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GNSS "New Signals in Space" – Revisited

Bob Green, PLS
Frontier Precision
Albuquerque, NM/Arvada, CO

- **Session Objectives**
  - **Review of GNSS Satellite Positioning Systems**
  - **Discuss GNSS Modernization "New Signal in Space"**
    - **GPS, GLONASS, BeiDou and GALILEO**
  - **Atmospheric and Ionospheric Errors**
  - **Free Online Planning Tools**
  - **What if OPUS Goes Down?**
    - **Free Resources**

Bob Green, PLS

Geospatial Analyst
Frontier Precision

- **Geospatial Analyst – Frontier Precision / 5.5 + Years**
- **Professional Land Surveyor – 33 years**
  - **46 years Total Land Surveying Experience**
- **Past 2 Term Member of The Monitor Panel to the (NKA) Colorado State Board of Licensure for Architects, Professional Engineers and Professional Land Surveyors**
- **Past 2 Term Member of the Survey Engineering Industrial Advisory Committee – New Mexico State University**
- **Published Author, Public Speaker and Measurement Technology Advocate**
- **Government and Private Sector Trainer and Consultant**
  - US Air Force Space Command Wing, US Marine Corps, Department of Defense, US Border Patrol, Army Corps of Engineers, USBR at Hoover Dam Homeland Security and NASA at White Sands Test Facility
- **GPS/GNSS Pioneer and Innovator**
- **Retired Rodeo Cowboy and Rancher**

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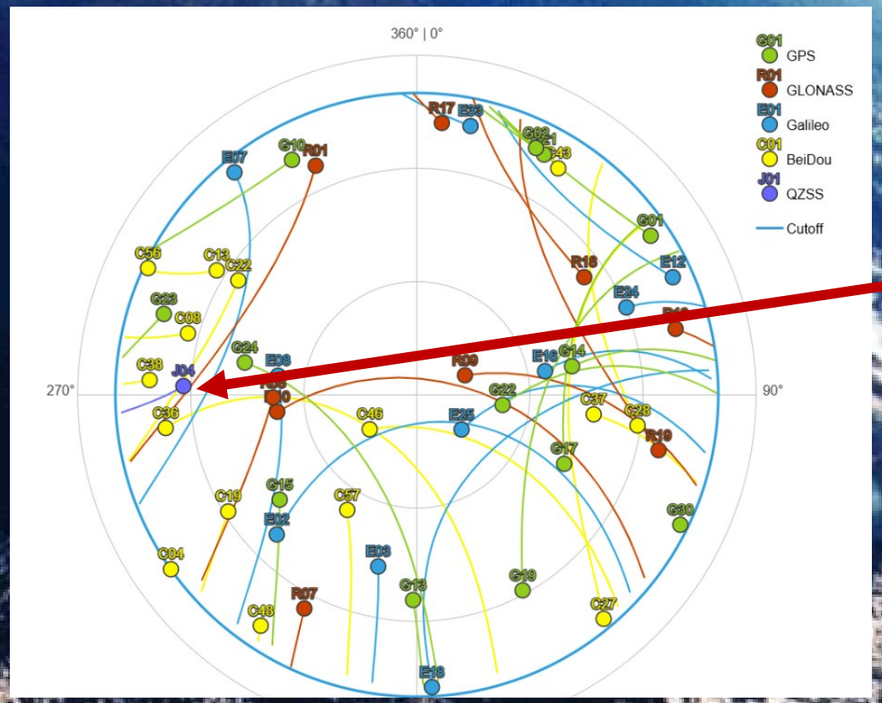
Following in the Footsteps of Historic Surveys

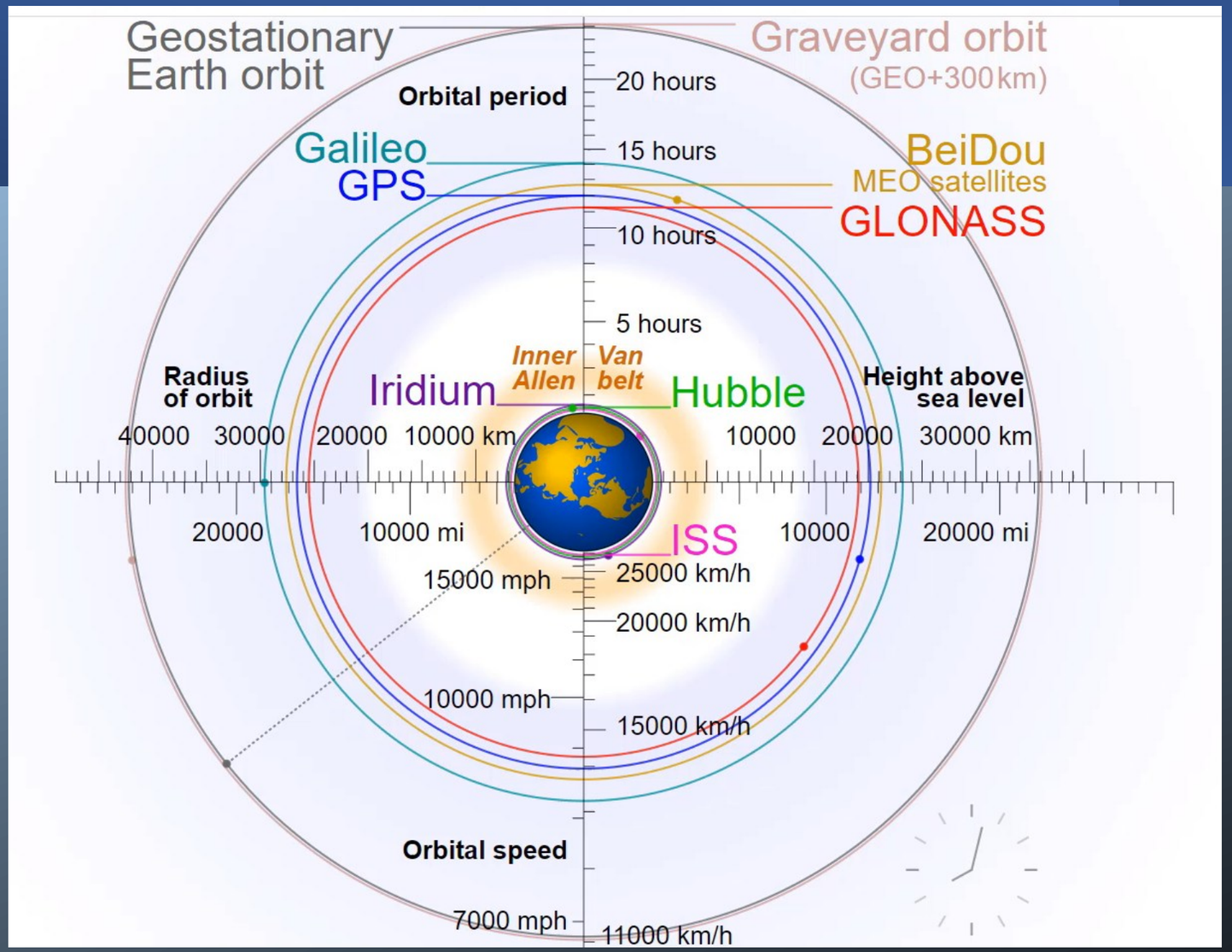
1770’s → 1970’s → Today

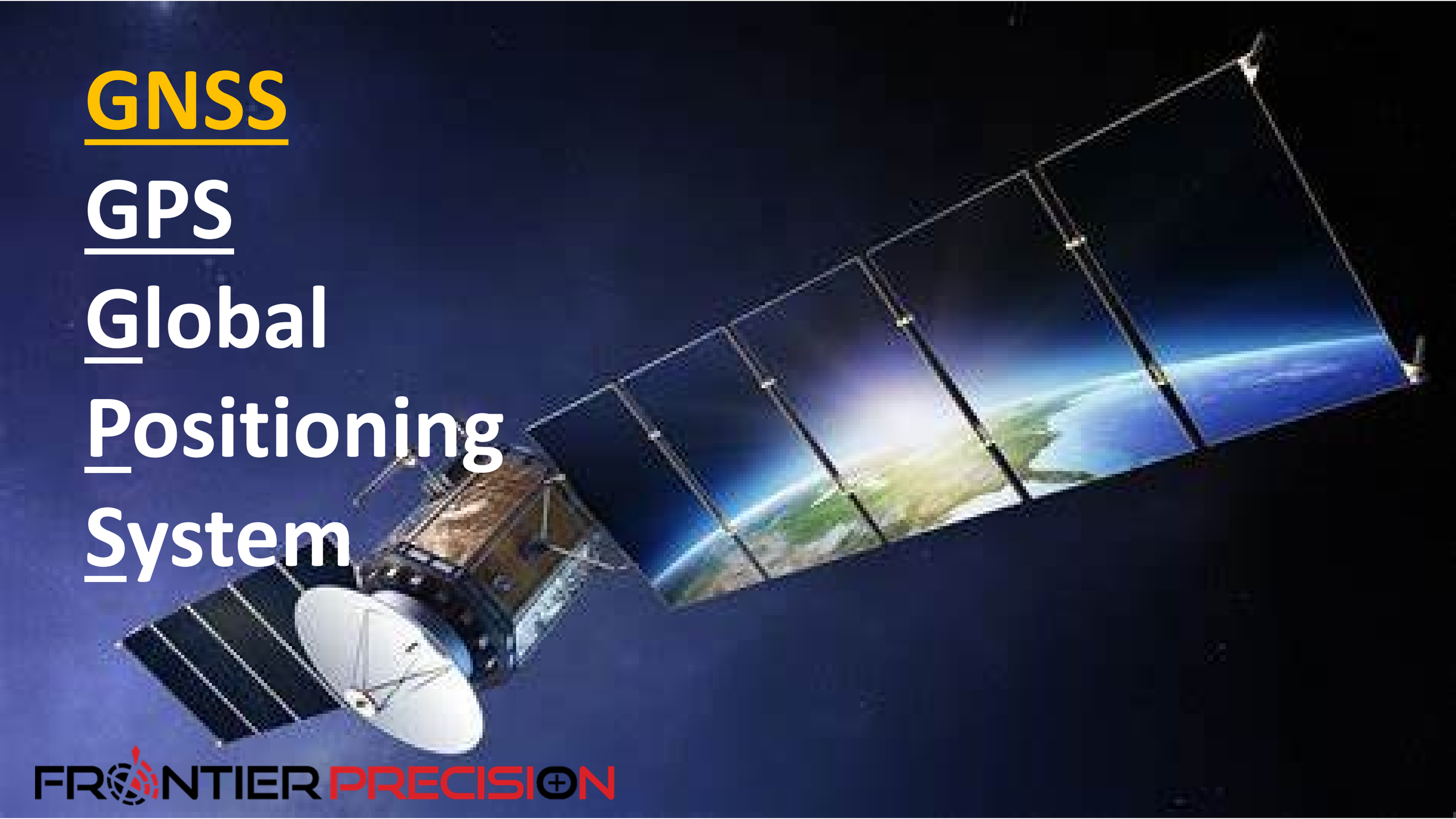
GNSS Constellations



- **G**lobal **P**ositioning **S**ystem (GPS)
- **Gl**obal **O**rbiting **N**avigation **S**atellite **S**ystem (GLONASS)
- GALILEO Satellite Navigation System
- BeiDou 3 (BDS)
- **Q**uasi-**Z**enith **S**atellite **S**ystem (QZSS)
  The Quasi-Zenith Satellite System (QZSS) has a ground station in Hawaii at Kokee Park. QZSS is a Japanese satellite system that provides positioning and communication services to the Asia-Oceania region.
- **I**ndian **R**egional **N**avigation Satellite **S**ystem (IRNSS) (NavIC)

GNSS Constellations Orbits




GNSS
GPS
Global
Positioning
System
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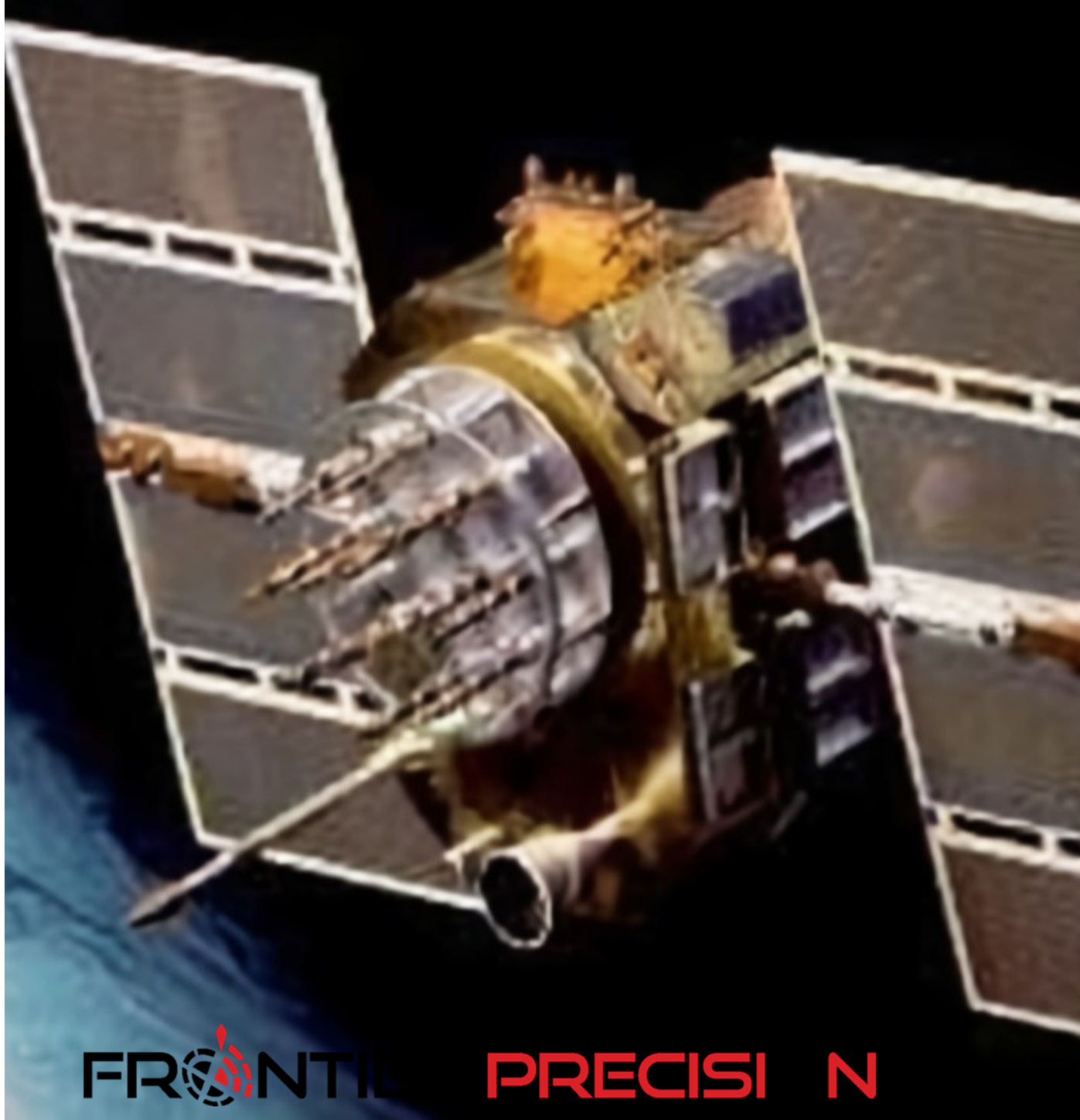
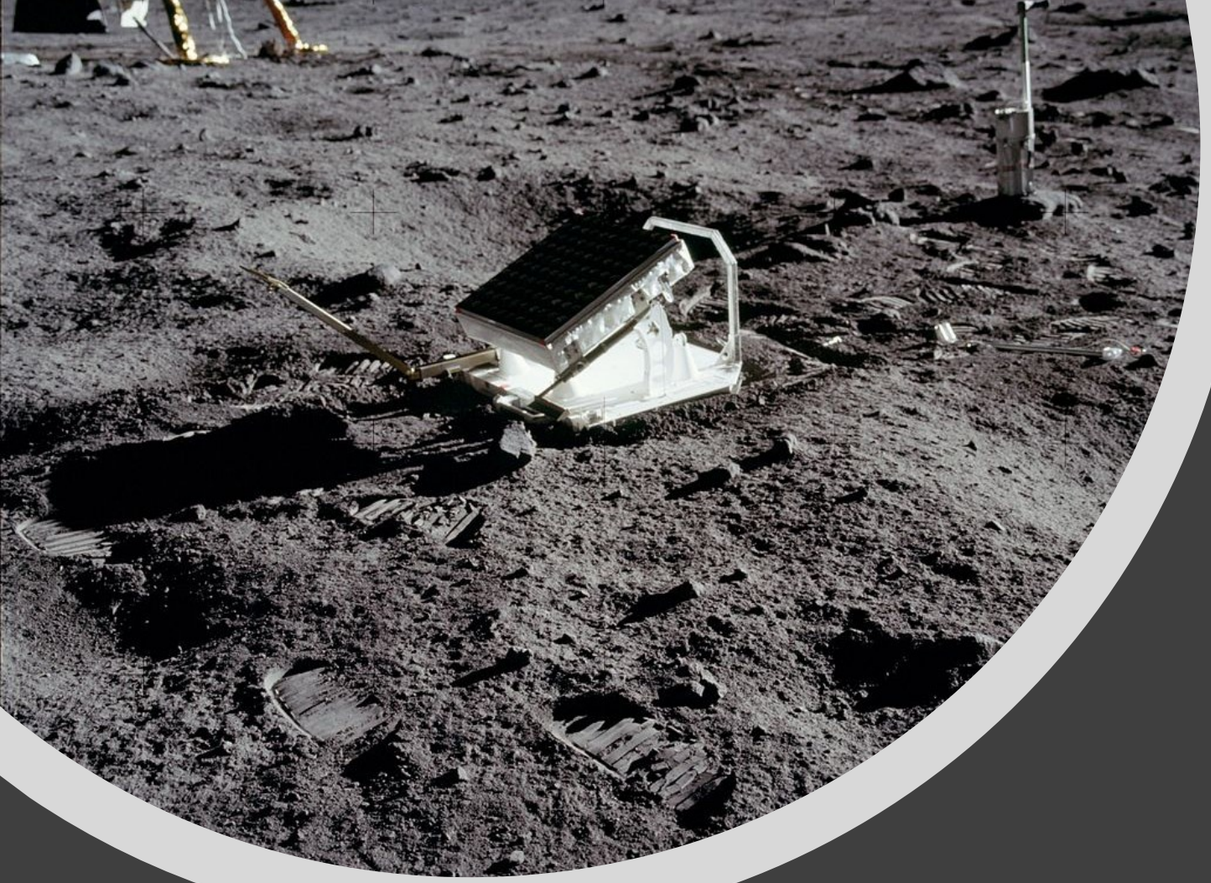
• GPS: Global Positioning System

- US Department of Defense Satellite System
  - 31 Current Operational Satellites
  - First GPS Satellite Launched February 22, 1978, IOC 3/23/1994, FOC 7/17/1995
  - Codeless/Semi-Codeless Signals Support will discontinue 2 years after 24 L5 Sats are in the Constellation https://www.gps.gov/technical/codeless/
  - GPS Block III continued
    - First GPS III tracked January 13th, 2020 (SVN 74)
    - 10 GPS Block III's Developed and Manufactured by Lockheed Martin, Waterton Canyon, Littleton, CO
      - 6 Currently Operational
    - Future: GPS Block IIIF (Follow On), will include 22 SV's being developed by Lockheed Martin

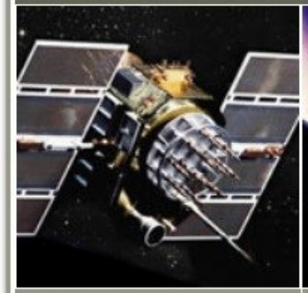
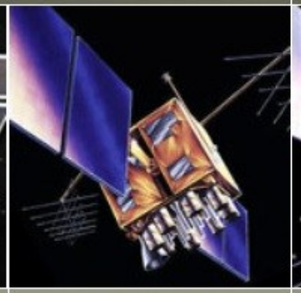
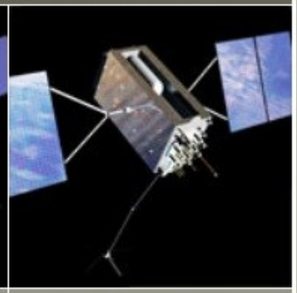


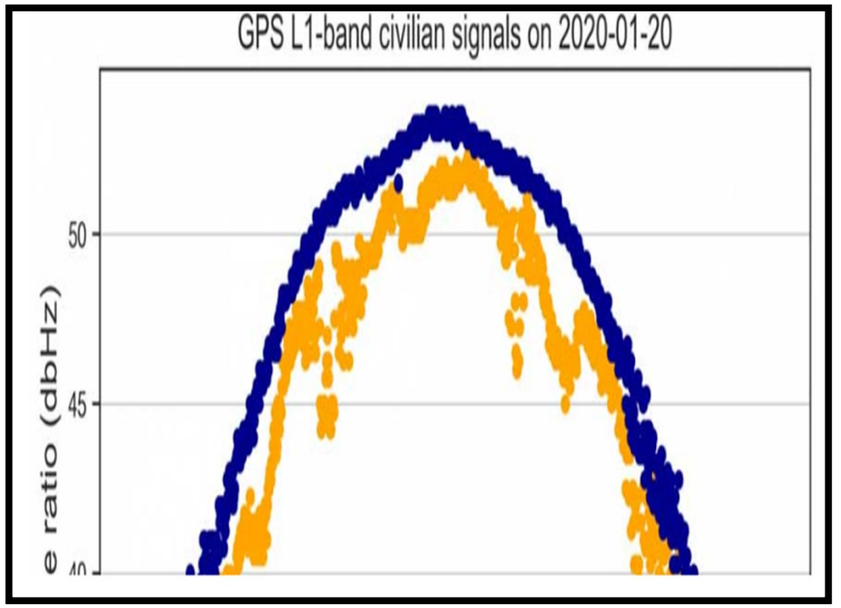


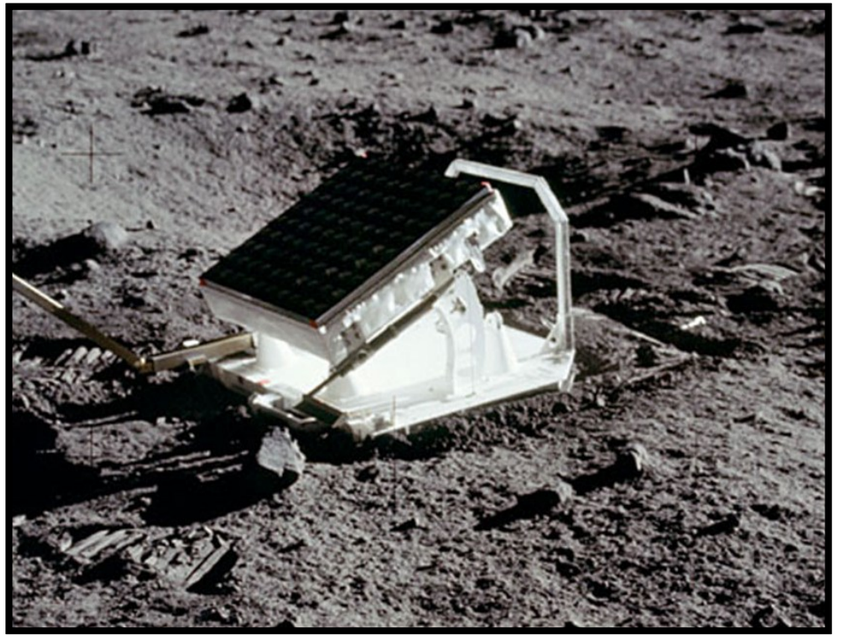
July 20, 1969, Neil Armstrong Walks on the Moon

Lunar Laser Ranging Retro Reflector - Block IIIF Satellites

Current GPS Satellite Constellation – TRI-FREQ!

LEGACY SATELLITES		MODERNIZED SATELLITES		
				
BLOCK IIA	**BLOCK IIR**	**BLOCK IIR-M**	**BLOCK IIF**	**GPS III/IIIF**
0 operational	6 operational	7 operational	12 operational	6 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) *LEARN MORE* ➡ ▪ 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) *LEARN MORE* ➡ ▪ 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) *LEARN MORE* ➡ ▪ Enhanced signal reliability, accuracy, and integrity ▪ No Selective Availability *LEARN MORE* ➡ ▪ 15-year design lifespan ▪ IIIF: laser reflectors; search & rescue payload





Receiver WebUI GPS Tracking

Satellites - Tracking Information

ALL | GPS | GLONASS | Galileo | BeiDou | QZSS | SBAS | MSS

SV	Type	Elev. [°]	Azim. [°]	L1-C/No [dBHz]	L1	L2-C/No [dBHz]	L2	L5-C/No [dBHz]	L5	Iono	IODE	URA [m]	Type
5	GPS	13.68	179.48	38.9	CA	25.1/39.0	E/CM+CL	-	-		3	2	IIR-M
6	GPS	47.47	39.95	48.1	CA	38.5/47.3	E/CM+CL	50.0	I+Q		35	2	IIF
11	GPS	86.37	281.62	48.5/51.1	CA/BOC	44.5/53.8	E/CM+CL	55.7	I+Q		122	2	III
12	GPS	58.06	314.93	48.7	CA	40.9/47.2	E/CM+CL	-	-		14	2	IIR-M
17	GPS	10.49	82.45	39.9	CA	19.9/33.5	E/CM+CL	-	-		108	2.8	IIR-M
19	GPS	31.08	69.48	42.8	CA	30.8	E	-	-		21	2	IIR
20	GPS	38.67	162.51	46.4	CA	34.0	E	-	-		50	2	IIR
22	GPS	15.69	135.55	37.9	CA	23.8	E	-	-		51	2	IIR
24	GPS	24.25	230.16	43.2	CA	29.5/42.8	E/CM+CL	47.3	I+Q		96	2.8	IIF
25	GPS	27.48	315.14	42.1	CA	26.9/40.3	E/CM+CL	44.5	I+Q		20	2	IIF

2024-06-07T16:19:14Z (UTC)

Iono –
A **green**, **yellow**, **orange**, or **red** icon indicates the level of ionosphere disturbance that the RTK base station is experiencing on each satellite.

GOOD URA's See Next Slide!

1.Alternative BOC (altBOC): This type combines multiple BOC signals to improve performance.
2.Multiplexed BOC (MBOC): This type combines BOC and other modulation techniques to enhance signal robustness.
3. L1C - BOC

GPS L2c Modernized Signal

Second Civil Signal: L2C

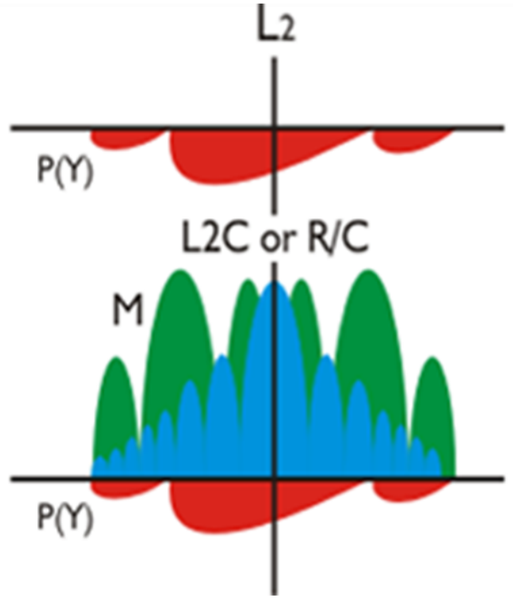
Status

- **Pre-operational** signal with message set "healthy"
- Broadcasting from 25 GPS satellites (as of January 1, 2024)
- Began launching in 2005 with GPS Block IIR-M

Features

1227.60 MHz

- Radio Navigation Satellite Services (RNSS) radio band
- Modern signal design (CNAV), including multiple message types and forward error correction
- Bi-Phase Shift Key (BPSK) modulation CM and CL
- Includes dedicated channel for codeless tracking



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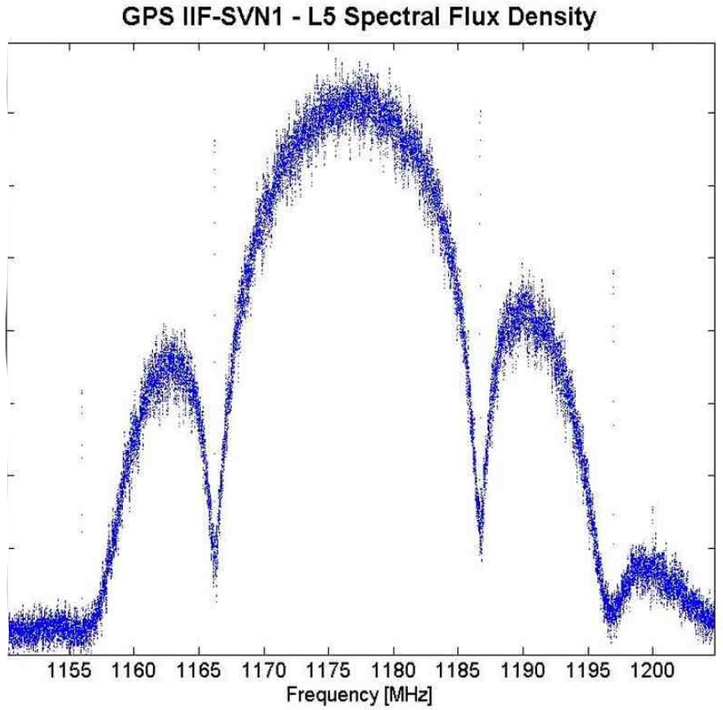
- **GPS**
  - **L5 – 1176.45Mhz**
    - Currently satellites broadcasting L5 = 12 IIF's + 6 Block III's
    - 3rd Carrier Observable
    - Positive impact for surveying
      - Due to wide bandwidth and comparatively longer spreading codes, the L5 signal is expected to give a high processing gain
      - Improved Ionospheric Modeling
      - Will enhance RTK vector lengths



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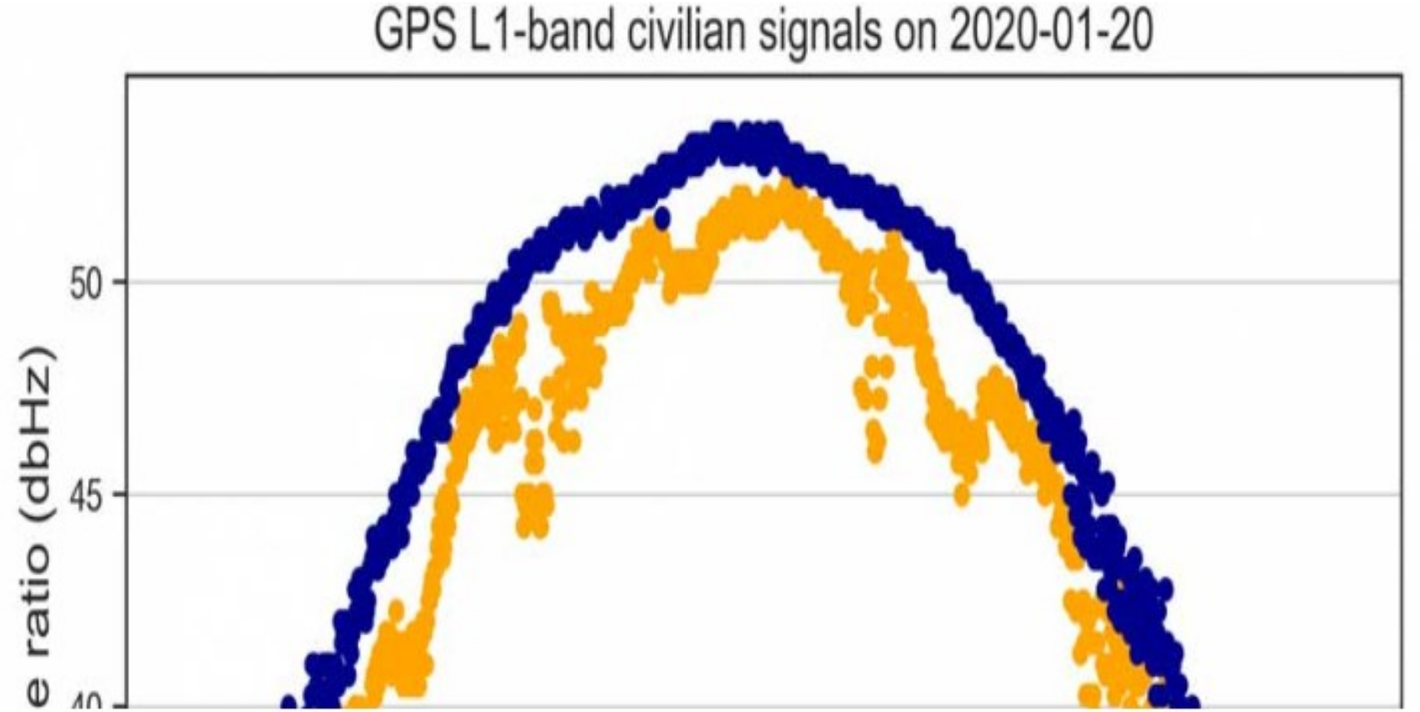
GNSS

- **GPS**
  - **L1C goes live -1575.42Mhz** (On GPS III SV's (6))
    - Stronger signal than traditional L1
    - More accurate signal than traditional L1
    - For better intercommunication with other GNSS Constellations



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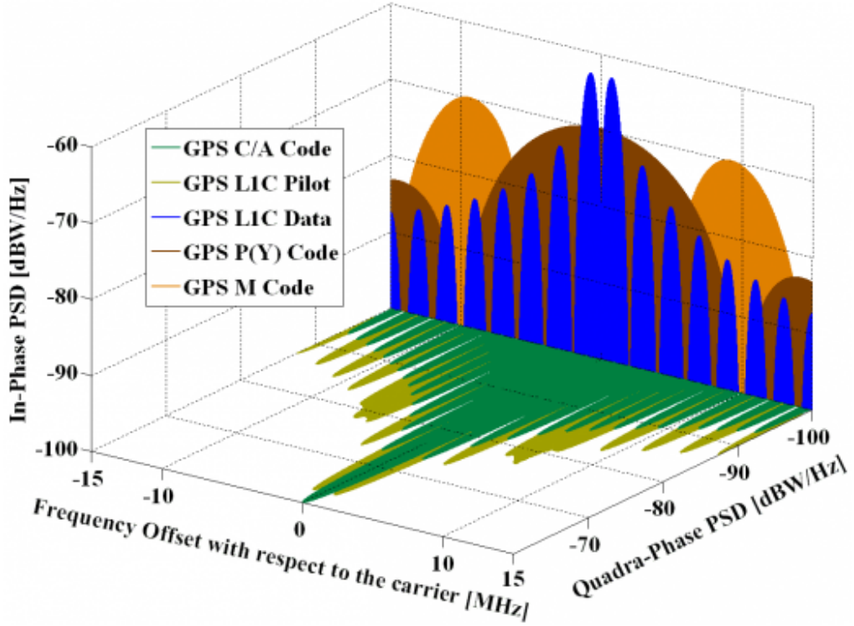
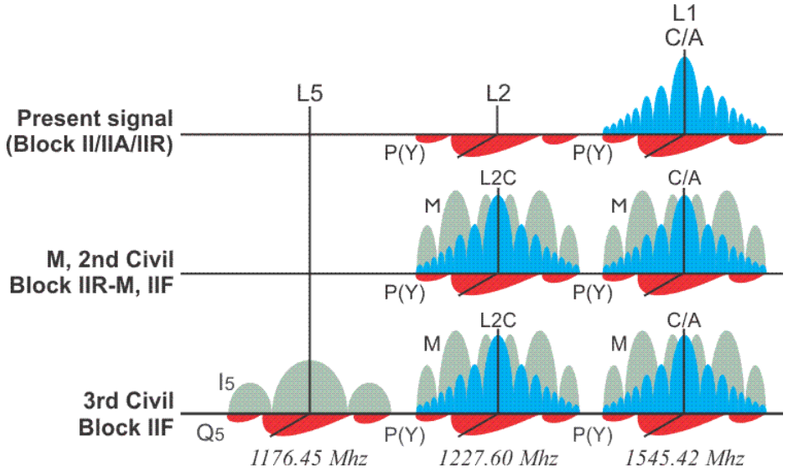
GNSS

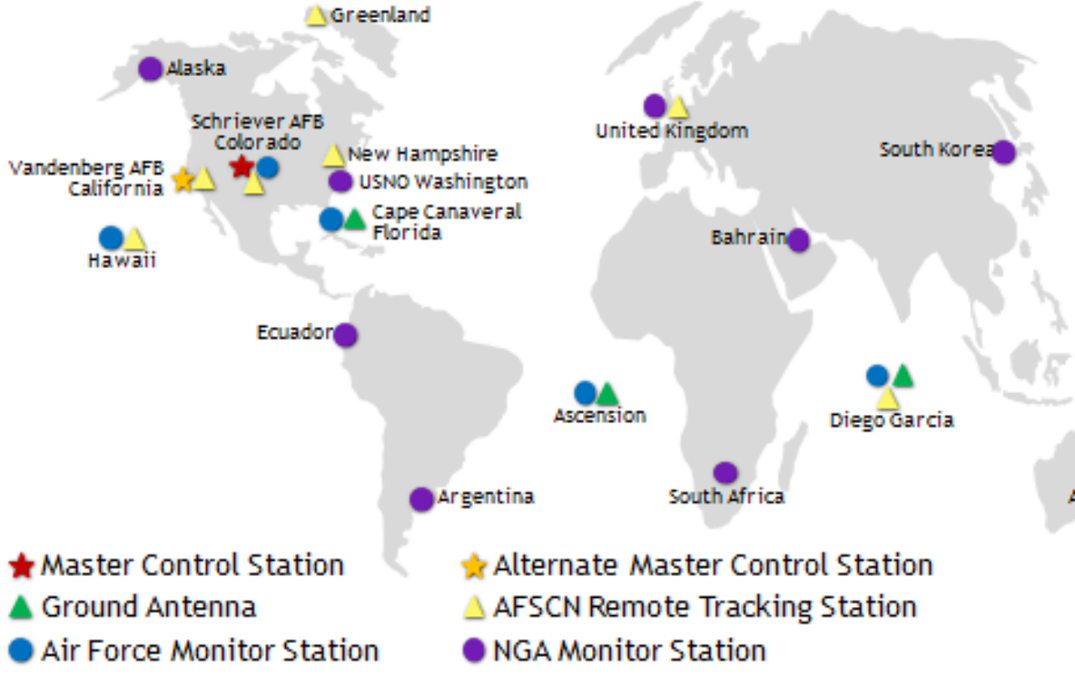
- **GPS Modernization**
  - **GPS III Benefits**
    - GPS III will broadcast 4 civilian signals
      - L1 C/A
      - L2C
      - L5
      - L1C
    - The new L1C signal is compatible with other GNSS constellations
      - Europe - Galileo
      - China- BeiDou
      - India - IRNSS
      - Japan – QZSS
    - Anti-Jamming Technology
    - GPS III, launched without Selective Availability (SA) feature





GNSS

- **GPS Modernization**
  - Control Segment
    - Legacy Accuracy Improvement Initiative
      - Completed in 2008
      - Expanded monitor stations from 6 to 16
        - Now 12 Command and 16 Monitor Stations
      - GPS Intrusion Protection Reinforcement – Nov ‘15
    - Operational Control System (OCX)
      - Improved Support, Monitor, and Control



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Receiver WebUI GPS Tracking

ALL | GPS | GLONASS | Galileo | BeiDou | QZSS | NavIC | SBAS | MSS

SV	Type	Elev. [°]	Azim. [°]	L1-C/No [dBHz]	L1	L2-C/No [dBHz]	L2	L5-C/No [dBHz]	L5	Iono	IODE	URA [m]	Type
1	GPS	18.48	45.91	29.4	CA	31.8	CM+CL	34.8	I+Q	●	55	2	III
6	GPS	15.83	158.95	-	CA	-	E	-	I+Q	-	-	-	IIF
13	GPS	27.53	214.40	38.1	CA	-	E	-	-	●	94	2	IIR
14	GPS	45.15	79.49	43.1	CA	25.4	CM+CL	37.5	I+Q	●	72	2	III
15	GPS	22.87	256.13	35.4	CA	28.1	CM+CL	-	-	●	17	2	IIR-M
17	GPS	66.53	65.21	44.9	CA	36.6	CM+CL	-	-	●	107	2	IIR-M
19	GPS	73.32	184.86	34.4	CA	20.1	E	-	-	●	54	2	IIR
22	GPS	64.15	60.95	40.4	CA	20.9	E	-	-	●	116	2	IIR
24	GPS	36.97	305.71	37.4	CA	31.9	CM+CL	33.7	I+Q	●	53	2	IIF
30	GPS	17.86	143.31	36.7	CA	31.0	CM+CL	33.8	I+Q	●	87	2	IIF

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GNSS

GLONASS

Global Navigation Satellite System

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GNSS

- **GLONASS**
  - Russian Aerospace Defense Forces
    - 26 Total Satellites in Constellation
    - 24 Current Operational Satellites
    - October 2011 returned to full constellation of 24 Satellites
      - Cooperation between Russia and India dates back to December 2004
    - 3 Orbital Planes/8 Slots per plane
    - Originally Supplementary now more Complementary to GPS
    - July 2013 – Proton Rocket Crash
      - 3 GLONASS SV's destroyed
    - Ephemeris Issues throughout 2016

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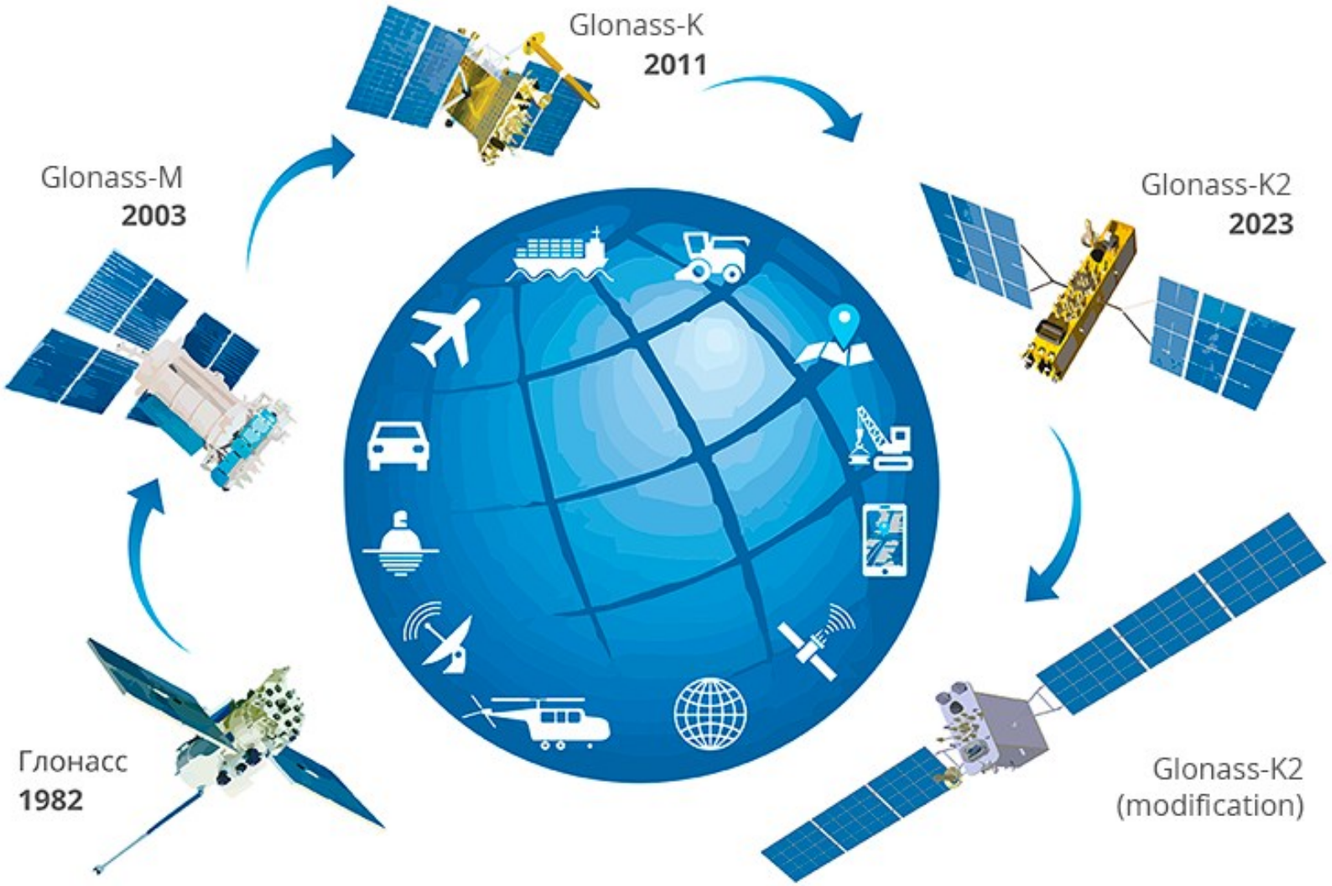
GLONASS Signal Structure

Designation	Frequency	Description
L1	1598.0625-1609.3125 MHz	Legacy GLONASS and GLONASS M FDMA broadcasted signal
L2	1242.9375-1251.6875 MHz	Legacy GLONASS and GLONASS M FDMA broadcasted signal
L3OC	1202.025 MHz	GLONASS K and K2 CDMA broadcasted signal
L1OC and L2OC	1600.995 MHz (Centered) 1248.06 MHz (Centered)	GLONASS K and K2 CDMA broadcasted signal
L5OCM	1176.45 MHz	GLONASS KM Satellite broadcast CDMA signal

GLONASS Satellite Evolution



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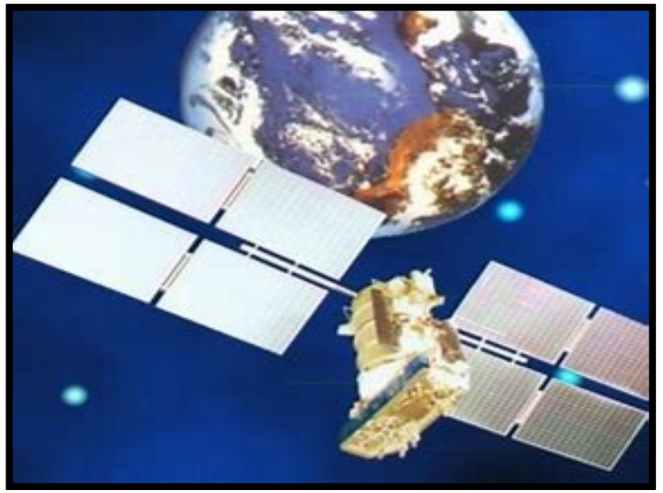
Current GLONASS Satellite Constellation

GLONASS logo

Country/ies of origin	Soviet Union (now Russia)
Operator(s)	Roscosmos (Russia)
Type	Military, civilian
Status	Operational
Coverage	Global
Accuracy	2.8–7.38 metres
Constellation size	
Nominal satellites	24
Current usable satellites	26
First launch	12 October 1982; 42 years ago
Last launch	2 March 2025

Orbital characteristics	
Regime(s)	3 × MEO planes
Orbital height	19,130 km
Orbital period	$^{8}/_{17}$ sd, 11 hours and 16 minutes
Revisit period	8 sidereal days
Website	glonass-iac.ru/en

Datum PZ 90



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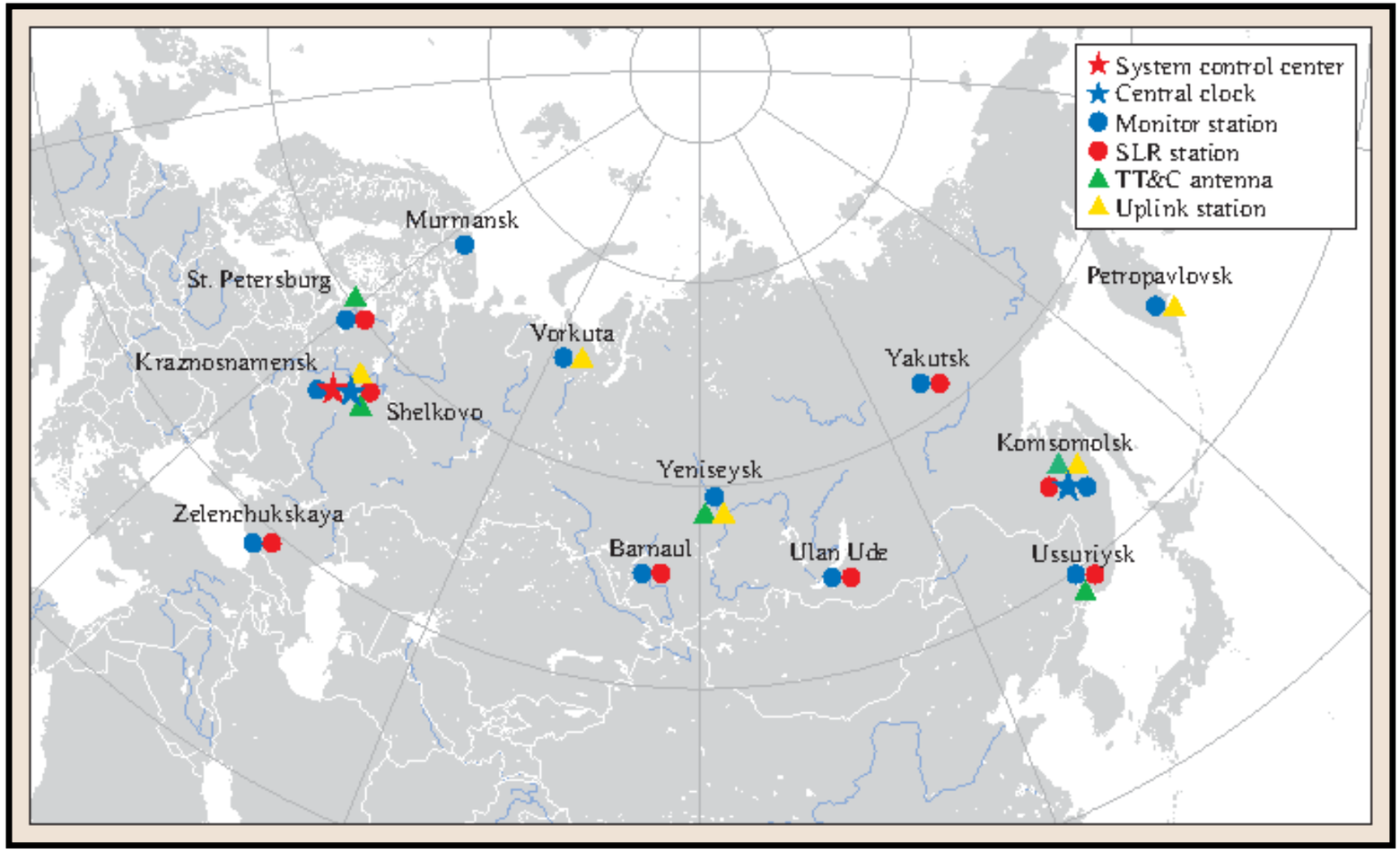
GLONASS Control Segment

- Operated by Russian Government
- 13 Stations within former Soviet Union Territory
- 5 Stations in Brazil – Working on a 6th – Contract Signed for a 7th
- 1 Station in South Africa @ Hartebeesthoek Radio Astronomy Observatory



Receiver WebUI GLONASS Tracking

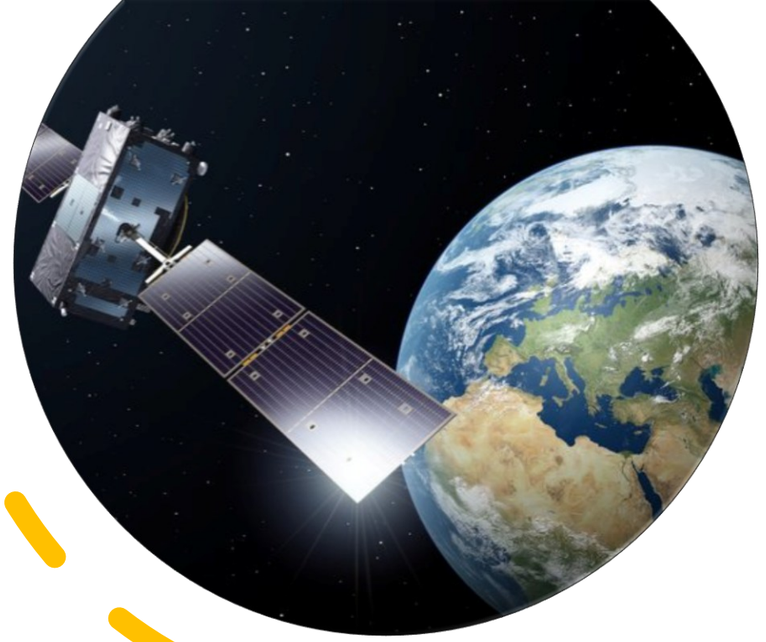
ALL | GPS | **GLONASS** | Galileo | BeiDou | QZSS | NavIC | SBAS | MSS

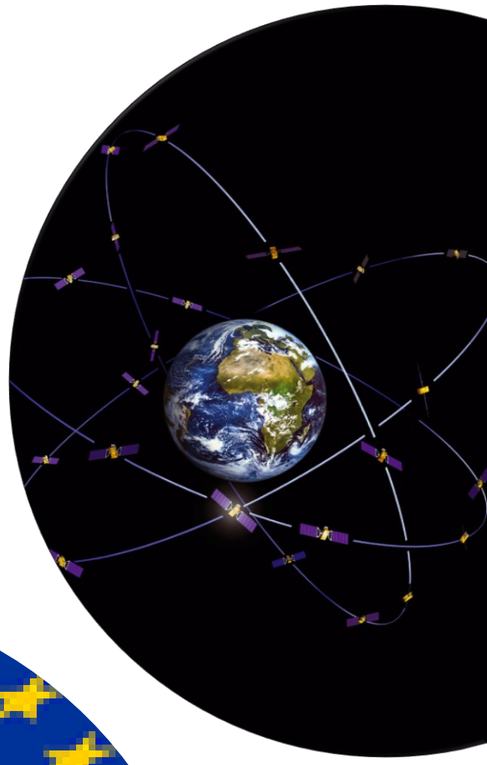
SV	Type	Elev. [°]	Azim. [°]	L1-C/No [dBHz]	L1	L2-C/No [dBHz]	L2	Iono	IODE	URA [m]	Type
6	GLONASS	20.38	287.19	-	CA	-	CA	-	-	-	-
7	GLONASS	14.00	334.57	-	CA	-	CA	-	-	-	-
14	GLONASS	18.66	102.81	33.5	CA	21.5	CA		79	2.5	M
15	GLONASS	64.04	60.69	36.6	CA	36.3	CA		79	2	M
16	GLONASS	42.65	315.28	38.5	CA	-	CA		79	4	M
17	GLONASS	61.29	105.65	31.1	CA	32.9	CA		79	4	M
18	GLONASS	31.20	170.12	-	CA	-	CA	-	-	-	-
24	GLONASS	27.80	34.64	34.2	CA	-	CA		79	4	M

GNSS

GALILEO

European Space Agency





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GNSS

- **GALILEO**
  - European Union and European Space Agency
    - Civilian Control
    - Global Coverage
    - First Service offerings – 2016
      - Multiple Signal Services
    - Full Coverage (30 SV's) planned – 2020
    - First 2 Operational SV's launched 2011
    - 2014 – Faulty Launch
      - 2 SV's in wrong Orbit
      - Year Long "Einstein Test" to correct
    - currently 27 usable SV's (28 in orbit)
    - E1, E5 and E6 frequencies CDMA RHCP

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Galileo Control Segment

FRONTIER PRECISION

ALL | GPS | GLONASS | **Galileo** | BeiDou | QZSS | NavIC | SBAS | MSS

SV	Type	Elev. [°]	Azim. [°]	E1-C/No [dBHz]	E1	E5-C/No [dBHz]	E5	Iono	IODE	URA [m]
4	Galileo	35.71	242.95	29.1	CBOC	32.3	Alt	●	23	3.12
6	Galileo	35.88	275.44	29.0	CBOC	39.5	Alt	●	23	3.12
9	Galileo	28.03	302.54	35.7	CBOC	29.6	Alt	●	24	3.12
13	Galileo	31.46	66.37	35.3	CBOC	40.9	Alt	●	24	3.12
21	Galileo	38.46	77.19	42.5	CBOC	41.6	Alt	●	24	3.12
23	Galileo	76.35	336.36	40.5	CBOC	45.9	Alt	●	21	3.12
26	Galileo	29.86	128.35	19.8	CBOC	31.5	Alt	●	23	3.12
31	Galileo	30.05	277.03	35.8	CBOC	31.3	Alt	●	17	3.12

Galileo Satellite Tracking

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GNSS

BeiDOU

“Big Dipper”

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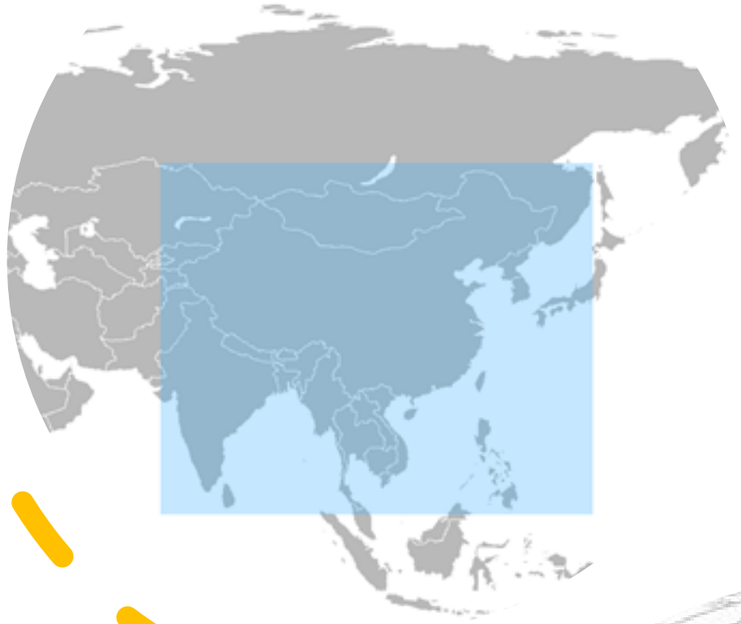
- **BeiDou (Big Dipper) – Chinese Satellite Navigation System**
  - Three Step Strategy
    - Phase 1 - 2000-2003 Launch 3 Experimental BeiDou Satellites
      - First Satellite Launch: October 30, 2000 (BeiDou 1A) Regional Coverage of China
    - Phase 2 - By 2012 – BeiDou Regional Coverage of China and Asia Pacific Region / (BeiDou-2 AKA Compass)
    - Phase 3 – By 2020 – Global BeiDou Navigation System (BDS-3)
    - Schedule to be complete in 2020 ✓
    - Final Launch June 23, 2020 – 35 Satellite Constellation
  - 1 Master Control, 2 Upload Stations and 30 Monitor Stations
  - Global Accuracy
    - 3.6m Horizontal / 6.6 Vertical



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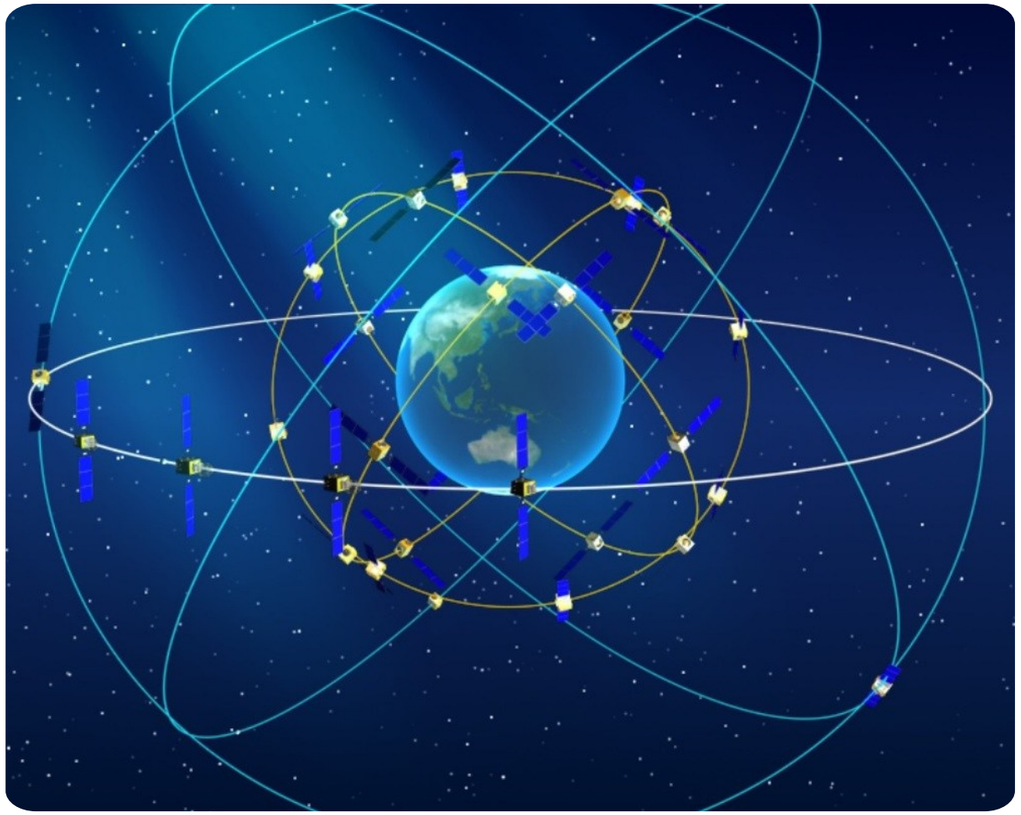

BeiDou Satellite Constellation

- 6 Orbital Planes
  - 35 Satellites
    - 5 Geostationary
    - 27 in Medium Earth Orbit (MEO)
    - 3 in Inclined Geosynchronous Orbit
- 55 Degree Inclination
- Altitude
  - 21,500 km (MEO)
  - 38,300 km (HEO)

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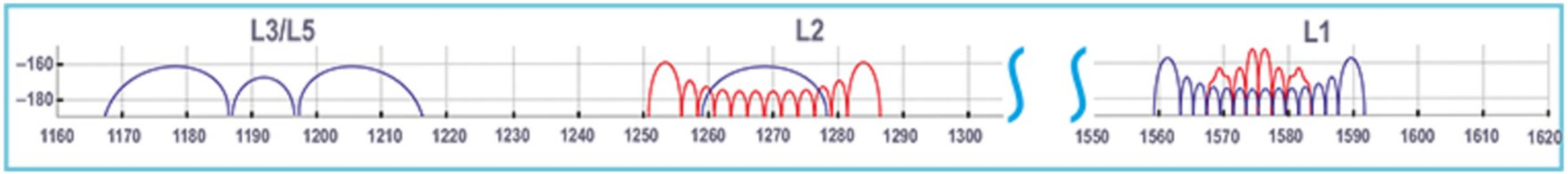
BeiDou 3 Signal Structure

BEIDOU SIGNALS



SPECTRAL CHARACTERISTICS OF BEIDOU NAVIGATION SIGNALS

Range	Carrier frequency, MHz	Signal	PRN code duration, symbols	Clock rate, MHz	Type of modulation	Data symbol rate, bit/s
B1	1 575,42	B1-CD B1-CP B1D B1P	2 046	1,023 1,023 2, 046	MBOC (6, 1, 1/11) MBOC (6, 1, 1/11) BOC (14, 2)	50/100 no 50/100
B2	1 191,79	B2aD B2aP B2bD B2bP	2 046	10,23 10,23 10,23 10,23	AltBOC (15, 10) AltBOC (15, 10) AltBOC (15, 10) AltBOC (15, 10)	25/50 no 50/100 no
B3	1 268,52	B3 B3-AD B3-AP		10,23 2,5575 2,5575	QPSK (10) BOC (15, 2,5) BOC (15, 2,5)	500 50/100 no

BOC Modulation developed to allow interoperability of satellite navigation systems and to improve multi-path mitigation

FRONTIER PRECISION

Receiver WebUI BeiDou Tracking

ALL | GPS | GLONASS | Galileo | **BeiDou** | QZSS | NavIC | SBAS | MSS

SV	Type	Elev. [°]	Azim. [°]	B1-C/No [dBHz]	B1	B2-C/No [dBHz]	B2	B3-C/No [dBHz]	B3	Iono	IODE	URA [m]	Type
26	BeiDou	32.43	301.01	38.4/33.9	B1I/B1C	35.8	B2A	38.5	B3I	●	1	2.4	MEO
29	BeiDou	63.69	130.16	46.3/46.5	B1I/B1C	41.4	B2A	43.2	B3I	●	1	2.4	MEO
30	BeiDou	32.41	50.87	41.1/33.7	B1I/B1C	37.4	B2A	39.8	B3I	●	1	2.4	MEO
35	BeiDou	21.12	196.26	-	B1I	-	-	-	B3I	-	-	-	MEO
36	BeiDou	35.13	114.50	29.3/31.0	B1I/B1C	39.3	B2A	34.6	B3I	●	1	2.4	MEO
45	BeiDou	85.24	53.57	38.6/42.4	B1I/B1C	29.0	B2A	38.7	B3I	●	1	2.4	MEO
58	BeiDou	64.87	186.03	-	B1I	-	-	-	B3I	-	-	-	MEO

Trimble On-Line Planning Tools

Local
Time:
2021-02-25 00:00 UTC +00:00

Satellite Selection

Change selection

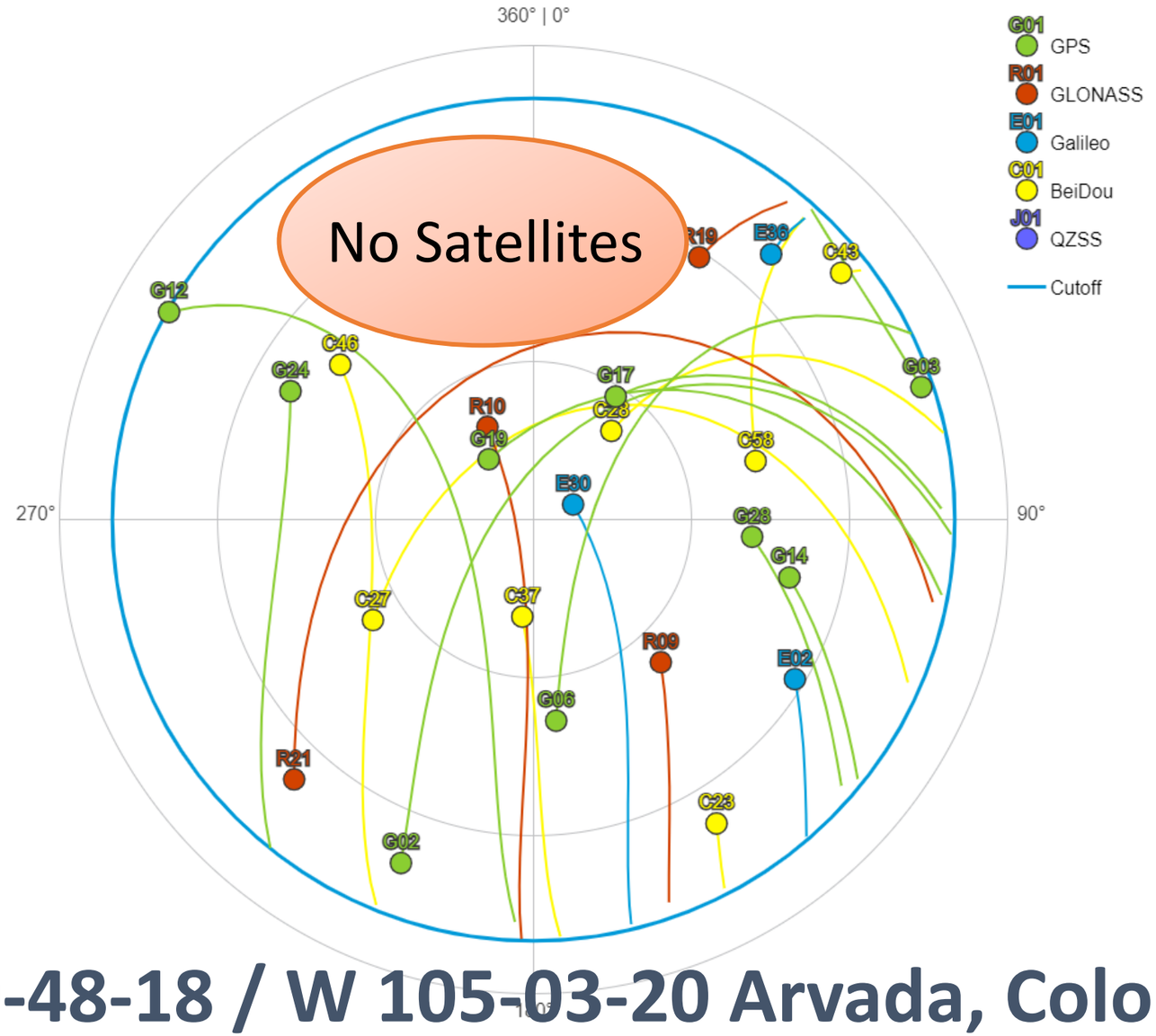
Satellites: **122/130**

System: active	Satellites	
	Selected	Healthy
GPS ✔	31	31
GLONASS ✔	22	22
Galileo ✔	16	16
BeiDou ✔	49	49
QZSS ✔	4	4

My Settings

Change settings

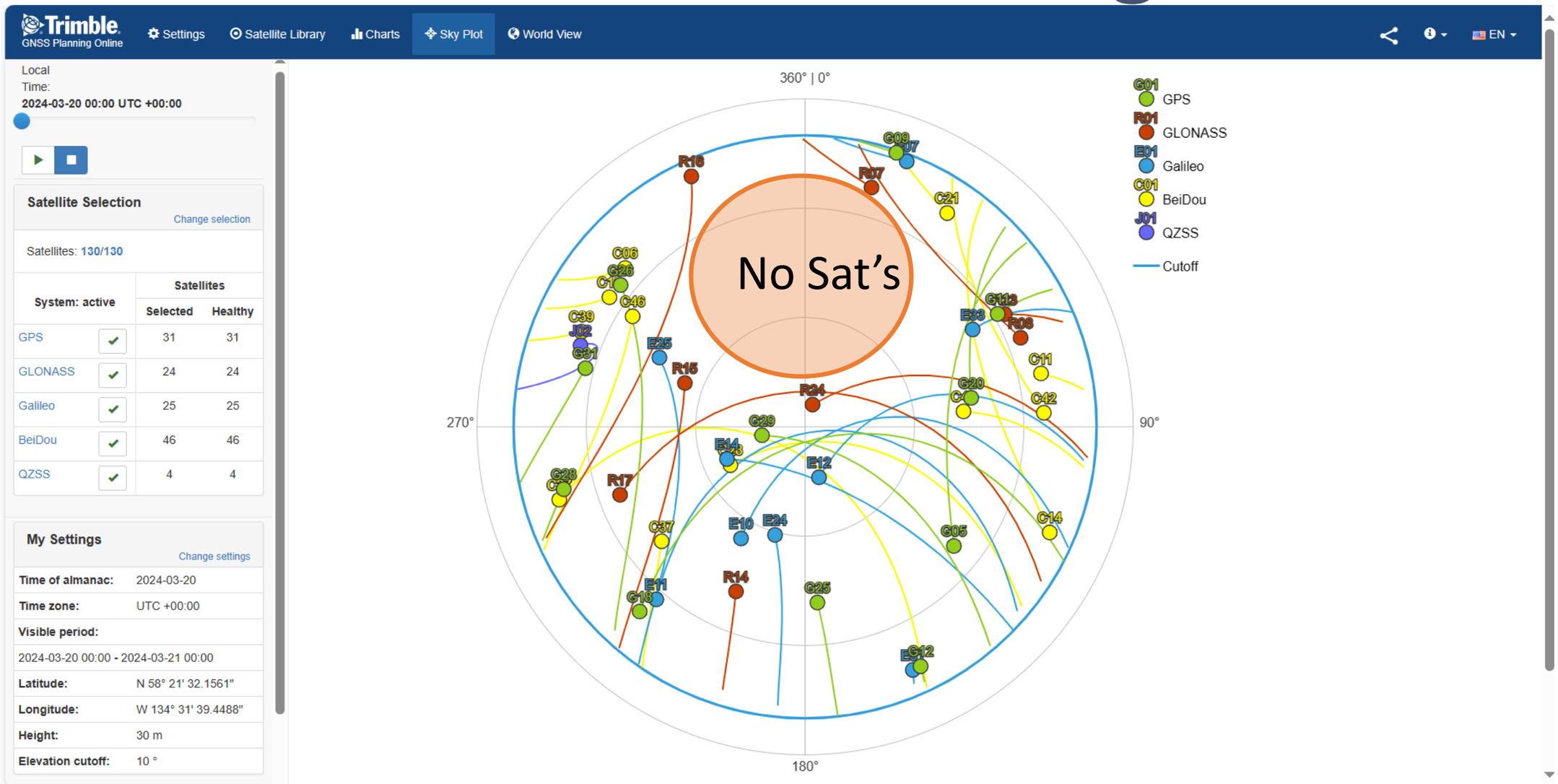
Time of almanac:	2021-02-25
Time zone:	UTC +00:00
Visible period:	
2021-02-25 00:00 - 2021-02-26 00:00	
Latitude:	N 39° 48' 18.5386"
Longitude:	W 105° 3' 20.3432"
Height:	1,585 m
Elevation cutoff:	10 °



N 39-48-18 / W 105-03-20 Arvada, Colorado

FRONTIER PRECISION

Trimble On-Line Planning Tools



DOT Juneau, Alaska

FRONTIER PRECISION

Trimble On-Line Planning Tools

Local
Time:
2023-12-28 13:00 UTC -7:00

Satellite Selection

Change selection

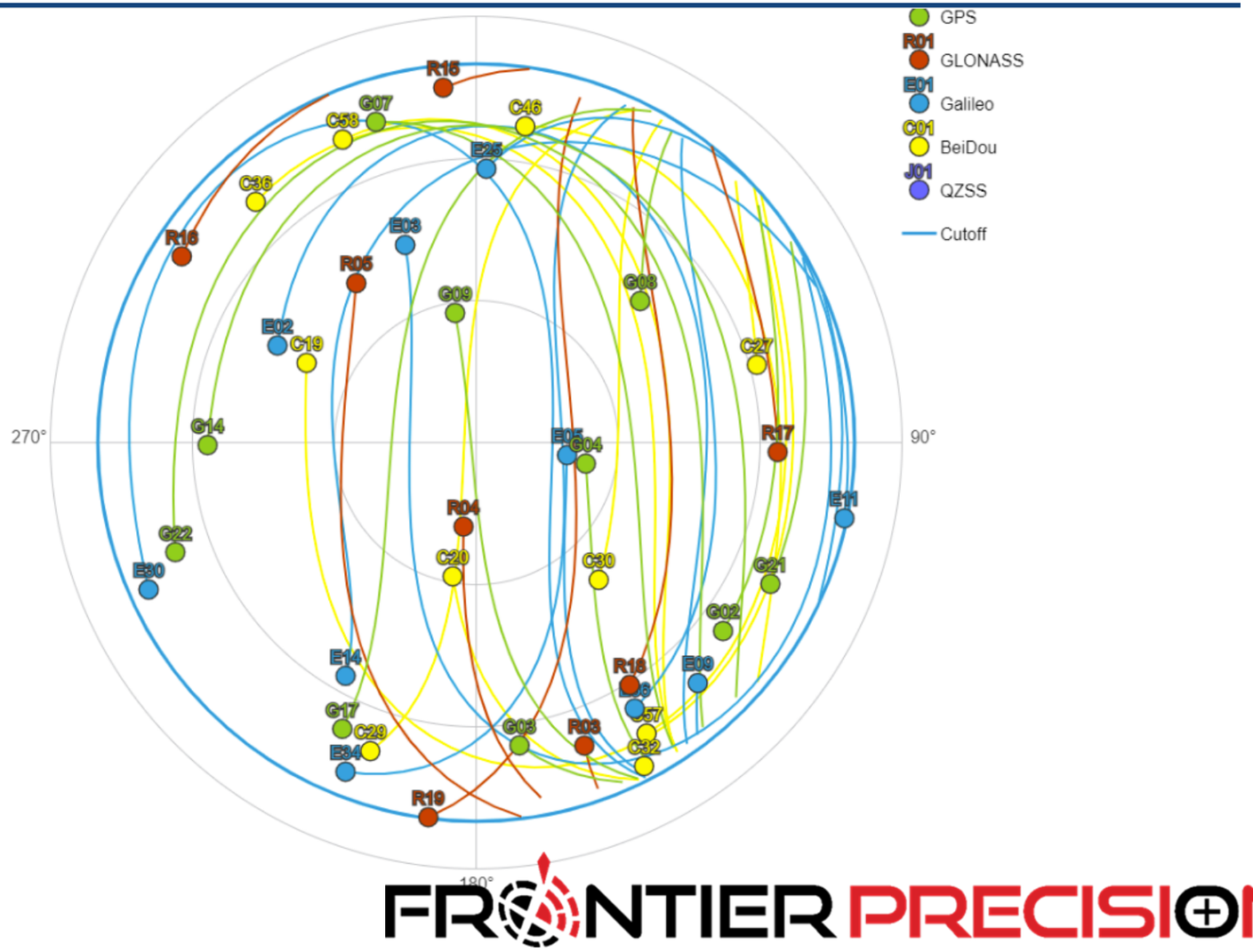
Satellites: 130/130

System: active		Satellites	
		Selected	Healthy
GPS	✔	31	31
GLONASS	✔	24	24
Galileo	✔	25	25
BeiDou	✔	46	46
QZSS	✔	4	4

My Settings

Change settings

Time of almanac:	2023-12-28
Time zone:	UTC -7:00
Visible period:	
2023-12-28 13:00 - 2023-12-29 13:00	
Latitude:	N 0° 0' 0"
Longitude:	W 105° 3' 20"
Height:	0 m
Elevation cutoff:	10 °



FRONTIER PRECISION

N 00-00-00 / W 105-03-20 Equator, Pacific Ocean

CENTERPOINT RTX POST-PROCESSING SERVICE
FREE MANUFACTURER GENERIC SERVICE

- Better than 2 cm horizontal accuracy (1 hour of observation recommended, 24hr max)
- Now with BeiDou data
- Supports a variety of manufactures receivers and file formats
- User selectable reference frames
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WELCOME TO TRIMBLE CENTERPOINT® RTX POST-PROCESSING SERVICE

Trimble RTX© is a global GNSS technology that provides centimeter-level positioning, worldwide, at any time.

This application allows you to upload GNSS observation data to the CenterPoint RTX post-processing service and receive positioning calculations. The positioning calculations are performed in the observation epoch (current epoch) of ITRF2008 for data sets that were collected prior to March 23rd 2017, and ITRF2014 for data sets that were collected on or after March 23rd 2017. Transformation can be performed by selecting a different coordinate system and tectonic plate. Complete the form below to receive your calculations via email.

1. **Select a coordinate system and tectonic plate:**

Coordinate System: NAD83-2011

Tectonic Plate: North America

2. **Select a file to upload:**

Choose File 62732400.T02

New Enhancements

The CenterPoint RTX post-processing service now supports all dual frequency GNSS receivers.

Antennas must be on the Supported Antennas list. The post-processing service will not process unsupported antennas. See also: Supported Antennas

Observation files must meet the following requirements:

- Data formats accepted include Trimble proprietary data formats (e.g. DAT, T01, T02, T04, Quark) and the standard RINEX 2 and RINEX 3 data formats
- For optimal processing results, it is recommended to provide at least 60 minutes of observations.
- Data files cannot exceed 24 hours in length
- Data files must be static only
- Data files must contain dual frequency pseudorange and carrier phase observations (L1 and L2)
- Data must have been collected after 14 May 2011
- BeiDou data is included since 04 Jun 2014
- Galileo data is included since 01 Jan 2017
- If your observation data consists of several files, please compress them to a ZIP archive and upload the zipped file. All files in the ZIP archive must belong to the same station.

3. **Provide your email address:**

Email: bob@frontierprecision.com

☑ I accept the terms of use listed in the Disclaimer section below.

American Surveyor Magazine GNSS/PPP Article

Are Satellite-Based Correction Services the "Next Utility"?

ROBERT L. GREEN, PS // 06.20.2021

American Surveyor Magazine Hoover Dam "POC" Survey

THANK YOU

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- **303-728-4984**

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