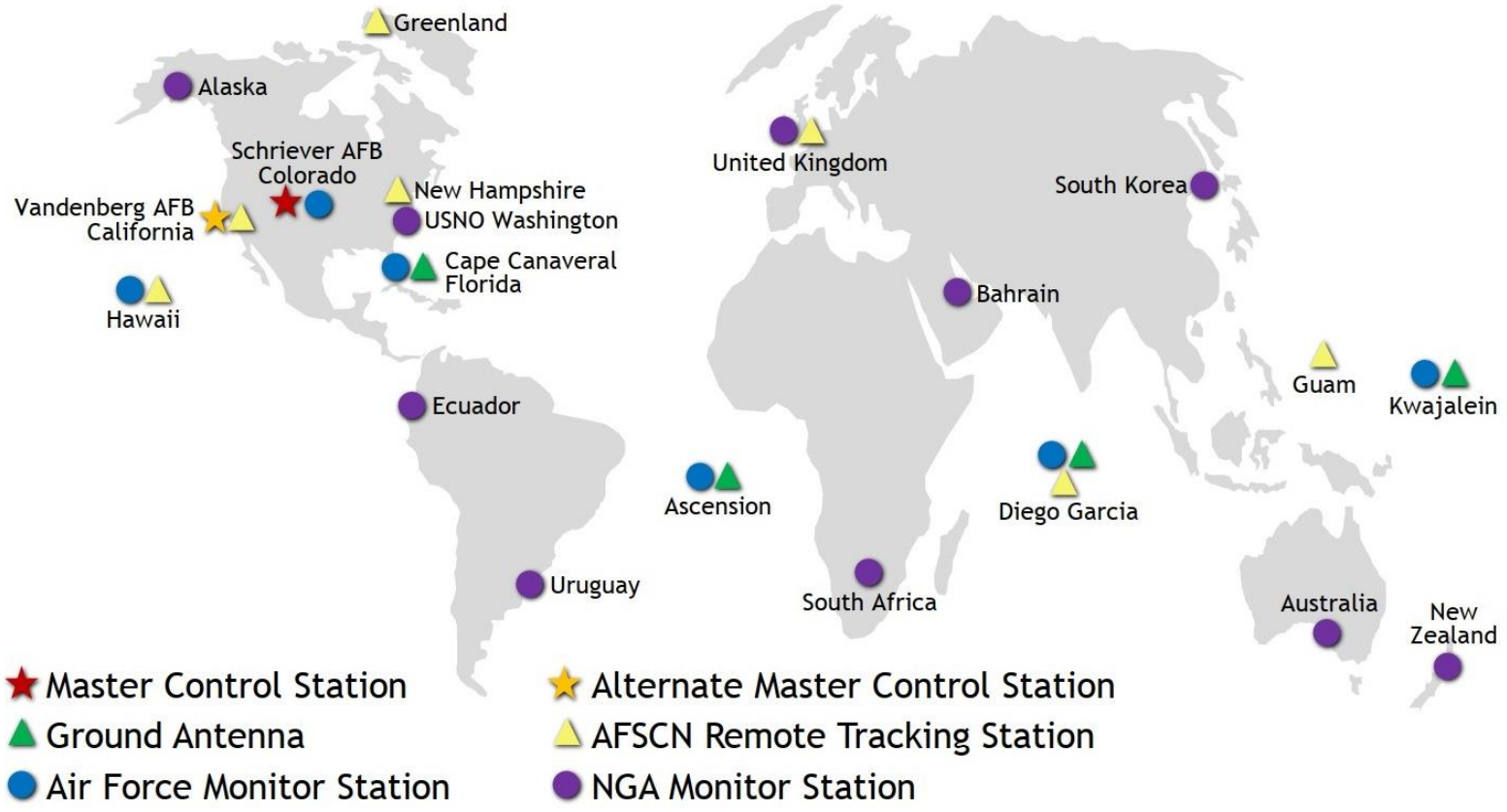
Current and future civil GPS signals at different frequencies (September 8, 2020)

Usable for RTK

Signal	L1 C/A	L1 P(Y)	L1C	L2 P(Y)	L2C	L5
GPS IIR	●	●		●		
GPS IIR-M	●	●		●	●	
GPS IIF	●	●		●	●	●
GPS IIIA/IIIF	●	●	●	●	●	●
Available on ≥ 12 GPS satellites by*	Now	Now	2027	Now	**Now**	**Now**
Available on 24 GPS satellites by	Now	Now	2030	Now	2023	2027
Benefit	As today	As today	Max inter-operability	As today	Stronger signal	Stronger signal, multi-frequency RTK

*12 satellites is the minimum number of satellites to be beneficial for RTK

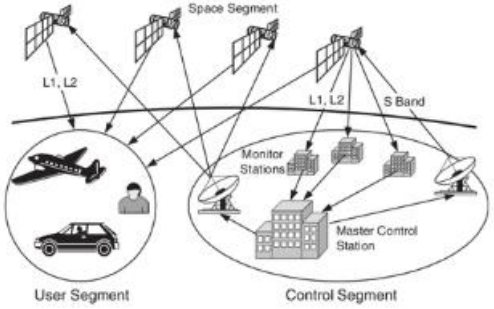
GPS
Control Segment



Distribution of GPS control segment stations (Source: https://www.gps.gov/systems/gps/control/)

GPS
Control Segment, User Segment

- **Control segment**



  - The Next-Generation GPS Operational Control Segment (OCX) will fully support, monitor and control the modernized civil signals.
  - OCX Block 0: Launch and Checkout System (LCS) supporting launch and early on-orbit spacecraft bus checkout on GPS III satellites, delivered in November 2017
  - GPS III Contingency Operations (COps) supporting the interim GPS III operations, delivered in May 2019
  - OCX Block 1: Operational capability to control all legacy satellites and civil signals (L1 C/A), military signals (L1P(Y), L2P(Y)), the GPS III satellites, the modernized civil signal (L2C) and the aviation safety-of-flight signal (L5), delivery in June 2021

- **User segment**
  - Resilient PNT capabilities using modernized signals L2C, L5 and L1C
  - Dual-frequency (L1/L5) SBAS (WAAS) with GPS and Galileo

Contents

GLONASS
Space Segment

GLONASS M

GLONASS K1

GLONASS K2

Number of satellites in the GLONASS constellation (September 8, 2020)

GLONASS satellite	GLONASS M	GLONASS K1	GLONASS K2	GLONASS KM	Operational /Total
Number	23/25*	0/2**	0	0	23/27
≥ 12 GLO satellites available by	Now	2023		After 2025	–

* M satellites #GC 716 as spares, #GC 731 in maintenance
** K1 satellite #GC 701 in flight tests phase, #GC 702 in maintenance

- GLONASS M satellite #GC 760 was launched on March 16, 2020
- Launch of one GLONASS K1 satellite planned on October 17, 2020

GLONASS
Space Segment

Current and future civil GLONASS signals at different frequencies (September 8, 2020)

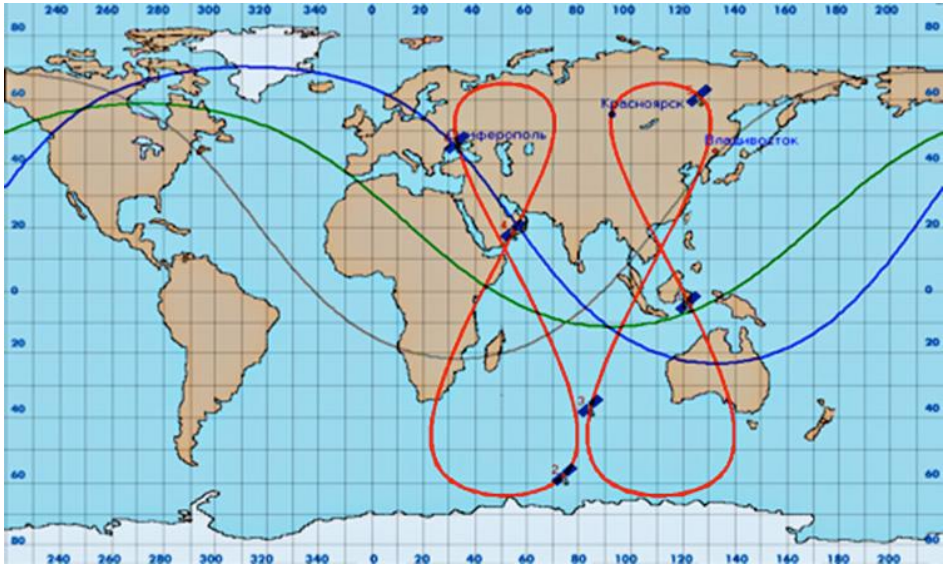
	Frequency Division Multiple Access (FDMA)		Code Division Multiple Access (CDMA)			
Signal	**L1**	**L2**	**L3**	**L1**	**L2**	**L5**
GLONASS M	●	●	●*			
GLONASS K1	●	●	●			
GLONASS K2	●	●	●	●	●	
GLONASS KM	●	●	●	●	●	●
Benefit	As today	As today	Longer RTK baselines	No GLONASS bias, better interoperability		Longer RTK baselines

* GLONASS M satellites for SVs 755+ also include the L3 signal

Currently not beneficial to RTK

- Currently, there are eight L3-capable GLONASS satellites
  - Six M satellites (GC# 755–760) and two K1 satellites (GC# 701, 702)
- K2 satellite will transmit CDMA signals in the GLONASS L1, L2 and L3 bands

High-Orbit GLONASS
Space Segment



Objective:
Improving the reception of GLONASS signals in large urban areas

High-Orbit GLONASS – Ground track in red. (Image: Roscosmos)

- Beginning development of High-Orbit GLONASS in 2019
- Six GLONASS-B satellites with two “figure-8” ground tracks
- Transmitting the new CDMA signals in the GLONASS L1, L2 and L3 bands
- Launch of the first GLONASS-B satellite in 2023 (full constellation by the end of 2025)

GLONASS
Control Segment

ODTS: orbit determination and time synchronization

- Expansion of the global network for enhanced ODTS

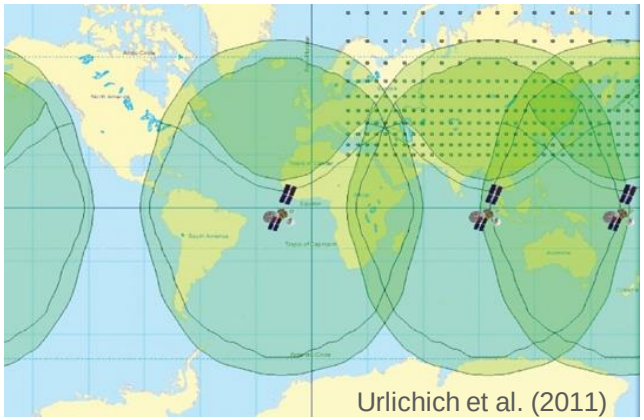
Russia station network SDCM

Foreign organizations stations

- Ensuring the ODTS accuracy of up to 0.1 m in real time during the next few years
- Introduction of advanced systems for satellite control and performance monitoring
- Transition to PZ-90.11 Geodetic Reference System which is aligned to the International Terrestrial Reference Frame (ITRF) at the mm level
- Synchronization of the GLONASS time scale to Coordinated Universal Time (UTC) at the level of less than 2 ns

GLONASS
User Segment

- Improving the quality of GLONASS services at a user level
- Completing System of Differential Correction and Monitoring (SDCM)
  - Currently L1 SBAS for **GPS and GLONASS** with 3 geostationary satellites


Urlichich et al. (2011)

ESA, navipedia

  - SDCM network consisting of 19 stations in Russia and 5 stations abroad
  - Support of L3 (GLO) and L5 (GPS+GLO) planned
- Development of real-time Precise Point Positioning (PPP) service for civil users

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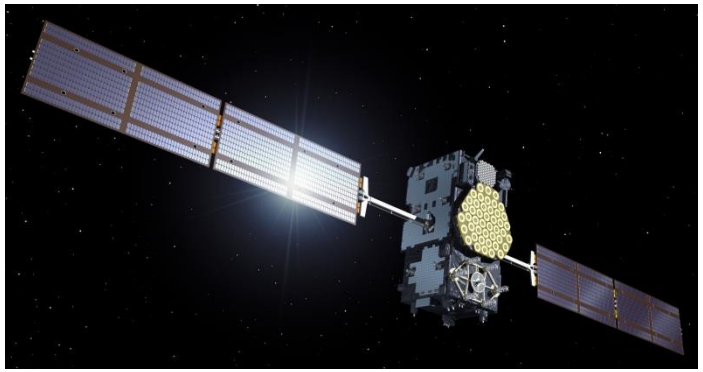
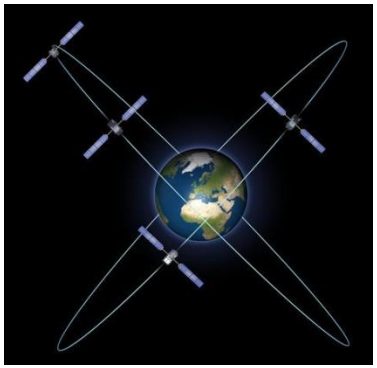
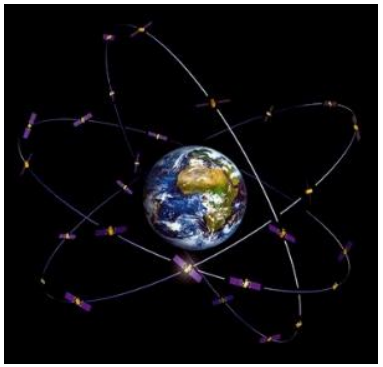
Galileo
Space Segment



Galileo satellite



IOV constellation



FOC constellation

Number of satellites in the Galileo constellation (September 10, 2020)

Galileo constellation	IOV	FOC (now)	FOC (2020/2021)	Operational/Total
Number of satellites	3/4*	19/22**	24 + 6 spares	22/26

* 1 IOV satellite GSAT0104 not available since May 27, 2014 (down to single frequency)
** 2 FOC satellites GSAT0201 and GSAT0202 in wrong orbits (foreseen to be hot back-up)
** 1 FOC satellite GSAT0204 not usable

- With 22 satellites providing services since February 11, 2019
- First of 12 Batch-3 Galileo satellites expected to be available for launch by late 2020
- Start of the in-orbit validation of transition satellites from 2025 onwards

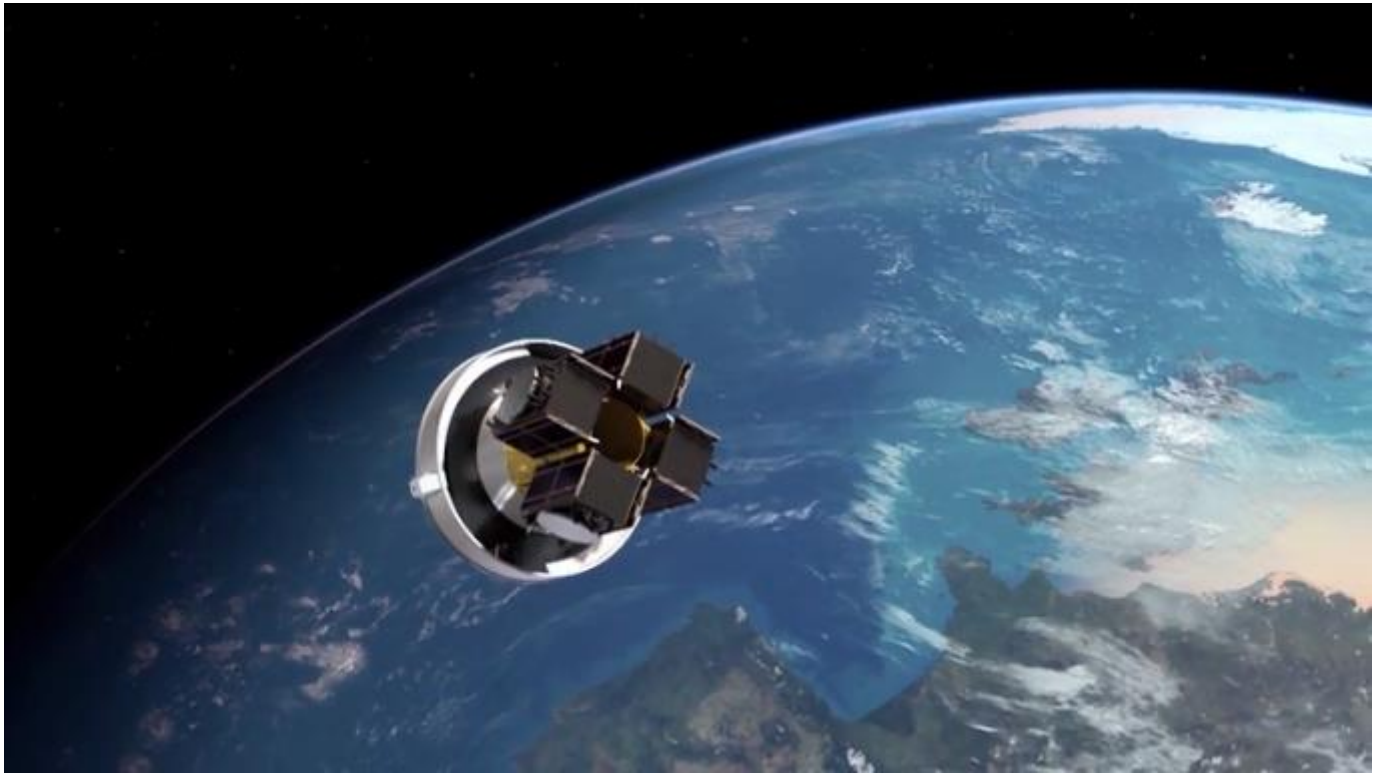
Galileo

Ariane 5 Launch

This video shows the Galileo liftoff on 25 July 2018 from Europe's Spaceport in French Guiana atop an Ariane 5 launcher (source: ESA).

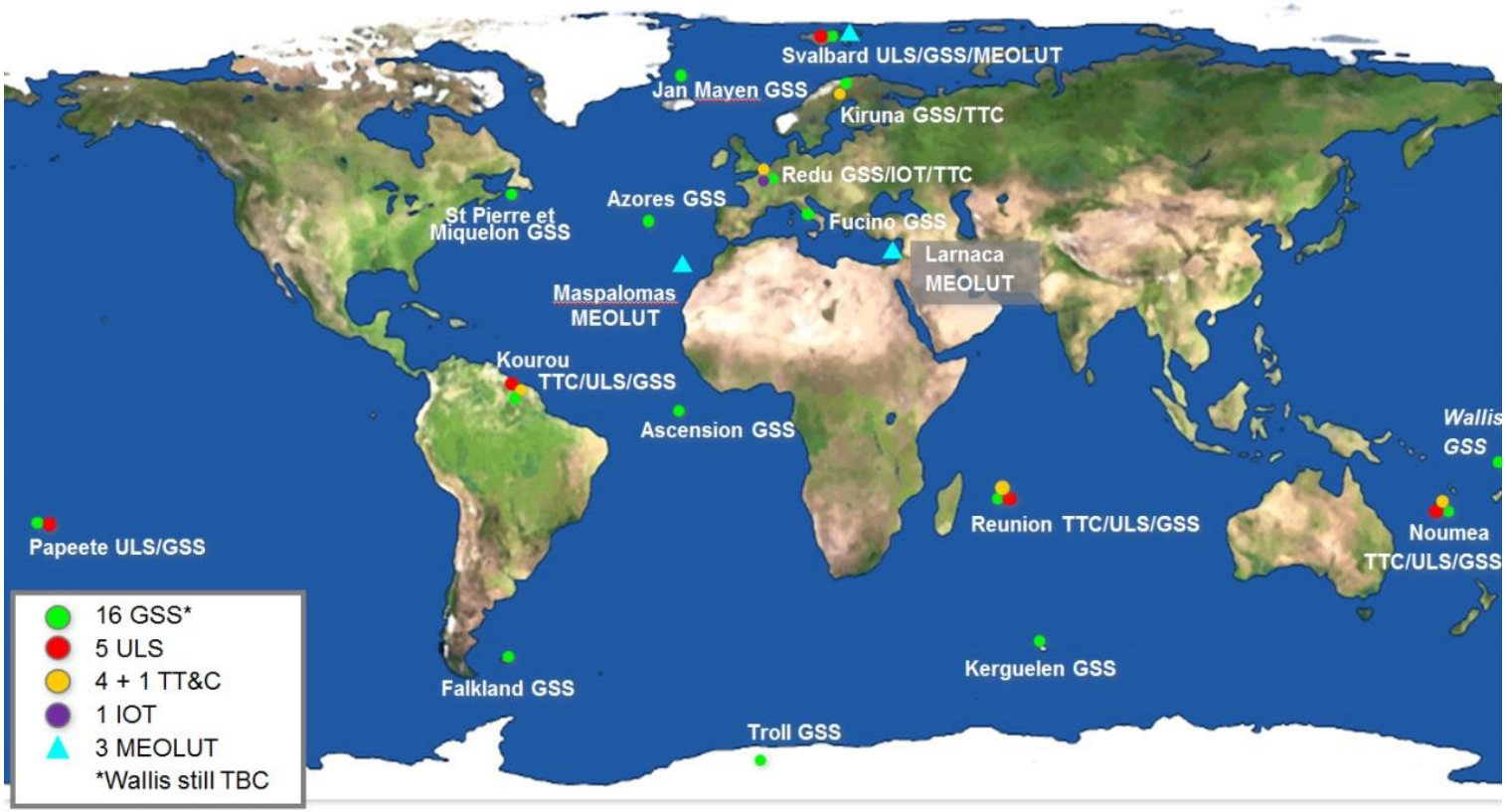
Galileo

Ariane 5 Dispenser



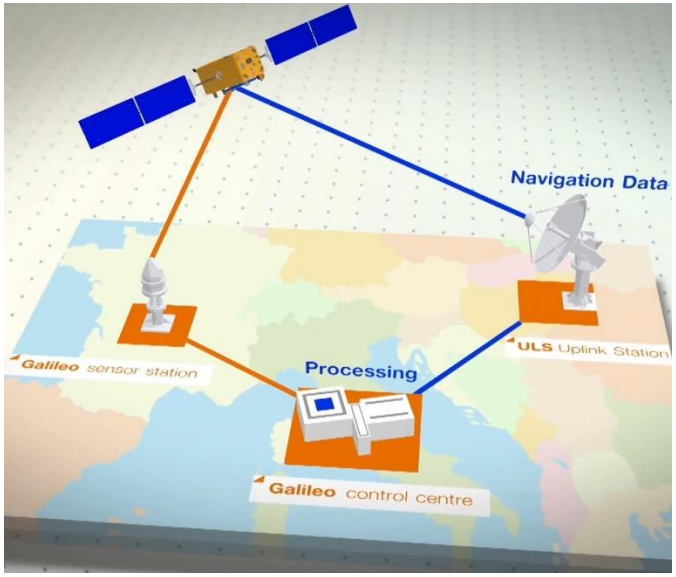
This animation shows how the four Galileo satellites launched with an Ariane 5 rocket in November 2016 were dispensed in space (source: ESA)

Galileo
Control Segment



Distribution of Galileo's control segment stations (GPS World, 2015)

Galileo
Control Segment Updates



- Upgrading the system architecture to manage a constellation of up to 41 Galileo satellites
- Improving service operability and system robustness through additional telemetry, tracking, and command capabilities
- Upgrading the Galileo Ground Mission Segment and the Galileo Security Monitoring Centers (GSMC)
  - Upgrading Galileo's system architecture for more accurate navigation products
  - Construction of additional navigation message uplink and sensor stations

Galileo
User Segment

Galileo services and the associated signals (September 10, 2020)

Service	E1	E5a	E5b	AltBOC	E6
Open Service (OS)	●	●	●	Derived from E5a and E5b, not a separate signal, but requires an own channel	
Commercial Service (CS)	●	●	●		●
Safety of Life (SoL) Service	●	●	●		
Public Regulated Service (PRS)	●				●
Benefit	The additional Galileo satellites and signals will in general improve the RTK performance (longer baselines, better availability in canopy and urban areas).			Best multipath suppression	High Accuracy Service

- Galileo Navigation Message Authentication (NMA) available over E1B in 2021
- High Accuracy Service (HAS) enabling 2-dm level positioning by providing un-encrypted high accuracy correction data in E6B for free
- EGNOS version 3 supporting GPS and Galileo at L1 and L5 by 2025

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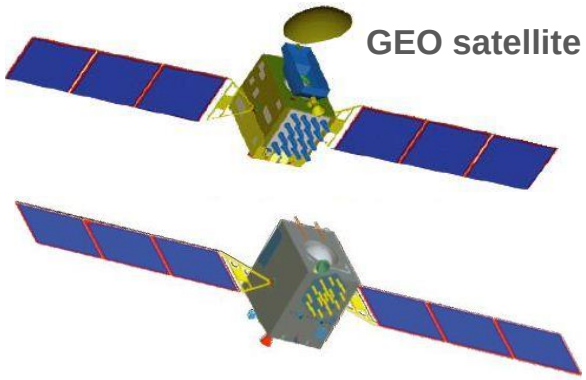
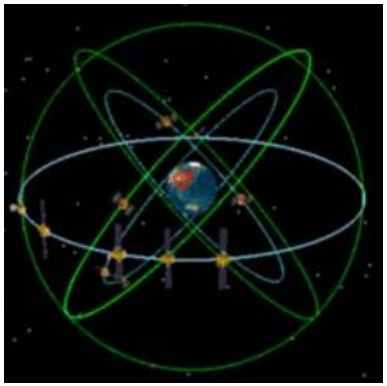
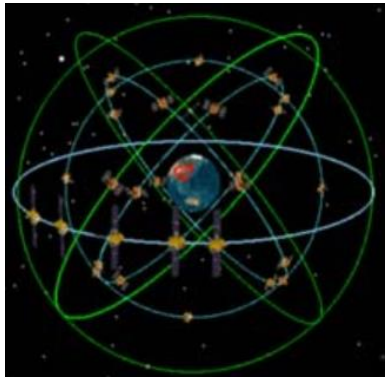
BeiDou
Space Segment



MEO satellite



Regional system (BDS-2)



Global system (BDS-3)

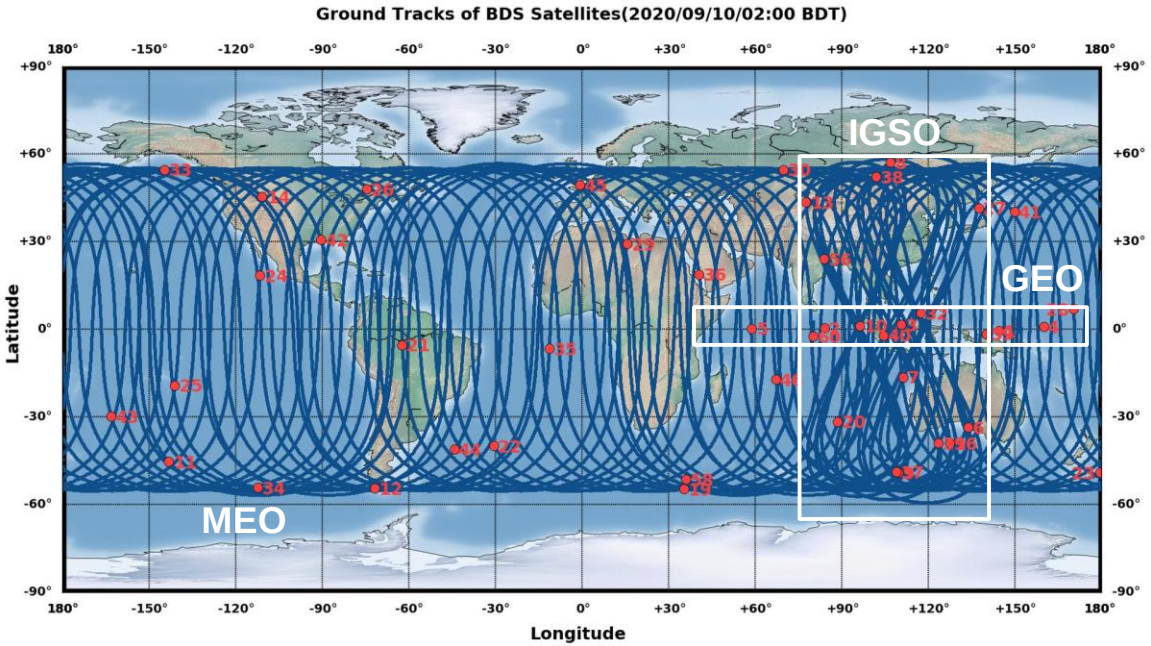
Number of satellites in the BeiDou constellation (September 10, 2020)

BeiDou satellite	GEO	IGSO	MEO	Total
Altitude (km)	35 786	35 786	21 528	–
Regional system (BDS-2) Operational now	5	7	3	15
Global system (BDS-3) Operational / In orbit / Planned	2/3/3	3/5*/3	24/26**/24	29/34/30

* Including the IGSO01-S and IGSO02-S test satellites
** Including the MEO01-S and MEO02-S test satellites

A total of 44 BeiDou satellites (27 MEO) are currently operational.

BeiDou
Space Segment



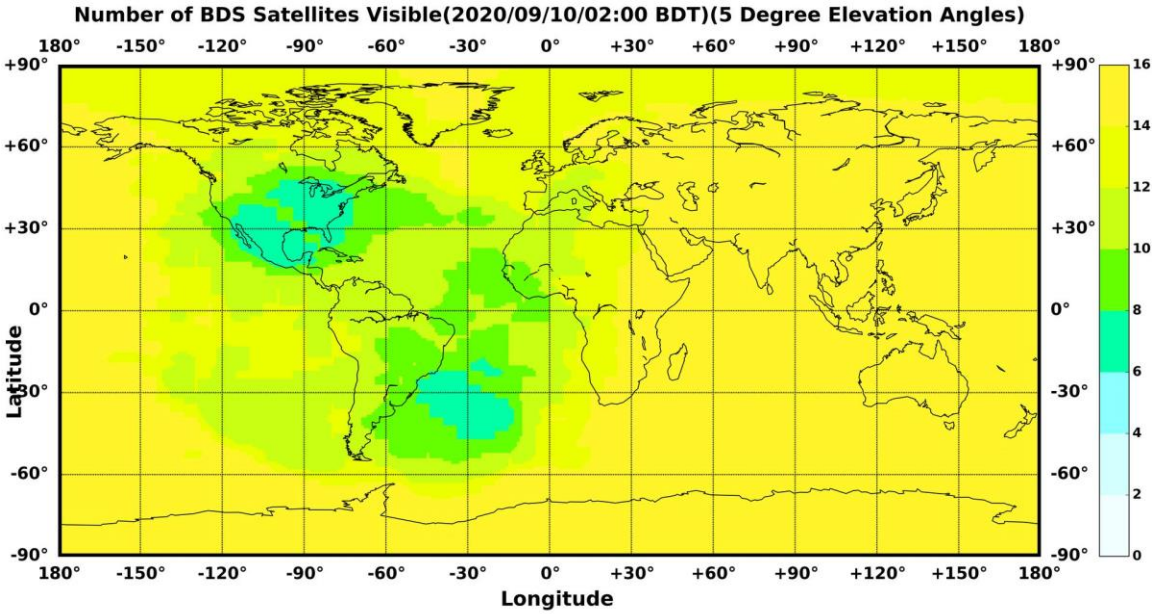
Ground tracks of the BeiDou satellites (Source: http://en.beidou.gov.cn/SYSTEMS/Ephemeris/)

- GEO satellites: located over the Indian Ocean and the Pacific
- IGSO satellites: symmetrical “figure-8” ground tracks

Limited changes in satellite geometry

- MEO satellites: similar ground track pattern as the GPS satellites

BeiDou
Space Segment



Number of visible BeiDou satellites (Source: http://en.beidou.gov.cn/SYSTEMS/)

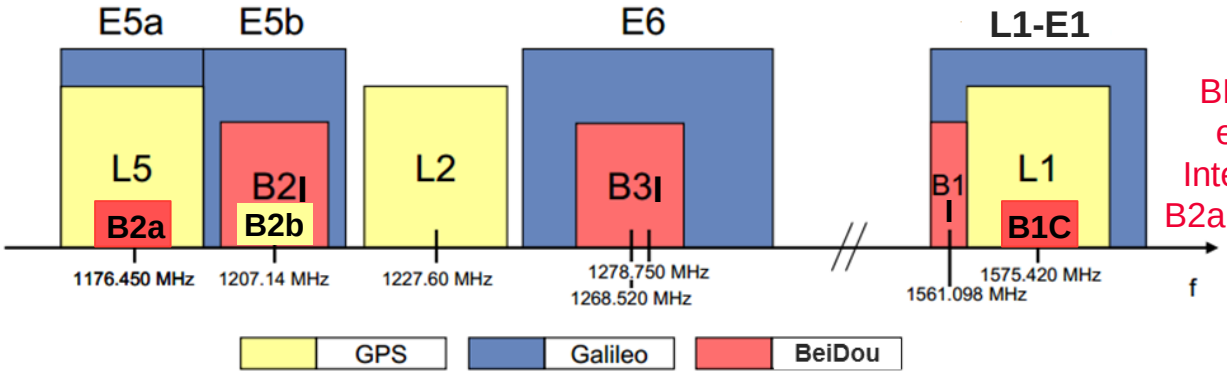
- Launch of the last BDS-3 GEO-3 satellite on June 23, 2020
- BDS-3 has been formally commissioned on July 31, 2020

BeiDou
Space Segment

BeiDou signals at different frequencies (September 10, 2020)

Signal	B1I	B2I	B3I
BeiDou-2 (BDS-2)	●	●	●

Signal	B1I	B1C	B2a	B2b	B3I
BeiDou-3 (BDS-3)	●	●	●	●	●
Benefit	1) The additional BeiDou satellites and signals will in general improve the RTK performance, particularly in canopy and urban canyons. 2) Better interoperability using B1C, B2a and B2b				



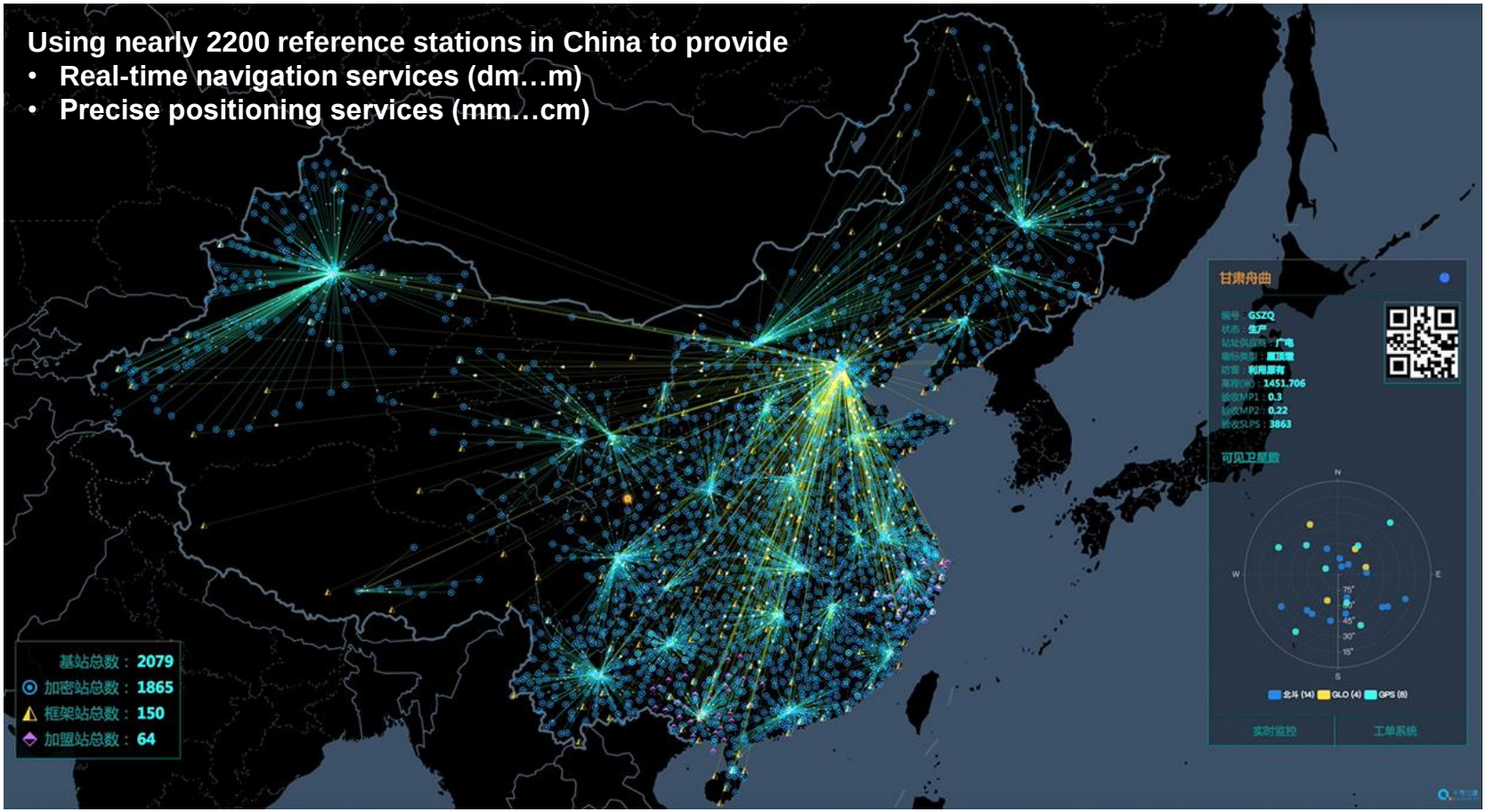
BDS-3 satellites equipped with Interoperable B1C B2a and B2b signals

Comparison of the GPS, Galileo and BeiDou frequency bands

BeiDou
Control Segment, User Segment

- **Control segment**
  - One master control station (MCS): responsible for the operational control of the system (orbit determination, navigation messages, ephemerides, etc.)
  - Two uplink stations (US): send the data generated by the MCS to the satellites
  - 30 monitoring stations (MS): track the constellation continuously
- **User segment**
  - Single-frequency (SF) service through BDSBAS-B1C signal
  - Dual-Frequency Multi-Constellation (DFMC) service through BDSBAS-B2a
  - Providing PPP-B2b service in China and surrounding areas
  - BDS/GNSS Ground-based Augmentation System

BeiDou
User Segment



China's National Reference Station Network. (Image: BeiDou)

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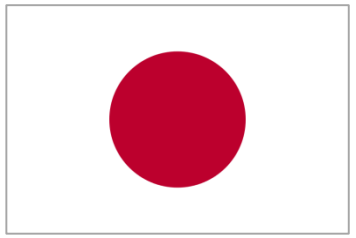
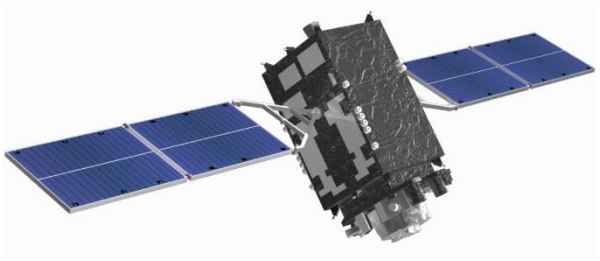
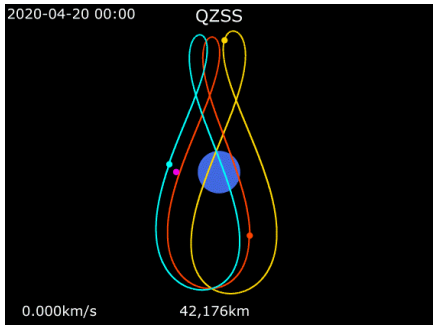


QZSS
Space Segment



QZSS satellite

Satellite orbit



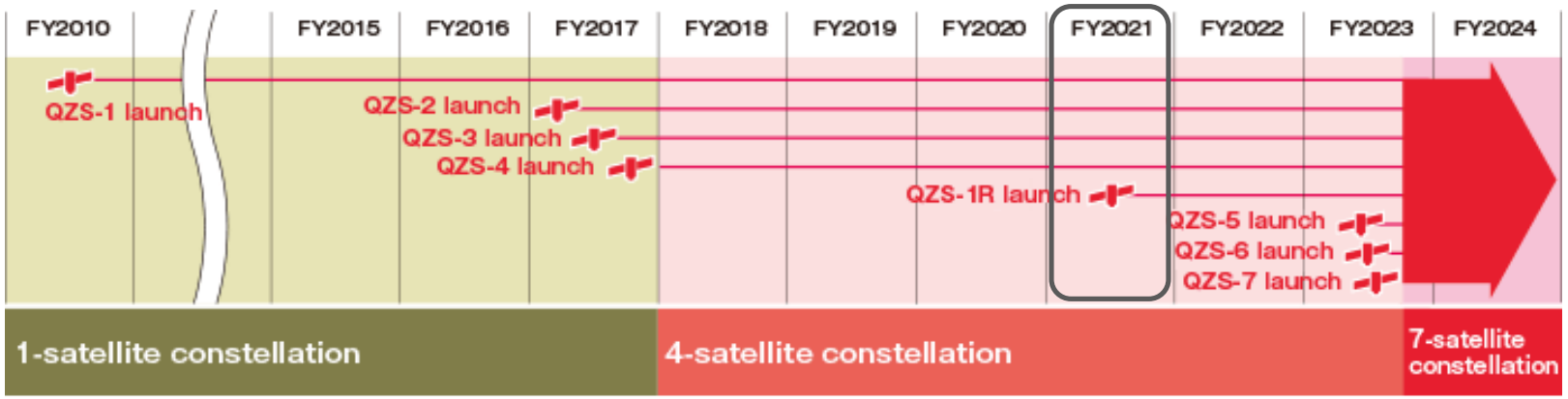
Satellite ground track

Number of satellites in the QZSS constellation (September 10, 2020)

Date	Now	2023
Number of satellites	4	7

- QZSS is Japan's regional system and transmits the same signals as GPS.
- One quasi-zenith satellite (QZS) satellite can be seen from Japan for 16 hours. With four QZS, signals can be constantly received from three QZS.
- Asymmetrical “figure-8” satellite ground tracks due to highly-inclined, elliptical and geosynchronous orbits (slower speed in the smaller half of the figure-8)

QZSS
Space Segment



QZSS programme schedule (source: http://qzss.go.jp/en/overview/services/sv01_what.html, September 10, 2020)

FY: Fiscal Year
QZS: Quasi-Zenith Satellite

- QZS-1R scheduled to be launched in 2021
- QZS-1R has the ability to transmit the L1C/B signal

QZSS
Space Segment

Navigation signals usable for RTK

QZSS signals for positioning service and their compatibility with GPS IIIA (September 10, 2020)

Satellite	Orbit	L1C/A	L1C/B	L1C	L1S	L1Sb	L2C	L5	L5S	L6	S-band
QZS-1	QZO	●		●	●		●	●		●	
QZS-2	QZO	●		●	●		●	●	●	●	
QZS-3	GEO	●		●	●	●	●	●	●	●	●
QZS-4	QZO	●		●	●		●	●	●	●	
QZS-1R	QZO		●	●	●		●	●	●	●	
GPS IIIA	MEO	●		●			●	●			

L1C/A, L1C/B, L1C, L2C, L5: Satellite Positioning, Navigation and Timing Service (PNT)

L1S: Sub-meter Level Augmentation Service (SLAS)

L1S: Satellite Report for Disaster and Crisis Management (DC Report)

L1Sb: SBAS Transmission Service starting from around 2020

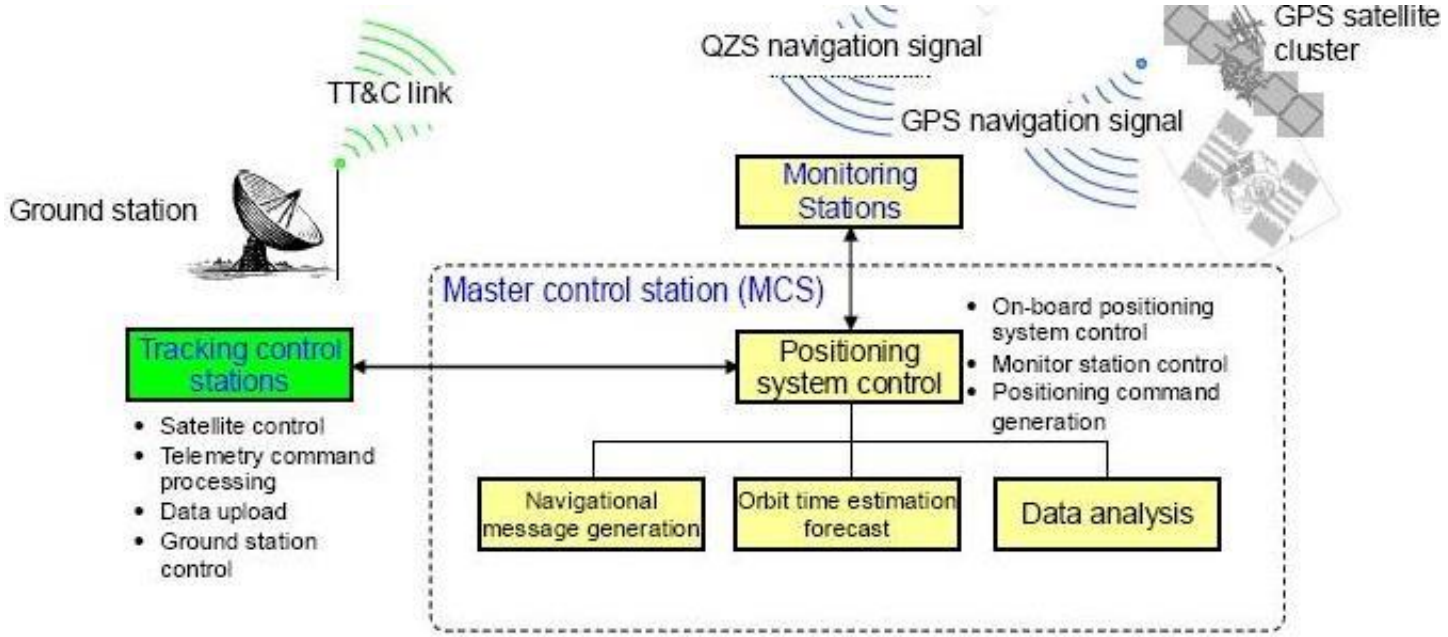
L5S: Positioning Technology Verification Service

L6: Centimeter Level Augmentation Service (CLAS)

S-band: QZSS Safety Confirmation Service (2GHz band)

QZSS
Control Segment

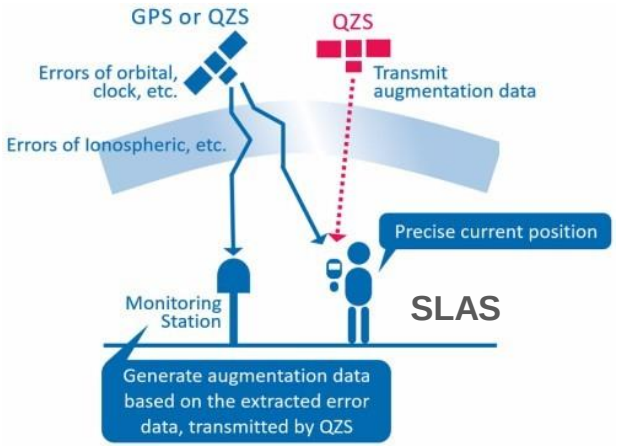
- Master control station (MCS)
- Tracking control stations (TT&C link)
- Monitoring stations (MS)

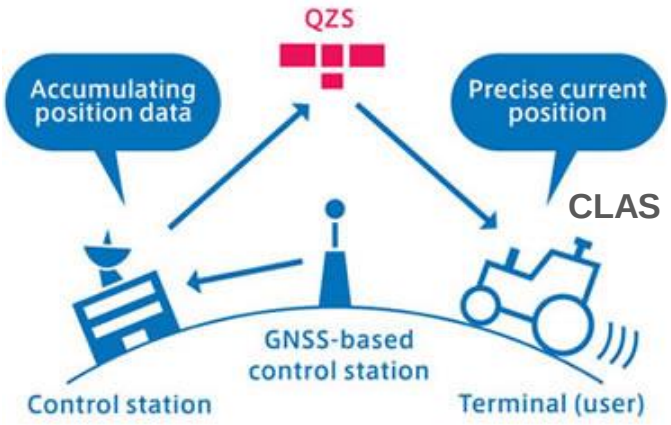


Elements of the QZSS control segment (Image: JAXA)

QZSS
User Segment

- QZSS services were started officially on November 1, 2018
- Sub-meter Level Augmentation Service (SLAS) via L1S
- Centimeter Level Augmentation Service (CLAS) via L6
- L1S/L6 data provision service





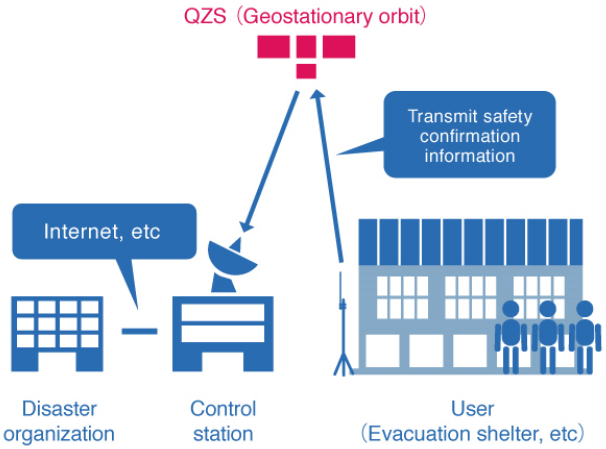
Graphic source: http://qzss.go.jp/en, September 10, 2020

QZSS
User Segment

- Message services send short messages used for disaster and crisis management and rescue operations.
- Satellite Report for Disaster and Crisis Management (DC Report) via L1S
- QZSS Safety Confirmation Service (Q-ANPI) via S-band
- DC Reports can also be received in the Southeast Asia and Oceanic regions, whereas the Q-ANPI service can only be used in Japan and its coastal areas.

DC Report

Q-ANPI



Graphic source:
http://qzss.go.jp/en,
September 10, 2020

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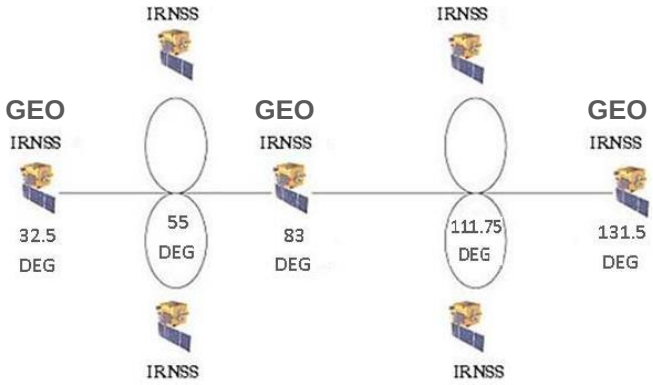
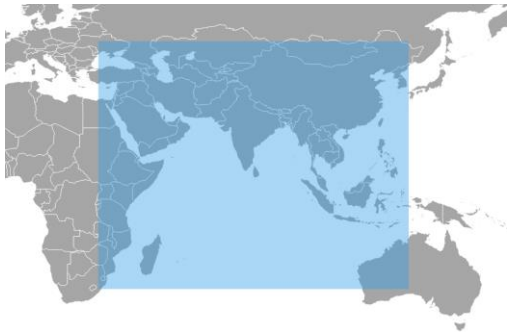
NavIC
Space Segment

NavIC satellite



Satellite constellation



NavIC coverage

Number of satellites in the NavIC constellation (September 10, 2020)

NavIC satellite	GEO	GSO	Total
Number	3	4	7

GEO: Geostationary orbit, GSO: Geosynchronous orbit

- "Figure-8" ground tracks of the GSO satellites due to an inclination of 29°
- Operation in L5 (as GPS) and S band (2492.028 MHz)
- It is planned that future satellites will broadcast a new signal in L1 (1575.42 MHz)

NavIC
Control Segment, User Segment

- **Control segment**
  - Spacecraft control center
  - ISRO navigation center at Byalalu (navigation parameters)
  - 17 range and integrity monitoring stations (ORB, ION)
  - Uplink and telemetry stations
  - Data communication network, etc.
- **User segment**
  - Standard positioning service (SPS) and restricted service (RS)
  - NavIC receivers operating in single frequency (L5 or S-band) for SPS and in dual frequency (L5 and S-band) for both SPS and RS service

ISRO: Indian Space Research Organisation
ORB, ION: Orbit and ionospheric corrections

Contents

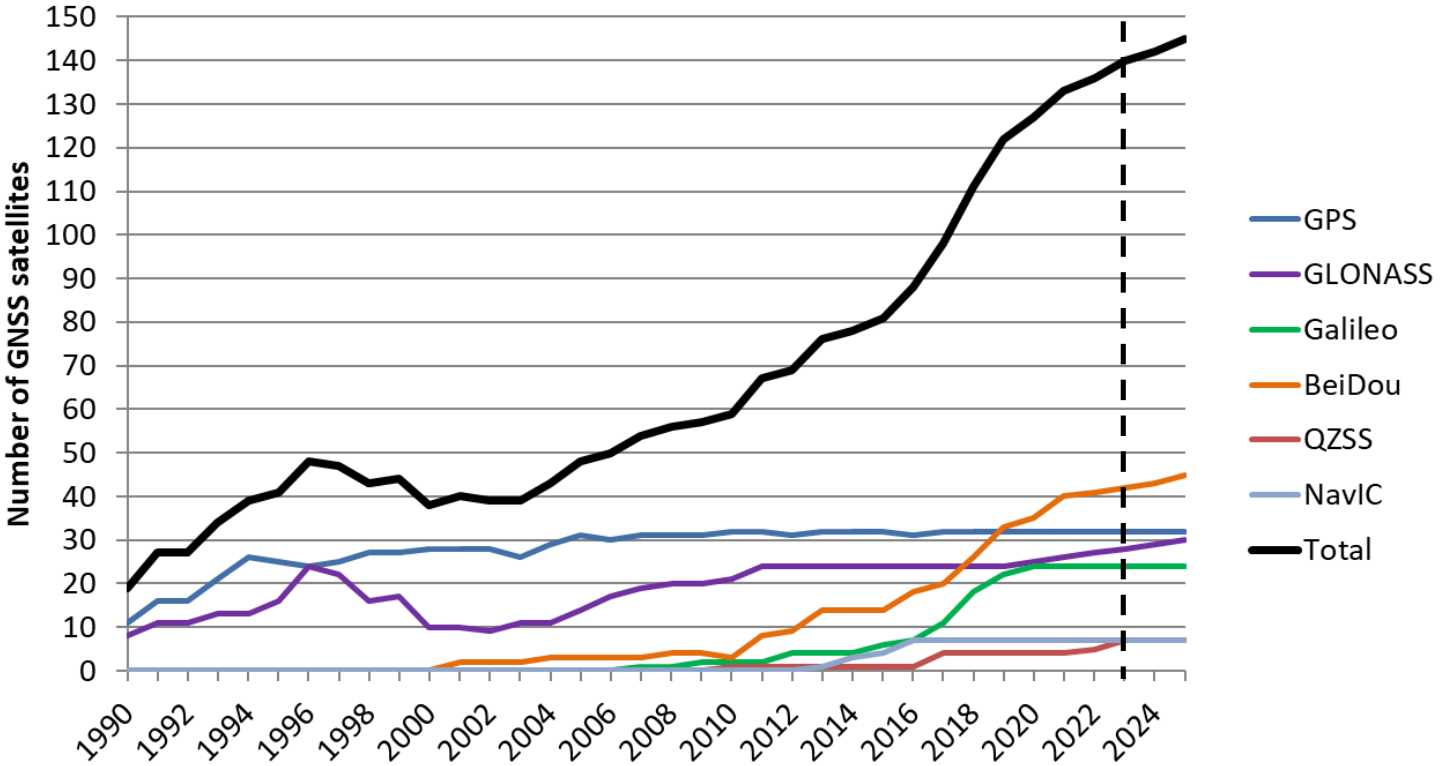
Leica GNSS
Modernization Strategy

- GNSS modernization is highly dynamic, which requires a **flexible** and **sustainable** modernization strategy.
- In 2006, Leica Geosystems introduced the **Future Proof** concept.
- Leica Geosystems is the only manufacturer that provides **a drop-in replacement of the GNSS engine** if needed.
  - Structures of new signals are subject to change.
  - A new GNSS engine is required if the signal structure changes.
  - Our GNSS cards always have the same footprint, the same fixing and the same connections.
- In order to take full benefit from GNSS modernization, a **high channel count** is necessary.

Leica GNSS
Modernization Strategy

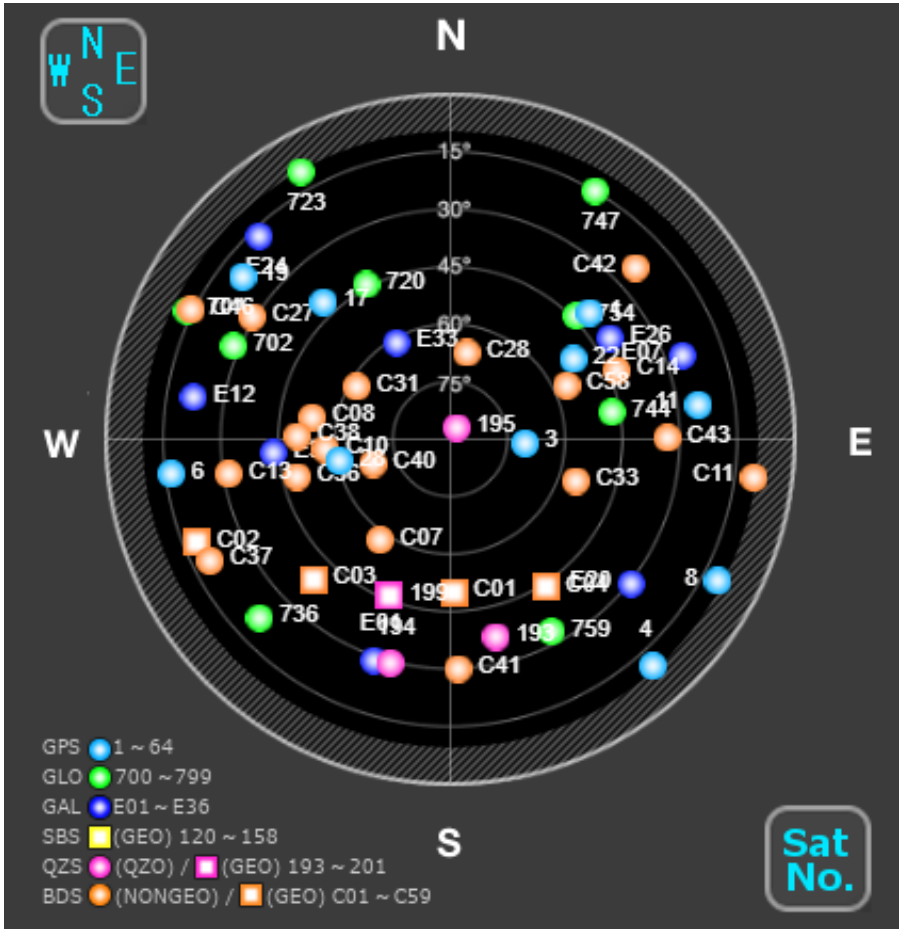
- A **high channel count** is needed due to
  - Rapidly increasing number of GNSS satellites

About 140 satellites are usable by 2023



- when it has to be **right**

Leica GNSS
Modernization Strategy



- Location: Tokyo, Japan
- Date: 2020-09-10
- Open sky condition
- GPS+GLO+GAL+BDS+QZSS
- Cut-off angle: 10 degrees
- 54 satellites usable

Time : 2020/09/10 08:35
UTC : 2020/09/09 23:35

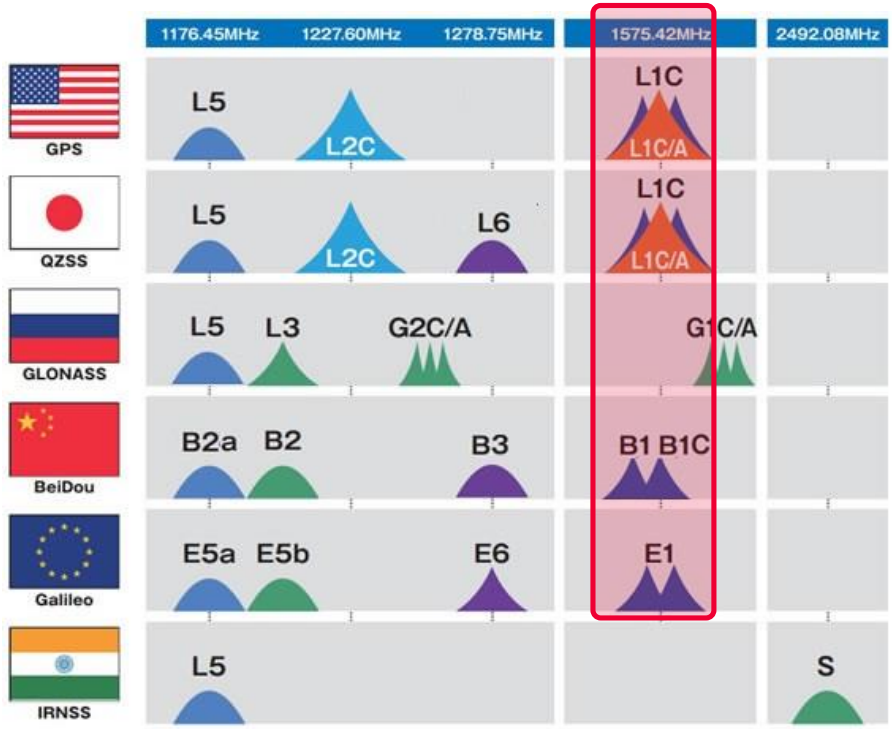
DOP Information

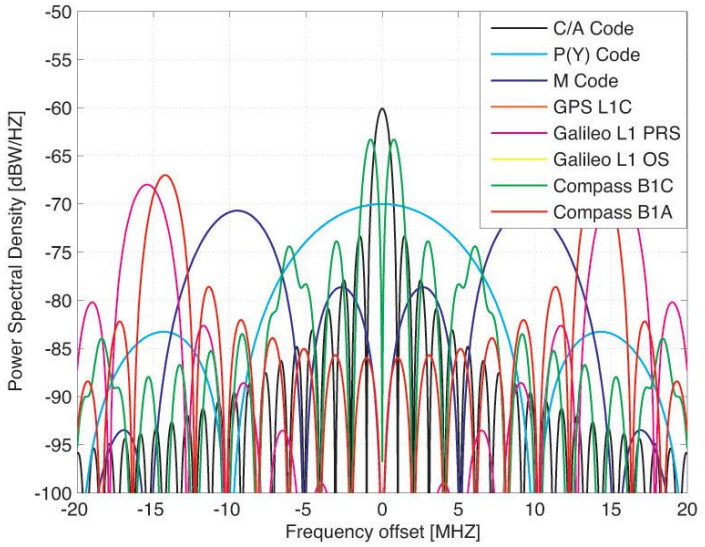
HDOP: 0.36	Visible GNSS: 54		
VDOP: 0.59	QZS: 4	GPS: 10	GLO: 9
	BDS: 23	GAL: 8	SBS: 0

Available on http://app.qzss.go.jp/GNSSView/gnssview.html, September 10, 2020

Leica GNSS
Modernization Strategy

- A **high channel count** is needed due to
  - Availability and usability of multi-frequency GNSS signals





GNSS signals in L1/B1/E1 (Liu et al., 2010)

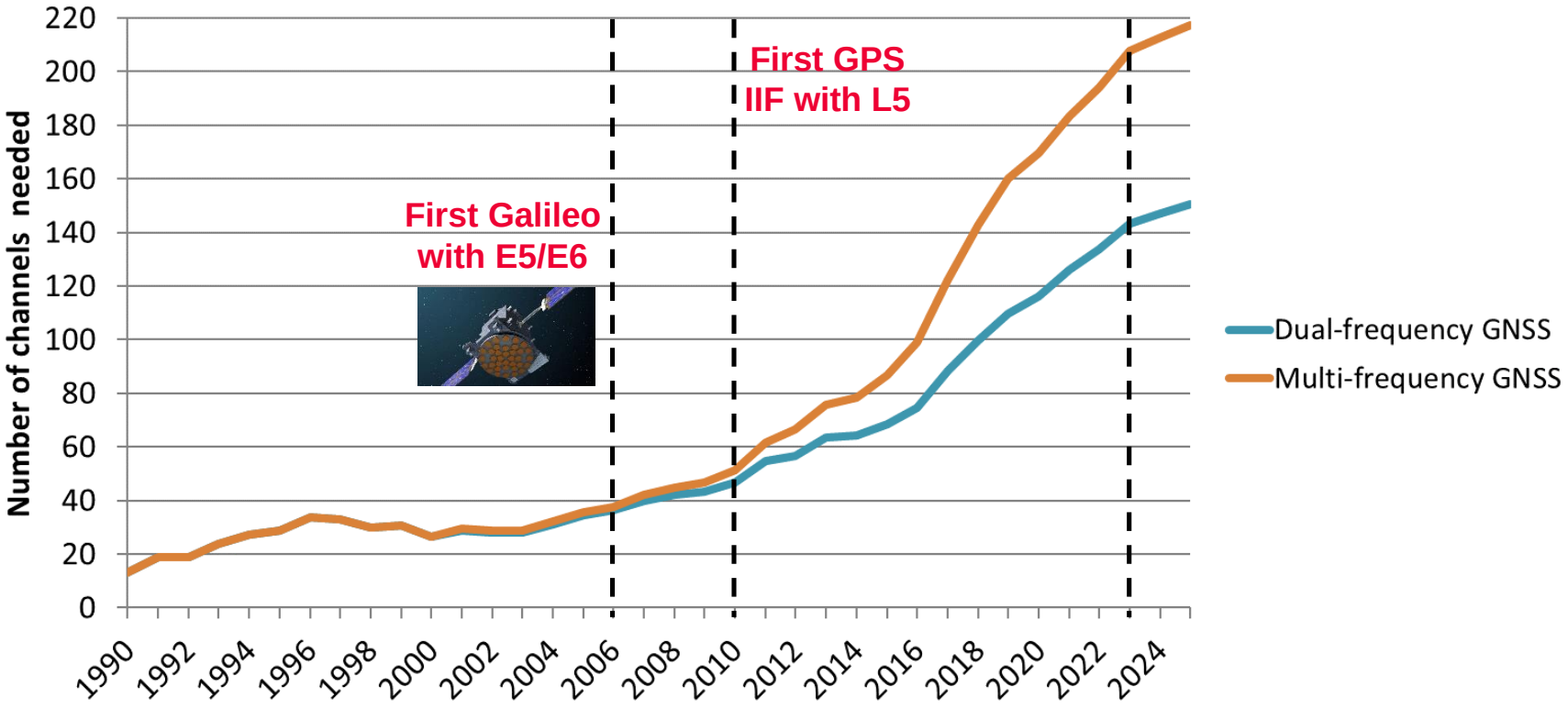
- when it has to be **right**

Leica GNSS
Modernization Strategy

GNSS future proof

More than 200 channels are needed from 2023 onwards for multi-frequency GNSS

Number of channels needed



- when it has to be **right**

Leica Geosystems

Leica GNSS
Modernization Strategy

- The latest generation of GNSS engine ME7 in GS07, GS10, GS14, GS15, GS16, GS18 T/I and GS25 tracks all existing and future planned GNSS signals:
  - A high channel count of 555
  - Improved signal acquisition speed and sensitivity
- Leica Future Proof is the **best modernization strategy** since it accounts for the highly dynamic changes of GNSS and fulfils customer needs:
  - Latest equipment that tracks all available signals today and tomorrow
  - Latest equipment that keeps its value (secured investment)
  - Top performance

Leica GNSS
Modernization Strategy

Overview of GPS signals supported by Leica GNSS (September 10, 2020)

System	Access	Signal	GS08plus	GS07	GS14	GS10/15/25	GS10/14/15/16/18 T/18 I/25
GPS	CDMA	L1 C/A	S	S	S	S	S
		L1 P(Y)	C	C	C	C	C
		L1C	C	C	C	C	C
		L2 P(Y)	S	S	S	S	S
		L2C	S	S	S	S	S
		L5	N	S	U	S	S

CDMA: Code Division Multiple Access

- S: Supported, means that these signals can be currently tracked without any upgrades.
- C: Fully hardware compatible, means that these signals can be tracked after firmware upgrades.
- U: Hardware upgradable, means that these signals can be tracked after hardware upgrades (e.g., GNSS board exchange)
- N: Not supported

Leica GNSS
Modernization Strategy

Overview of GLONASS signals supported by Leica GNSS (September 10, 2020)

System	Access	Signal	GS08plus	GS07	GS14	GS10/15/25	GS10/14/15/16/ 18 T/18 I/25
GLONASS	FDMA	L1 C/A	S	S	S	S	S
		L1 P	C	C	C	C	C
		L2 C/A	C	S	U	U	S
		L2 P	S	S	S	S	S
	CDMA	L3	N	C	C	C	C
		L1 C/A*	C	C	C	C	C
		L1 P*	C	C	C	C	C
		L2 C/A*	C	C	C	C	C
		L2 P*	C	C	C	C	C
		L5*	N	C	U	C	C

* Future signals that are not transmitted yet and may change.
FDMA: Frequency Division Multiple Access
CDMA: Code Division Multiple Access
S: Supported, C: Fully hardware compatible, U: Hardware upgradable, N: Not supported

Leica GNSS
Modernization Strategy

Overview of Galileo and BeiDou signals supported by Leica GNSS (September 10, 2020)

System	Access	Signal	GS08plus	GS07	GS14	GS10/15/25	GS10/14/15/16/ 18 T/18 I/25
Galileo	CDMA	E1	N	S	S	S	S
		E5a	N	S	U	S	S
		E5b	N	S	S	S	S
		Alt-BOC	N	S	U	S	S
		E6	N	C	U	U	C
BeiDou	CDMA	B1I	N	S	S	S	S
		B2I	N	S	S	S	S
		B3I	N	S	U	U	S
		B1C	N	S	U	U	S
		B2a	N	S	U	U	S
		B2b	N	C	U	U	C

CDMA: Code Division Multiple Access
S: Supported, C: Fully hardware compatible, U: Hardware upgradable, N: Not supported

Leica GNSS
Modernization Strategy

Overview of QZSS and NavIC signals supported by Leica GNSS (September 10, 2020)

System	Access	Signal	GS08plus	GS07	GS14	GS10/15/25	GS10/14/15/16/ 18 T/18 I/25
QZSS	CDMA	L1 C/A	N	S	C	C	S
		L1 C/B	N	C	C	C	C
		L1C	N	C	C	C	C
		L1S	N	C	C	C	C
		L1Sb	N	C	C	C	C
		L2C	N	S	C	C	S
		L5	N	S	U	C	S
		L5S	N	C	U	C	C
		L6	N	C	U	U	C
		S-band	N	N	N	N	N
NavIC	CDMA	L5	N	C	U	C	C
		S-band	N	N	N	N	N

S: Supported, C: Fully hardware compatible, U: Hardware upgradable, N: Not supported

References

GPS
http://www.gps.gov/systems/gps/modernization/

GLONASS
http://glonass-iac.ru/en/

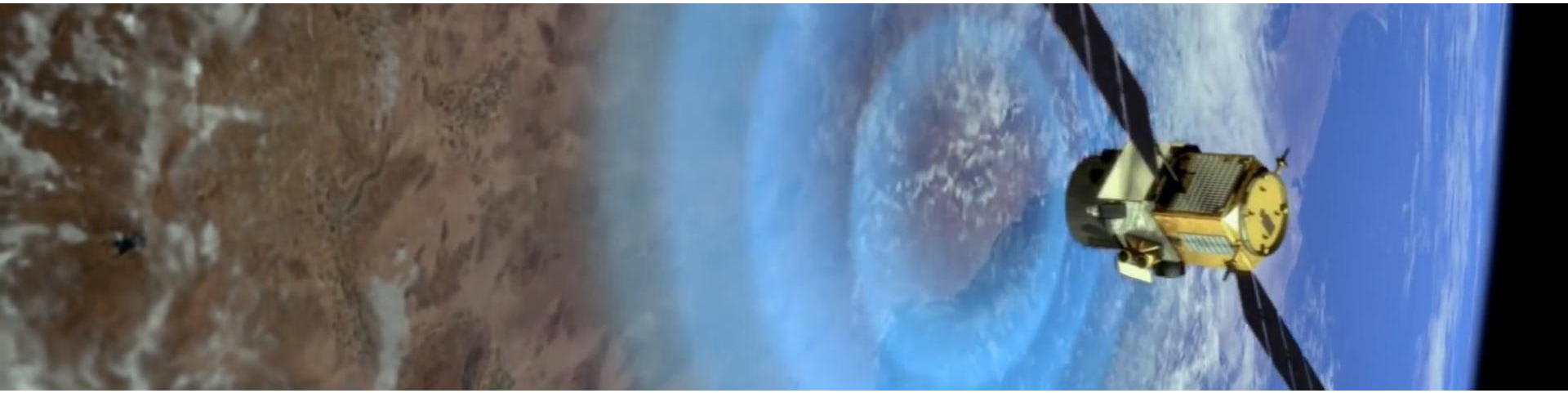
Galileo
http://www.gsc-europa.eu/system-status/Constellation-Information
http://www.esa.int/Our_Activities/Navigation

BeiDou
http://en.beidou.gov.cn/index.html
http://www.csno-tarc.cn/en/

QZSS
https://qzss.go.jp/en/
https://directory.eoportal.org/web/eoportal/satellite-missions/q/qzss

NavIC
http://www.isro.gov.in/spacecraft/satellite-navigation

Future Unlimited



To explore GNSS solutions to meet your needs, please contact us.