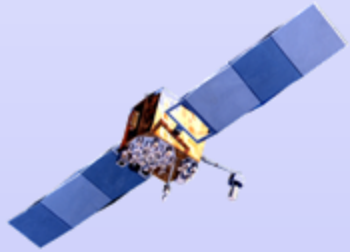

GNSS as Primary Time Source

WSTS 2022 TUTORIAL SESSION

May 9, 2022

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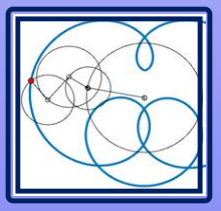
Two Messages About GNSS

1. GNSS are extremely useful
   - Constellations are growing
   - Provide reliable, extremely accurate real-time UTC time and frequency for mostly free
   - Excellent navigation
   - A global > $100B industry

2. GNSS signals are dangerously vulnerable to both accidental and intentional interference



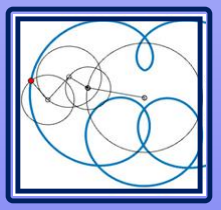
The Family of Global Navigation Satellite Systems

GPS	Galileo	GLONASS	Beidou/Compass
US	EU	Russia	China

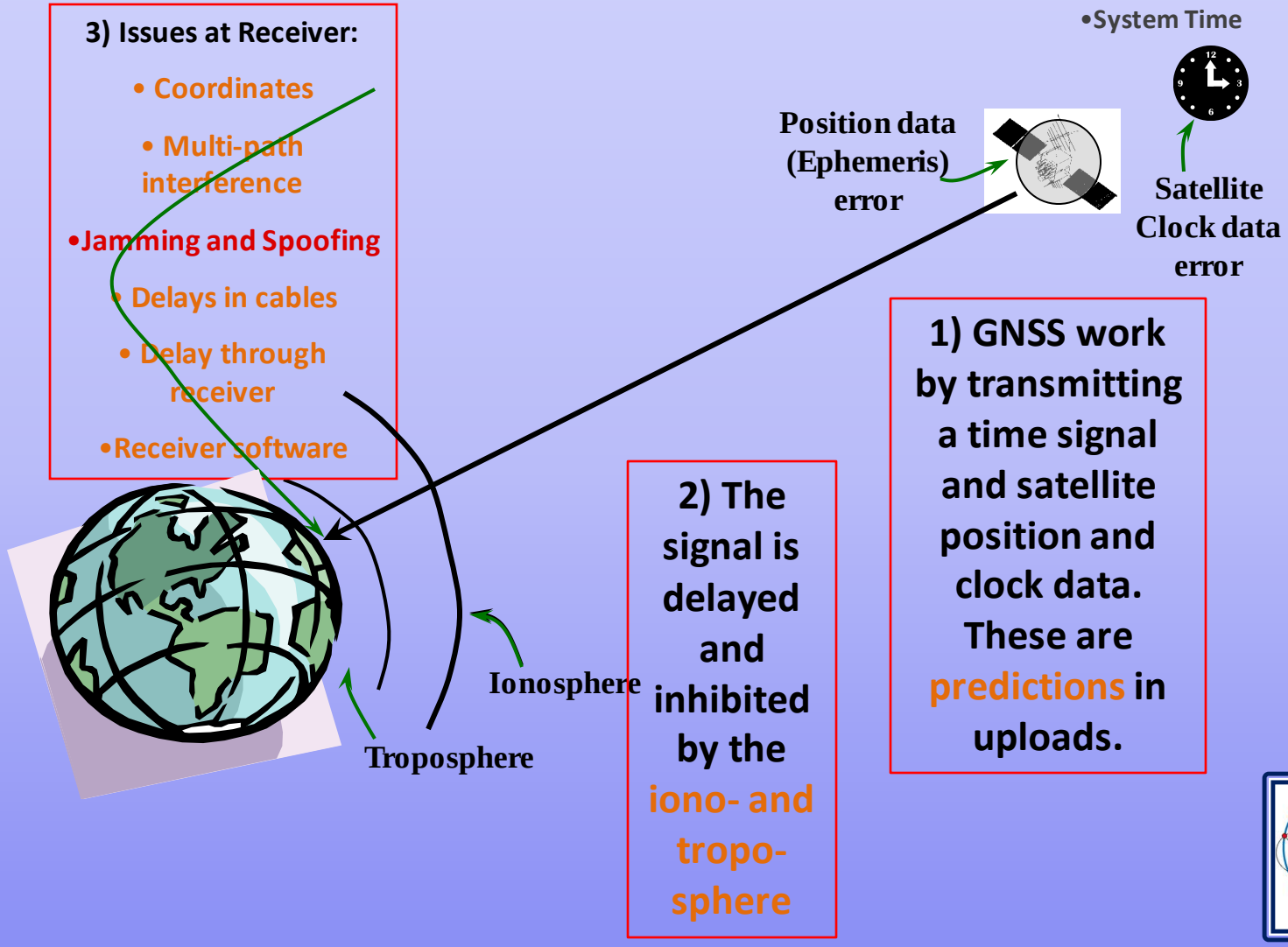
Others are Regional Navigation Satellite Systems

GNSS: General Properties

- Position, Navigation, Timing (PNT)
- Four + synchronized timing signals from known locations in space—timestamped at receiver and used to solve for x,y,z, and t or lat,lon, hgt and time
- Two + frequencies measure ionosphere
- Control, Space, User Segments
- Open and Restricted Services
- All signals are weak and clustered in the L-band spectrum
  - Allows interoperability
  - But also makes it is relatively easy to jam GNSS and spoof

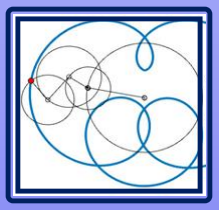


Time from GNSS:
Intentional and Unintentional Error Sources

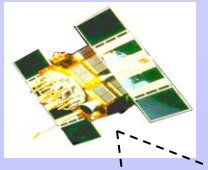


Time From GNSS

- Time signals are the basis of positioning
- Clocks on Satellite Vehicles (SVs) are free-running
  - Data provides the offset in Time and Frequency
  - System time is offset from UTC
- The positions of the satellite and receiver are needed for the delay
- SV Clocks and positions are ***predicted*** and uploaded, for GPS about once per day



GNSS-aided Time and Frequency Systems



GNSS

T/F System

Quartz Crystal Oscillator

GNSS Rcvr

Compare

Tune

Qz Osc.

Output Time & Freq.

Or

GNSS Rcvr

Compare

Tune

Rubidium Vapor Atomic Oscillator

Rb Vapor Phy Pkg

•Qz Osc.

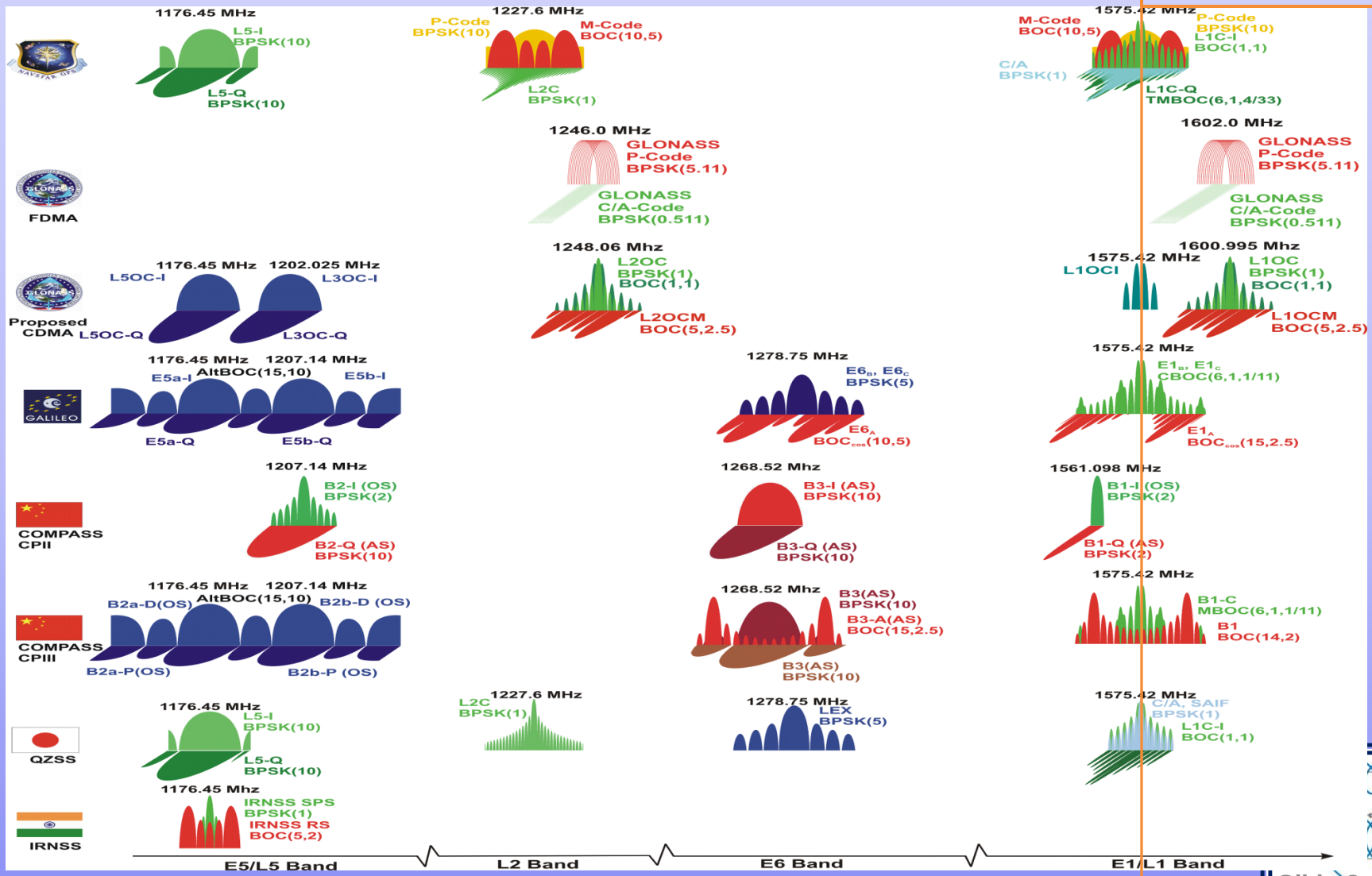
Output Time & Freq.

Rb oscillator 100 to 1000 times better Holdover Performance

Courtesy H. Fruehauf, ViaLogy LLC

T/F System

Spectra of GNSS's



GNSS Vulnerability

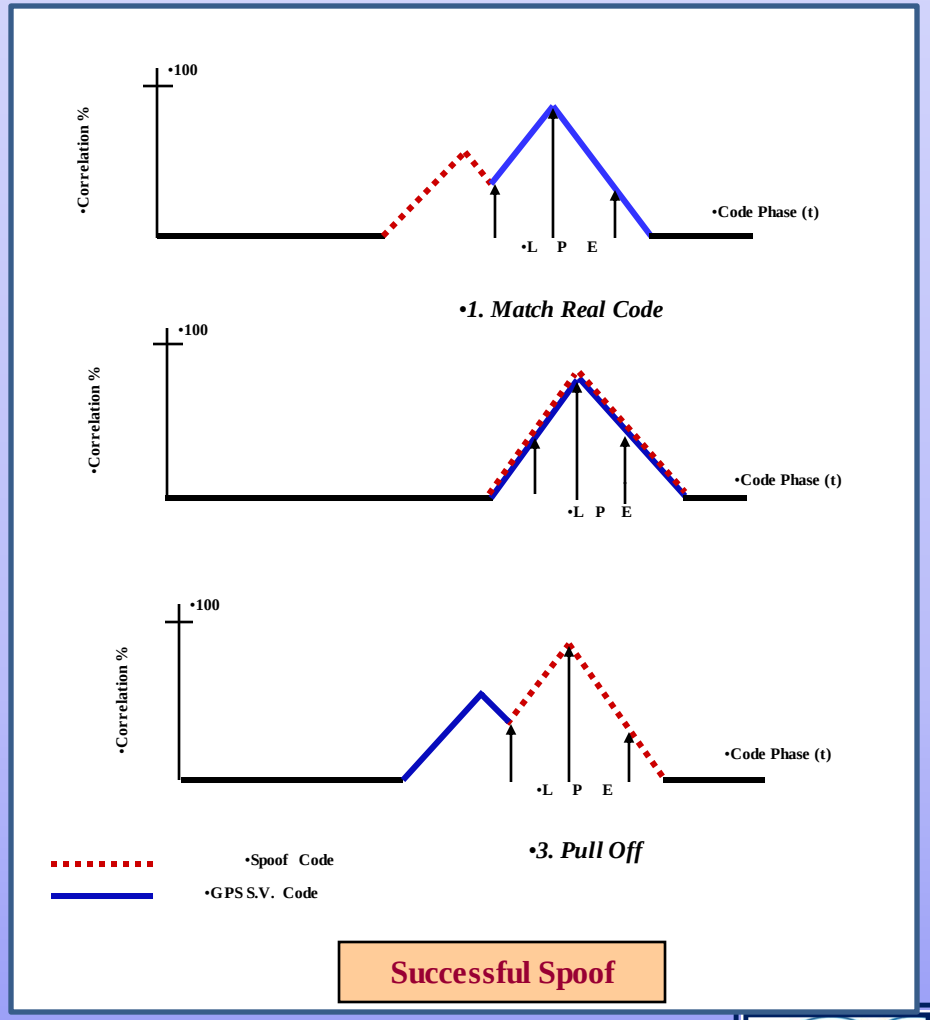
- GNSS best feature and worst problem: it is extremely reliable
  - Leads users to not use backup systems
- Jamming Power Required at GNSS Antenna
  - On order of a Picowatt (10^{-12} watt)
- Many Jammer Models Exist
  - Watt to MWatt Output – Worldwide Militaries
  - Lower Power (<100 watts); Available online, though perhaps illegal

"Personal Privacy" Device

Military Jammer

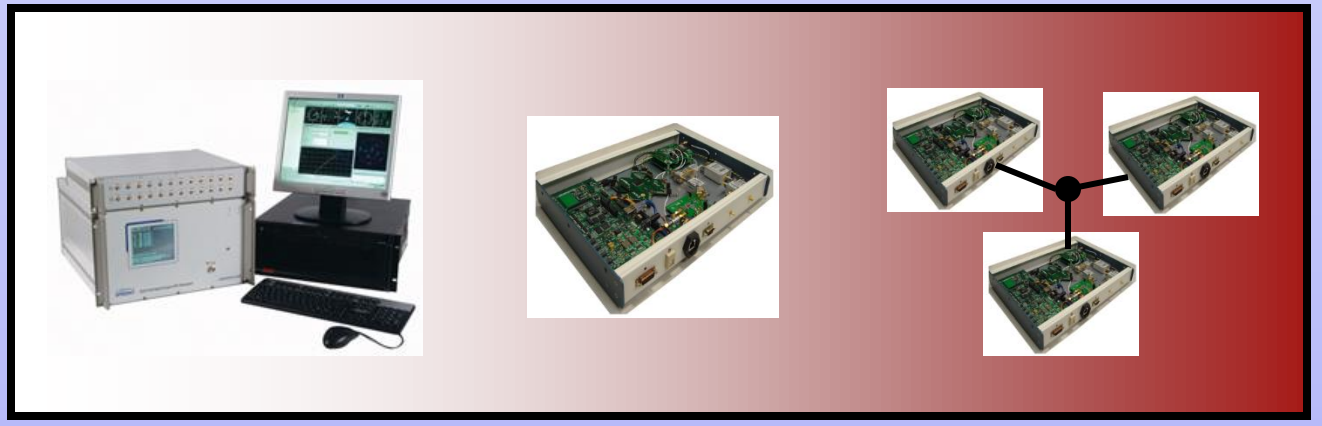
Spoofing/Meaconing

- Spoof – Counterfeit GNSS Signal
  - C/A Code Short and Well Known
  - Widely Available Signal Generators
  - Many possible techniques
- Meaconing – Delay & Rebroadcast
- Possible Effects
  - Force receiver to give wrong position or time or both
  - No warning from receiver without special anti-spoof design
- No “Off-the-Shelf” Mitigation



Civil GNSS Spoofing Threat Continuum*

Simplistic ***Intermediate*** ***Sophisticated***



Commercial signal simulator

Portable software radio

Coordinated attack by multiple phase-locked spoofers

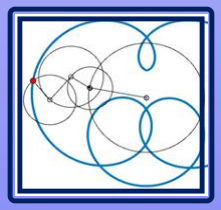
*** Courtesy of Coherent Navigation, Inc**

Spoofing example, GPS World, April 2020:
‘circle spoofing’ in Tehran

This heat map shows GPS spoofing at a government complex in Tehran,which houses the Ministry of Defense, Communication Regulatory Authority, Telecommunications Infrastructure Company, and Ministry of Telecommunications and Technology. (Screenshot: courtesy of Dana Goward)

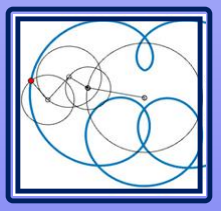
“Some of GPS devices received fake signal and show the fake valid location. Yesterday I test a device, it can get signal and give real position. After 10 minutes the device show moving around a big circle in Tehran by 35 km/h speed. I can’t fix this problem by restarting the device. “The GPS module time is correct but the location is not. I attach Excel file of data and map of the track. I can’t get any response from Communications Regulatory Authority (CRA) of The I.R. of Iran. Do you know about this?”

https://www.gpsworld.com/gps-circle-spoofing-discovered-in-iran/



Conclusions

- GNSSs are very accurate both for time and frequency, many signals free for use, and are very reliable
  - Perhaps their greatest advantage and disadvantage!
  - Signals are subject to interference



EXTRA SLIDES:
CURRENT STATUS OF GNSS CONSTELLATIONS AS OF WSTS 2022

From the Civil GPS Service Interface Committee (CGSIC) Meeting 20 Sep 2021

GPS Constellation Status

37 Satellites • 30 Set Healthy
Baseline Constellation: 24 Satellites

Satellite Block	Quantity	Average Age (yrs)	Oldest
GPS IIR	8 (4*)	19.6	24.1
GPS IIR-M	7 (1*)	13.9	15.9
GPS IIF	12	7.6	11.3
GPS III	4 (1*)	1.4	2.7

*Not set healthy

As of 1 Sep 21

GPS Signal in Space (SIS) Performance

From 7 Aug 20 to 7 Aug 21

Average URE*	Best Day URE	Worst Day URE
50.0 cm	31.5 cm (20 Apr 21)	70.4 cm (13 Mar 21)

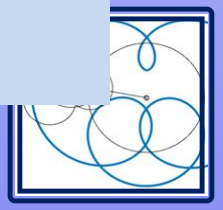
*All User Range Errors (UREs) are Root Mean Square values

Current GLONASS Constellation: Mostly GLONASS-K

2nd Generation – GLONASS M – GLONASS-M in the process of being phased out. Its last launch was expected in late 2018. Some satellites are in use and has been superseded by the GLONASS-K, the third-generation satellites.

3rd Generation – GLONASS K – GLONASS-K is the latest satellite design is a substantial improvement of the previous GLONASS-M second-generation satellites, having a longer lifespan and better accuracy.

4th Generation – GLONASS K2 – GLONASS-K2 is the next satellite design intended as a part of the GLONASS satellite navigation system. The launch of the first next-generation GLONASS K2 satellite is set for late 2021. It is an evolution of the previous GLONASS-K third-generation satellites, adding CDMA signals, improving accuracy and increasing power. It is 70% heavier and has 170% more power.



GLONASS: GLObal NAvigation Satellite System

GLONASS constellation status at 04.05.2022

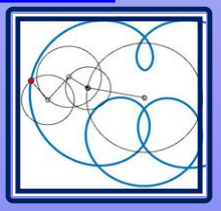
	Total satellites in constellation	25
	In operation	23
	In commissioning phase	0
	In maintenance	2
	Under check by the Satellite Prime Contractor	0
	Spares	0
	In flight tests phase	0

https://www.glonass-iac.ru/glonass/sostavOG/

Current Status of Galileo System
as of 12 October 2021

- 3 IOV (In-Orbit Validation) with one Rb clock and two Passive Hydrogen Maser (PHM)
- 21 usable FOC (Full Operational Capability) all with PHM
- Galileo Second Generation (G2G) under design and development

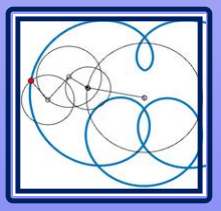
https://www.esa.int/Applications/Navigation/Galileo/Galileo_a_constellation_of_navigation_satellites



Current Status of Galileo System as of 7 December 2021

Block	Launch period	Satellite launches			In operation and healthy
		Full success	Failure	Planned	
GIOVE	2005–2008	2	0	0	0
IOV	2011–2012	4	0	0	3
FOC	From 2014	22	2	10	21
G2G	From 2024	0	0	12	0
Total		28	2	22	24

https://en.wikipedia.org/wiki/Galileo_(satellite_navigation)#Constellation

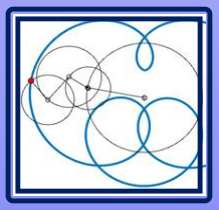


BDS-3 Was Formally Commissioned on July 31, 2020

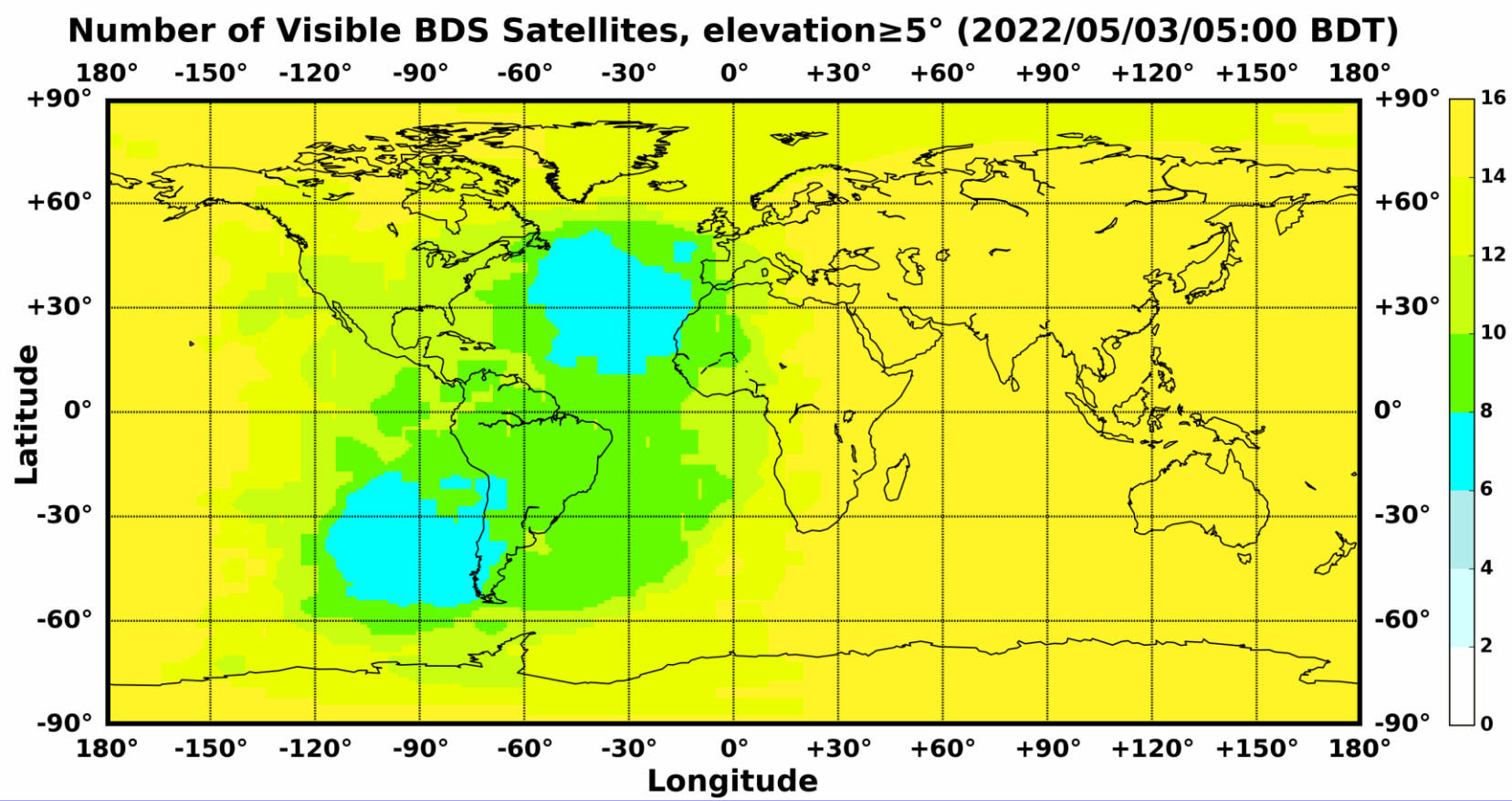
- There were 15 operational BDS-2 satellites (5GEOs + 7IGSOs + 3MEOs, with open service navigation signals B1I/B2I/B3I

- There were 27 operational BDS-3 non-GEO satellites (24 MEOs + 3IGSOs) providing open service for global users with signals B1C/B2a/B1I/B3I/B2b, using PRN from 19 to 61.

- There were 3 BDS-3 GEO satellites providing open service for global users with signals B1I/B3I, BDSBAS-B1C/BDSBAS-B2a and B2b-PPP.



Beidou System 03 May 2022



http://en.beidou.gov.cn/SYSTEMS/Monitoringandevaluation/202205/t20220503_24075.html