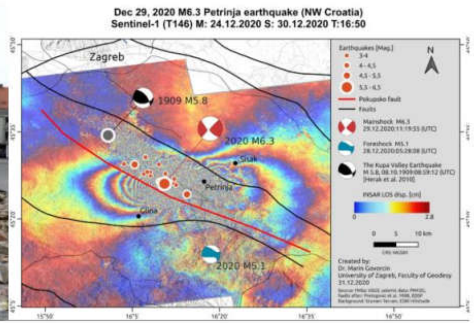


Danijel Šugar

EO4GEO training: Fast disaster response – satellite technologies for surface displacement monitoring

GNSS

July 12th – 14th, 2021

University of Zagreb – Faculty of Geodesy

Co-funded by the Erasmus+ Programme of the European Union

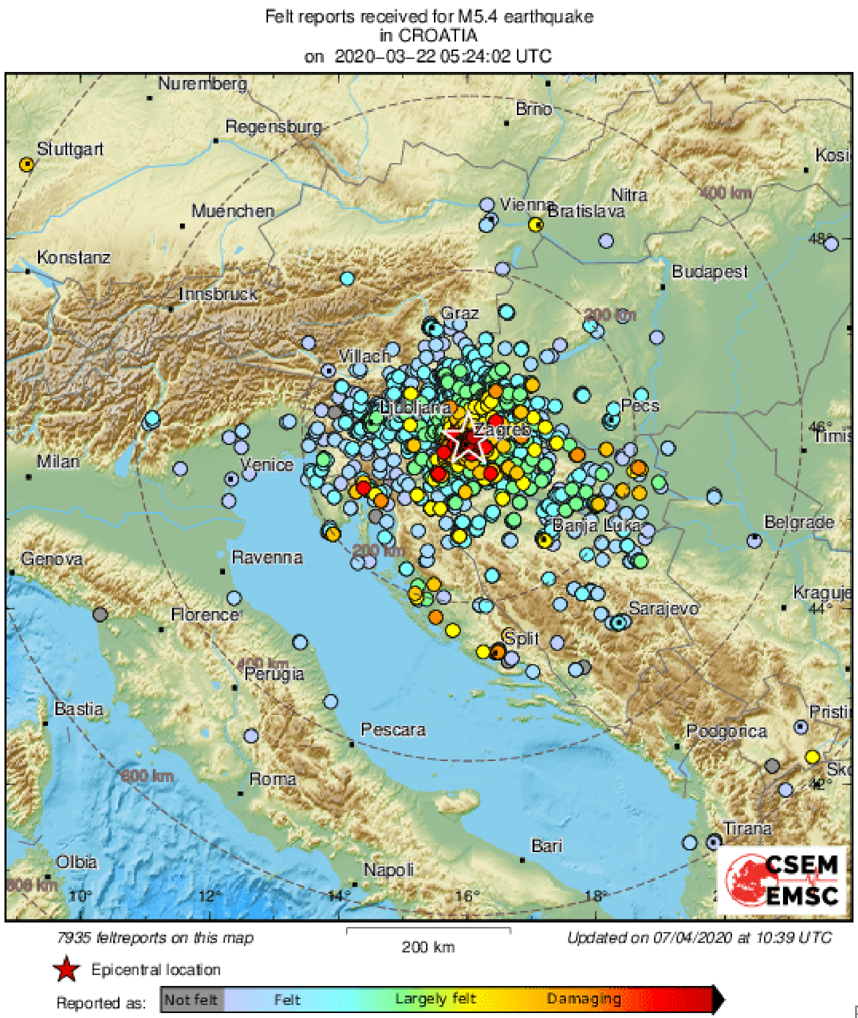
Outline:

- Motivation instead of introduction
- Global Navigation Satellite System (GNSS) – overview & current status
- Global, Continental and Regional (State) Networks
- Error sources
- Measuring methods
- Precise Point Positioning (PPP)

Case studies:

- Zagreb (22nd March 2020)
- Petrinja (28th & 29th December 2020 – 6th January 2021)

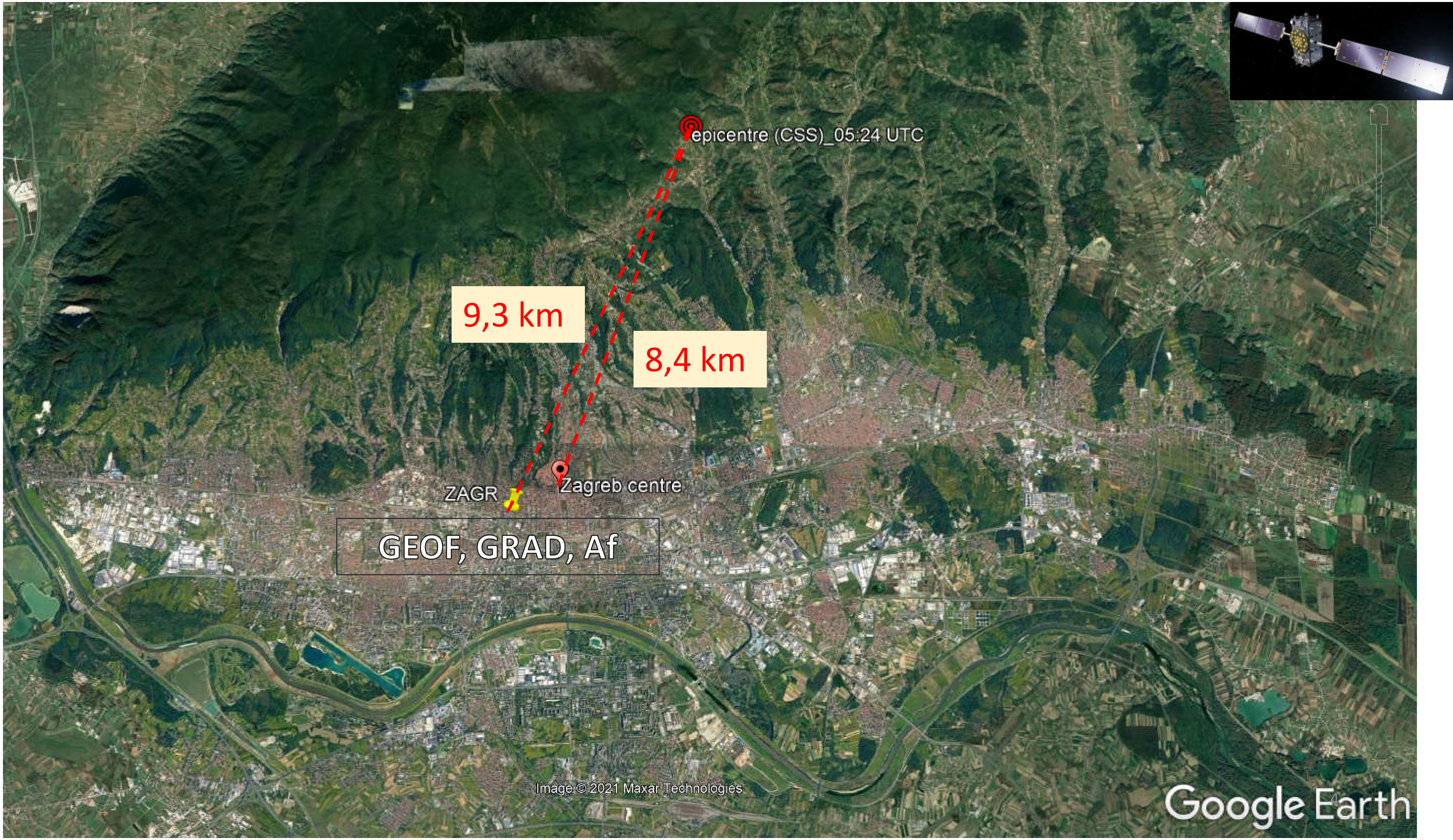
Motivation instead of introduction



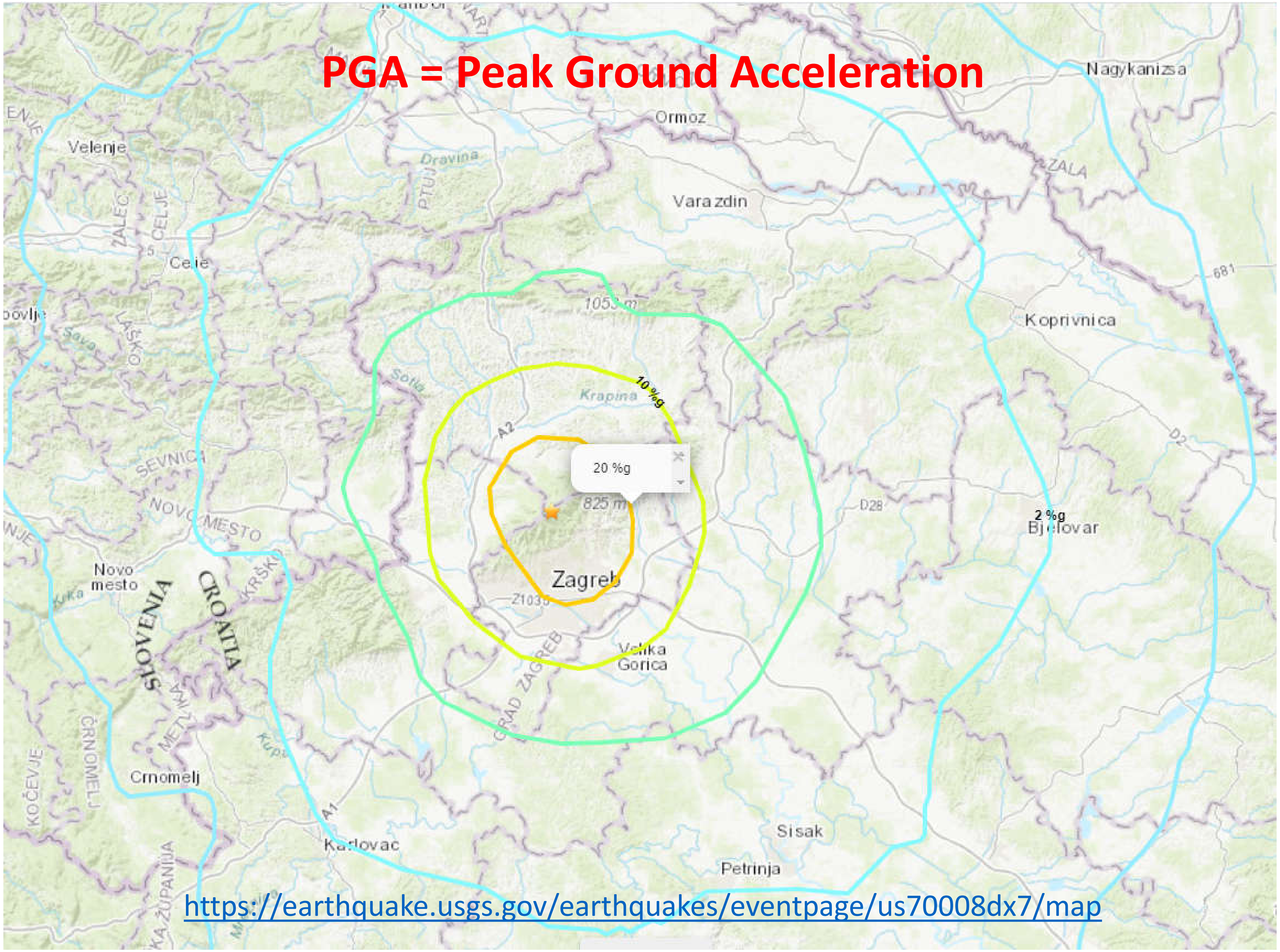
https://www.emsc-csem.org/#2

Zagreb earthquake, 22nd March 2020

Source	Croatian Seismological Survey (CSS)
Latitude	45.884°
Longitude	16.013°
Depth	8.3 km
Magnitude	M_L = 5.5
Time of origin	05:24:03.1 UTC

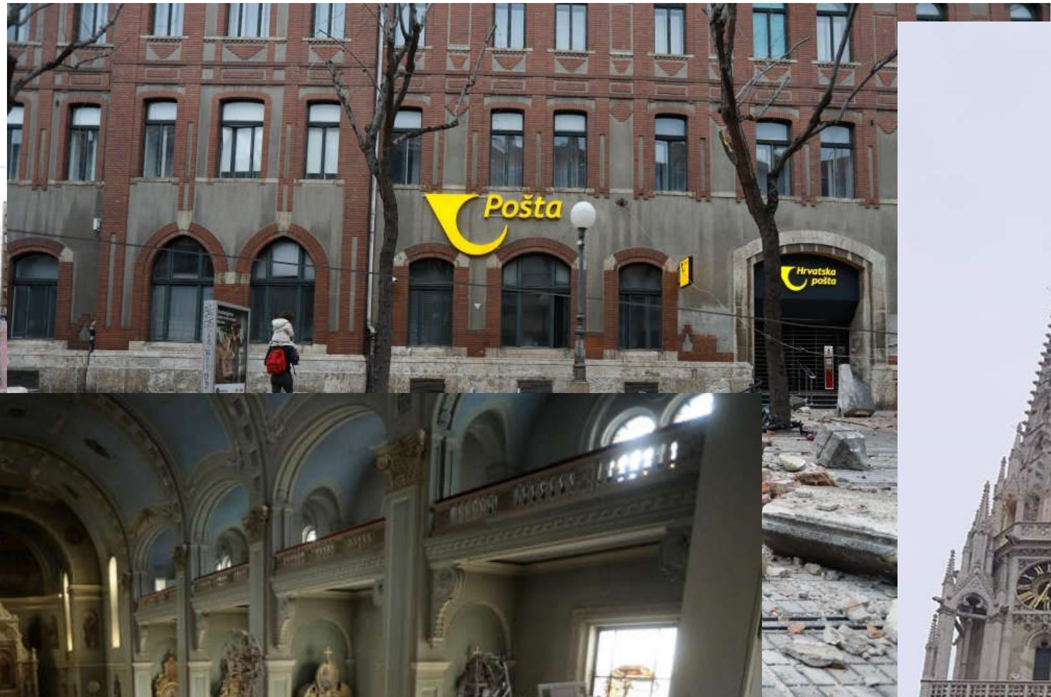

epicentre (CSS)_05:24 UTC
9,3 km
8,4 km
ZAGR
Zagreb centre
GEOF, GRAD, Af
Image © 2021 Maxar Technologies
Google Earth

PGA = Peak Ground Acceleration



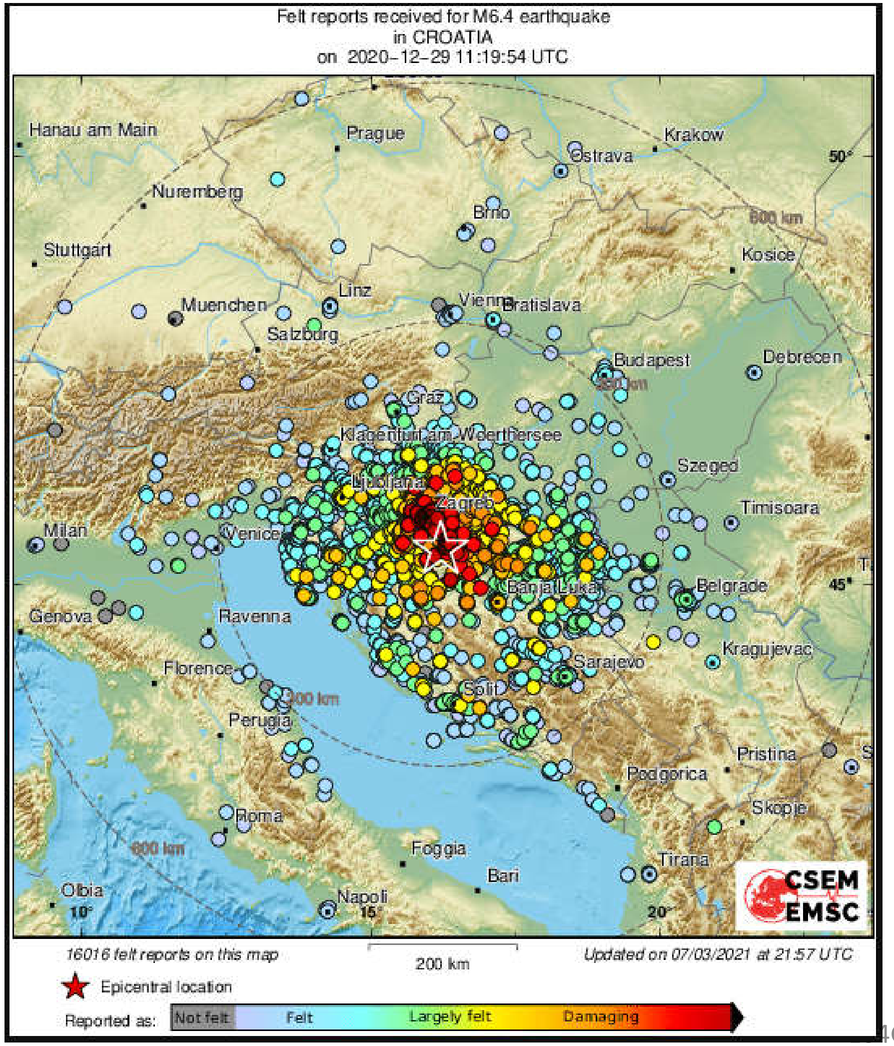
https://earthquake.usgs.gov/earthquakes/eventpage/us70008dx7/map

Zagreb centre, 22nd March 2020



GEOF, GRAD, Af: 22nd March 2020

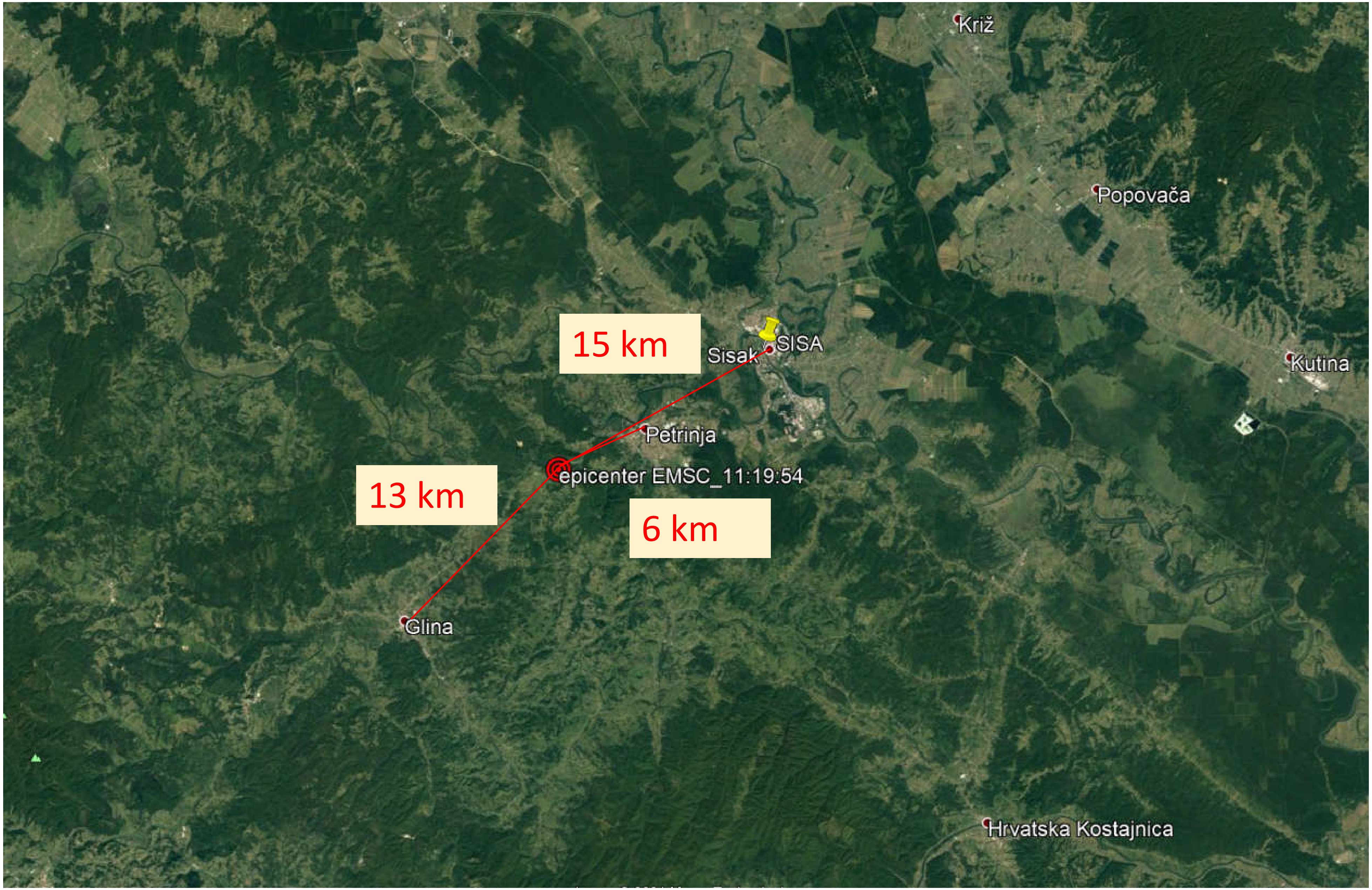
Motivation instead of introduction



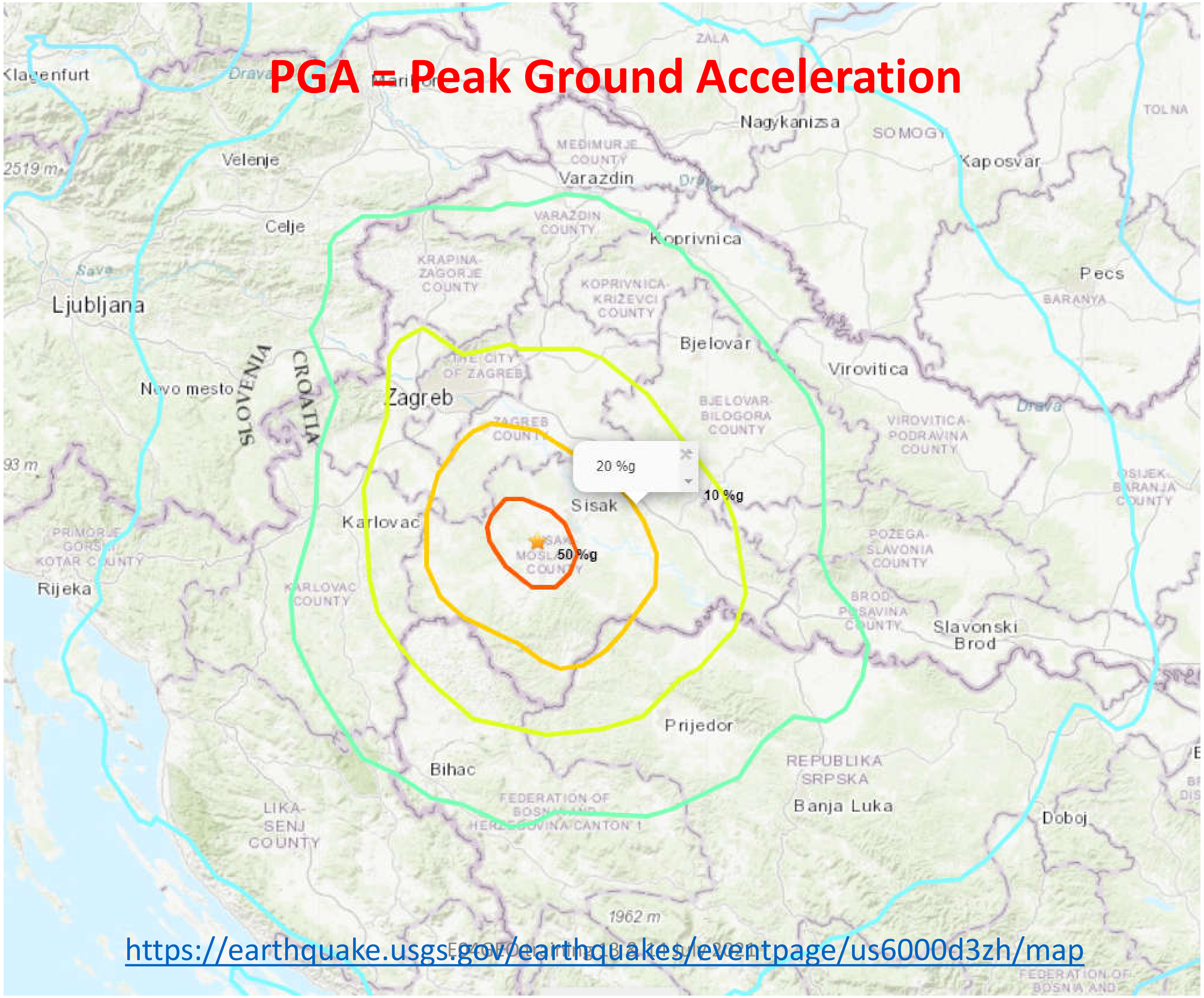
https://www.emsc-csem.org/#2

Petrinja earthquake, 29th December 2020

Source	EMSC
Latitude	45.42°
Longitude	16.21°
Depth	10 km
Magnitude	$M_w = 6.4$
Time of origin	11:19:54.1 UTC


Križ
Popovača
15 km
Sisak
SISA
Kutina
Petrinja
epicenter EMSC_11:19:54
13 km
6 km
Glina
Hrvatska Kostajnica

PGA = Peak Ground Acceleration



https://earthquake.usgs.gov/earthquakes/eventpage/us6000d3zh/map

Petrinja centre, 29th December 2020

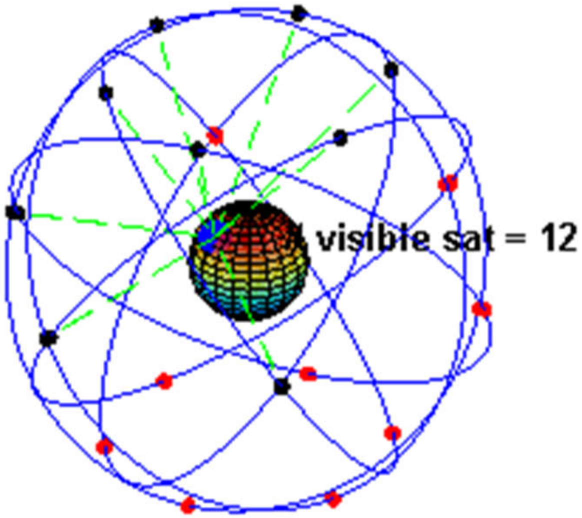
Global Navigation Satellite System (GNSS) – overview & current status

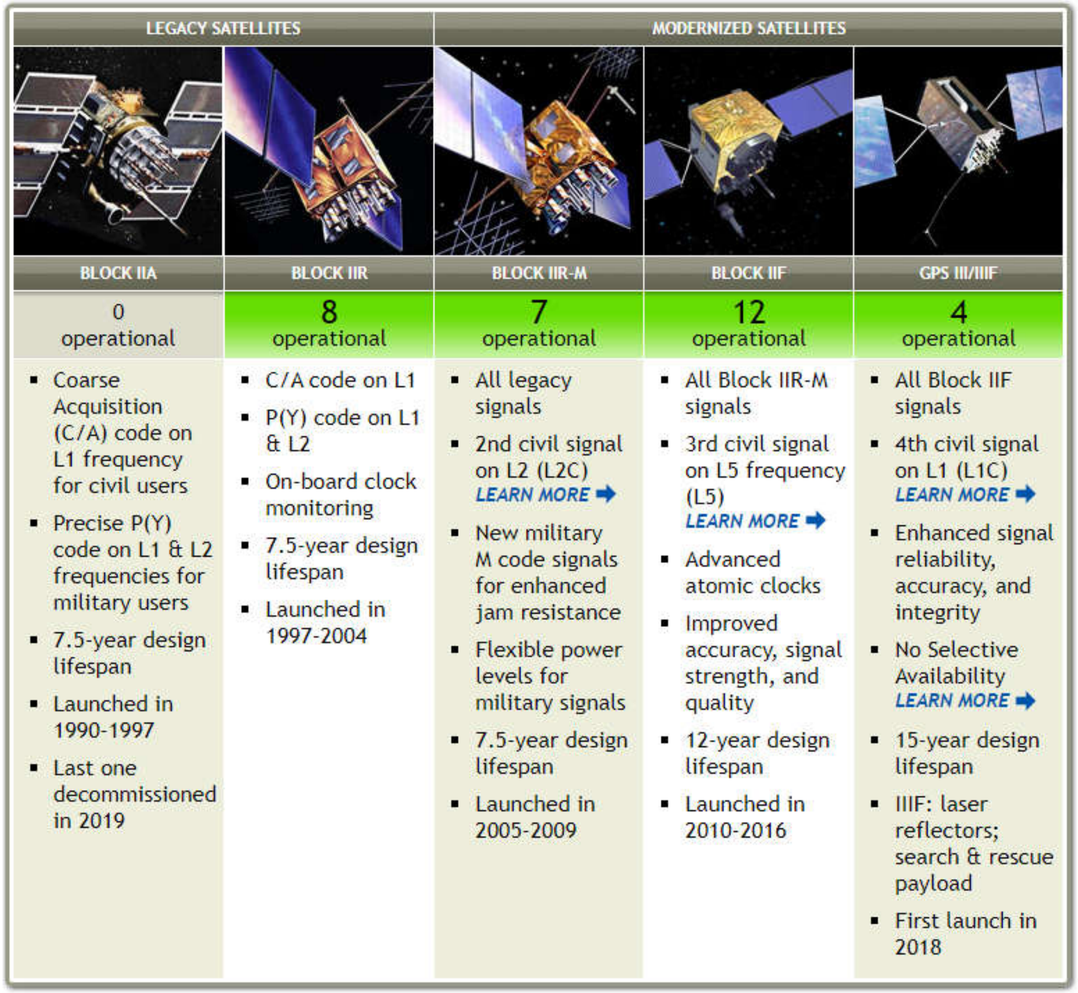
Global Positioning System (GPS)

- Position Velocity Timing (PVT)
- Position Navigation Timing (PNT)
- 1973 – system design
- 1978 – launched the first Block-I satellite
- 1993 – IOC (*Initial Operational Capability*)
- 17th July 1995 – FOC (*Full Operational Capability*): 24 operational satellites
- CDMA (*Code Division Multiple Access*)
- GPS Time (6th January 1980),
  GPS Week (86 400 x 7 = 604 800 s)
- Segments: Space, Control, User

GPS Calendar 2021

July			
Gregor. Date	Day Num-ber	Week / Day	Modif. Julian Day
11 Sun	192	2166 0	59 406
12 Mon	193	1	407
13 Tue	194	2	408
14 Wed	195	3	409
15 Thu	196	4	410
16 Fri	197	5	411
17 Sat	198	6	412
18 Sun	199	2167 0	59 413





LEGACY SATELLITES		MODERNIZED SATELLITES		
BLOCK IIA	BLOCK IIR	BLOCK IIR-M	BLOCK IIF	GPS III/IIIF
0 operational	8 operational	7 operational	12 operational	4 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 ▪ First launch in 2018

Space segment:

- 6 orbital planes
- almost circular orbits at altitude approx. 20200 km
- orbit inclination: 55°
- Orbital period: ½ sideral day: 11h 58min
- Current constellation: 31 operational satellites

https://www.gps.gov/systems/gps/space/

GPS III

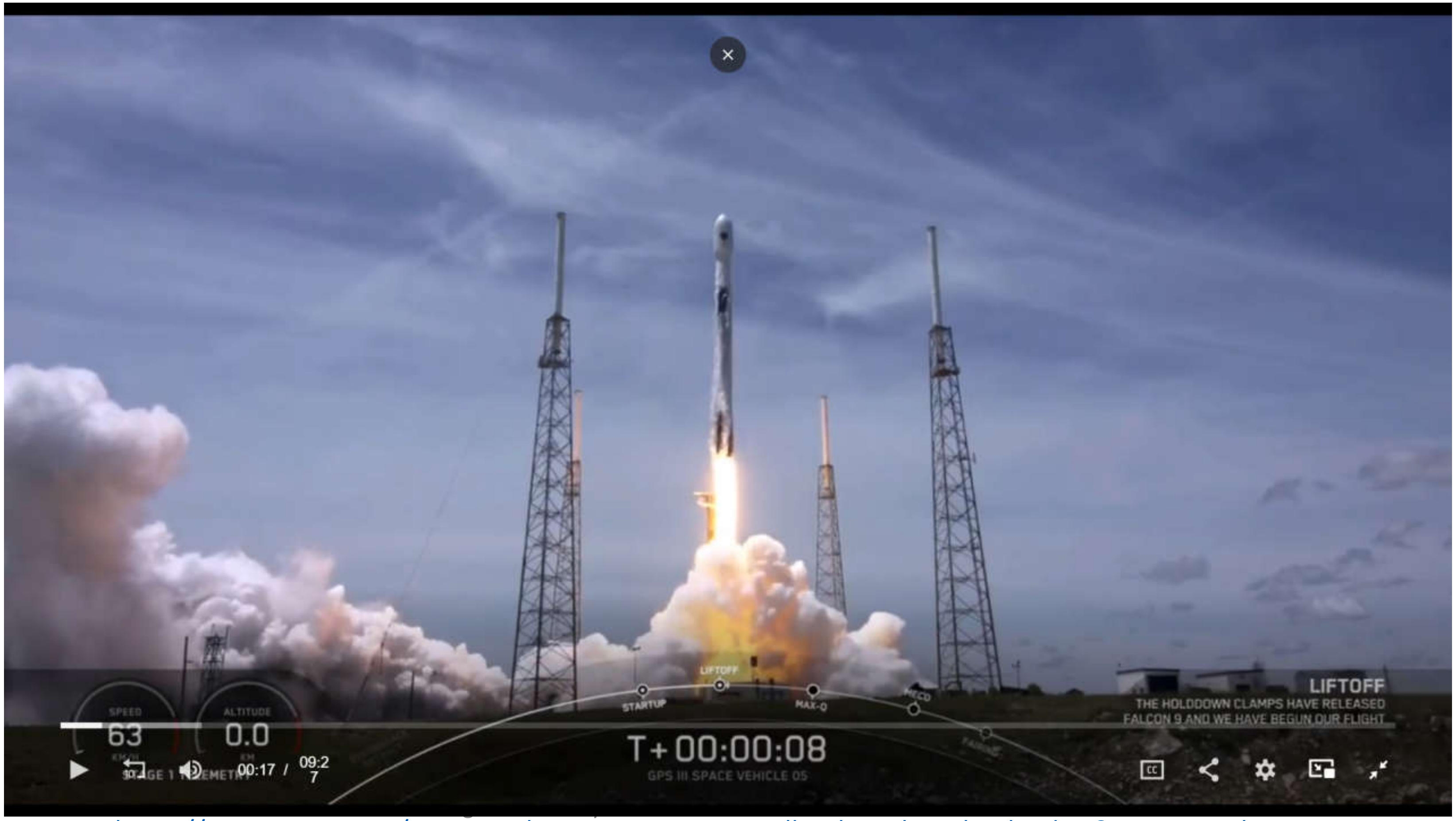
GPS III will meet users' emerging needs and respond to tomorrow's threats with improved safety, signal integrity and unbelievable accuracy.

- On contract for 10 GPS III satellites
- Doubled design life of 15 years
- 3 times more accurate
- 8 times improved anti-jam capability
- L1C Global Navigation Satellite Systems (GNSS) compatibility
- Search and Rescue, Laser Reflector Array and Digital Payload at SV 11+
- Proven compatible with the current GPS constellation and the OCX ground control segment
- Designed to evolve to incorporate new technology and changing mission needs

LOCKHEED MARTIN

Global Positioning System (GPS)

- Latest launch: 17th June 2021, Cape Canaveral, Florida
- GPS III-SV05
  Neil Armstrong
- Lochheed
  Martin
- Space X
  Falcon 9



https://www.space.com/spacex-military-gps-iii-sv05-satellite-launch-rocket-landing?jwsource=cl

GPS CONSTELLATION STATUS, 11.07.21

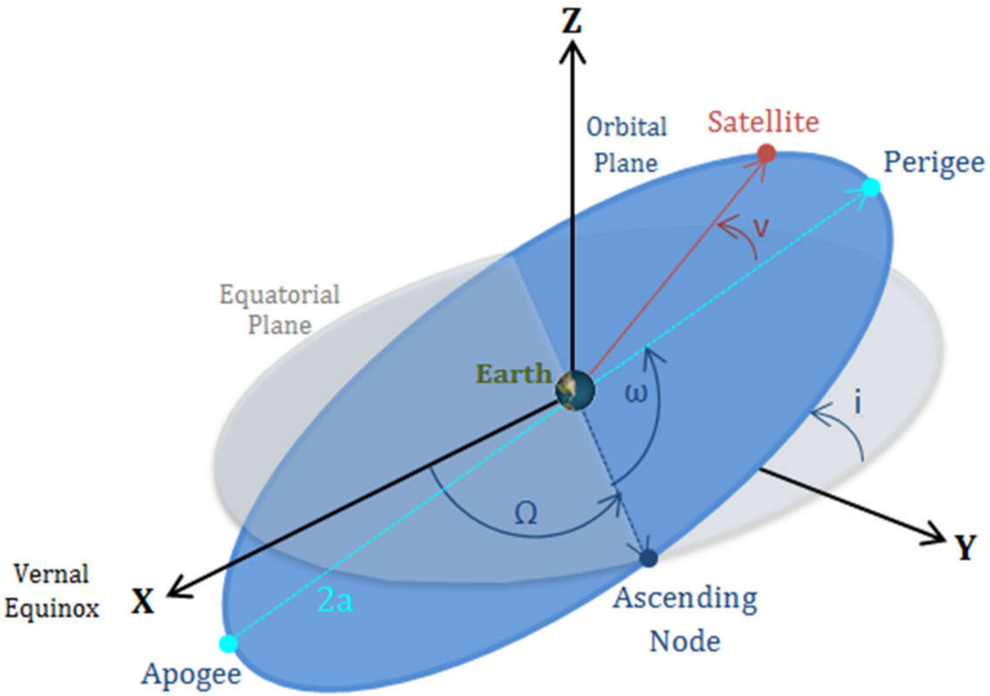
Total satellites in constellation	32 SC
Operational	30 SC
In commissioning phase	1 SC
In maintenance	1 SC
In decommissioning phase	-

Plane	Slot	PRN	NORAD	Type SC	Launch date	Input date	Outage date	Life-time (months)	Notes
A	1	24	38833	II-F	04.10.12	14.11.12		103.9	
	2	31	29486	IIR-M	25.09.06	13.10.06		177.0	
	3	30	39533	II-F	21.02.14	30.05.14		85.4	
	4	7	32711	IIR-M	15.03.08	24.03.08		159.7	
B	1	16	27663	II-R	29.01.03	18.02.03		220.9	
	2	25	36585	II-F	28.05.10	27.08.10		130.6	
	4	12	29601	IIR-M	17.11.06	13.12.06		175.0	
	5	26	40534	II-F	25.03.15	20.04.15		74.8	
	6	14	46826	III-A	05.11.20	02.12.20		7.3	
	6		34661	IIR-M	24.03.09				
C	1	29	32384	IIR-M	20.12.07	02.01.08		162.4	
	2	27	39166	II-F	15.05.13	21.06.13		96.7	
	3	8	40730	II-F	15.07.15	12.08.15		71.0	
	4	17	28874	IIR-M	26.09.05	13.11.05		188.0	
	5	19	28190	II-R	20.03.04	05.04.04		207.3	
D	1	2	28474	II-R	06.11.04	22.11.04		199.7	
	2	1	37753	II-F	16.07.11	14.10.11		117.0	
	3	21	27704	II-R	31.03.03	12.04.03		219.1	
	4	6	39741	II-F	17.05.14	10.06.14		85.1	
	5	11	48859	III-A	17.06.21				In commissioning phase
	6	18	44506	III-A	22.08.19	01.04.20		15.3	
E	1	3	40294	II-F	29.10.14	12.12.14		79.0	
	2	10	41019	II-F	30.10.15	09.12.15		67.1	
	3	5	35752	IIR-M	17.08.09	27.08.09		142.6	
	4	20	26360	II-R	11.05.00	01.06.00		253.5	
	5	23	45854	III-A	30.06.20	01.10.20		9.3	
	6	22	28129	II-R	21.12.03	12.01.04		210.1	
F	1	32	41328	II-F	05.02.16	09.03.16		64.1	
	2	15	32260	IIR-M	17.10.07	31.10.07		164.4	
	3	9	40105	II-F	02.08.14	17.09.14		81.8	
	4	4	43873	III-A	23.12.18	13.01.20		17.9	
	6	13	24876	II-R	23.07.97	31.01.98		281.5	

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

Global Positioning System (GPS)

- **Space segment**

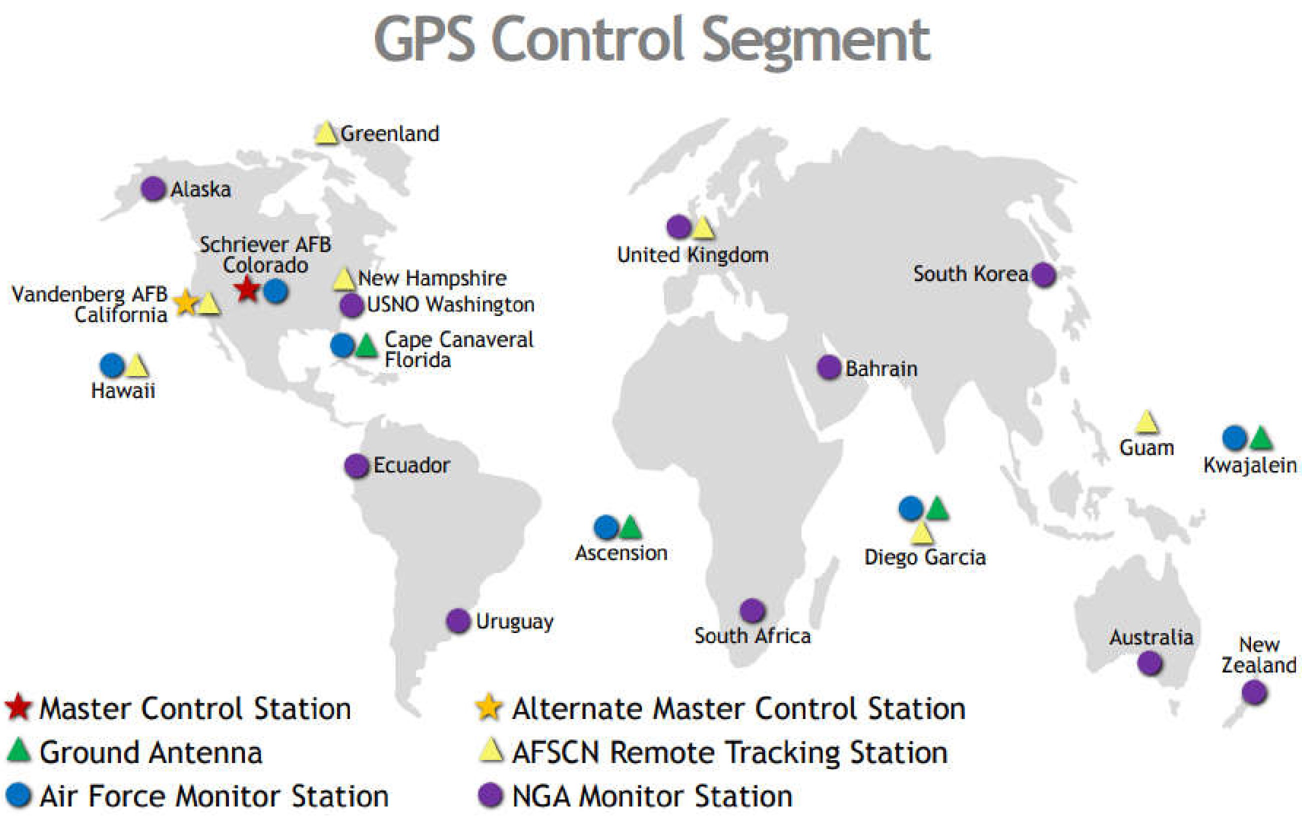


Keplerian elements:

a: Semi-major axis of orbital ellipse
e: Numerical eccentricity of the orbit
i: Inclination of orbital plane
Ω: Right ascension of Ascending Node (RAAN)
ω: Argument of perigee
v: True anomaly
u: Argument of latitude (u = v+ ω)

https://www.gsc-europa.eu/system-service-status/orbital-and-technical-parameters

GPS Control segment



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.

https://www.gps.gov/systems/gps/control/

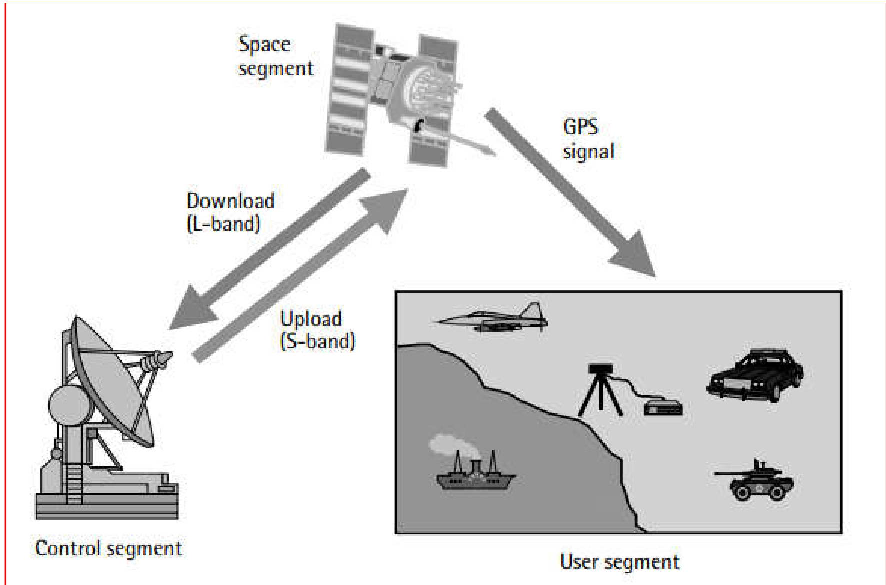


Figure 1.2 GPS segments.

Master Control Station-MCS

GPS Constellation & Frequency bands

Parameter	GPS
Orbital Period (MEO)	11hrs 58min
Orbital Height (MEO)	22,200 Km
Inclination (MEO)	55°
Number of Orbital Planes (MEO)	6
Number of satellites	24 MEOs + 6 spares
Reference frame	WGS-84
Reference time	GPS Time (GPST)

Lower L-band

Upper L-band

L5 **L2** **L1**

Power Spectral Density (PDS)

$$L1 = f_o \times 154 = 1575.42 \text{ MHz}$$

$$L2 = f_o \times 120 = 1227.60 \text{ MHz}$$

$$L5 = f_o \times 115 = 1176.45 \text{ MHz}$$

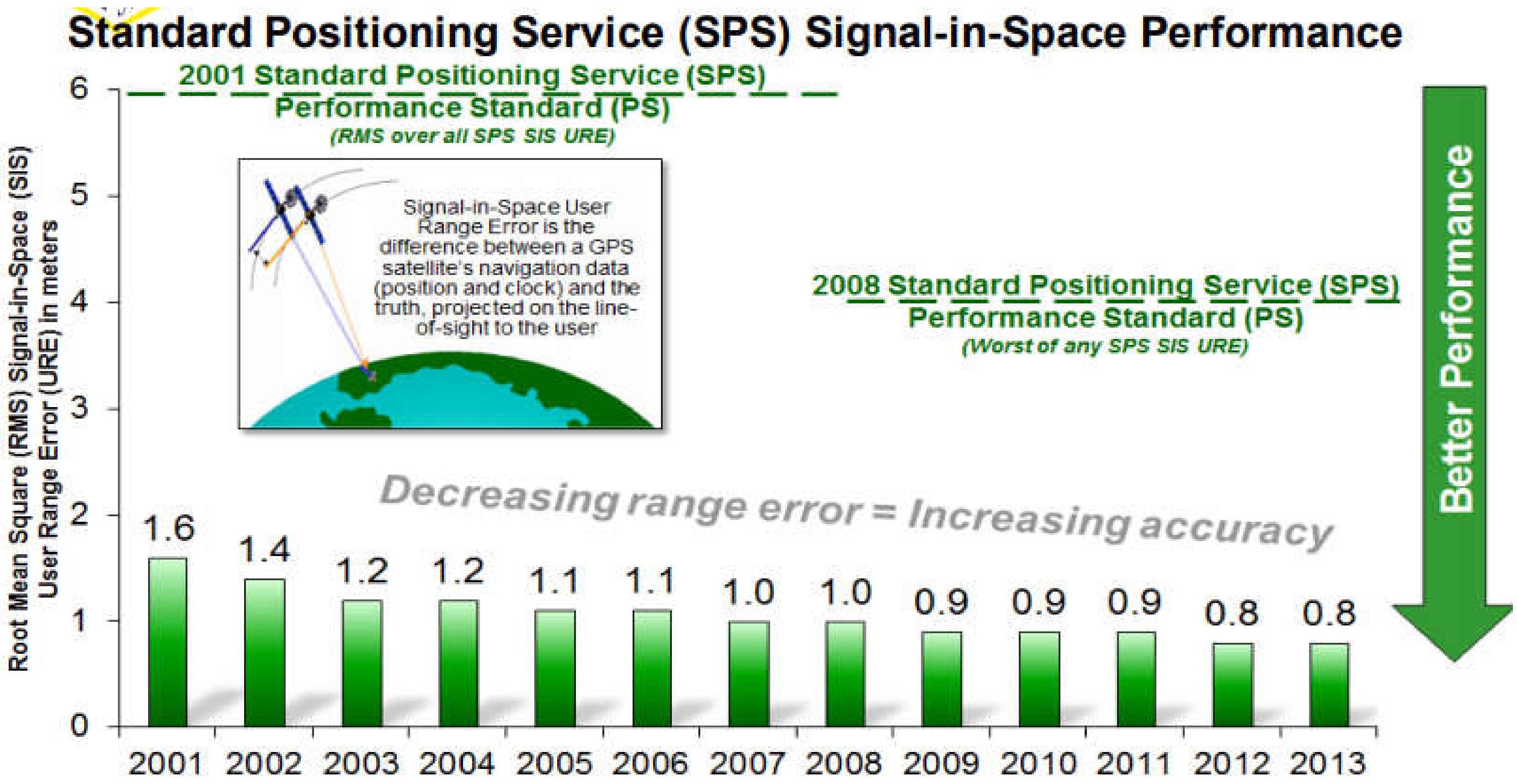
SYSTEM	PROVIDER	SIGNAL
GPS		L1
		L1 C
		L2
		L2 C
		L5

GNSS User Technology Report

European Global Navigation Satellite Systems Agency

Global Positioning System (GPS)

- **Signal-in-Space (SIS)**



https://www.gps.gov/governance/advisory/meetings/2014-06/bailey.pdf

Trimble
GNSS Planning Online

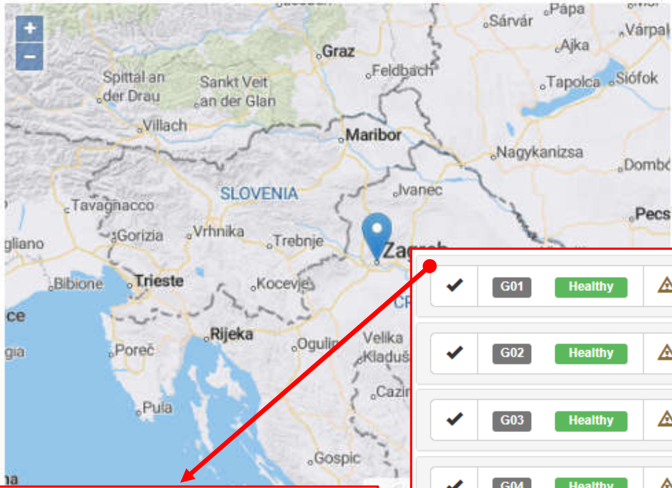
GPS satellites visibility: Zagreb, 13th July 2021

http://www.gnssplanningonline.com/

Settings

- Latitude: N 45° 48' 30.756" °
- Longitude: E 15° 57' 54.8642" °
- Height: 165 m
- Elevation cutoff: 10 °
- Day: 13/07/2021 Today
- Start time: 00:00 UTC +02:00
- Period [hours]: 24
- Time zone: (UTC+01:00) Sarajevo, Skopje, Warsaw, Zagreb

✔ Apply

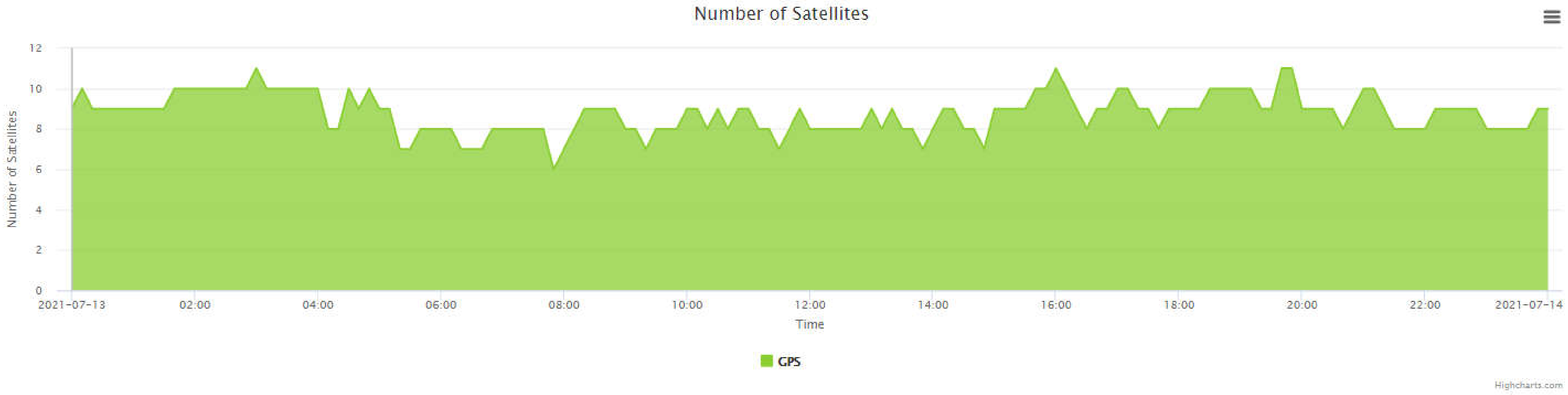


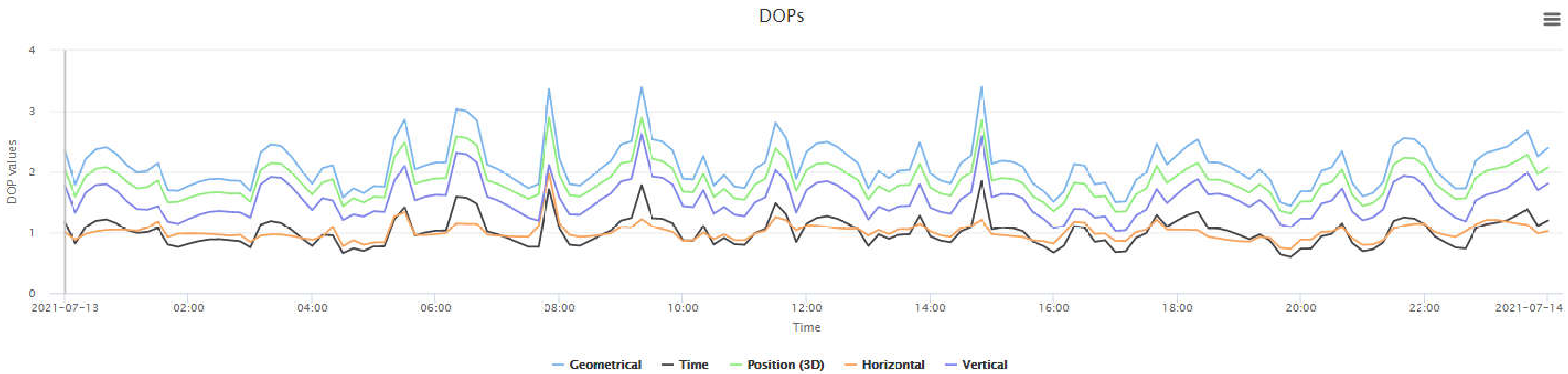
Satellite Selection			
Satellites: 31/129			
System: active		Satellites	
		Selected	Healthy
GPS	✔	31	31
GLONASS	✖	0	23
Galileo	✖	0	18
BeiDou	✖	0	48
QZSS	✖	0	4

Health status:	Healthy 0
Eccentricity:	0.010994
Semimajor axis:	26,559,593.0 m
Right ascension of ascending node:	148.594°
Argument of perigee:	49.069°
Mean anomaly:	147.301°
Inclination:	56.418°
Rate of right ascension:	-0.0004486 °/sec * 10^3
Satellite clock offset:	0 nsec
Satellite clock drift:	0 nsec/s

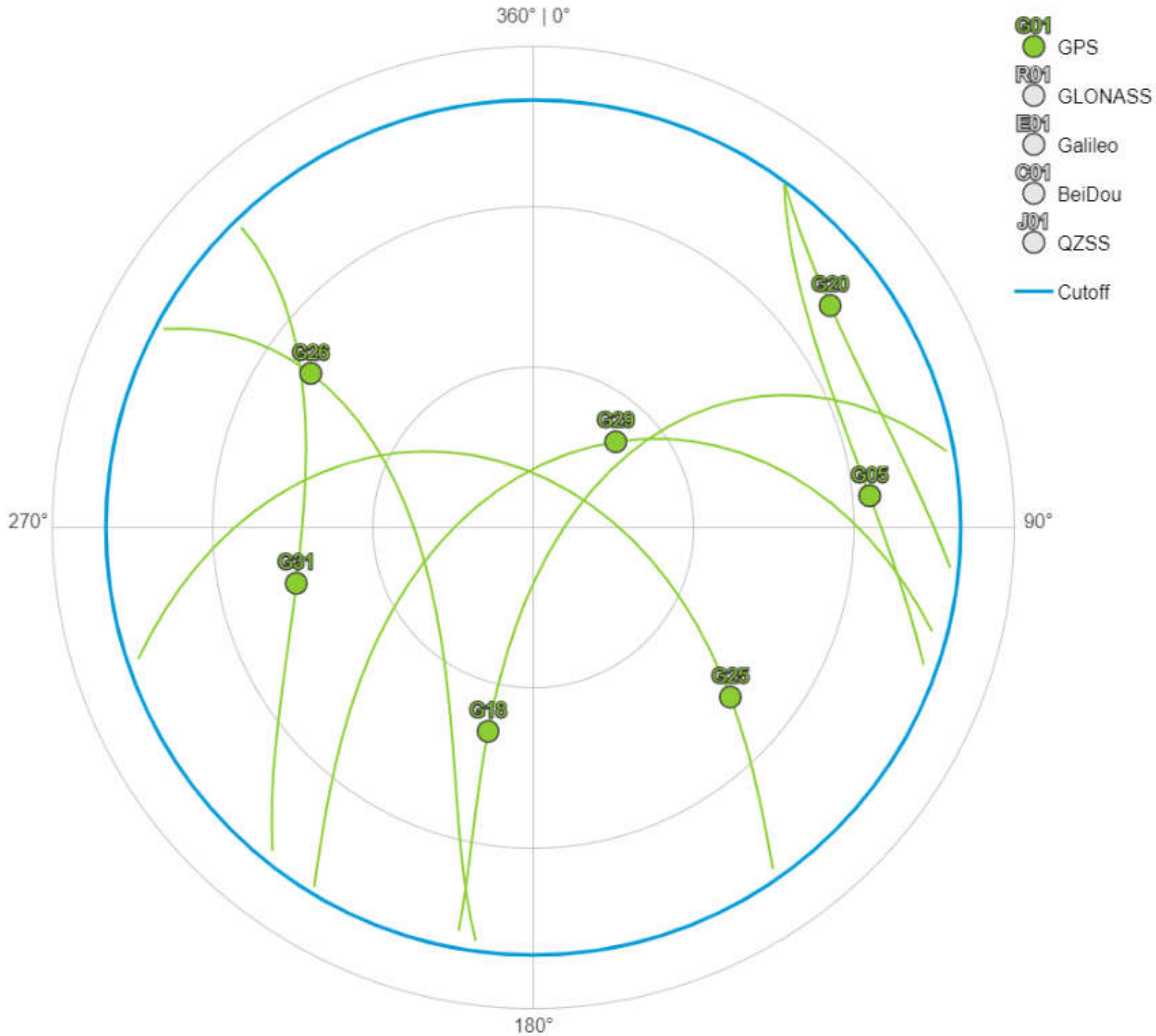
✔	G01	Healthy	✔	G13	Healthy	✔	G24	Healthy
✔	G02	Healthy	✔	G14	Healthy	✔	G25	Healthy
✔	G03	Healthy	✔	G15	Healthy	✔	G26	Healthy
✔	G04	Healthy	✔	G16	Healthy	✔	G27	Healthy
✔	G05	Healthy	✔	G17	Healthy	✔	G28	Healthy
✔	G06	Healthy	✔	G18	Healthy	✔	G29	Healthy
✔	G07	Healthy	✔	G19	Healthy	✔	G30	Healthy
✔	G08	Healthy	✔	G20	Healthy	✔	G31	Healthy
✔	G09	Healthy	✔	G21	Healthy	✔	G32	Healthy
✔	G10	Healthy	✔	G22	Healthy			
✔	G12	Healthy	✔	G23	Healthy			

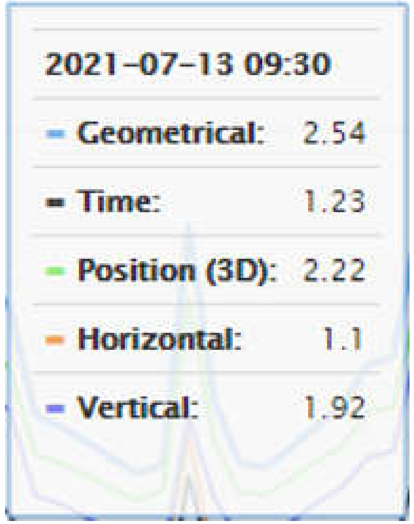
GPS satellites visibility, Zagreb, 13th July 2021, 0-24h (UTC+2)





GPS satellites visibility, Zagreb, 13th July 2021, 09:30 (UTC+2)



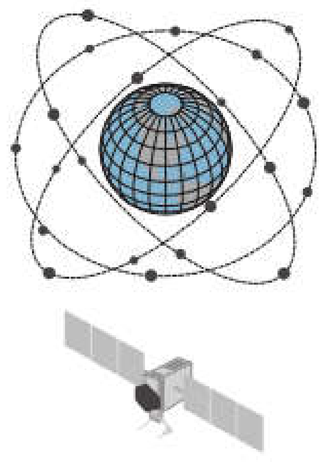


$$\frac{\mathrm{VDOP}}{\mathrm{HDOP}} = \frac{1.92}{1.1} = 1.75$$

Heights determined with GPS are 1.5 – 2 times worse than position

GLONASS - Globalnaja navigacionaja sputnikovaja sistema

- 1982 – launched the first satellite
- 1996 - FOC (*Full Opetational Capability*) – 24 satellites
- System degradation: in 2002 there were only 7 operational satellites
- 2011 – FOC reestablished
- 3 orbital planes
- Orbital altitude 19 130 km
- Orbit inclination 64.8°
- Orbital period 11h 15min
- PZ-90.11
- UTC(SU)
- FDMA – Frequency Division Multiple Access



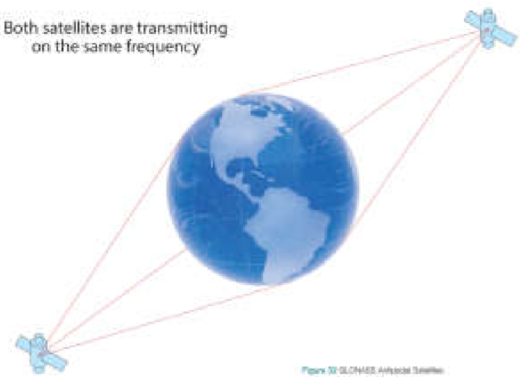
GLONASS
3 Orbital planes
21 Satellites + 3 spares
64.8° Inclination angle
Altitude 19,100 km

CAPABILITIES	GLONASS	GLONASS-M	GLONASS-K	GLONASS-K2
Time of Deployment	1982-2005	2003-2016	2011-2018	2017+
Status	Decommissioned	In use	Design maturation based on in-orbit validation	In development
Nominal Orbit Parameters	Circular Altitude - 19,100 km Inclination - 64,8° Period - 11 h 15 min 44 sec			
Number of Satellites in the Constellation (Used for Navigation)	24			
Number of Orbital Planes	3			
Number of Satellites in a Plane	8			
Design Lifetime, years	3.5	7	10	10
Mass, kg	1500	1415	935	1600
Clock Stability, as per Specification/Observed	$5*10^{-13}$ / $1*10^{-13}$	$1*10^{-13}$ / $5*10^{-14}$	$1*10^{-13}$ / $5*10^{-14}$	$1*10^{-14}$ / $5*10^{-15}$
Signal Type	FDMA	FDMA (+CDMA for SVs 755-761)	FDMA and CDMA	FDMA and CDMA

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


```
Glonass G1        1602+k*9/16
        G2        1246+k*7/16
```

k = -7, -6, … +5, +6.



GLONASS

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		139.0	+	+ 10:38 11.07.21	In operation
2	1	-4	747	26.04.13	04.07.13		98.6	+	+ 10:38 11.07.21	In operation
3	1	05	744	04.11.11	08.12.11		116.3	+	+ 10:38 11.07.21	In operation
4	1	06	759	11.12.19	03.01.20		19.0	+	+ 10:38 11.07.21	In operation
5	1	01	756	17.06.18	29.08.18		36.8	+	+ 10:38 11.07.21	In operation
6	1	-4	733	14.12.09	24.01.10		139.0	+	+ 10:38 11.07.21	In operation
7	1	05	745	04.11.11	18.12.11		116.3	+	+ 10:38 11.07.21	In operation
8	1	06	743	04.11.11	20.09.12		116.3	+	+ 10:38 11.07.21	In operation
9	2	-2	702	01.12.14	15.02.16		79.4	+	+ 10:38 11.07.21	In operation
10	2	-7	723	25.12.07	22.01.08		162.6	+	+ 10:38 11.07.21	In operation
11	2	00	705	25.10.20			8.5	-	- 10:38 11.07.21	Flight Tests
12	2	-1	758	27.05.19	22.06.19		25.5	+	+ 10:38 11.07.21	In operation
13	2	-2	721	25.12.07	08.02.08		162.6	+	+ 10:38 11.07.21	In operation
14	2	-7	752	22.09.17	16.10.17		45.6	+	+ 10:38 11.07.21	In operation
15	2	00	757	03.11.18	27.11.18		32.3	+	+ 10:38 11.07.21	In operation
16	2	-1	736	02.09.10	04.10.10		130.4	+	+ 10:38 11.07.21	In operation
17	3	04	751	07.02.16	28.02.16		65.1	+	+ 10:38 11.07.21	In operation
18	3	-3	754	24.03.14	14.04.14		87.6	+	+ 10:38 11.07.21	In operation
19	3	03	720	26.10.07	25.11.07		164.6	+	+ 10:38 11.07.21	In operation
20	3	02	719	26.10.07	27.11.07		164.6	+	+ 10:38 11.07.21	In operation
21	3	04	755	14.06.14	03.08.14		85.0	+	+ 10:38 11.07.21	In operation
22	3	-3	735	02.03.10	28.03.10		136.4	+	+ 10:38 11.07.21	In operation
23	3	03	732	02.03.10	28.03.10		136.4	+	+ 10:38 11.07.21	In operation
24	3	02	760	16.03.20	14.04.20		15.8	+	+ 10:38 11.07.21	In operation
15	2		716	25.12.06	12.10.07	24.11.18	174.6			Spares
11	2		753	29.05.16	27.06.16	19.11.20	61.4			Maintenance
20	3	-6	701	26.02.11			124.5			Flight Tests

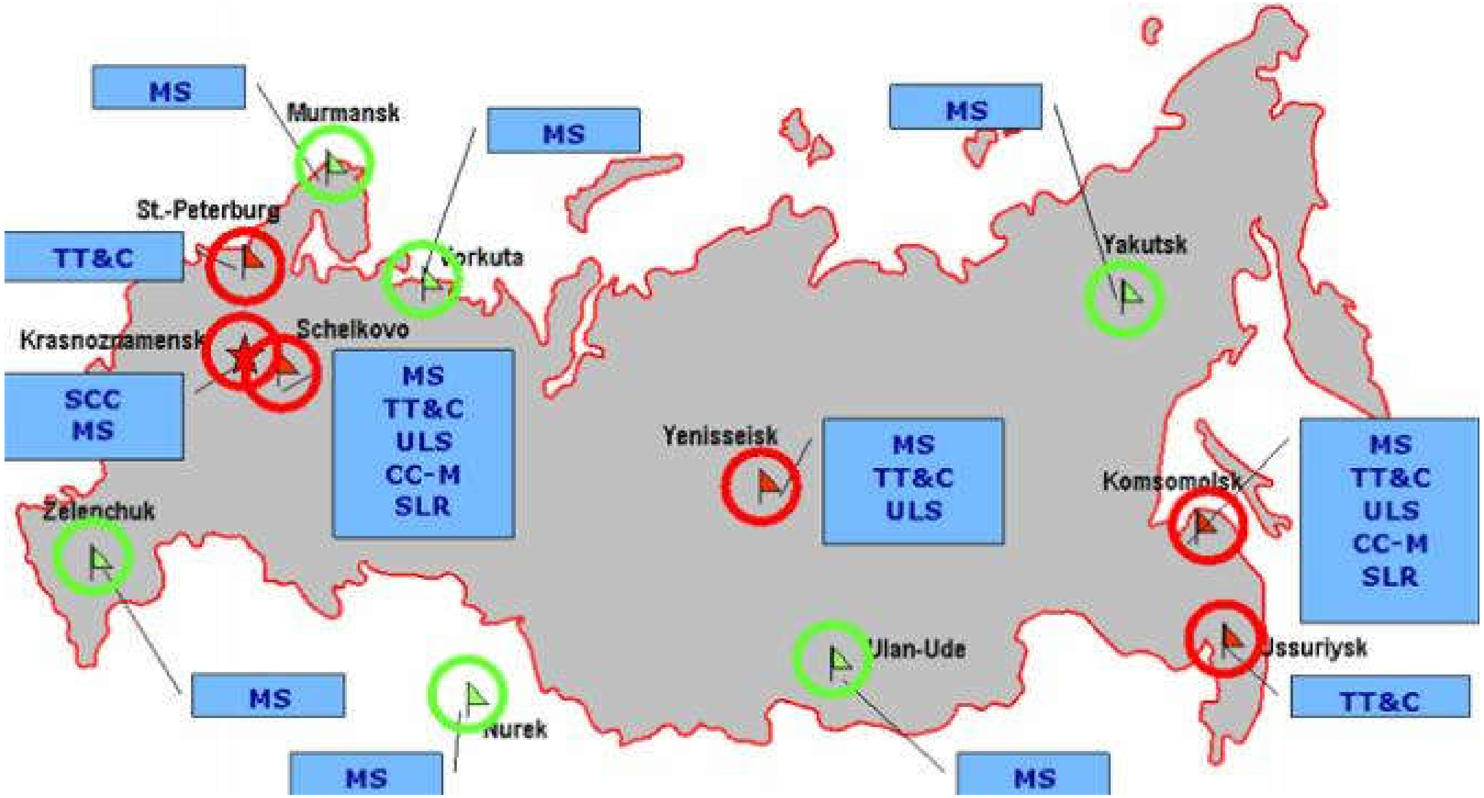
https://www.glonass-iac.ru/en/GLONASS/

GLONASS CONSTELLATION STATUS, 11.07.2021

Total satellites in constellation	27 SC
Operational	23 SC
In commissioning phase	-
In maintenance	1 SC
Under check by the Satellite Prime Contractor	-
Spares	1 SC
In flight tests phase	2 SC

Launching of GLONASS-K, 25th October 2020 on Soyuz-2 rocket from the Plesetsk cosmodrome

GLONASS control segment



http://www.navipedia.net/index.php/GLONASS_Ground_Segment

- System Control Centre (Kraznoznamensk - Moscow)
- Central Clock (Schelkovo)
- 5 Telemetry, Tracking and Command – TT&C
- 3 Upload Stations – ULS
- 2 Laser Ranging Stations (SLR)
- 10 Monitoring and Measuring Stations (MS)

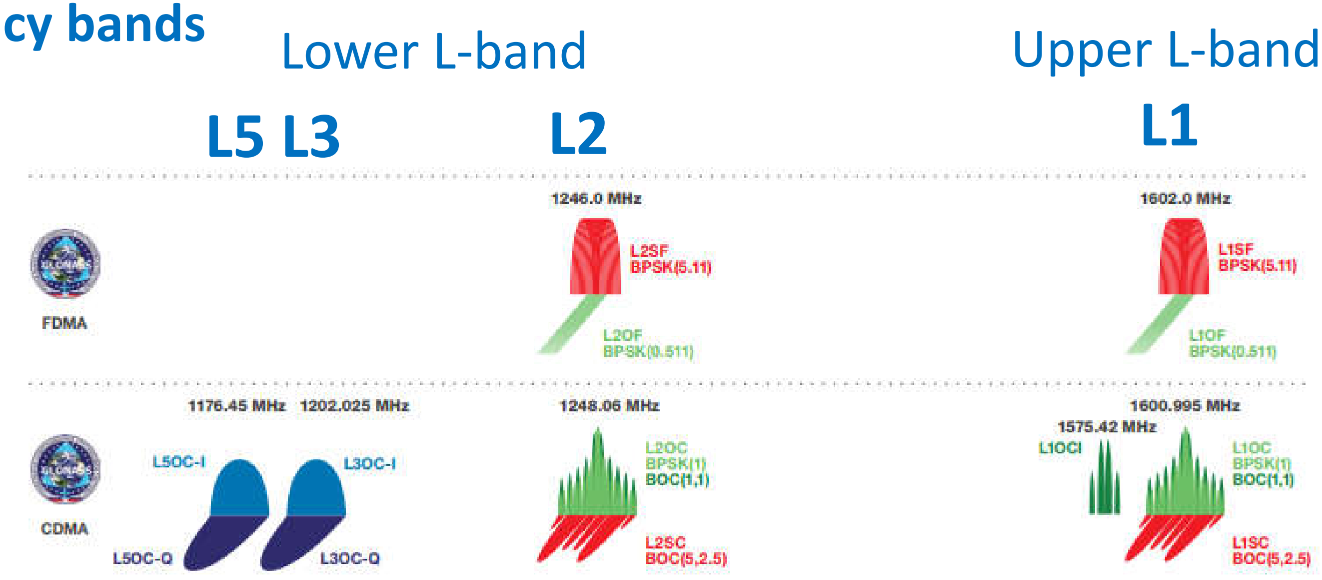
additional Tracking Stations outside Russian territory

GLONASS Constellation & Frequency bands

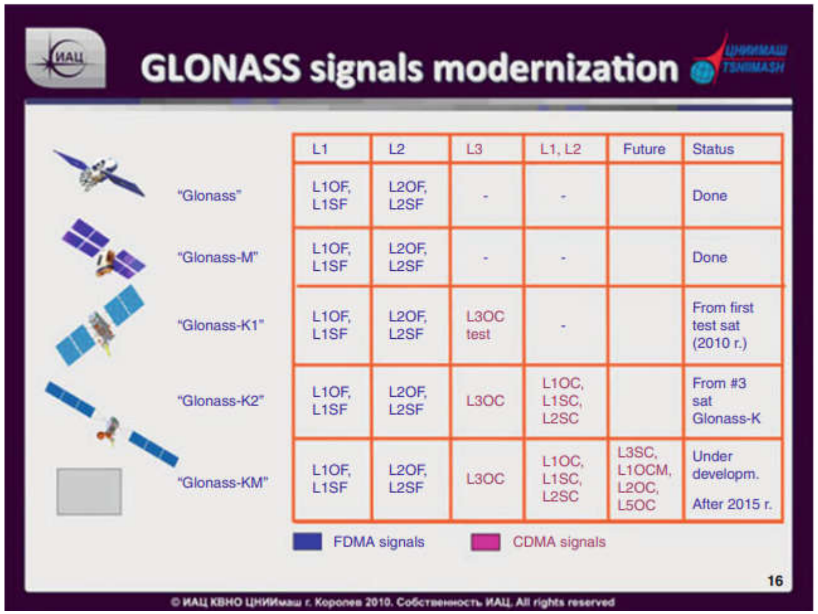
Parameter	GLONASS
Orbital Period (MEO)	11hrs 15mins
Orbital Height (MEO)	19,100 Km
Inclination (MEO)	64,8°
Number of Orbital Planes (MEO)	3
Number of satellites	24 MEOs + 2 spares
Reference frame	PZ-90
Reference time	GLONASS Time (GLONASST)

GNSS User Technology Report

European Global Navigation Satellite Systems Agency



Power Spectral Density (PDS)



GLONASS signals modernization

	L1	L2	L3	L1, L2	Future	Status
"Glonass"	L1OF, L1SF	L2OF, L2SF	-	-		Done
"Glonass-M"	L1OF, L1SF	L2OF, L2SF	-	-		Done
"Glonass-K1"	L1OF, L1SF	L2OF, L2SF	L3OC test	-		From first test sat (2010 г.)
"Glonass-K2"	L1OF, L1SF	L2OF, L2SF	L3OC	L1OC, L1SC, L2SC		From #3 sat Glonass-K
"Glonass-KM"	L1OF, L1SF	L2OF, L2SF	L3OC	L1OC, L1SC, L2SC	L3SC, L1OCM, L2OC, L5OC	Under developm. After 2015 г.

FDMA signals CDMA signals

16

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GLONASS	L1 FDMA L1 CDMA L2 FDMA L2 CDMA L3 CDMA L5 CDMA

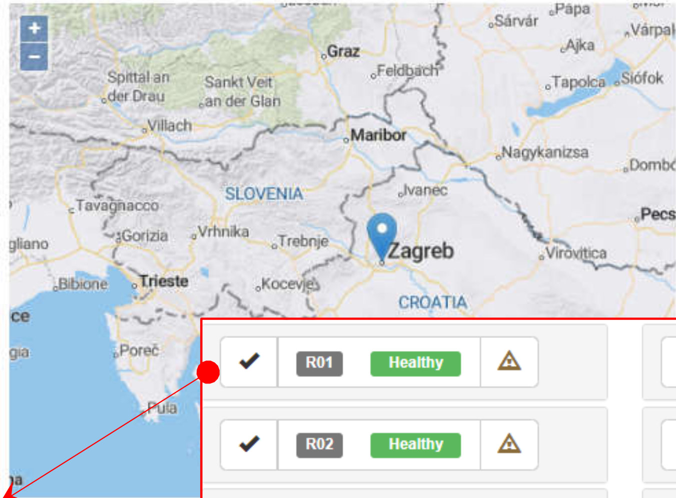
GLONASS satellites visibility: Zagreb, 13th July 2021

Trimble GNSS Planning Online

http://www.gnssplanningonline.com/

Settings

Latitude:	N 45° 48' 30.756" °
Longitude:	E 15° 57' 54.8642" °
Height:	165 m
Elevation cutoff:	10 °
Day:	13/07/2021 Today
Start time:	00:00 UTC +02:00
Period [hours]:	24
Time zone:	(UTC+01:00) Sarajevo, Skopje, Warsaw, Zagreb



Satellite Selection

Change selection

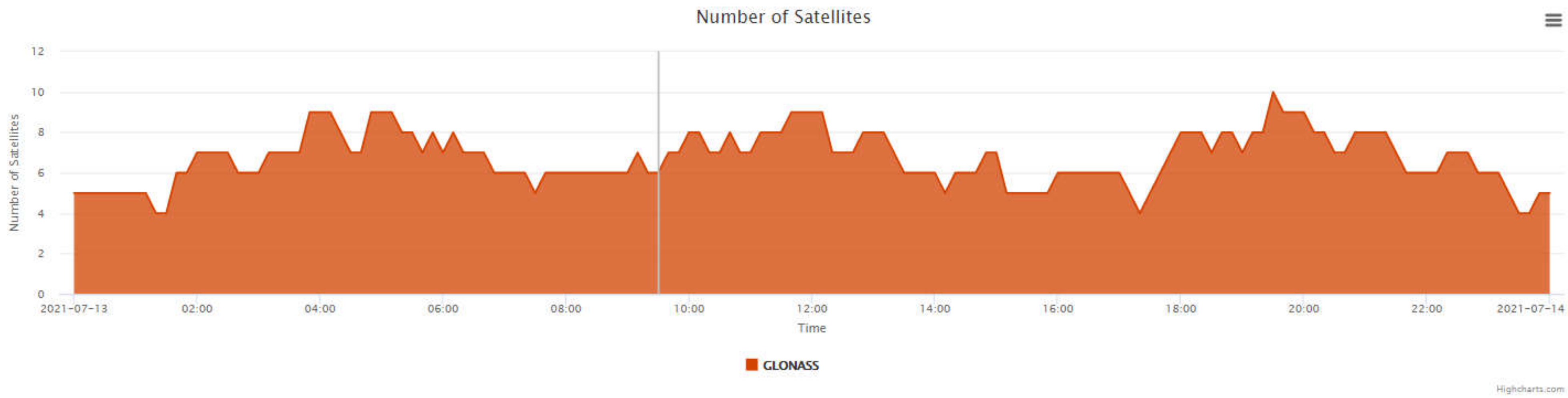
Satellites: 23/129

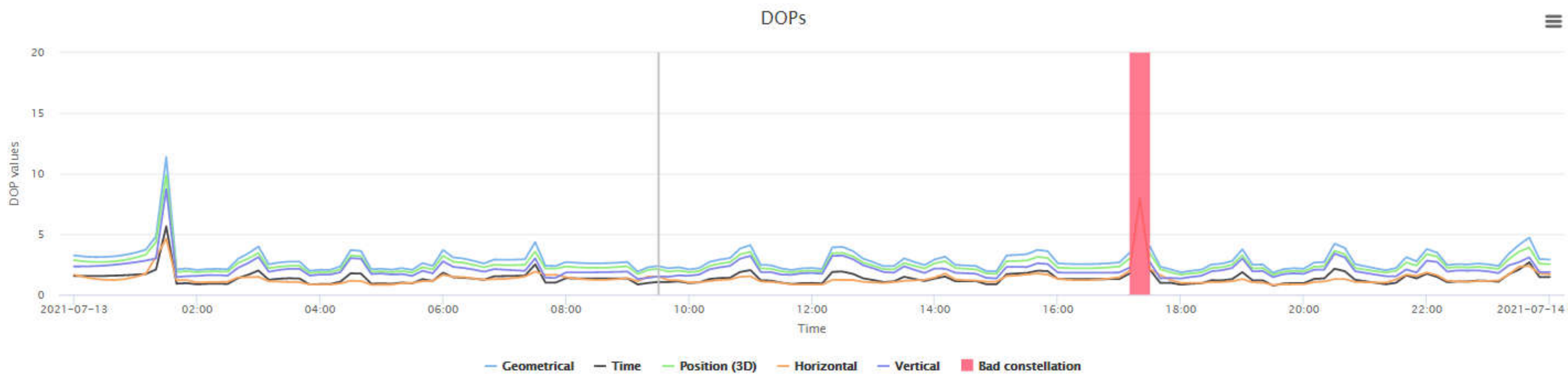
System: active		Satellites Selected	Satellites Healthy
GPS	✗	0	31
GLONASS	✓	23	23
Galileo	✗	0	18
BeiDou	✗	0	48
QZSS	✗	0	4

✓ R01 Healthy	✓ R09 Healthy	✓ R17 Healthy
✓ R02 Healthy	✓ R10 Healthy	✓ R18 Healthy
✓ R03 Healthy	R11 Unhealthy	✓ R19 Healthy
✓ R04 Healthy	✓ R12 Healthy	✓ R20 Healthy
✓ R05 Healthy	✓ R13 Healthy	✓ R21 Healthy
✓ R06 Healthy	✓ R14 Healthy	✓ R22 Healthy
✓ R07 Healthy	✓ R15 Healthy	✓ R23 Healthy
✓ R08 Healthy	✓ R16 Healthy	✓ R24 Healthy

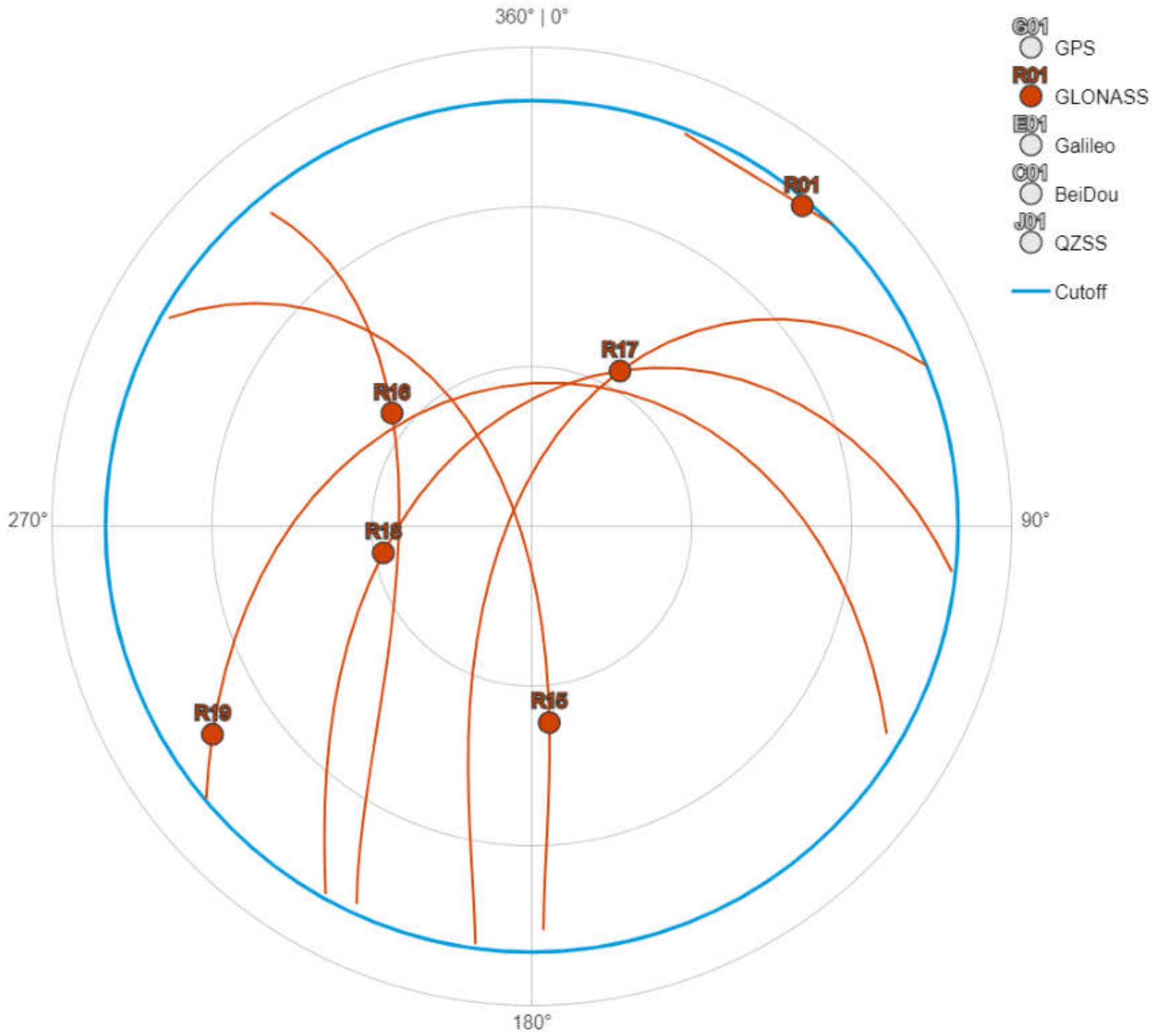
Health status:	Healthy 0
Eccentricity:	0.00047
Semimajor axis:	25,508,560.4 m
Right ascension of ascending node:	-120.589°
Argument of perigee:	-28.542°
Mean anomaly:	28.508°
Inclination:	64.262°
Rate of right ascension:	-0.0003929 °/sec * 10^3
Satellite clock offset:	-80108.6 nsec
Satellite clock drift:	0 nsec/s

GLONASS satellites visibility, Zagreb, 13th July 2021, 0-24h (UTC+2)





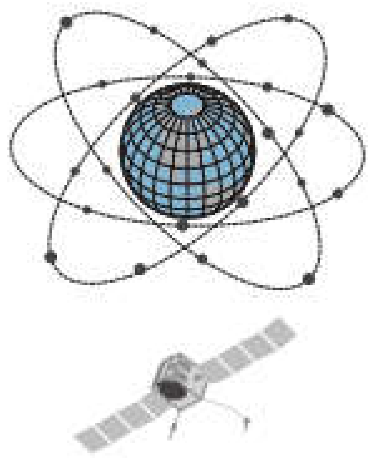
GLONASS satellites visibility, Zagreb, 13th July 2021, 0-24h (UTC+2)



$$\frac{\mathrm{VDOP}}{\mathrm{HDOP}} = \frac{1.5}{1.5} = 1.00$$

Galileo

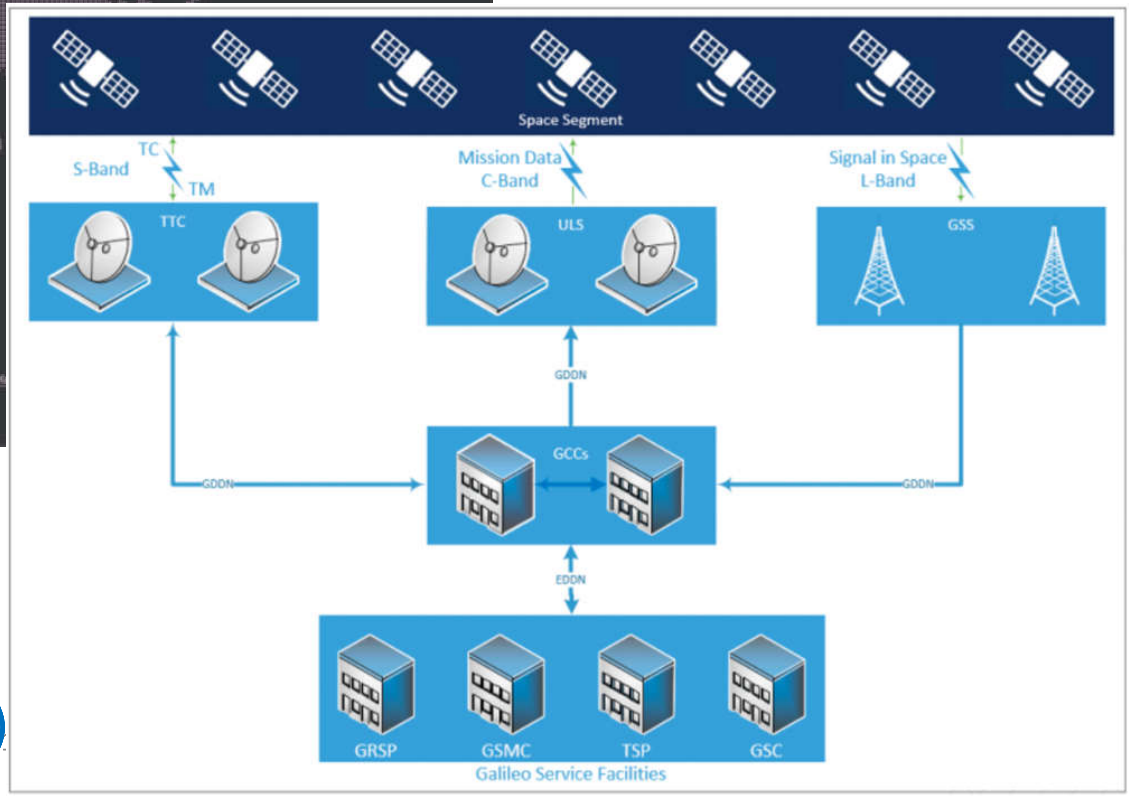
- Galileo di Vincenzo Bonaiuti de' Galilei (Pisa, 1564 – Arcetri, 1642)
- System financed by EC (European Commission)
- System developed by ESA (European Space Agency)
- First GNSS under civilian control
- 27 satellites + 3 spares
- 3 almost circular orbit at altitude 23222 km
- Orbit inclination: 56°
- Orbital period: 14h 04min
- Currently Galileo system is under development



Galileo
3 Orbital planes
27 Satellites + 3 spares
56° Inclination angle
Altitude 23,222 km

Galileo Control Segment

Galileo Ground Segment Architecture



- 2 Control Centers
- Galileo Sensor Stations (GSS),
- Galileo Uplink Stations (ULS),
- Telemetry, Tracking & Control stations (TT&C)

Galileo development:

- GioveA (2005.) i GioveB (2008.) – **G**alileo **I**n **O**rbit **V**alidation **E**lements
- 2005-2014: IOV phase
- from 2014 on: FOC phase

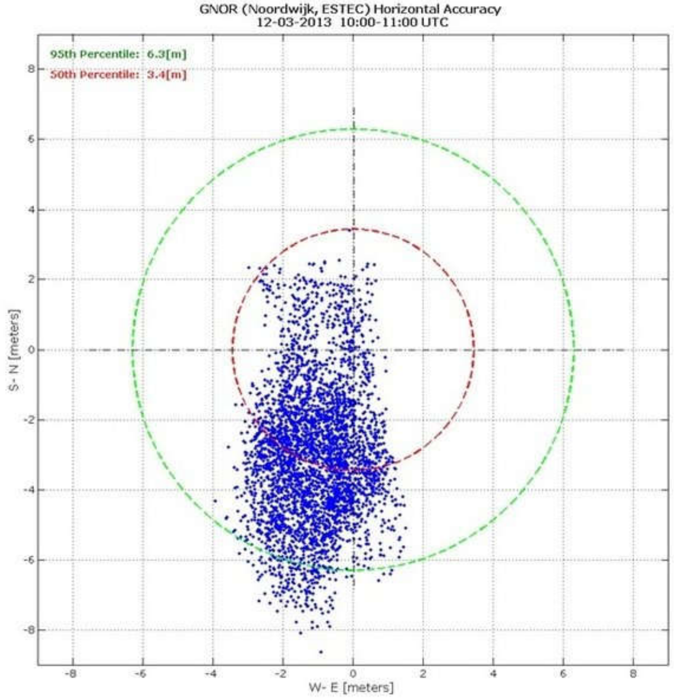
Satellites	Mission Name	Launch Dates	Satellite names	Status
Sat. 26	Galileo Sat 23, 24,25,26	25.07.2018	GSAT-222	In-orbit Testing
Sat. 25			GSAT-221	
Sat. 24			GSAT-220	
Sat. 23			GSAT-219	
Sat. 22	Galileo Sat 19, 20,21,22	12.12.2017	GSAT-218	
Sat. 21			GSAT-217	
Sat. 20			GSAT-216	
Sat. 19			GSAT-215	
Sat. 18	Galileo Sat 15, 16, 17, 18	17.11.2016	GSAT-214	Operational status on
Sat. 17			GSAT-213	
Sat. 16			GSAT-212	www.gsc-europa.eu/system-status/Constellation-Information
Sat. 15			GSAT-207	
Sat. 14	Galileo Sat 13 & 14	24.05.2016	GSAT-211	
Sat. 13			GSAT-210	
Sat. 12	Galileo Sat 11 & 12	17.12.2016	GSAT-209	
Sat. 11			GSAT-208	
Sat. 10	Galileo Sat 9 & 10	11.09.2015	GSAT-206	
Sat. 9			GSAT-205	
Sat. 8	Galileo Sat 7 & 8	27.03.2015	GSAT-204	
Sat. 7			GSAT-203	
Sat. 6	Galileo Sat 5 & 6	22.08.2014	GSAT-202	
Sat. 5			GSAT-201	
Sat. 4	IOV-2	12.10.2012	GSAT-104	
Sat. 3			GSAT-103	
Sat. 2	IOV-1	21.10.2011	GSAT-102	
Sat. 1			GSAT-101	
GIOVE-B		27.04.2008		Retired
GIOVE-A		28.12.2005		Retired

4 satellites deployed with a single launch vehicle

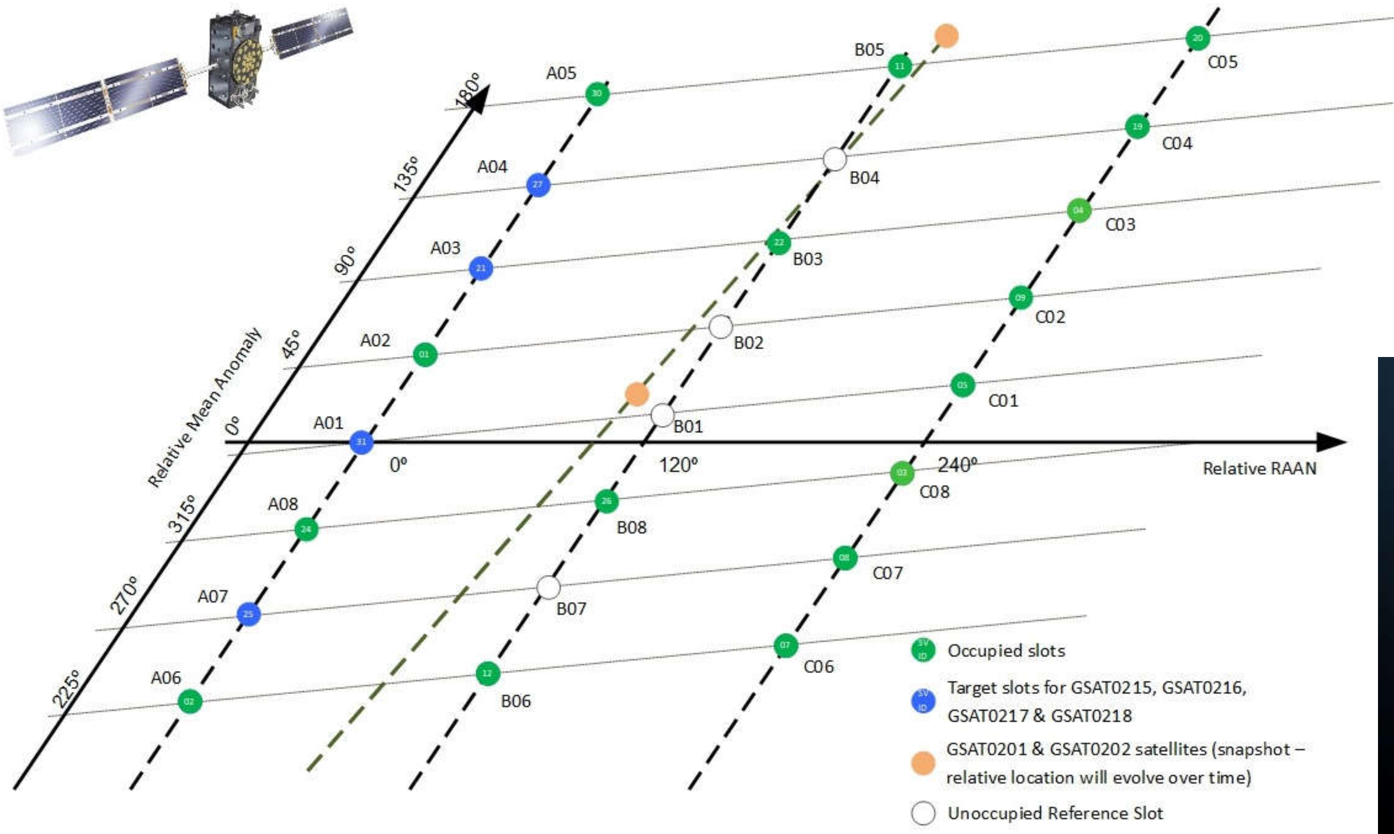
Launched in eccentric orbit!

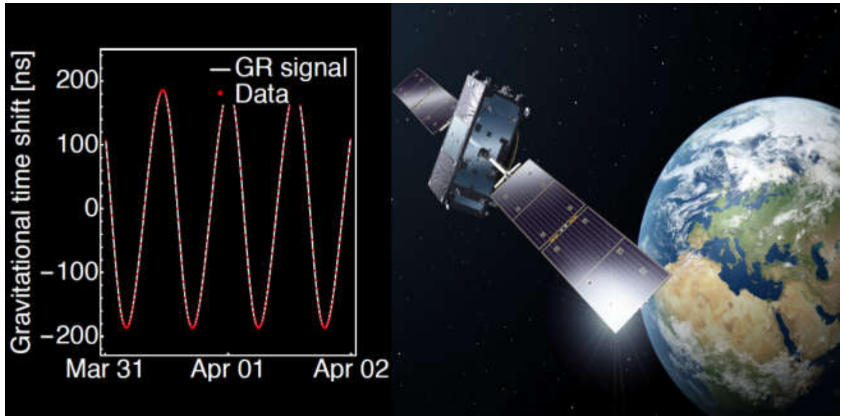
12th March 2013

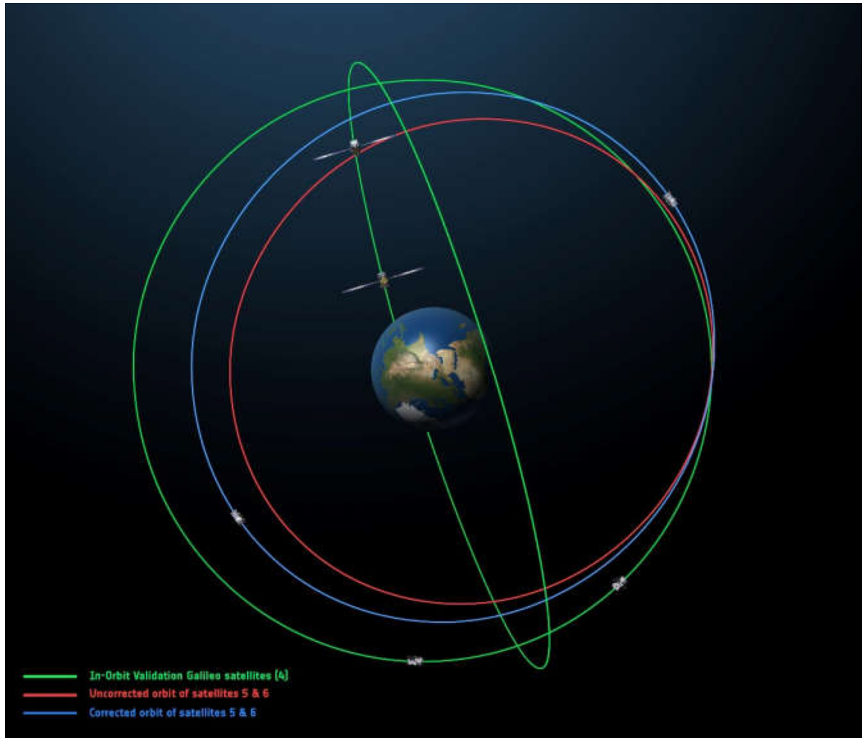
- first position fix



Galileo


Relative Mean Anomaly
0°
45°
90°
135°
180°
225°
270°
315°
Relative RAAN
0°
120°
240°
A01
A02
A03
A04
A05
A06
A07
A08
B01
B02
B03
B04
B05
B06
B07
B08
C01
C02
C03
C04
C05
C06
C07
C08
Occupied slots
Target slots for GSAT0215, GSAT0216, GSAT0217 & GSAT0218
GSAT0201 & GSAT0202 satellites (snapshot – relative location will evolve over time)
Unoccupied Reference Slot


Gravitational time shift [ns]
200
100
0
−100
−200
Mar 31
Apr 01
Apr 02
GR signal
Data


In-Orbit Validation Galileo satellites (4)
Uncorrected orbit of satellites 5 & 6
Corrected orbit of satellites 5 & 6

GALILEO Initial services:

- **Declaration on 15th December 2016**
- **Galileo satellites (Space Segment) and infrastructure on Earth (Control Segment) were ready for the provision of 3 services:**
    - **Open Service**
    - **Public Regulated Service**
    - **Search and Rescue Service**
- **Initial services were declared with 18 satellites in constellation:**
    - **12 operational satellites**
    - **4 being deployed (in-orbit-testing)**
    - **2 satellites launced in eccentric orbit (EO)**

Galileo services:

once fully operational, Galileo will offer four high-performance services worldwide:

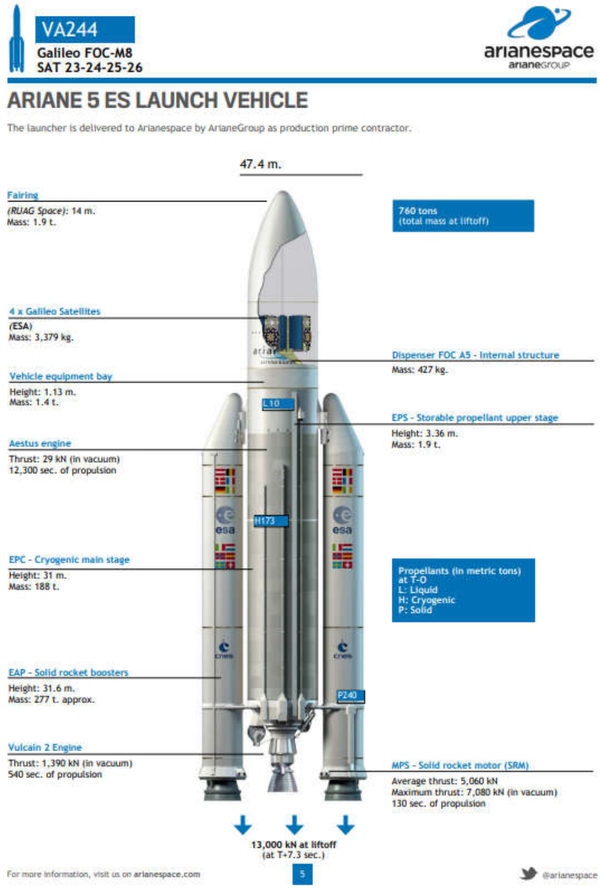
- **Open Service (OS)**: Galileo open and free of charge service set up for positioning and timing services. In the future, the Galileo Open Service will also provide Navigation Message Authentication, which will allow the computation of the user position using authenticated data extracted from the navigation message.
- **High Accuracy Service (HAS)**: A service complementing the OS by providing an additional navigation signal and added-value services in a different frequency band. The HAS signal can be encrypted in order to control the access to the Galileo HAS services.
- **Public Regulated Service (PRS)**: Service restricted to government-authorised users, for sensitive applications that require a high level of service continuity.
- **Search and Rescue Service (SAR)**: Europe's contribution to COSPAS-SARSAT, an international satellite-based search and rescue distress alert detection system.

https://www.euspa.europa.eu/galileo/services

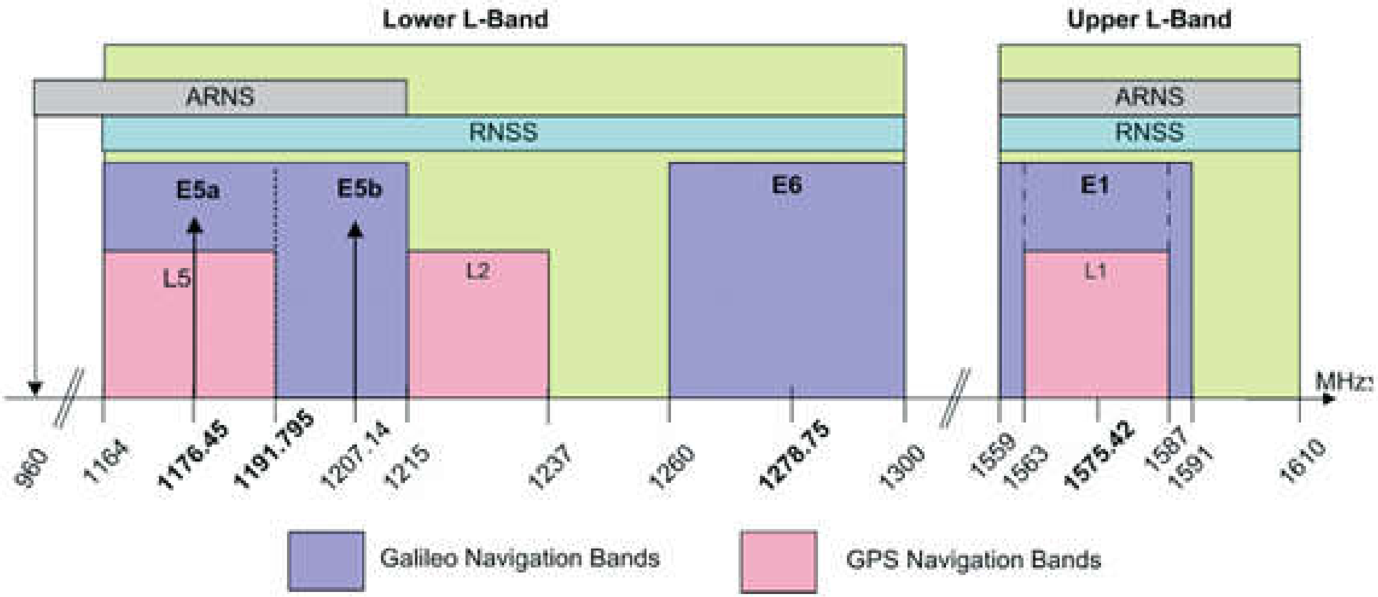
Latest launching of GALILEO satellites 23-24-25-26, 25th July 2018, Kourou, French Guiana

https://www.esa.int/ESA_Multimedia/Videos/2018/07/Highlights_of_Galileo_23_26_launch#.YOrmSRLnhbB.link

Ariane 5 flight VA244, operated by Arianespace



Galileo frequencies



- E1 … 1575,42 MHz
- E6 … 1278,75 MHz (Commercial Service)
- E5a … 1176,45 MHz
- E5b … 1207,14 MHz
- E5 AltBOC … 1191.795 MHz (Alternative BOC modulation)

http://galileognss.eu/galileo-frequency-bands/

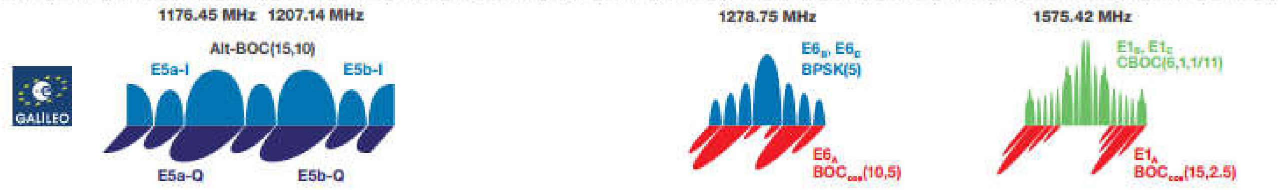
Galileo Constellation & Frequency bands

Parameter	Galileo
Orbital Period (MEO)	14hrs 04mins
Orbital Height (MEO)	23,222 Km
Inclination (MEO)	56°
Number of Orbital Planes (MEO)	3
Number of satellites	24 MEOs + 6 spares
Reference frame	GTFR
Reference time	Galileo System Time (GST)

Lower L-band

Upper L-band

E5a E5b **E6** **E1**



Power Spectral Density (PDS)

Signal	Carrier Frequency (MHz)	Receiver Reference Bandwith (MHz)
E1	1575.42	24.552
E6	1278.75	40.92
E5	1191.795	51.15
E5a	1176.45	20.46
E5b	1207.14	20.46

Galileo Signals Carrier Frequency and Bandwith

GNSS User Technology Report

European Global Navigation Satellite Systems Agency

GALILEO E1 E5 E6

Galileo – current constellation

- **26 satellites in constellation (22 usable (operational), 1 Not Available, 3 Not Usable)**

Satellite Name[1]	SV ID[2]	Clock[3]	Status[4]	Active NAGU[5]	NAGU Type[6]	NAGU Subject[7]
GSAT0101	E11	RAFS	USABLE			
GSAT0102	E12	PHM	USABLE			
GSAT0103	E19	PHM	USABLE			
GSAT0104	E20	RAFS	NOT AVAILABLE	2014014	UNP_UNUFN	UNAVAILABLE FROM 2014-05-27 UNTIL FURTHER NOTICE
GSAT0201	E18	PHM	NOT USABLE	2021008	GENERAL	GSAT0201 AND GSAT0202 UNAVAILABLE
GSAT0202	E14	PHM	NOT USABLE	2021008	GENERAL	GSAT0201 AND GSAT0202 UNAVAILABLE
GSAT0203	E26	PHM	USABLE			
GSAT0204	E22	RAFS	NOT USABLE	2017045	GENERAL	GSAT0204 REMOVED FROM ACTIVE SERVICE ON 2017-12-08 UNTIL FURTHER NOTICE FOR CONSTELLATION MANAGEMENT PURPOSES
GSAT0205	E24	PHM	USABLE			
GSAT0206	E30	PHM	USABLE			
GSAT0207	E07	PHM	USABLE			
GSAT0208	E08	PHM	USABLE			
GSAT0209	E09	PHM	USABLE			
GSAT0210	E01	PHM	USABLE			
GSAT0211	E02	PHM	USABLE			
GSAT0212	E03	PHM	USABLE			
GSAT0213	E04	PHM	USABLE			
GSAT0214	E05	PHM	USABLE			
GSAT0215	E21	PHM	USABLE			
GSAT0216	E25	PHM	USABLE			
GSAT0217	E27	PHM	USABLE			
GSAT0218	E31	PHM	USABLE			
GSAT0219	E36	PHM	USABLE			
GSAT0220	E13	PHM	USABLE			
GSAT0221	E15	PHM	USABLE			
GSAT0222	E33	PHM	USABLE			

https://www.gsc-europa.eu/system-service-status/constellation-information

PHM = Passive Hydrogen Maser,
RAFS = Rubidium Atomic Frequency Standard.

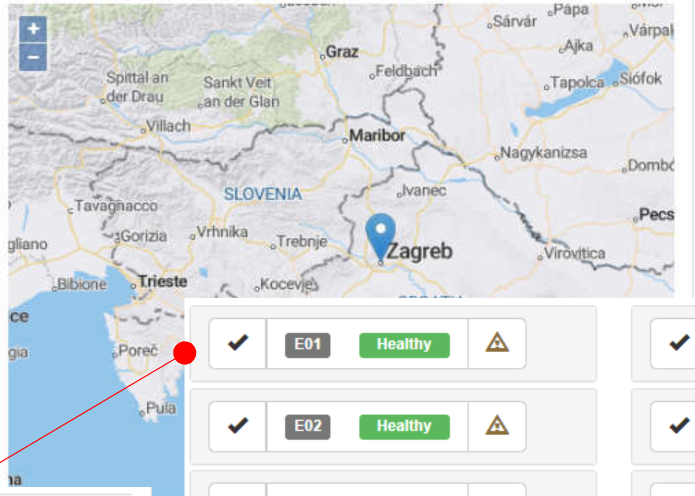
Trimble
GNSS Planning Online

Galileo satellites visibility: Zagreb, 13th July 2021

http://www.gnssplanningonline.com/

Settings

Latitude:	N 45° 48' 30.756" °
Longitude:	E 15° 57' 54.8642" °
Height:	165 m
Elevation cutoff:	10 °
Day:	13/07/2021 Today
Start time:	00:00 UTC +02:00
Period [hours]:	24
Time zone:	(UTC+01:00) Sarajevo, Skopje, Warsaw, Zagreb



Health status:	Healthy 0
Eccentricity:	0.000031
Semimajor axis:	29,601,216.5 m
Right ascension of ascending node:	17.556°
Argument of perigee:	-97.581°
Mean anomaly:	-104.200°
Inclination:	56.055°
Rate of right ascension:	-0.0002934 °/sec * 10^3
Satellite clock offset:	-1125335.7 nsec
Satellite clock drift:	-0.01 nsec/s

Selected	Satellite	Status
✔	E01	Healthy
✔	E02	Healthy
✔	E03	Healthy
✔	E04	Healthy
✔	E05	Healthy
✔	E07	Healthy
✔	E08	Healthy
✔	E09	Healthy
✔	E11	Healthy
✔	E12	Healthy
	E13	Unhealthy
	E15	Unhealthy
✔	E19	Healthy
	E21	Unhealthy
✔	E24	Healthy
✔	E25	Healthy
	E26	Unhealthy
✔	E27	Healthy
✔	E30	Healthy
✔	E31	Healthy
✔	E33	Healthy
✔	E36	Healthy

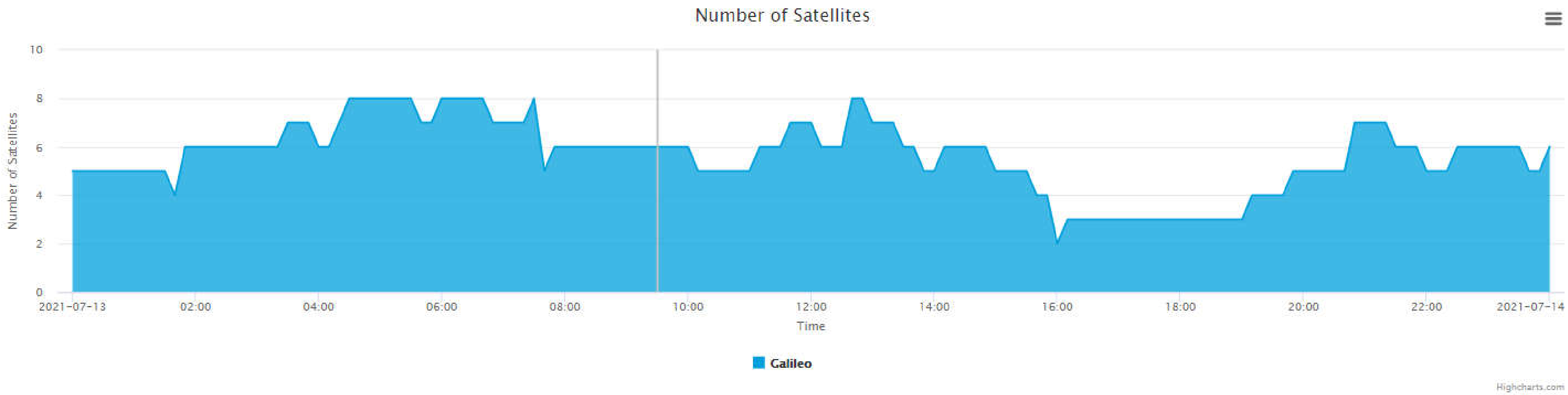
Satellite Selection

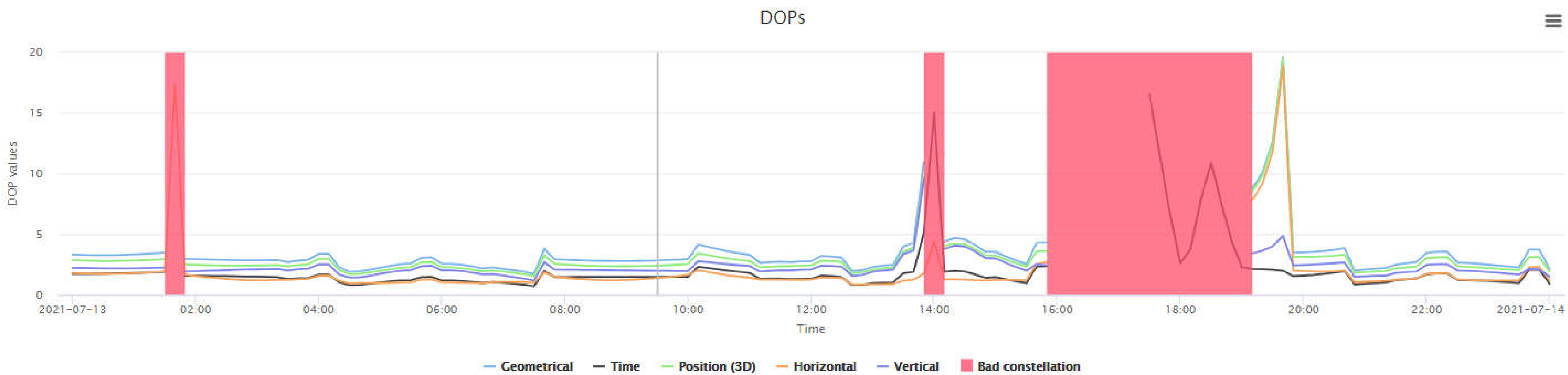
Change selection

Satellites: 18/129

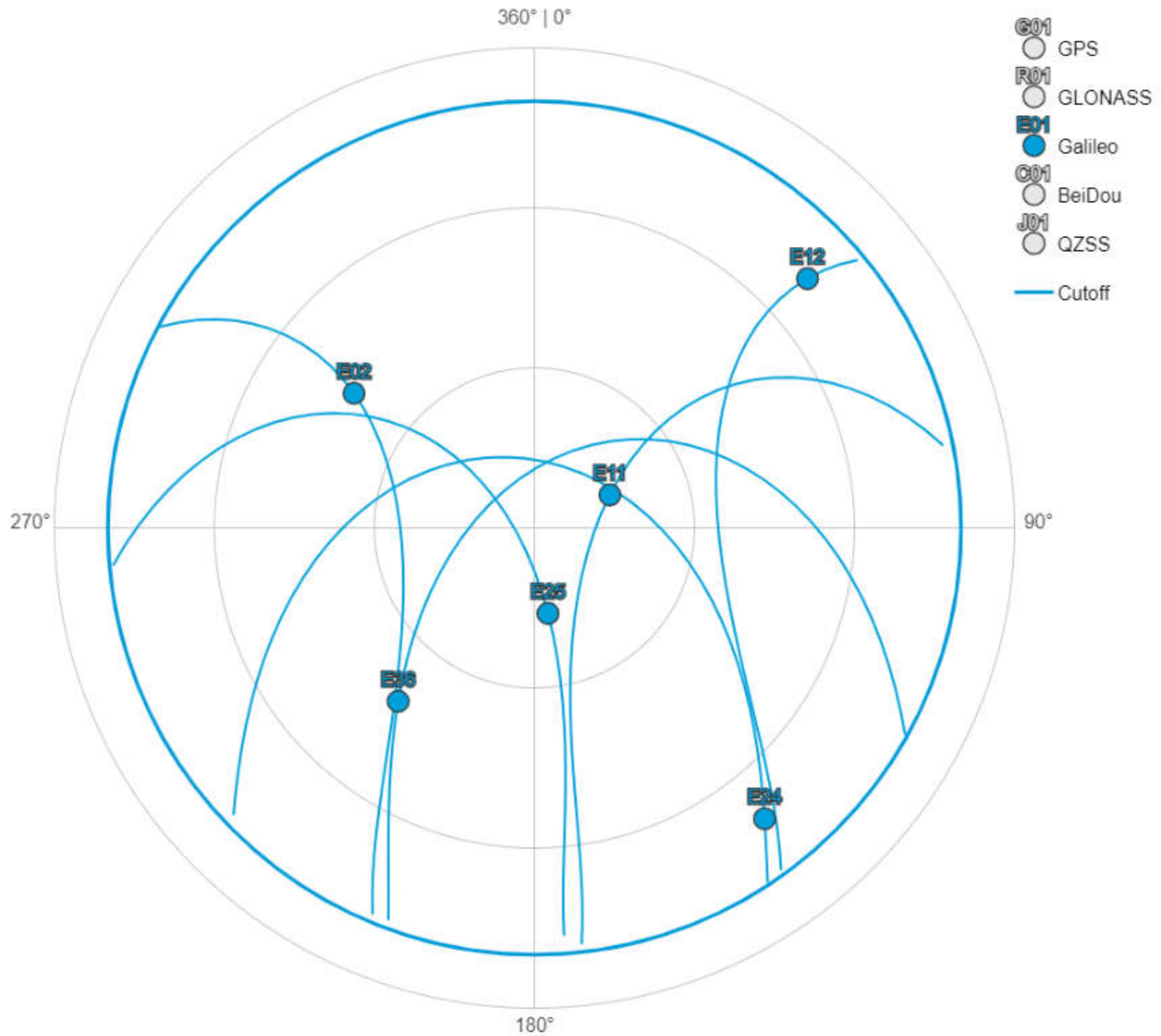
System: active		Satellites: Selected	Satellites: Healthy
GPS	✖	0	31
GLONASS	✖	0	23
Galileo	✔	18	18
BeiDou	✖	0	48
QZSS	✖	0	4

Galileo satellites visibility, Zagreb, 13th July 2021, 0-24h (UTC+2)





Galileo satellites visibility, Zagreb, 13th July 2021, 0-24h (UTC+2)



$$\frac{\text{VDOP}}{\text{HDOP}} = \frac{1.98}{1.37} = 1.44$$

BeiDou

- **1983 – concept of chinese regional navigational system with 3 geostationary satellites (GEO)**
- **2003 – system BeiDou-1 deployed**
- **2006 – official announcement of development 2nd generation of national GNSS including constellation of satellites in MEO orbits - BeiDou-2 (or Compass)**
- **2012 – system declared operational in Asia-Pacific region**
- **31th July 2020 - BDS-3, the global version of the BeiDou Navigation Satellite System (BDS), was formally commissioned, marking the completion of its three-step development process**
- **BeiDou System Time (BDT)**
- **CGCS2000 (China Geodetic Coordinate System 2000)**

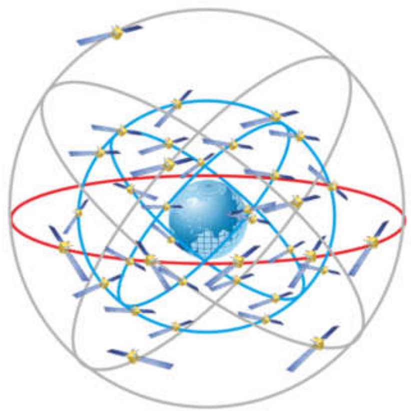
In Chinese, the Big Dipper Constellation is known as BeiDou

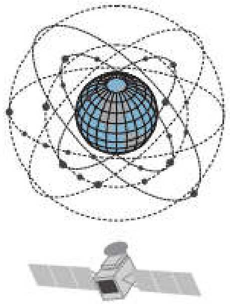
NovAtel Inc. (2015): An Introduction to GNSS

BeiDou

Satellites	5 GEO	3 IGSO	27 MEO
Orbital Planes	–	–	3
Orbital Inclination	–	55 degrees	55 degrees
Orbit Radius	35,787 km	35,787 km	21,528 km

- **35 satellites in constellation**
  - ✓ **5 BeiDou- GEO (58.75° E, 80° E, 110.5° E, 140° E and 160° E);**
  - ✓ **27 BeiDou- MEO satellites (orbital period 12h 53min; inclination 55°)**
  - ✓ **3 BeiDou- IGSO (Inclined GeoSynchronous Orbit)**





BeiDou
6 Orbital planes
35 Satellites + 5 GEO + 27 MEO + 3 IGSO
55° Inclination angle
Altitude 38,300 km, 21,500 km

BeiDou

- Latest launch of BDS satellite – 23rd June 2020
- Xichang Satellite Launch Center in southwest China's Sichuan Province
- Long March-3B carrier rocket
- completion of the deployment of BDS-3 global navigation system

https://www.gpsworld.com/china-completes-beidou-3-worldwide-navigation-constellation/

http://www.xinhuanet.com/english/2020-06/23/c_139161359.htm

BEIDOU CONSTELLATION STATUS 11.07.21

Total satellites in constellation	49
SV is included in operational orbital constellation	44
SV is not included in operational orbital constellation	5

BEIDOU CONSTELLATION STATUS 11.07.21

Satellite Number	NORAD	Satellite Name	Type of system	Launch date	Life-time (days)	Notes
C01	44231	GEO-8	BDS-2	17.05.19	786	In operation
C02	38953	GEO-6	BDS-2	25.10.12	3181	In operation
C03	41586	GEO-7	BDS-2	12.06.16	1855	In operation
C04	37210	GEO-4	BDS-2	01.11.10	3905	In operation
C05	38091	GEO-5	BDS-2	25.02.12	3424	In operation
C06	36828	IGSO-1	BDS-2	01.08.10	3997	In operation
C07	37256	IGSO-2	BDS-2	18.12.10	3858	In operation
C08	37384	IGSO-3	BDS-2	10.04.11	3745	In operation
C09	37763	IGSO-4	BDS-2	27.07.11	3637	In operation
C10	37948	IGSO-5	BDS-2	02.12.11	3509	In operation
C11	38250	MEO-3	BDS-2	30.04.12	3359	In operation
C12	38251	MEO-4	BDS-2	30.04.12	3359	In operation
C13	41434	IGSO-6	BDS-2	30.03.16	1929	In operation
C14	38775	MEO-6	BDS-2	19.09.12	3217	In operation
C16	43539	IGSO-7	BDS-2	10.07.18	1097	In operation
C19	43001	MEO-1	BDS-3	05.11.17	1344	In operation
C20	43002	MEO-2	BDS-3	05.11.17	1344	In operation
C21	43208	MEO-3	BDS-3	12.02.18	1245	In operation
C22	43207	MEO-4	BDS-3	12.02.18	1245	In operation
C23	43581	MEO-5	BDS-3	29.07.18	1078	In operation
C24	43582	MEO-6	BDS-3	29.07.18	1078	In operation
C25	43603	MEO-11	BDS-3	25.08.18	1051	In operation
C26	43602	MEO-12	BDS-3	25.08.18	1051	In operation
C27	43107	MEO-7	BDS-3	12.01.18	1276	In operation
C28	43108	MEO-8	BDS-3	12.01.18	1276	In operation
C29	43245	MEO-9	BDS-3	30.03.18	1199	In operation
C30	43246	MEO-10	BDS-3	30.03.18	1199	In operation
C32	43622	MEO-13	BDS-3	19.09.18	1026	In operation
C33	43623	MEO-14	BDS-3	19.09.18	1026	In operation
C34	43648	MEO-15	BDS-3	15.10.18	1000	In operation
C35	43647	MEO-16	BDS-3	15.10.18	1000	In operation
C36	43706	MEO-17	BDS-3	19.11.18	965	In operation
C37	43707	MEO-18	BDS-3	19.11.18	965	In operation
C38	44204	IGSO-1	BDS-3	20.04.19	813	In operation
C39	44337	IGSO-2	BDS-3	25.06.19	747	In operation
C40	44709	IGSO-3	BDS-3	05.11.19	614	In operation
C41	44864	MEO-19	BDS-3	16.12.19	573	In operation
C42	44865	MEO-20	BDS-3	16.12.19	573	In operation
C43	44793	MEO-21	BDS-3	23.11.19	596	In operation
C44	44794	MEO-22	BDS-3	23.11.19	596	In operation
C45	44543	MEO-23	BDS-3	23.09.19	657	In operation
C46	44542	MEO-24	BDS-3	23.09.19	657	In operation
C59	43683	GEO-1	BDS-3	01.11.18	983	In operation
C60	45344	GEO-2	BDS-3	09.03.20	489	In operation
C31	40549	IGSO-1S	BDS-3S	30.03.15	2295	Not in operational orbital constellation
C56	40938	IGSO-2S	BDS-3S	30.09.15	2111	Not in operational orbital constellation
C57	40749	MEO-1S	BDS-3S	25.07.15	2178	Not in operational orbital constellation
C58	40748	MEO-2S	BDS-3S	25.07.15	2178	Not in operational orbital constellation
C61	45807	GEO-3	BDS-3	23.06.20	383	Not in operational orbital constellation

30 BDS-3 MEO satellites

https://www.glonass-iac.ru/en/BEIDOU/index.php

BeiDou

- 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 GPS L1C and Galileo's E1.

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

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

BeiDou-3 Constellation & Frequency bands

Parameter	BeiDou III
Orbital Period (MEO)	12hrs 37min
Orbital Height (MEO)	21,528 Km
Inclination (MEO)	55°
Number of Orbital Planes (MEO)	3
Number of satellites	24 MEOs + 3 GEOs + 3 IGSOs + spares
Reference frame	CGCS 2000
Reference time	BeiDou Time (BDT)

Lower L-band

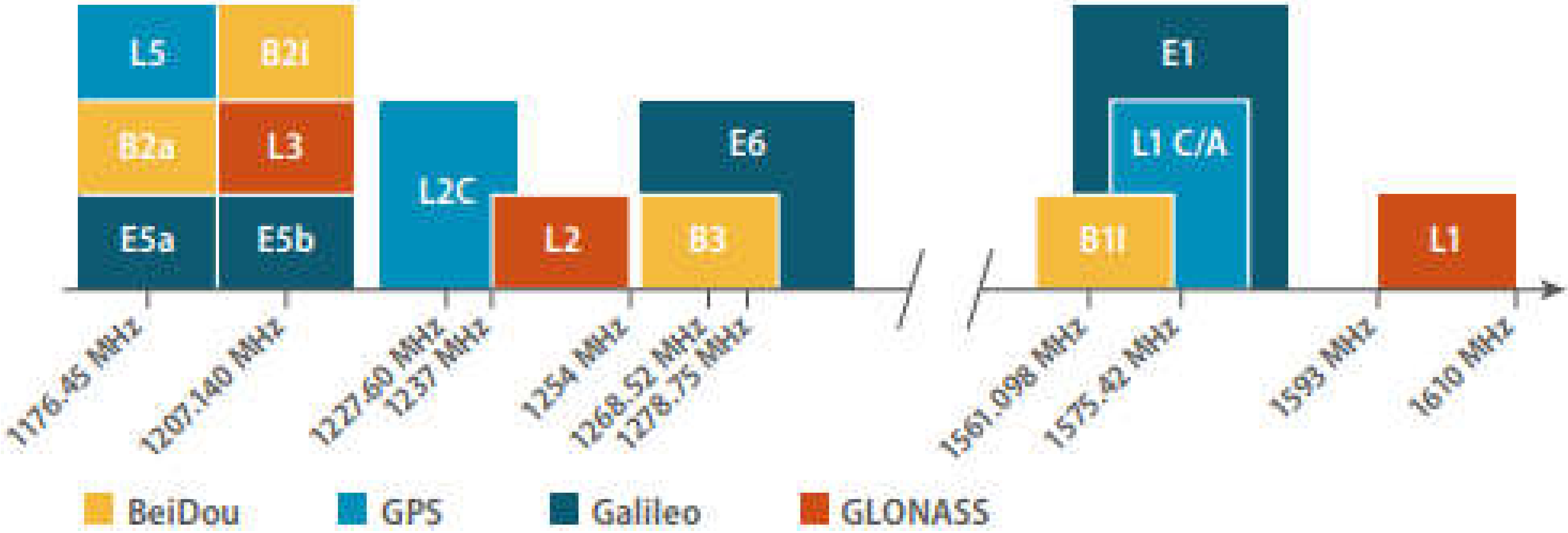
Upper L-band

B2 **B3** **B1**

Power Spectral Density (PDS)

BEIDOU		B1 B2 B3

GNSS FREQUENCIES IN THE L BAND



Trimble
GNSS Planning Online

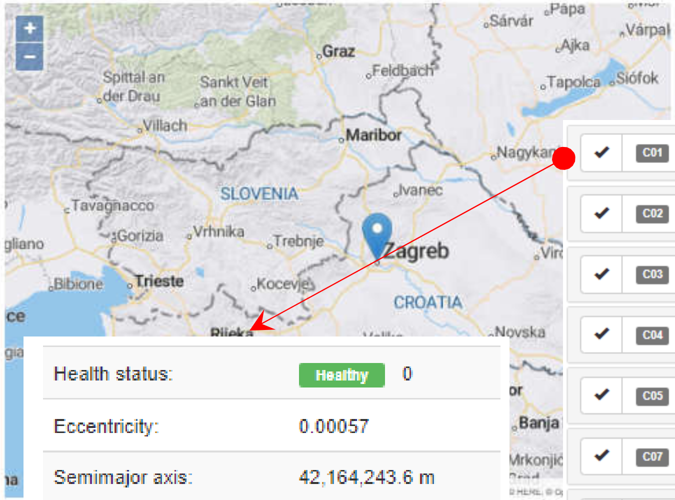
BeiDou satellites visibility: Zagreb, 13th July 2021

http://www.gnssplanningonline.com/

Settings

Latitude:	N 45° 48' 30.756" °
Longitude:	E 15° 57' 54.8642" °
Height:	165 m
Elevation cutoff:	10 °
Day:	13/07/2021 Today
Start time:	00:00 UTC +02:00
Period [hours]:	24
Time zone:	(UTC+01:00) Sarajevo, Skopje, Warsaw, Zagreb

✔ Apply



Health status:	Healthy 0
Eccentricity:	0.00057
Semimajor axis:	42,164,243.6 m
Right ascension of ascending node:	91.462°
Argument of perigee:	-156.026°
Mean anomaly:	-65.891°
Inclination:	0.301°
Rate of right ascension:	0.0000773 °/sec * 10^3
Satellite clock offset:	0 nsec
Satellite clock drift:	0 nsec/s

Satellite Selection

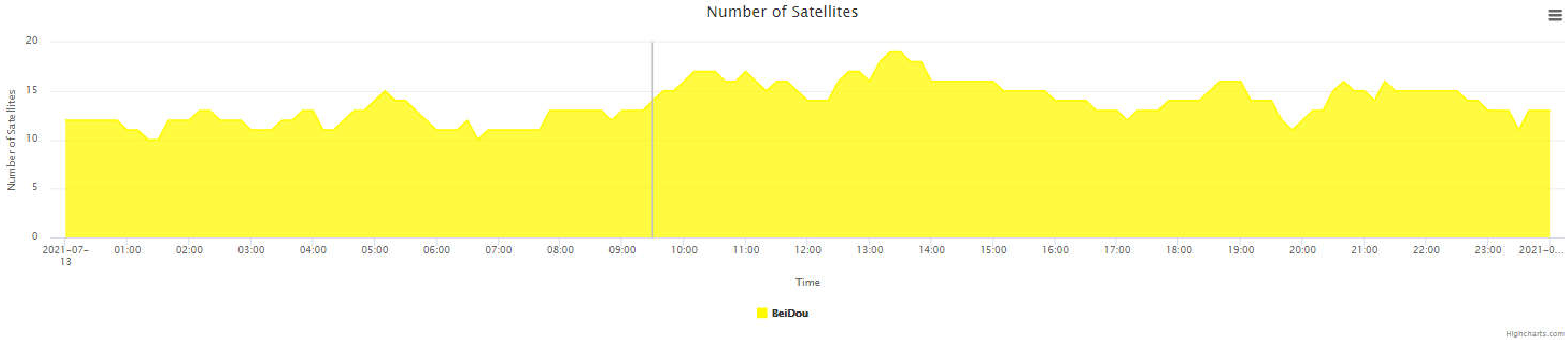
Change selection

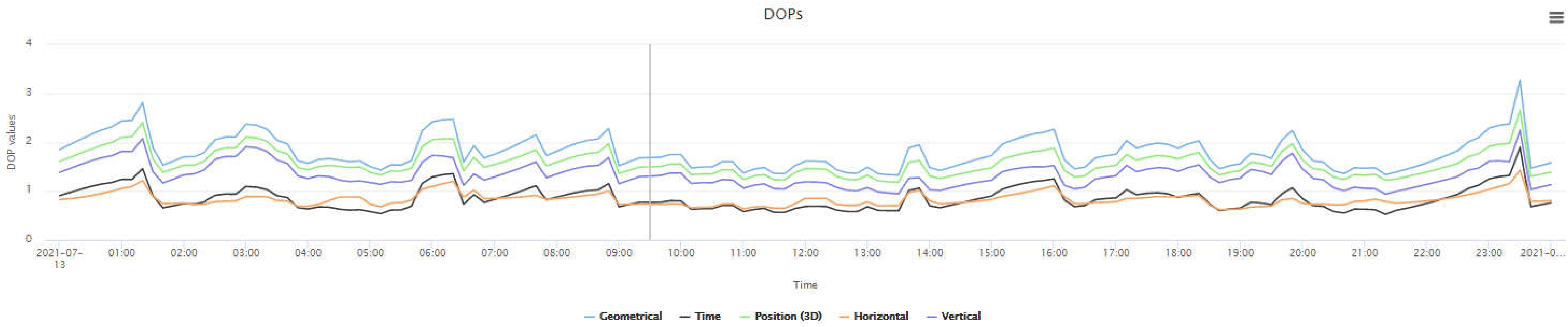
Satellites: 48/129

System: active		Satellites Selected	Satellites Healthy
GPS	✖	0	31
GLONASS	✖	0	23
Galileo	✖	0	18
BeiDou	✔	48	48
QZSS	✖	0	4

✔	C01	Healthy	✔	C21	Healthy	✔	C37	Healthy
✔	C02	Healthy	✔	C22	Healthy	✔	C38	Healthy
✔	C03	Healthy	✔	C23	Healthy	✔	C39	Healthy
✔	C04	Healthy	✔	C24	Healthy	✔	C40	Healthy
✔	C05	Healthy	✔	C25	Healthy	✔	C41	Healthy
✔	C07	Healthy	✔	C26	Healthy	✔	C42	Healthy
✔	C08	Healthy	✔	C27	Healthy	✔	C43	Healthy
✔	C09	Healthy	✔	C28	Healthy	✔	C44	Healthy
✔	C10	Healthy	✔	C29	Healthy	✔	C45	Healthy
✔	C11	Healthy	✔	C30	Healthy	✔	C46	Healthy
✔	C12	Healthy	✔	C31	Healthy	✔	C56	Healthy
✔	C13	Healthy	✔	C32	Healthy	✔	C57	Healthy
✔	C14	Healthy	✔	C33	Healthy	✔	C58	Healthy
✔	C16	Healthy	✔	C34	Healthy	✔	C59	Healthy

BeiDou satellites visibility, Zagreb, 13th July 2021, 0-24h (UTC+2)



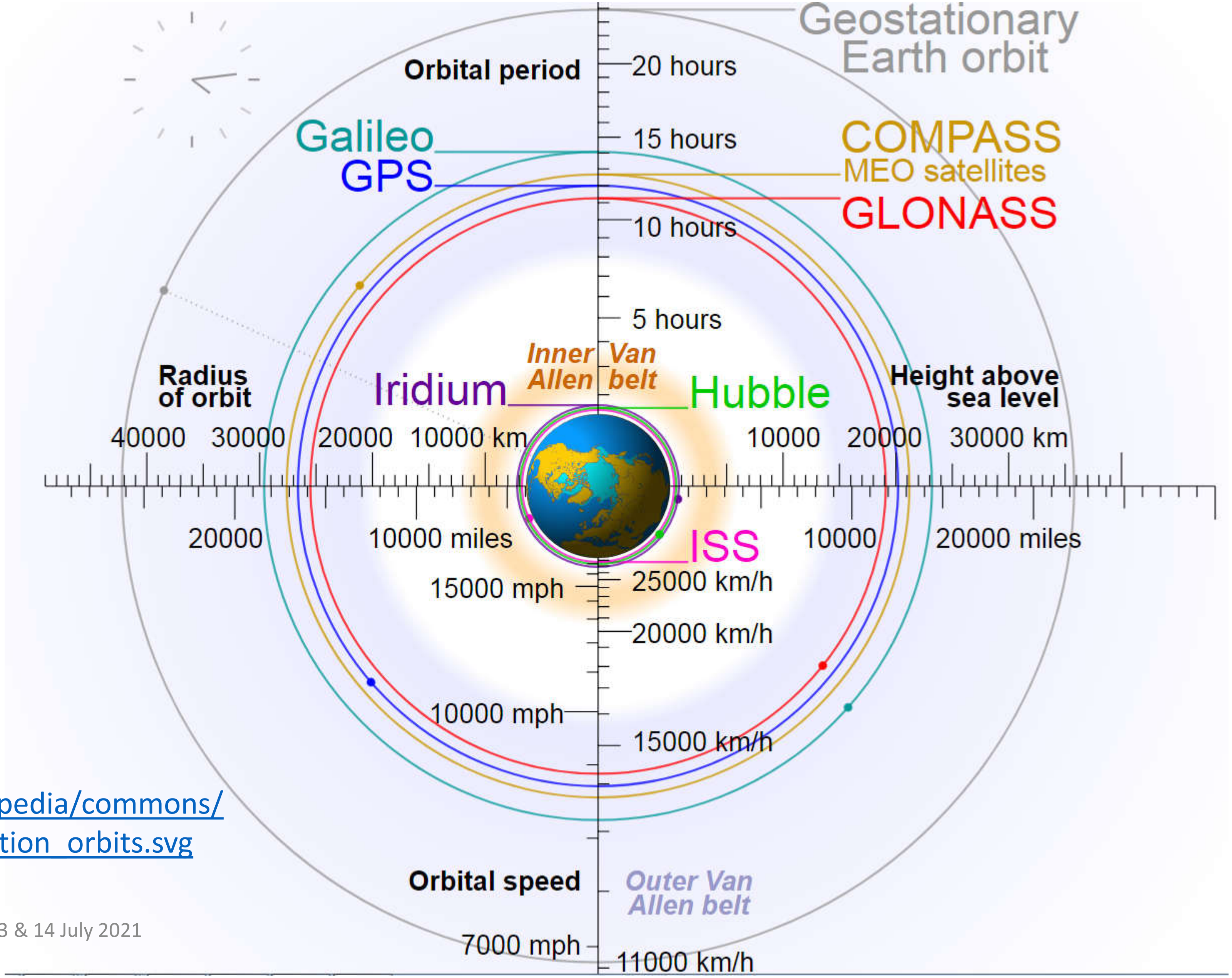


BeiDou satellites visibility, Zagreb, 13th July 2021, 0-24h (UTC+2)

$$\frac{VDOP}{HDOP} = \frac{1.31}{0,74} = 1.77$$

Kepler's Third Law

$$\frac{a^3}{T^2} = k$$



https://upload.wikimedia.org/wikipedia/commons/b/b4/Comparison_satellite_navigation_orbits.svg

GPS+GLO+GAL+BDS satellites visibility: Zagreb, 13th July 2021

Trimble GNSS Planning Online

http://www.gnssplanningonline.com/

Settings

- **Latitude:** N 45° 48' 30.756" °
- **Longitude:** E 15° 57' 54.8642" °
- **Height:** 165 m
- **Elevation cutoff:** 10 °
- **Day:** 13/07/2021 Today
- **Start time:** 00:00 UTC +02:00
- **Period [hours]:** 24
- **Time zone:** (UTC+01:00) Sarajevo, Skopje, Warsaw, Zagreb

Apply

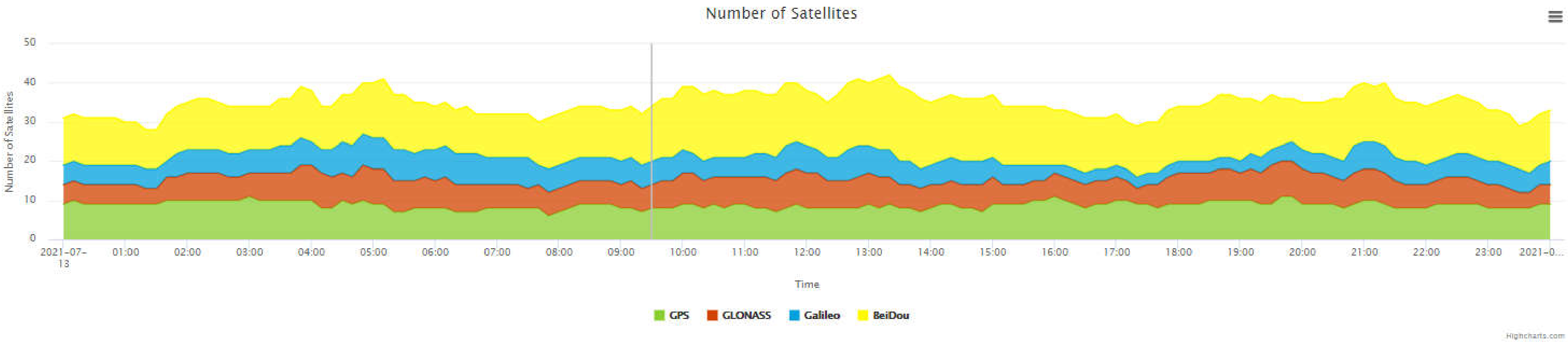
Satellite Selection

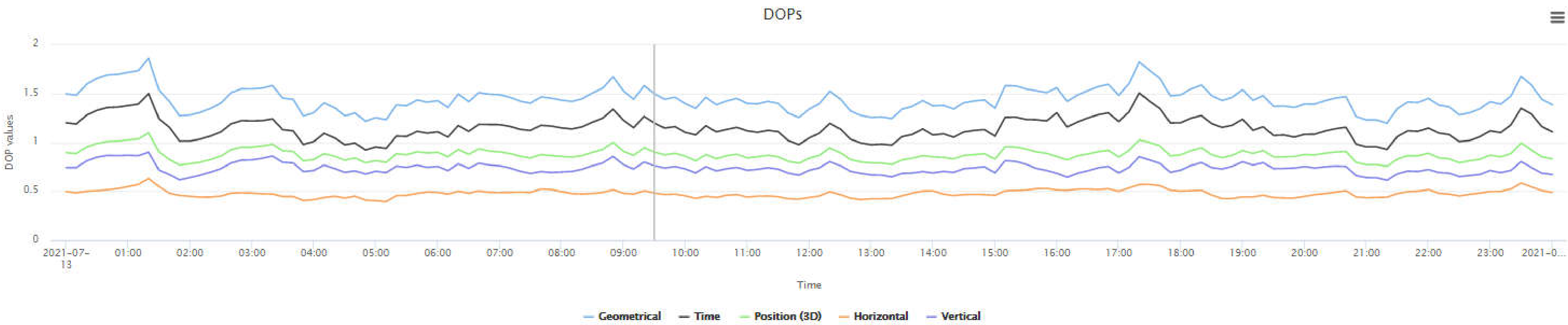
Change selection

Satellites: 120/129

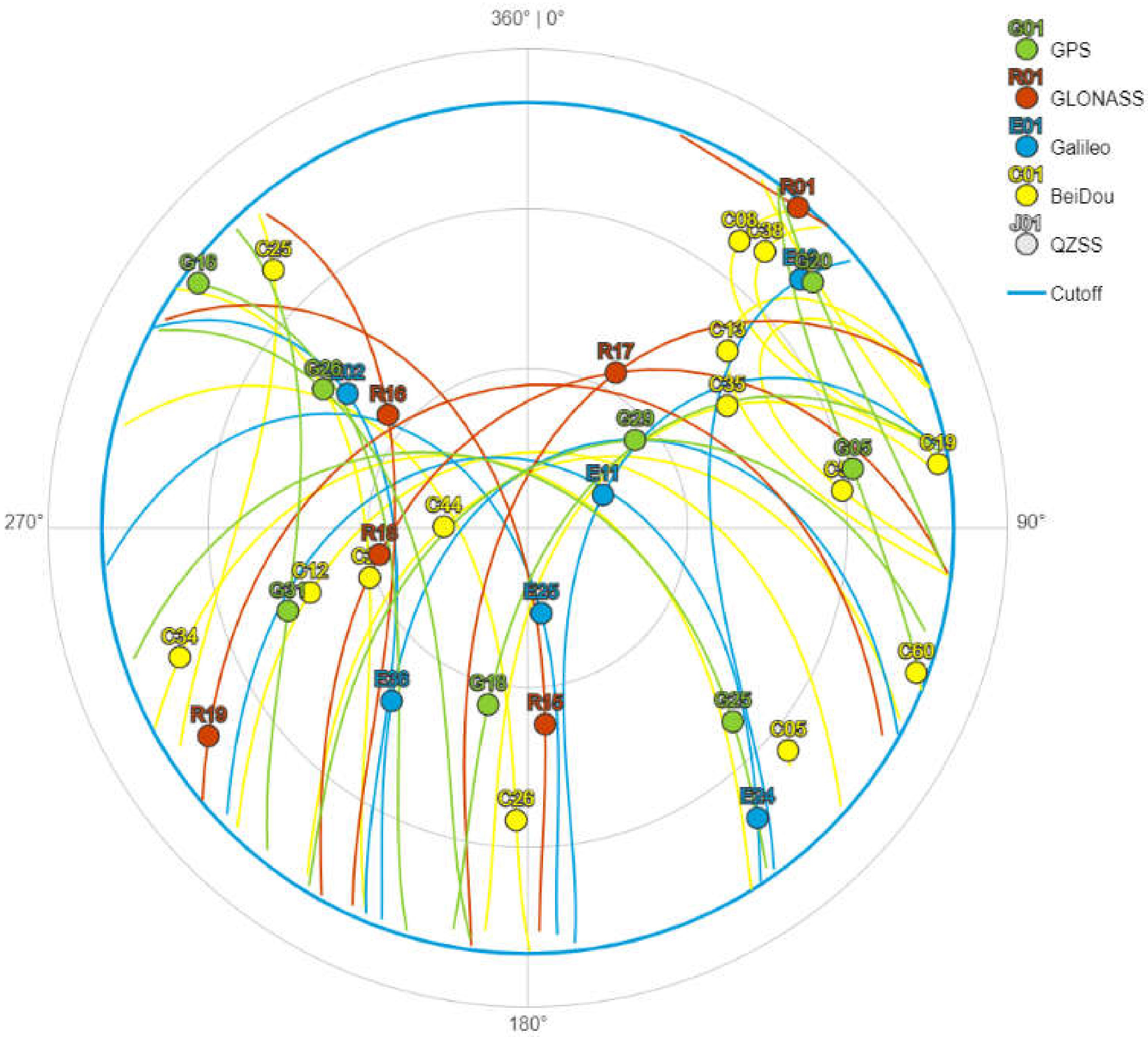
System: active		Satellites: Selected	Satellites: Healthy
GPS	✔	31	31
GLONASS	✔	23	23
Galileo	✔	18	18
BeiDou	✔	48	48
QZSS	✖	0	4

GPS+GLO+GAL+BDS satellites visibility, Zagreb, 13th July 2021, 0-24h (UTC+2)





GPS+GLO+GAL+BDS satellites visibility, Zagreb, 13th July 2021, 0-24h (UTC+2)



2021-07-13 09:30	
Geometrical:	1.5
Time:	1.2
Position (3D):	0.9
Horizontal:	0.48
Vertical:	0.76

$$\frac{\mathrm{VDOP}}{\mathrm{HDOP}} = \frac{0.76}{0.48} = 1.58$$

Global, Continental and Regional (State) Networks

- IGS – International GNSS Service
- EPN - EUREF Permanent GNSS Network
- CROPOS

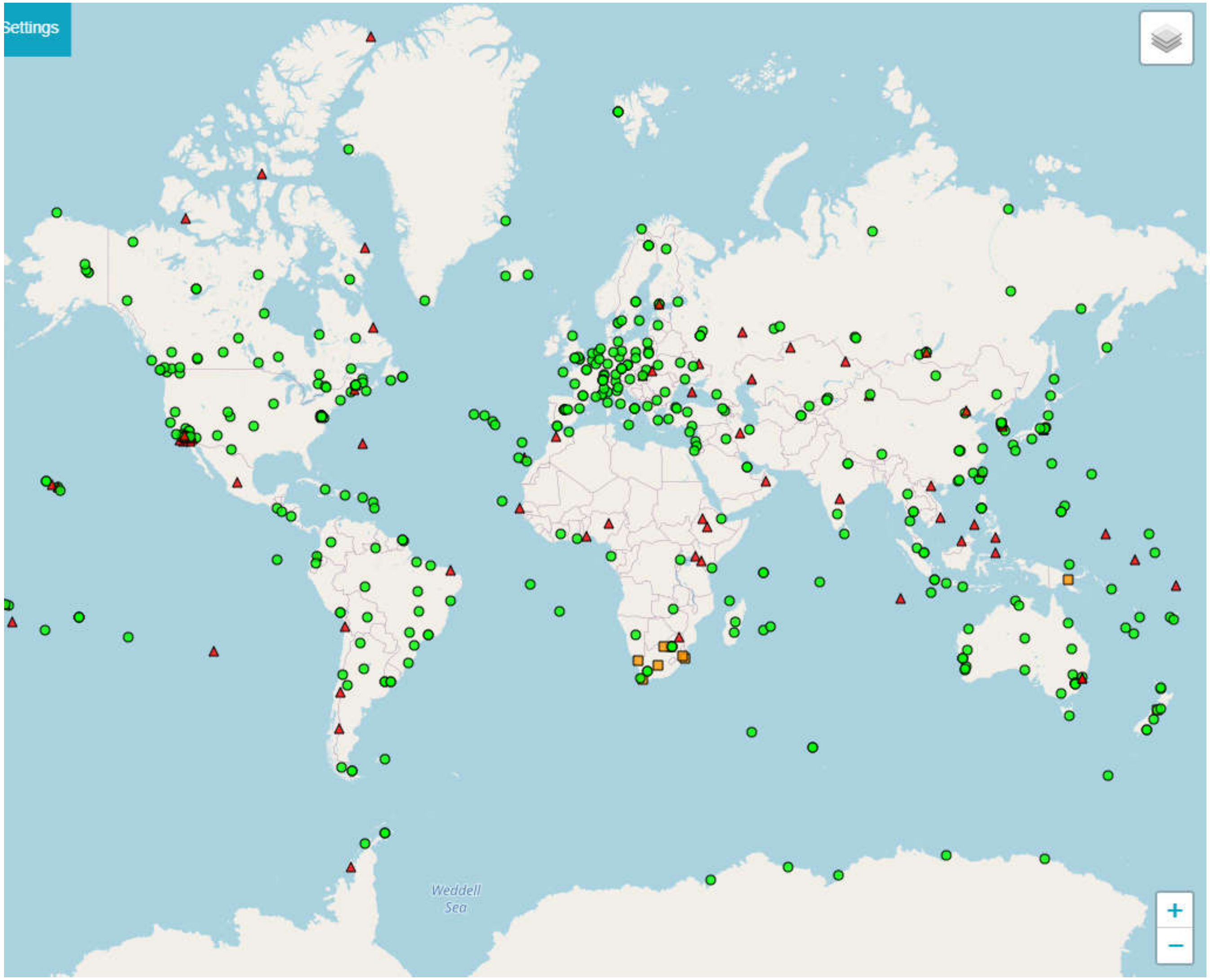
IGS – International GNSS Service

- **Voluntary federation of over 200 self-funding agencies, universities, and research institutions in more than 100 countries**
- **Providing free and open access to the highest precision products available for scientific advancement and public benefit**
- **Producing products that support realization of the International Terrestrial Reference Frame while providing access to tracking data from over 400 worldwide reference stations**
- **IGS in numbers:**

506	350	118	350
STATIONS	ORGANIZATIONS	COUNTRIES	MEMBERS

https://www.igs.org/

IGS – International GNSS Service



https://www.igs.org/network/#station-map-list

IGS – International GNSS Service

IGS INTERNATIONAL GNSS SERVICE

- IGS products support scientific research in:
  - Realization of the International Terrestrial Reference Frame (ITRF)
  - Monitoring deformation of the solid Earth
  - Monitoring Earth rotation
  - Monitoring variations in the hydrosphere (sea level, ice sheets, etc.)
  - Scientific satellite orbit determination
  - Monitoring the Earth's ionosphere and troposphere

PRODUCTS formats

- GNSS precise orbits: SP3 and SP3c (typically) formats
- GNSS Earth rotation parameters: IGS-specified format
- GNSS station positions: Software INdependent EXchange (SINEX) format
- GNSS troposphere ZPD: IGS-specified format
- GNSS ionosphere TEC: Ionosphere Exchange (IONEX) format

https://www.igs.org/

IGS – International GNSS Service

- **GPS Satellite Ephemerides / Satellite & Station Clocks**

Type		Accuracy	Latency	Updates	Sample Interval
Broadcast	orbits	~100 cm	real time	–	daily
	Sat. clocks	~5 ns RMS ~2.5 ns SDev			
Ultra-Rapid (predicted half)	orbits	~5 cm	real time	at 03, 09, 15, 21 UTC	15 min
	Sat. clocks	~3 ns RMS ~1.5 ns SDev			
Ultra-Rapid (observed half)	orbits	~3 cm	3 – 9 hours	at 03, 09, 15, 21 UTC	15 min
	Sat. clocks	~150 ps RMS ~50 ps SDev			
Rapid	orbits	~2.5 cm	17 – 41 hours	at 17 UTC daily	15 min
	Sat. & Stn. clocks	~75 ps RMS ~25 ps SDev			5 min
Final	orbits	~2.5 cm	12 – 18 days	every Thursday	15 min
	Sat. & Stn. clocks	~75 ps RMS ~20 ps SDev			Sat.: 30s Stn.: 5 min

https://www.igs.org/

IGS – International GNSS Service

- **Geocentric Coordinates of IGS Tracking Stations**

Type		Accuracy	Latency	Updates	Sample Interval
Final positions	horizontal	3 mm	11 – 17 days	every Wednesday	weekly
	vertical	6 mm			
Final velocities	horizontal	2 mm/yr	11 – 17 days	every Wednesday	weekly
	vertical	3 mm/yr			

- **Earth Rotation (**Polar Motion (PM), Polar Motion Rates (PM rate), Length-of-day (LOD)**)**
- **Atmospheric parameters**

Type	Accuracy	Latency	Updates	Sample Interval
Final tropospheric zenith path delay with N, E gradients	4 mm (ZPD)	< 4 weeks	daily	5 minutes
Final ionospheric TEC grid	2-8 TECU	~11 days	weekly	2 hours; 5 deg (lon) x 2.5 deg (lat)
Rapid ionospheric TEC grid	2-9 TECU	<24 hours	daily	2 hours; 5 deg (lon) x 2.5 deg (lat)

https://www.igs.org/

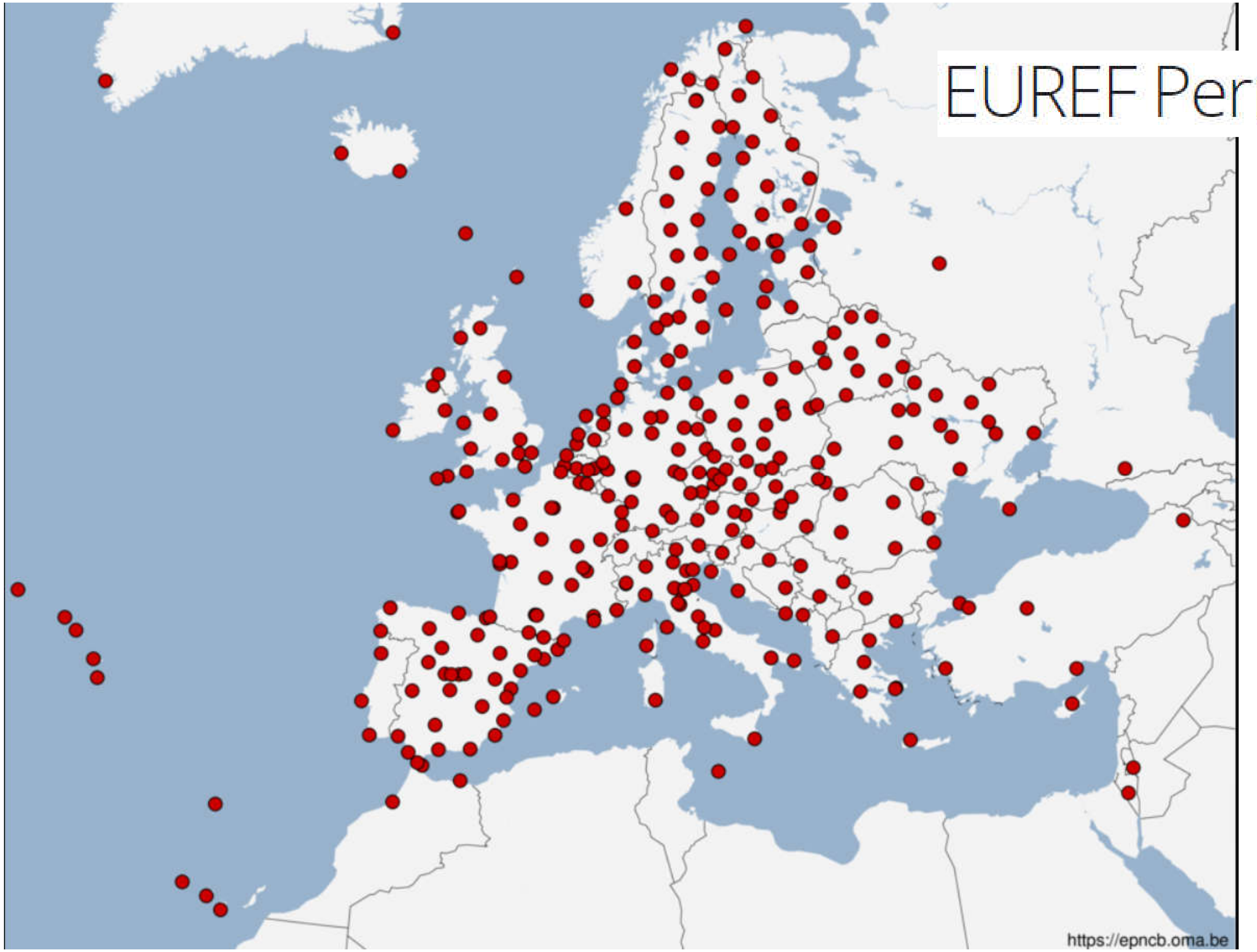
EPN – EUREF Permanent GNSS Network

- **voluntary federation of over 100 self-funding agencies, universities, and research institutions in more than 30 European countries.**
- **They work together to maintain the European Terrestrial Reference System (ETRS89)**
- **ETRS89 is realized by making publicly available the precise ETRS89 coordinates and GNSS observation data of a network of more than 200 permanent operating GNSS observing stations distributed over the European continent**
- **GNSS data from the EPN stations are freely available through the internet**

EUREF Permanent GNSS Network

https://www.epncb.oma.be/

EPN – EUREF Permanent GNSS Network

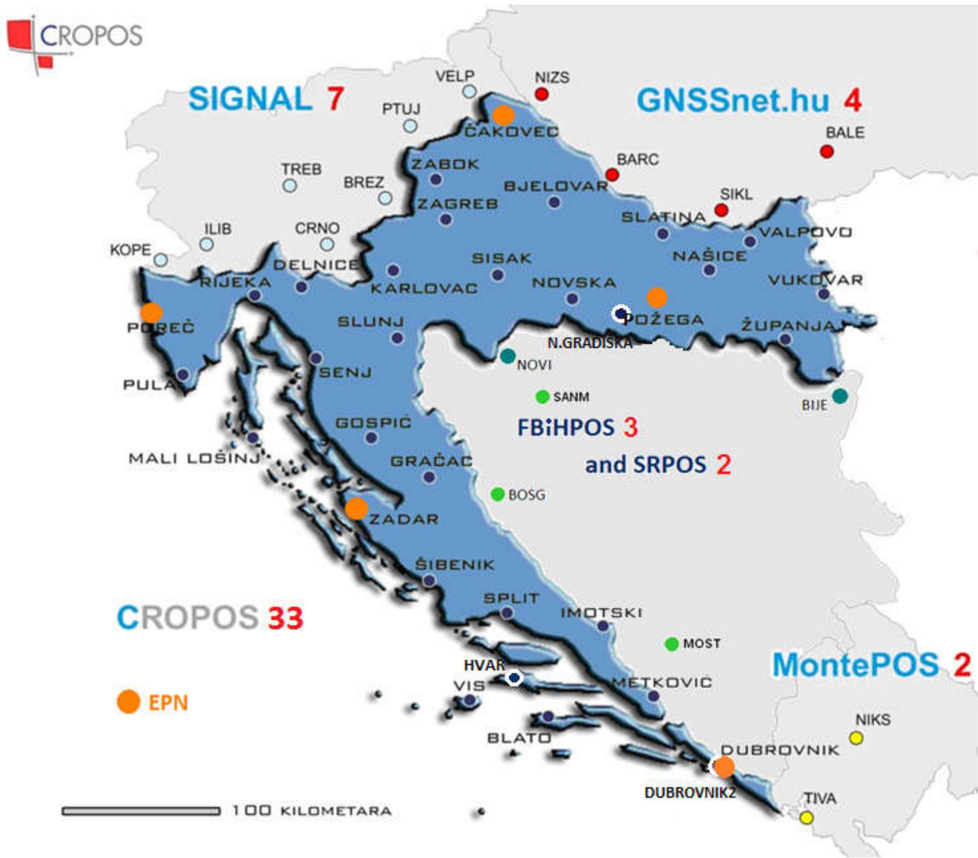


EUREF Permanent GNSS Network

https://www.epncb.oma.be/

CROPOS – Croatian Positioning System

- National permanent GNSS network
- Owned and managed by SGA
- 33 national GNSS stations
  + 18 stations (neighboring networks)
- Established in 2008
- Modernized in 2019

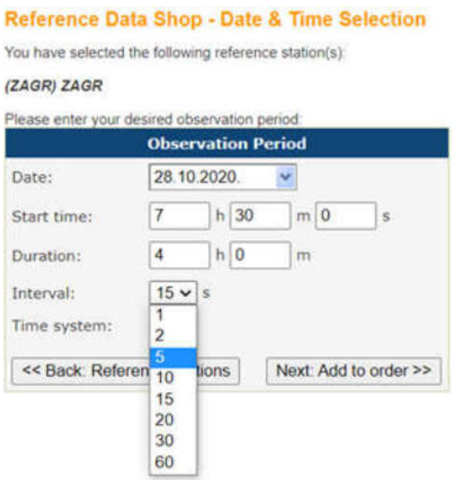


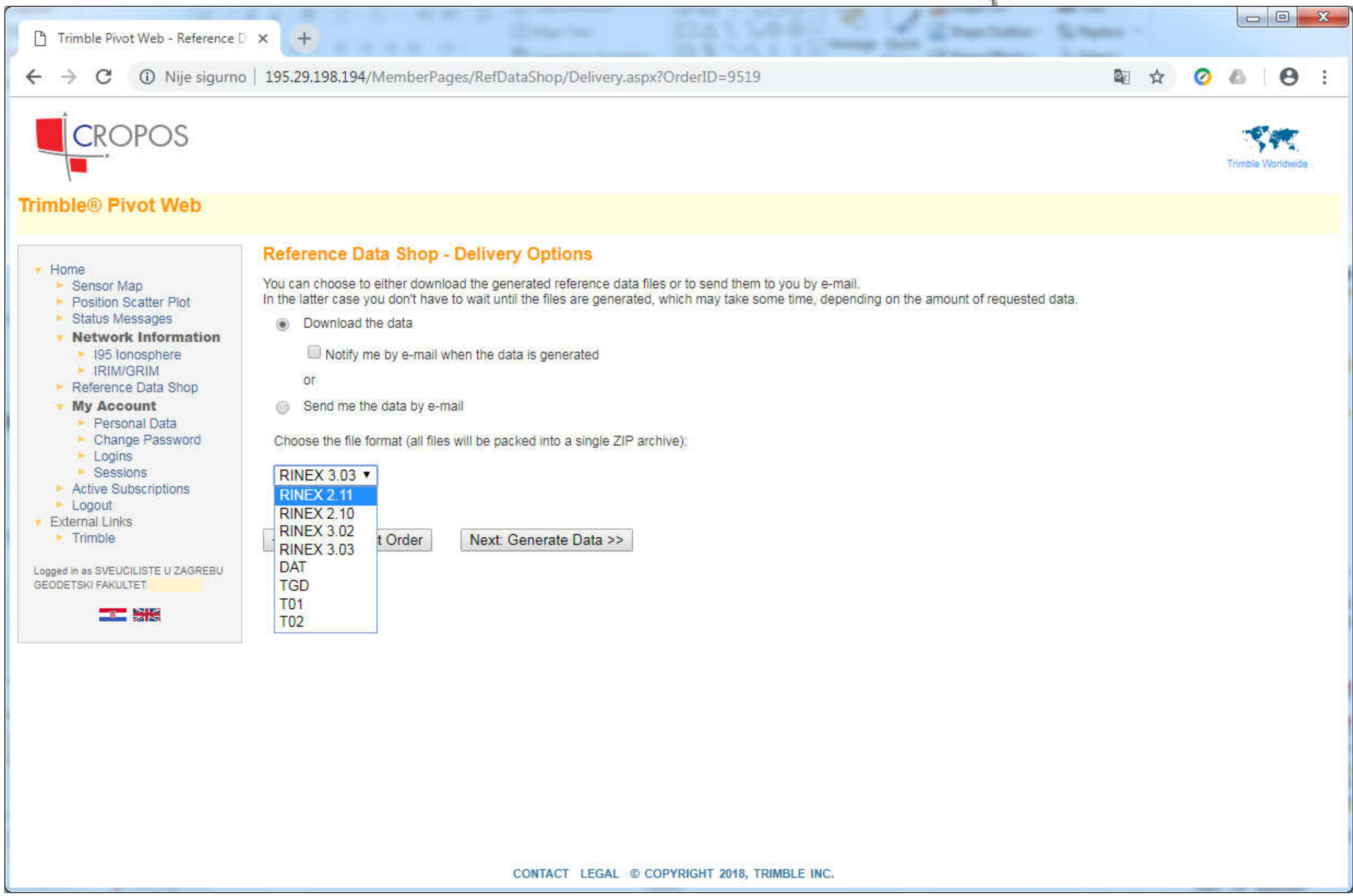
E04GEO training 13 & 14 July 2021

https://www.cropos.hr/

CROPOS – Croatian Positioning System

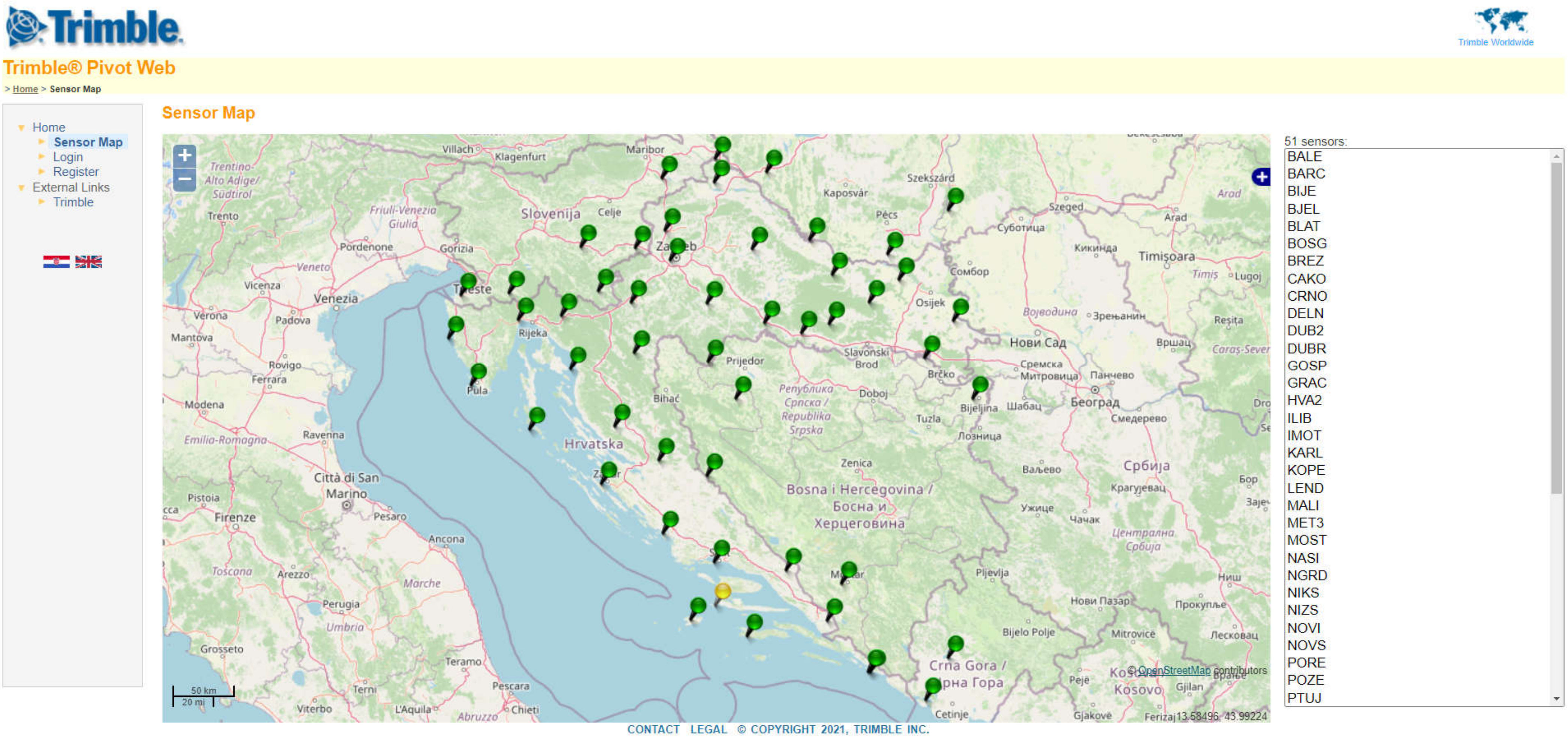
- **3 services:**
  - 2 in Real-Time: DPS, VPPS
  - 1 in Post-Processing: GPPS
- **GPPS (formats)**
  - Trimble proprietary
  - RINEX
  - 1, 2, 5, 10, 15, 20, 30, 60 sec





http://195.29.198.194/Map/SensorMap.aspx

CROPOS – Croatian Positioning System



E04GEO training 13 & 14 July 2021

http://195.29.198.194/Map/SensorMap.aspx

Error sources in GNSS

- Satellite clocks
- Orbit errors

- Ionospheric delays
- Tropospheric delays

- Receiver noise
- Multipath

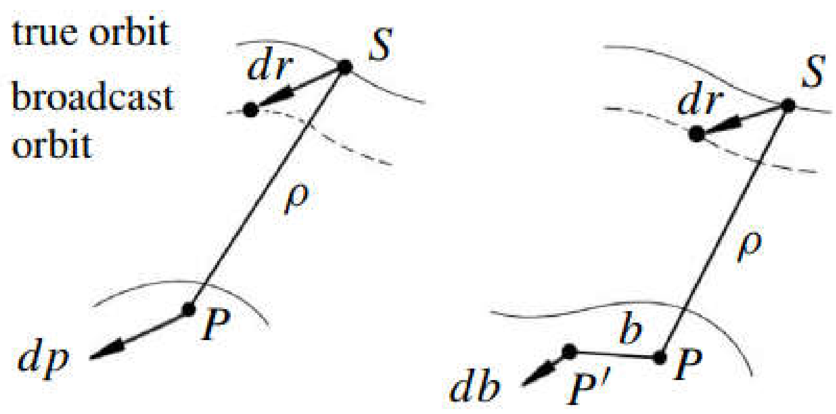
Contributing Source	Error Range	
Satellite clocks	±2 m	satellite
Orbit errors	±2.5 m	
Ionospheric delays	±5 m	medium
Tropospheric delays	±0.5 m	
Receiver noise	±0.3 m	receiver
Multipath	±1 m	

Error sources in GNSS

- **Satellite clocks**
  - The atomic clocks in the GNSS satellites are very accurate, but they do drift a small amount.
  - Example: 10 ns of clock error results in 3 m of position error
  - clock on the satellite is monitored by the GNSS ground control system and compared to a master clock
  - the satellite provides the user with an estimate of its clock offset
  - One way of compensating for clock error is to download precise satellite clock information (e.g. IGS)
  - Another way of compensating for clock error is to use a Differential or Relative positioning method

Error sources in GNSS

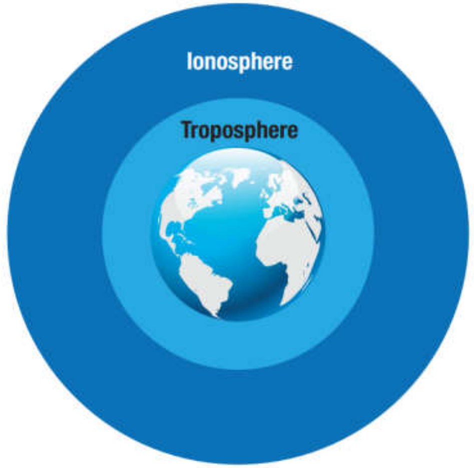
- **Orbit error**
  - GNSS ground control segment continually monitors the satellite orbit and calculates ephemeris
  - Broadcast ephemeris are updated by the Control segment
  - Nevertheless, they are predicted values containing certain error
  - One way of compensating for satellite orbit errors is to download precise ephemeris information (e.g. IGS)
  - Another way of compensating for satellite orbit errors is to use a Differential or Relative positiong method



$$\frac{db}{b} = \frac{dr}{\rho}$$

Seeber (2003): Satellite Geodesy

Error sources in GNSS



- **Ionospheric delays**
  - layer of atmosphere between 50 km and 1000 km above the Earth
  - contains electrically charged particles (electrons)
  - Ionospheric delay varies with solar activity
  - Dispersive medium for GNSS signals (frequency dependent)
  - TEC is the total number of electrons present along a path between the satellite and the receiver on earth, where 10^{16} electrons/m^2 = 1 TEC unit (TECU)
  - Ionospheric delay is frequency dependent, i.e. under normal conditions, dual-frequency (L1 and L2) code and carrier observations can be used to essentially remove ionospheric errors

$$\Delta_{\mathrm{ph}}^{\mathrm{Iono}} = -\frac{40.3}{f^2}\,\mathrm{TEC}\,,$$

Phase advance

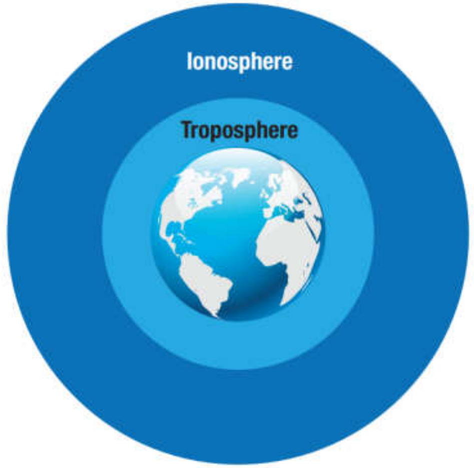
$$\Delta_{\mathrm{gr}}^{\mathrm{Iono}} = \frac{40.3}{f^2}\,\mathrm{TEC}$$

Code delay

Ionospheric refraction Δ^{Iono} = Measured – Geometric range

NovAtel Inc. (2015): An Introduction to GNSS
Hofmann-Wellenhof, Lichtenegger and Wasle (2008): GNSS

Error sources in GNSS



- **Tropospheric delay**
  - troposphere is the layer of atmosphere closest to the surface of the Earth (0-16 km)
  - Variations in tropospheric delay are caused by the changing humidity, temperature and atmospheric pressure
  - Troposphere is a nondispersive medium for frequencies < 15 GHz, therefore, it affects both L1 and L2 equally
  - Composed of Dry (90%; due to air pressure) and Wet component (10%; due to air humidity)
  - tropospheric models are normally used to estimate the amount of error caused by tropospheric delay
  - Another way of compensating for troposheric delay is to use a Differential or Relative positiong method (over short baselines)

NovAtel Inc. (2015): An Introduction to GNSS

Error sources in GNSS

- **Receiver noise**
  - refers to the position error caused by the GNSS receiver hardware and software
  - High end (geodetic) GNSS receivers tend to have less receiver noise than lower cost GNSS receivers

Alloy
GNSS REFERENCE RECEIVER

Static GNSS Surveying[4]

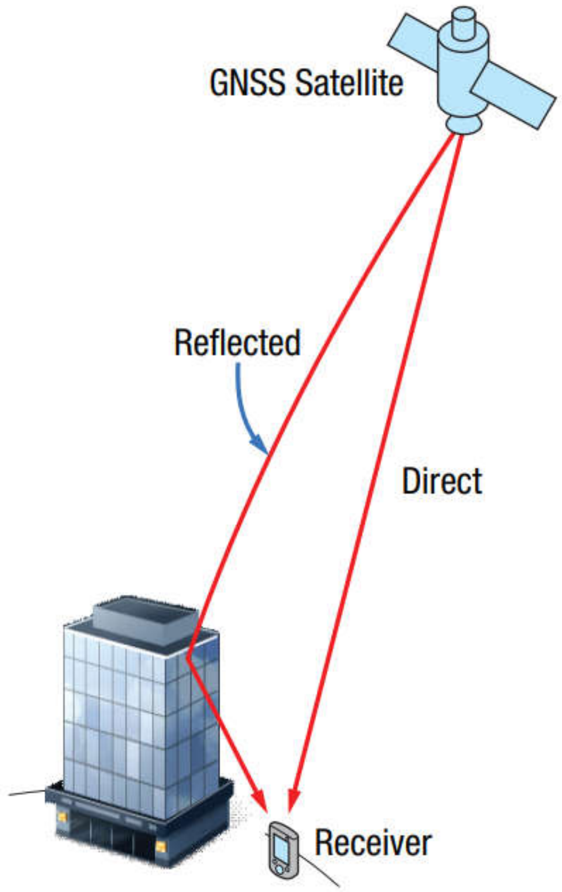
High-accuracy Static

Horizontal	3 mm + 0.1 ppm RMS
Vertical	3.5 mm + 0.4 ppm RMS

https://trl.trimble.com/docushare/dsweb/Get/Document-867350/022506-243C_Alloy_GNSS_Ref_Receiver_USL_DS_0919_LR.pdf

Error sources in GNSS

- **Multipath**
  - occurs when a GNSS signal is reflected off an object
  - reflected signal travels farther to reach the antenna, it arrives at the receiver slightly delayed
  - delayed signal can cause the receiver to calculate an incorrect position
  - The simplest way to reduce multipath errors is to place the GNSS antenna in a location that is away from the reflective surface
  - When this is not possible, the GNSS receiver and antenna must deal with the multipath signals



NovAtel Inc. (2015): An Introduction to GNSS

Error sources in GNSS

- DOP – Dilution Of Precision

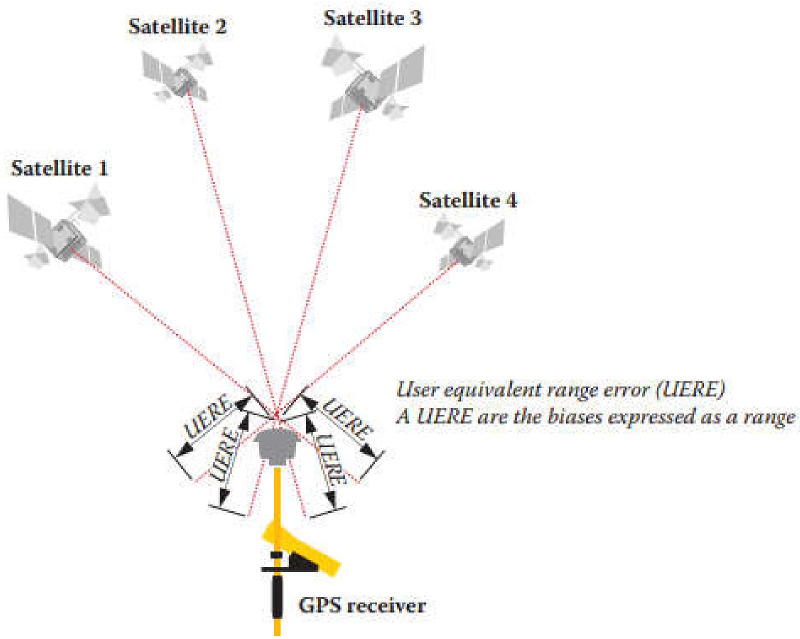
$$\sigma = \mathrm{DOP}\, \sigma_o$$

where

σ = uncertainty of the position

DOP = dilution of precision

σ_o = uncertainty of the measurements (user equivalent range error)



Van Sickle (2015): GPS for Land Surveyors

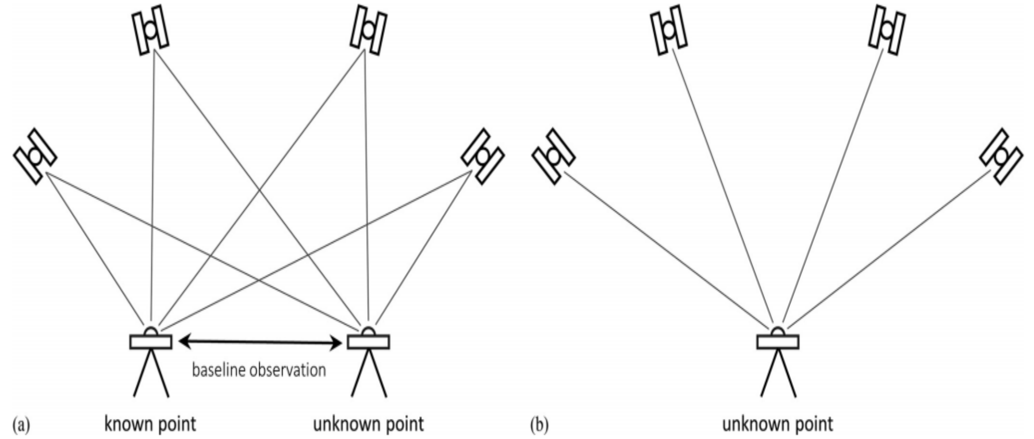
- User Equivalent Range Error (UERE) is the total error budget affecting a pseudorange
- UERE = square root of the sum of the squares of the individual biases

Measuring methods

- **4 parameters defining each measuring method (technique)**
  - Positioning method (Absolute versus Relative positioning)
  - Usage of receiver (Static versus Kinematic)
  - Observables (Code pseudoranges versus Phase pseudoranges)
  - Data processing – coordinates determination (Real-Time versus Post-Processing)

Measuring methods

- **Positioning method (Absolute versus Relative positioning)**
  - Absolute positioning = Point positioning = Single Point Positioning = single receiver which measures pseudoranges to four or more satellites
  - Relative positioning is possible if **two** receivers are used and (code or carrier phase) measurements, to the same satellites, are simultaneously made at two sites.
  - The measurements taken at both sites are directly combined.
  - Normally, the coordinates of one site are known and the position of the other site is to be determined relatively to the known site (i.e., the vector between the two sites is determined).

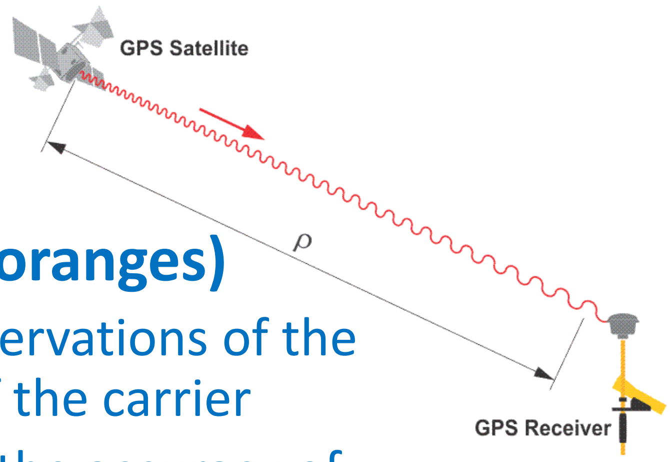


Jamieson and Gillins (2018)_Comparative Analysis of Online Static GNSS Postprocessing Services

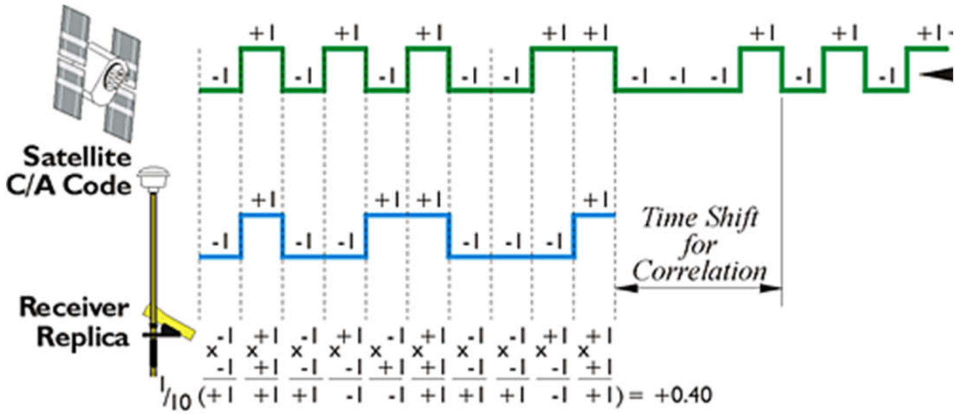
Measuring methods

- **Usage of receiver (Static versus Kinematic)**
  - Static denotes a stationary observation location, while kinematic implies motion
  - A temporary loss of signal lock in static mode is not as critical as in kinematic mode.
  - Attention should be paid to the difference between the terms “kinematic” and “dynamic”:
    - “kinematic” describes the pure geometry of a motion
    - “dynamic” considers the forces causing the motion.

Measuring methods



- **Observables (Code pseudoranges versus Phase pseudoranges)**
  - observables are pseudoranges as derived from run-time observations of the coded satellite signal or from measurements of the phase of the carrier
  - Generally, the accuracy of code ranges is at the meter level, the accuracy of carrier phases is in the millimeter range
  - The disadvantage of phase ranges is the fact that they are ambiguous by an integer number of full wavelengths, whereas the code ranges are virtually unambiguous
  - The determination of the phase ambiguities is often a critical issue in high-accuracy satellite-based positioning.



https://www.e-education.psu.edu/geog862/node/1752

Measuring methods

- **Data processing – coordinates determination (Real-Time versus Post-Processing)**
  - Basically, coordinates determination can be carried out in the field (real-time) or done afterwards (Post-Processing)
  - For real-time GNSS, the results must be available in the field immediately
  - The results are denoted as "instantaneous" if the observables of a single epoch are used for the position computation and the processing time is negligible.
  - Postprocessing refers to applications when data are processed in postmission

Relative positioning

- **Static relative positioning**
  - objective of relative positioning is to reduce or even eliminate error sources by **differencing** measurements taken at different stations at the same epoch
  - static relative positioning method is commonly used for geodetic surveys
  - required observation periods depend on:
    - baseline length
    - number of visible satellites
    - number of carrier frequencies
    - geometric configuration

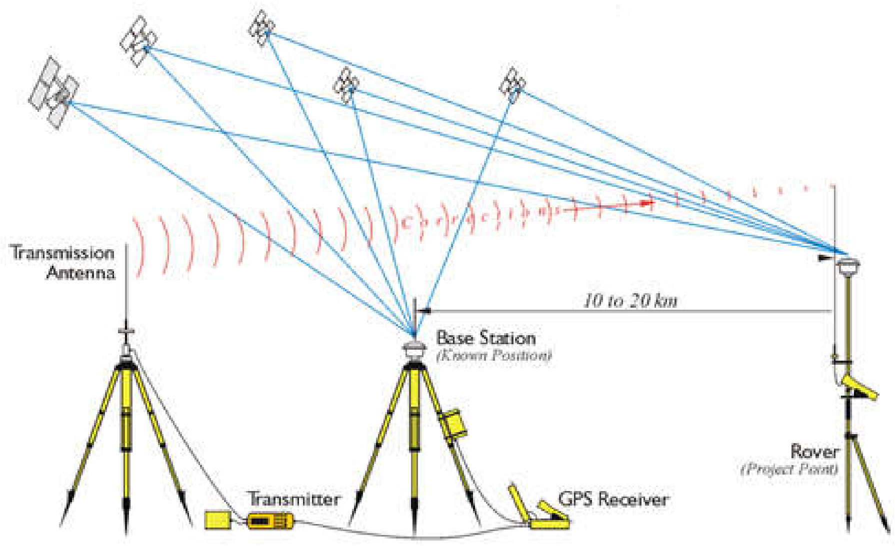
Receiver	Conventional static	Rapid static
Single-frequency	30 min + 3 min/km	20 min + 2 min/km
Dual-frequency	20 min + 2 min/km	10 min + 1 min/km

  - Rapid static (Fast static) technique is based on fast ambiguity resolution techniques. It generally uses code and carrier phase combinations on all frequencies
  - The accuracy is correlated with the baseline length and amounts to 1 to 0.1 ppm for baselines up to some 100 km

Hofmann-Wellenhof, Lichtenegger and Wasle (2008): GNSS

Relative positioning

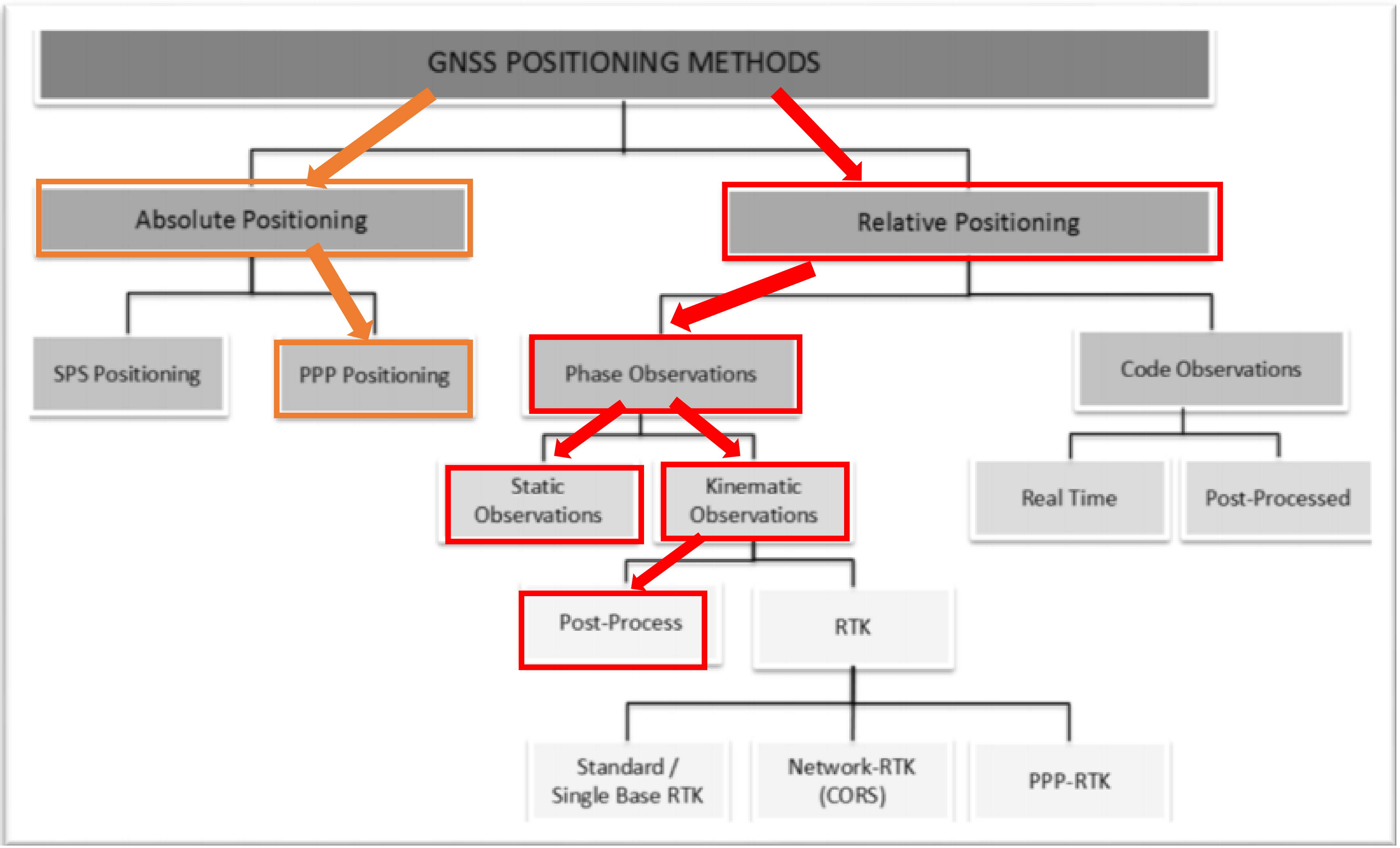
- **Kinematic relative positioning**
  - Kinematic surveys provides increased productivity
  - Relative position accuracies at the centimeter level can be achieved for baselines up to some 20 km
  - requires the resolution of the phase ambiguities before starting the survey
  - compared to the static mode, accuracy in the kinematic mode is worse mainly due to multipath and DOP variations
  - Kinematic relative positioning with ambiguities resolved in real-time is denoted as Real-Time Kinematic (RTK)



Mode	Horizontal accuracy
Static	5 mm + 0.5 ppm
Kinematic	5 cm + 5 ppm

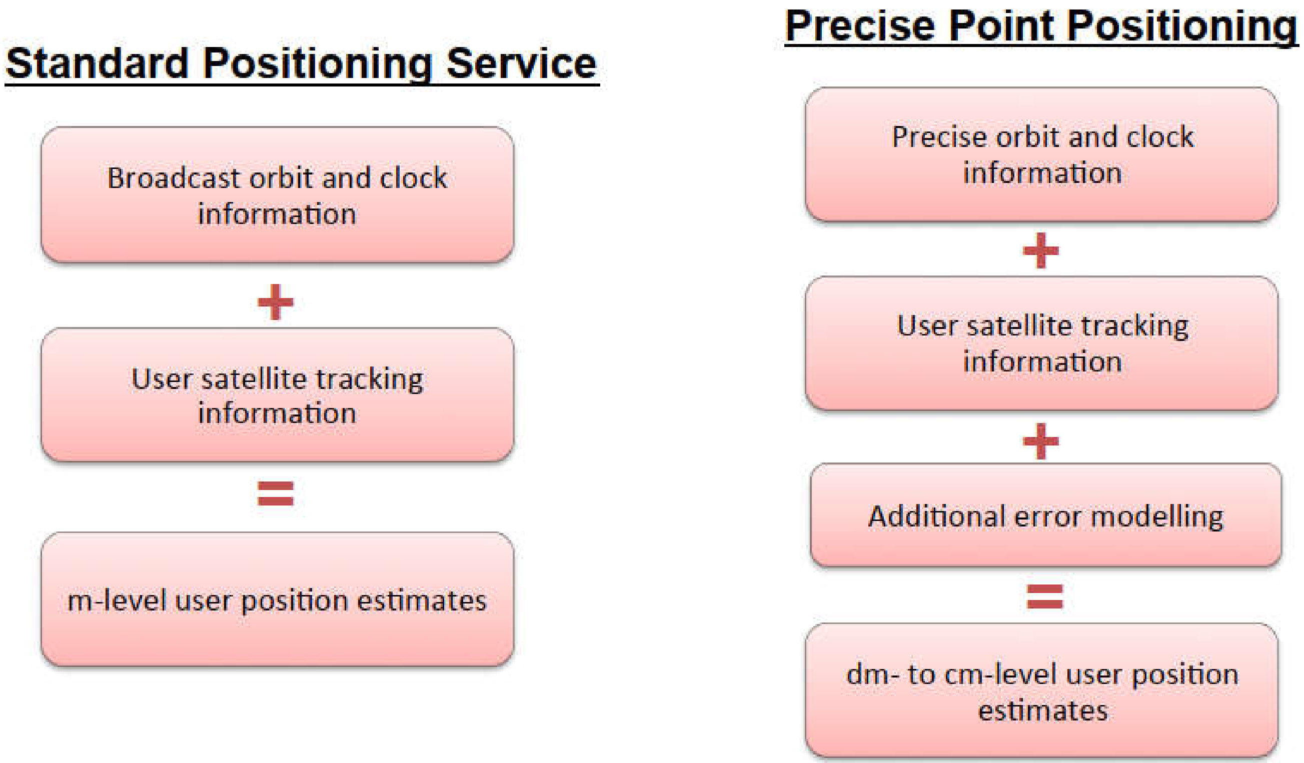
Hofmann-Wellenhof, Lichtenegger and Wasle (2008): GNSS

GNSS Positiong Methods taxonomy



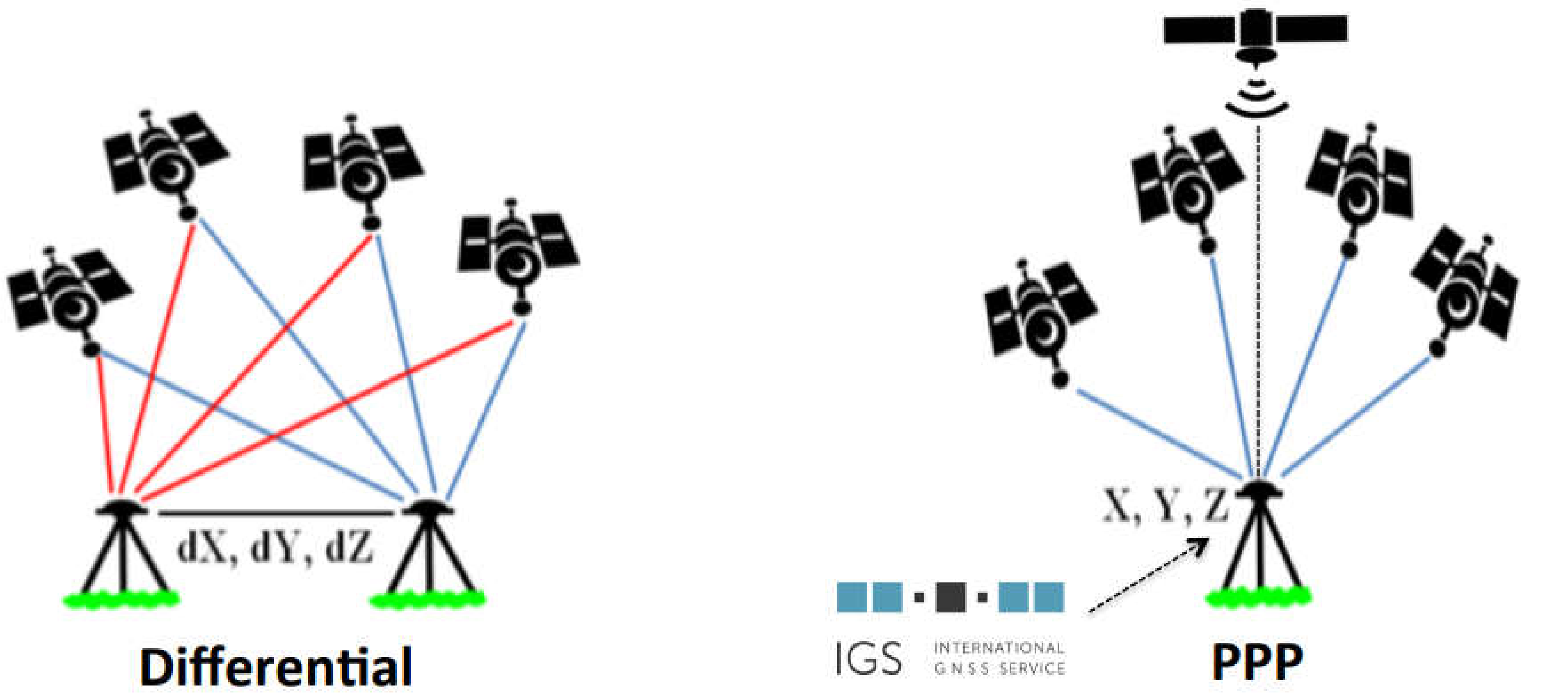
Precise Point Positioning (PPP)

- PPP is an absolute positioning technique that removes or models GNSS system errors to provide a high level of position accuracy from a single receiver



https://www.unoosa.org/documents/pdf/icg/2018/ait-gnss/16_PPP.pdf

How Does PPP Work?



PPP uses state space representation (SSR) correction products such as **precise satellite orbits**, **clocks** and **signal biases** from either commercial or/and public (e.g., IGS) that are delivered to the user via satellite and/or internet.

https://www.unoosa.org/documents/pdf/icg/2018/ait-gnss/16_PPP.pdf

Precise Point Positioning (PPP)

- Advantage: PPP also provides a positioning solution in a dynamic, global reference frame such as the International Terrestrial Reference Frame (ITRF)
- Disadvantage of PPP: most significant being the long convergence times (of the order of 20 minutes or more) necessary for the ambiguity float solution to converge so as to ensure centimetre-level positioning accuracy
- PPP requires a number of corrections to be applied to account for centimetre-level variations in undifferenced PR (pseudorange) and CPH (carrier-phase) observation biases

Precise Point Positioning (PPP)

Correction Type	PPP	Differential GNSS
Satellite Specific errors		
Precise satellite clock corrections	✓	×
Satellite antenna phase centre offset	✓	✓
Satellite antenna phase centre variations	✓	✓
Precise satellite orbits	✓	✓/×
Group delay differential	✓ (L1 only)	×
Relativity term	✓	×
Satellite antenna phase wind-up error	✓	×
Receiver Specific Errors		
Receiver antenna phase centre offset	✓	✓
Receiver antenna phase centre variations	✓	✓
Receiver antenna phase wind-up	✓	×
Geophysical Models		
Solid earth tide displacements	✓	×
Ocean loading	✓	×
Polar tides	✓	×
Plate tectonic motion	✓	×
Atmospheric Modelling		
Tropospheric delay	✓	✓
Ionospheric delay	✓ (L1 only)	×

Biases and errors that need to be applied or accounted for in typical PPP

RIZOS, JANSSEN, ROBERTS and GRINTER (2012): Precise Point Positioning: Is the Era of Differential GNSS Positioning Drawing to an End?

Precise Point Positioning (PPP)

- **PPP online services and applications**
  - Canadian Spatial Reference System Precise Point Positioning (CSRS-PPP) *(https://webapp.geod.nrcan.gc.ca/geod/tools-outils/ppp.php)*
  - magicGNSS *(https://magicgnss.gmv.com/)*
  - Automatic Precise Positioning Service – APPS
  - GNSS Analysis and Positioning Software – GAPS (http://gaps.gge.unb.ca/)
  - **Trimble CenterPoint RTX Post-Processing Service *(https://www.trimblertx.com/)***
  - **gLAB**

Software Characteristics

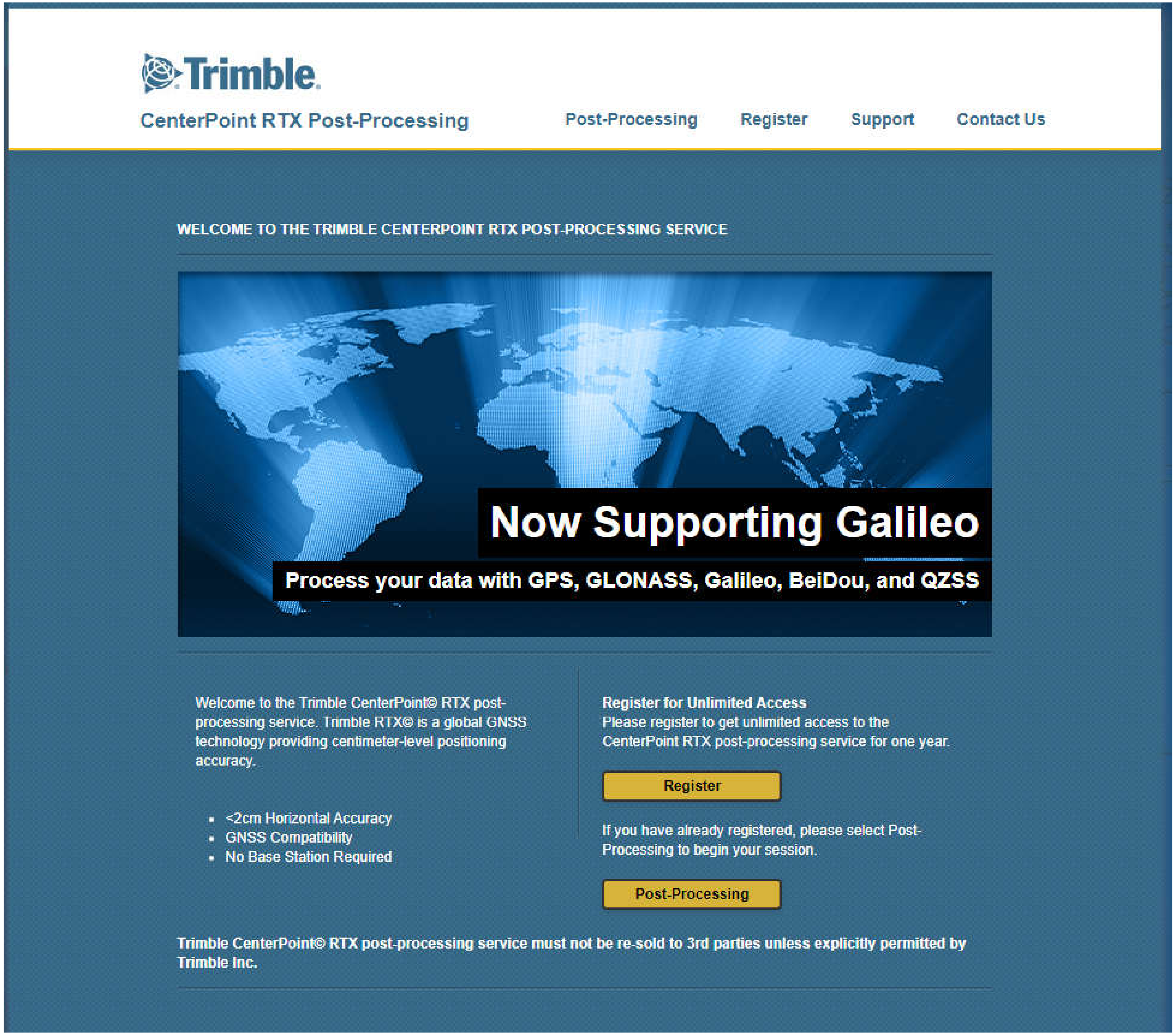
http://www2.unb.ca/gge/Resources/PPP/OnlinePPPs.html

Solution Type

	NRCan	GAPS	APPS	magicGNSS
Static Processing	All epochs / Smoothed	30-sec epochs / Forward only	5-min epochs / Smoothed	All epochs / Batch solution
Kinematic Processing	All epochs / Smoothed	All epochs / Forward only	5-min epochs / Smoothed	All epochs / Batch solution

Trimble RTX

- Trimble CenterPoint RTX post-processing service
- post-processing uses the Trimble RTX technology to post-process user-submitted GNSS observation files providing high-accuracy coordinates for anyone nearly anywhere in the world.



https://www.trimblertx.com/

ANNEX 2B: MAIN COMMERCIAL AUGMENTATION SERVICES

Name	Service	Stated Performance	Supported Constellations	Delivery Method	Method	Provider
Atlas	Atlas Basic	< 50 cm	GPS + GLONASS + Galileo + BeiDou	L band	PPP	Hemisphere
	Atlas H30	< 30 cm	GPS + GLONASS + Galileo + BeiDou	L band	PPP	
	Atlas H10	< 8 cm	GPS + GLONASS + Galileo + BeiDou	L band	PPP	
C-Nav	C-NavC^1	< 15 cm	GPS	L band	PPP	Oceaneering
	C-NavC^2	< 5 cm	GPS + GLONASS	Internet, L band	PPP	
GeoFlex	PPP Float L1	50 cm	GPS + GLONASS + Galileo + BeiDou	Internet, L band	PPP	GeoFlex
	PPP Float L1/L2	10 cm	GPS + GLONASS + Galileo + BeiDou	Internet, L band	PPP	
	PPP Fix	4 cm	GPS + GLONASS + Galileo + BeiDou	Internet, L band	PPP	
	Local PPP Fix&Rapid	4 cm	GPS + GLONASS + Galileo + BeiDou	Internet, L band	PPP	
	Global PPP Fix&Rapid	4 cm	GPS + GLONASS + Galileo + BeiDou	Internet, L band	PPP	
Here	HD GNSS	< 1 m	GPS + GLONASS + Galileo + BeiDou	Internet	PPP	Here
Magic	MagicPPP	< 10 cm	GPS + GLONASS + Galileo + BeiDou + QZSS	Internet	PPP	GMV
NAVCAST	NAVCAST	< 20 cm	GPS + Galileo	Internet	PPP	SpaceOpal
OmniSTAR	VBS	< 1 m	GPS	L band	DGNSS	Trimble
	HP	5-10 cm	GPS	L band	PPP	
	XP	8-10 cm	GPS	L band	PPP	
RTX	ViewPoint	< 1 m	GPS + GLONASS + Galileo + BeiDou + QZSS	Internet, L band	PPP	Trimble
	RangePoint	< 50 cm	GPS + GLONASS + Galileo + BeiDou + QZSS	Internet, L band	PPP	
	FieldPoint	< 10 cm	GPS + GLONASS + Galileo + BeiDou + QZSS	Internet, L band	PPP	
	CenterPoint	< 2 cm	GPS + GLONASS + Galileo + BeiDou + QZSS	Internet, L band	PPP	
	Sapa Premium +	< 10 cm with Integrity	GPS + GLONASS	Internet, L band	PPP-RTK	
Skylark	Skylark	10 cm	GPS + Galileo	Internet	PPP	Swift Navigation
Starfire	SF2	< 10 cm	GPS + GLONASS	L band	PPP	John Deere
	SF3	< 3 cm	GPS + GLONASS	L band	PPP	
Starfix	G2	< 10 cm	GPS + GLONASS	Internet, L band	PPP	Fugro
	G2+	< 3 cm	GPS + GLONASS	Internet, L band	PPP	
	G4	< 10 cm	GPS + GLONASS + Galileo + BeiDou	Internet, L band	PPP	
	XP2	< 10 cm	GPS + GLONASS	Internet, L band	PPP	
	HP	< 10 cm	GPS	Internet, L band	DGNSS	
	L1	< 1 m	GPS	Internet, L band	DGNSS	
TerraStar	TerraStar-L	50 cm	GPS + GLONASS	L band	PPP	Hexagon AB
	TerraStar-C	5 cm	GPS + GLONASS	L band	PPP	
	Terra Star-C PRO	3 cm	GPS + GLONASS + Galileo + BeiDou	L band	PPP	
Veripos	Apex	< 5 cm	GPS	L band	PPP	Hexagon AB
	Apex^2	< 5 cm	GPS + GLONASS	L band	PPP	
	Apex^5	< 5 cm	GPS + GLONASS + Galileo + BeiDou + QZSS	L band	PPP	
	Ultra	< 10 cm	GPS	L band	PPP	
	Ultra^2	< 10 cm	GPS + GLONASS	L band	PPP	
	Standard	< 1 m	GPS	L band	DGNSS	
	Standard^2	< 1 m	GPS + GLONASS	L band	DGNSS	

Trimble CenterPoint RTX

- Trimble RTX™ (Real Time eXtended) is a high-accuracy, global GNSS correction technology that combines real-time data with positioning and compression algorithms to provide centimeter level positioning accuracy
- Trimble RTX technology utilizes real-time data from a Trimble owned global reference station infrastructure to compute and relay satellite orbit, satellite clock, and other system adjustments to the receiver
- These adjustments are transmitted to the receiver via satellite, Internet Protocol (IP or Cellular), while post-processed results are sent to the user via email or a client interface
- The CenterPoint RTX post-processing service is a FREE service available for all users
- Users are required to register every year to get unlimited use of the service.

Trimble CenterPoint RTX

- The achievable accuracy level of the CenterPoint RTX post-processing service is 2 cm or better in the horizontal and approximately 6 cm in the vertical
- This is based on a minimum 1-hour observation file. As the data session approaches, but does not exceed 24 hours, accuracy can approach 1 cm in the horizontal and 3 cm in the vertical
- The CenterPoint RTX post-processing service supports any brand or model of dual frequency receiver
- Specific antenna types are supported by CenterPoint RTX post-processing service and are listed on http://TrimbleRTX.com/SupportedDevices.aspx

SUPPORTED ANTENNAS

IGS Name	Description
TRM105000.10 NONE	Zephyr 3 rover; switchable MSS filter in LNA; p/n 105000-10; L1/L2/L5/G1/G2/G3/E1/E2/E5ab/E6/BDS
TRM115000.00 NONE	Zephyr 3 Geodetic; switchable MSS filter in LNA; p/n 115000-00; L1/L2/L5/G1/G2/G3/E1/E2/E5ab/E6/BDS
TRM115000.00 TZGD	Zephyr 3 Geodetic; switchable MSS filter in LNA; p/n 115000-00; L1/L2/L5/G1/G2/G3/E1/E2/E5ab/E6/BDS

Trimble CenterPoint RTX

- **The the requirements of the observation file?**

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.

https://www.trimblertx.com/

Trimble CenterPoint RTX

- The achievable accuracy is very closely correlated to the length of the observation file
- It is recommended to use data sets that are a minimum of 1-hour in length to achieve 2 cm horizontal accuracy
- Data sets less than 1-hour will result in less accurate position results
- Data sets longer than 1-hour will yield even greater accuracy and can approach 1 cm
- The CenterPoint RTX post-processing service does not accept observation files that are longer than 24 hours
- The recommended observation rate is 10 seconds. Files with higher observation rates will be accepted, but the service will decimate to 10 seconds before processing. Files must have an observation rate higher than or equal to 60 seconds.

Trimble CenterPoint RTX

- **data sets that were collected prior to March 23rd, 2017 are derived in the observation epoch (current epoch) of ITRF2008**
- **data sets that were collected after March 23rd, 2017 are derived in the observation epoch (current epoch) of ITRF2014**
- **CenterPoint RTX corrected post-processed positions can be transformed to a number of reference frames (non exhaustive list):**
  - ITRF2014: Current Epoch, Epoch 2010.0
  - ITRF2008: Current Epoch, Epoch 2005.0
  - ITRF1989 (1988.0)
  - ITRF1994 (1993.0)
  - ITRF1996 (1997.0)
  - ITRF2000 (1997.0)
  - ITRF2005 (2000.0)
  - ETRS89 (1989.0)
  - ETRF2000-RO5 (2000.0)

  ....

Trimble CenterPoint RTX

- **The CenterPoint RTX post-processing service allows the transformation of the current epoch ITRF2008 / ITRF2014 position to another reference frame with a different reference epoch and based on a selected tectonic plate**
- **Transforming the positions computed at the observation epoch to a fixed epoch requires knowledge of the station velocity due to the tectonic plate motion**
- **If the velocity is not available, it must be determined from a tectonic plate model such as MORVEL56**

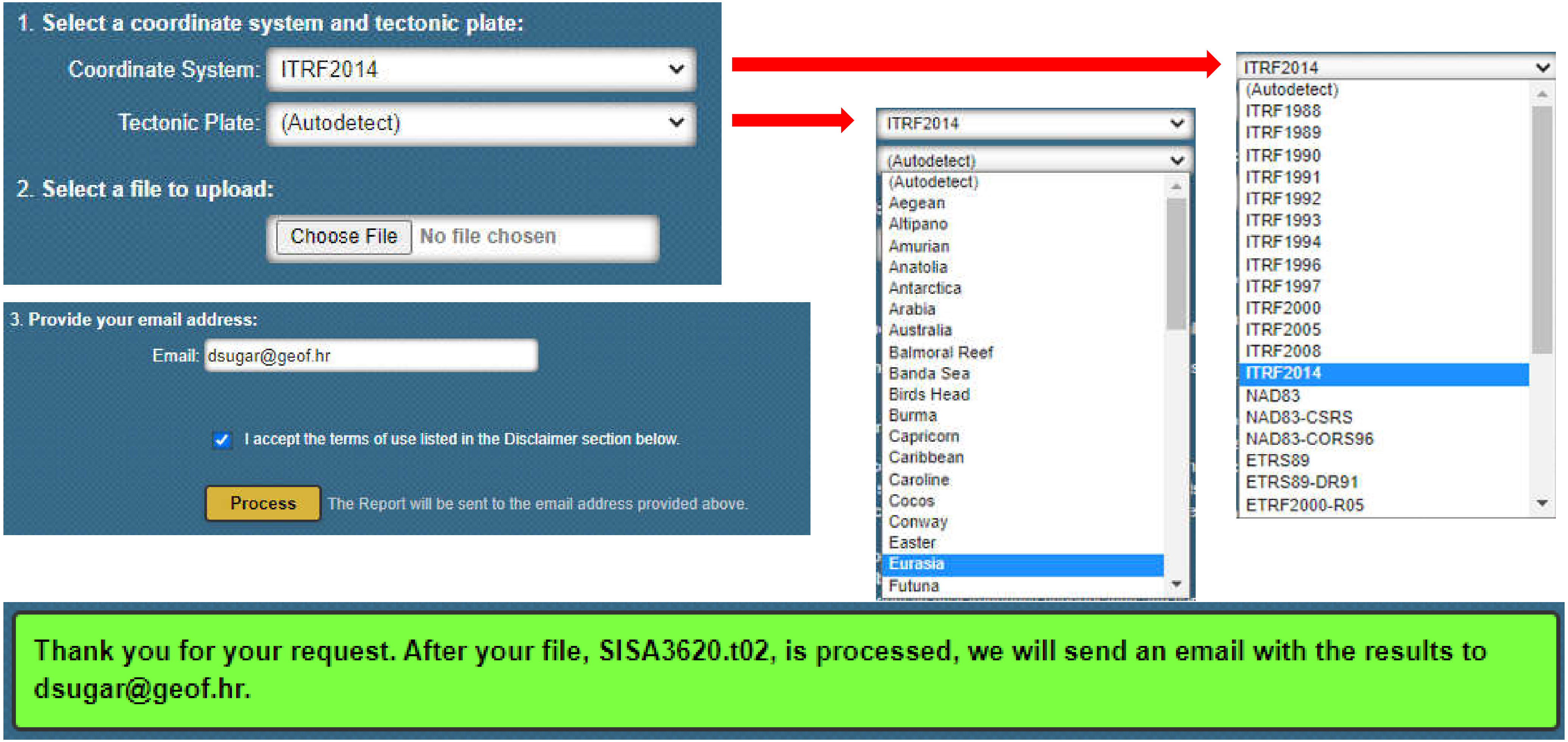
Trimble CenterPoint RTX

- **in June 2014 the tectonic plate model was changed from NUVEL-1A to MORVEL56, following tectonic plates are supported:**

1. Aegean
2. Altipano
3. Amurian
4. Anatolia
5. Antarctica
6. Arabia
7. Australian
8. Balmoral Reef
9. Banda Sea
10. Birds Head
11. Burma
12. Capricorn
13. Caribbean
14. Caroline
15. Cocos
16. Conway
17. Easter
18. Eurasian
19. Futuna
20. Galapagos
21. Indian
22. Juan de Fuca
23. Juan Fernandez
24. Kermadec
25. Lwandle
26. Macquarie
27. Manus
28. Maoke
29. Mariana
30. Molucca Sea
31. Nazca
32. New Hebrides
33. Niuafoou
34. North America
35. North Andes
36. North Bismarck
37. Nubia
38. Okhotsk
39. Okinawa
40. Pacific
41. Panama
42. Philippine Sea
43. Rivera
44. Sandwich
45. Scotia
46. Shetland
47. Solomon Sea
48. Somalia
49. South America
50. South Bismarck
51. Sundaland
52. Sur
53. Timor
54. Tonga
55. Woodlark
56. Yangtze

Trimble CenterPoint RTX

- **Three-step procedure:**



Trimble CenterPoint RTX

- **Three-step procedure:**

Trimble CORRECTION SERVICES

Dear Customer,

Your uploaded file (SISA3620.t02) was successfully processed.

The processing result is a report which contains coordinates in ITRF2014 (reference epoch) and ITRF08 (current epoch). For tectonic plate corrections the plate EURASIA was used. As per your request, the tectonic plate was determined automatically by the RTX-PP server based on the estimated latitude and longitude of the observation data.

The report is attached to this e-mail in XML and PDF formats.

This e-mail was generated automatically by TrimbleRTX.com.

Powered by Trimble CORRECTION SERVICES

Report_25540745.xml 5 KB

Report_25540745.pdf 114 KB

Trimble CenterPoint RTX – processing report

Trimble

Post-Processing Service Based on RTX Technology

TrimbleRTX.com

Contributor:	dsugar@geof.hr
Reference Name:	SISA3620.t02
Upload Date:	07/13/2021 14:15:24 UTC
Report Time Frame:	
Start Time:	12/27/2020 00:00:00 UTC
End Time:	12/27/2020 23:59:45 UTC
Observation File Type(s):	T02
Observation File(s):	SISA3620.t02
Antenna:	
Name:	TRM115000.00 TZGD
Height:	0.000 m
Reference:	Bottom of antenna mount
Receiver Name:	TRIMBLE ALLOY
Coordinate Systems:	ITRF2014
Tectonic Plate:	Eurasia (Auto-detected)
Tectonic Plate Model:	MORVEL56
Processing Interval:	15 s

Statistics

# Total Obs	# Usable Obs	# Used Obs	Percent
5760	5760	5760	100

Trimble CenterPoint RTX – processing report

Used Satellites

# Total Satellites:	80
GPS:	G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G12 G13 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30 G31 G32
GLONASS:	R01 R02 R03 R04 R05 R07 R08 R09 R12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22 R24
Galileo:	E01 E02 E03 E04 E05 E07 E08 E09 E11 E12 E13 E15 E19 E21 E24 E25 E26 E27 E30 E31 E33 E36
BeiDou:	C06 C07 C09 C10 C11 C12 C13 C14

Processing Results

ITRF2014 at Epoch 2010.0		
Coordinate	**Value**	**σ**
X	4297851.915 m	0.003 m
Y	1262317.958 m	0.003 m
Z	4525446.017 m	0.003 m
Latitude	45° 29' 7.48603" N	0.002 m
Longitude	16° 22' 4.76558" E	0.002 m
El. Height	158.894 m	0.004 m

ITRF2014 at Epoch 2020.99		
Coordinate	**Value**	**σ**
X	4297851.752 m	0.003 m
Y	1262318.133 m	0.003 m
Z	4525446.123 m	0.003 m
Latitude	45° 29' 7.49090" N	0.002 m
Longitude	16° 22' 4.77541" E	0.002 m
El. Height	158.895 m	0.004 m

Report Information

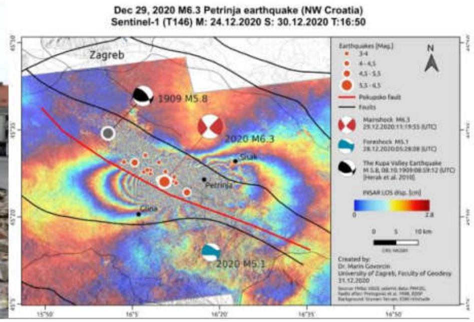
Trimble RTX Solution ID: 25540745
Solution Type: Static
Software Version: 8.5.0.19198
Creation Date: 07/13/2021 14:17:40 UTC

Recall what we went through...

- Motivation instead of introduction
- Global Navigation Satellite System (GNSS) – overview & current status
- Global, Continental and Regional (State) Networks
- Error sources
- Measuring methods
- Precise Point Positioning (PPP)

Case studies:

- Zagreb (22nd March 2020)
- Petrinja (28th & 29th December 2020 – 6th January 2021)

Danijel Šugar

EO4GEO training: Fast disaster response – satellite technologies for surface displacement monitoring

GNSS

July 12th – 14th, 2021

University of Zagreb – Faculty of Geodesy

Co-funded by the Erasmus+ Programme of the European Union