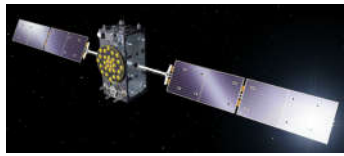
Danijel Šugar, Luka Blagus, Željko Bačić

Assessment of CROPOS GNSS stations stability after the Petrinja 2020-2021 earthquake series

GNSS SEMINÁŘ 2023

Brno, 2nd February 2023



Outline:

- Petrinja earthquake series
- CROPOS
- PPP method and PPP-PP services
- Processing results
- Permanent displacement estimation
- Conclusions

Petrinja earthquake series 2020-2021

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

Period (YYYY-MM-DD) 2020-12-23 to 2021-01-03

Location (in degrees) 44 < latitude < 46

16 < longitude < 17

Depth (in kms) Min Max

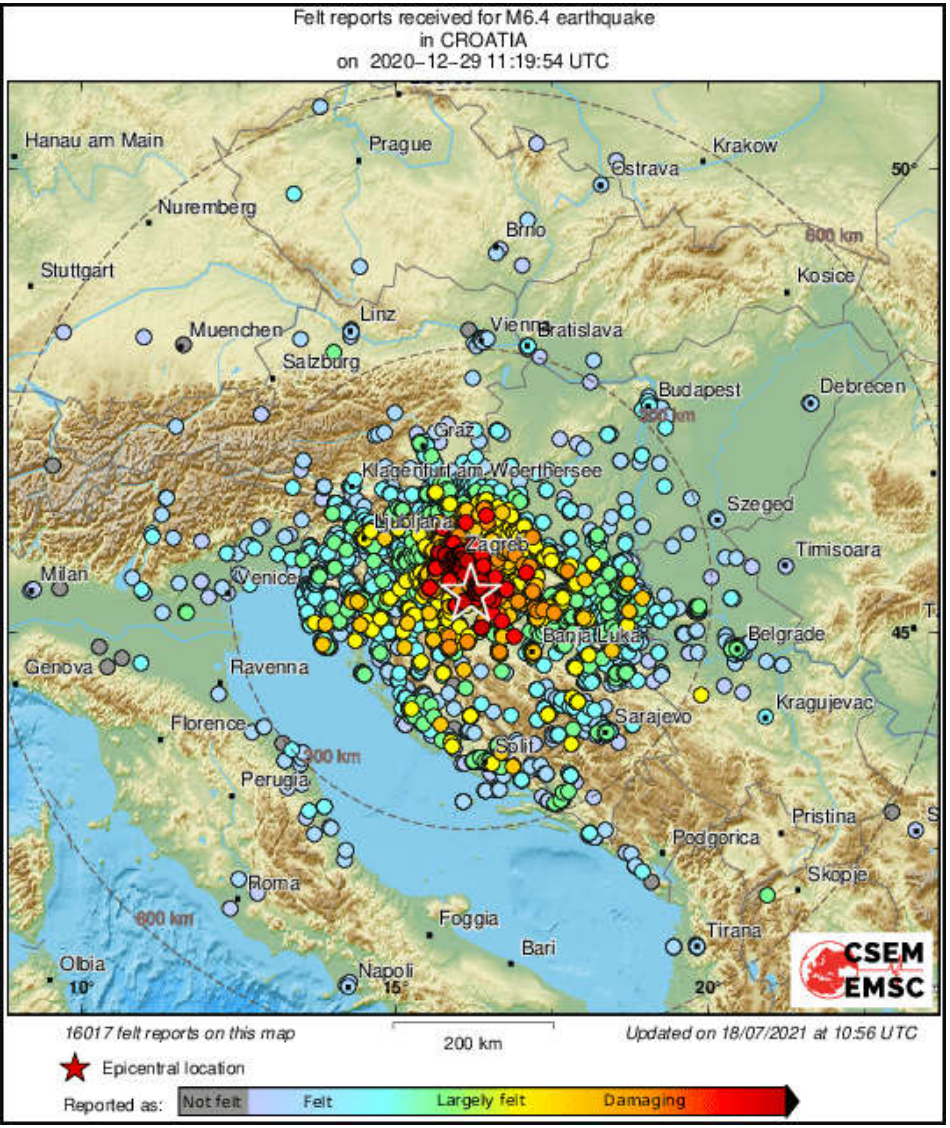
Magnitude Min 4.5 Max

Citizen Response	Date & Time UTC	Latitude degrees		Longitude degrees		Depth km	Mag[+]	Region name	[+]
				1					
3325 V	2020-12-28 05:28:07.1	45.42	N	16.22	E	10	5.2	CROATIA	
1484 V	2020-12-28 06:49:56.8	45.42	N	16.28	E	10	5.0	CROATIA	
3051 VII	2020-12-29 11:19:54.1	45.42	N	16.21	E	10	6.4	CROATIA	
3505 IV	2020-12-30 05:15:04.7	45.44	N	16.18	E	10	4.8	CROATIA	
1616 IV	2020-12-30 05:26:40.6	45.44	N	16.21	E	10	4.7	CROATIA	
				1					

Bold : Earthquakes with a magnitude ≥ 4.5 in Euro-med, or ≥ 5.5 in the world

Red : Earthquakes with a magnitude ≥ 5 in Euro-med, or ≥ 6 in the world

Petrinja earthquake on 29th December 2020

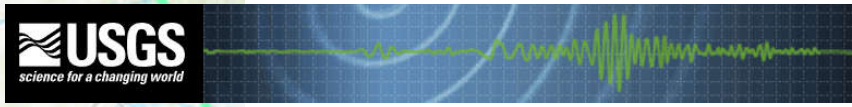


M 6.4 - CROATIA - 2020-12-29 11:19:54 UTC

- Magnitude **Mw 6.4**
- Region **CROATIA**
- Date time **2020-12-29 11:19:54.1 UTC**
- Location **45.42 N ; 16.21 E**
- Depth **10 km**

CSEM EMSC

Petrinja earthquake on December 29th 2020



M 6.4 - 2 km WSW of Petrinja, Croatia

2020-12-29 11:19:54 (UTC) | 45.424°N 16.257°E | 10.0 km depth

Peak Ground Accelleration - PGA

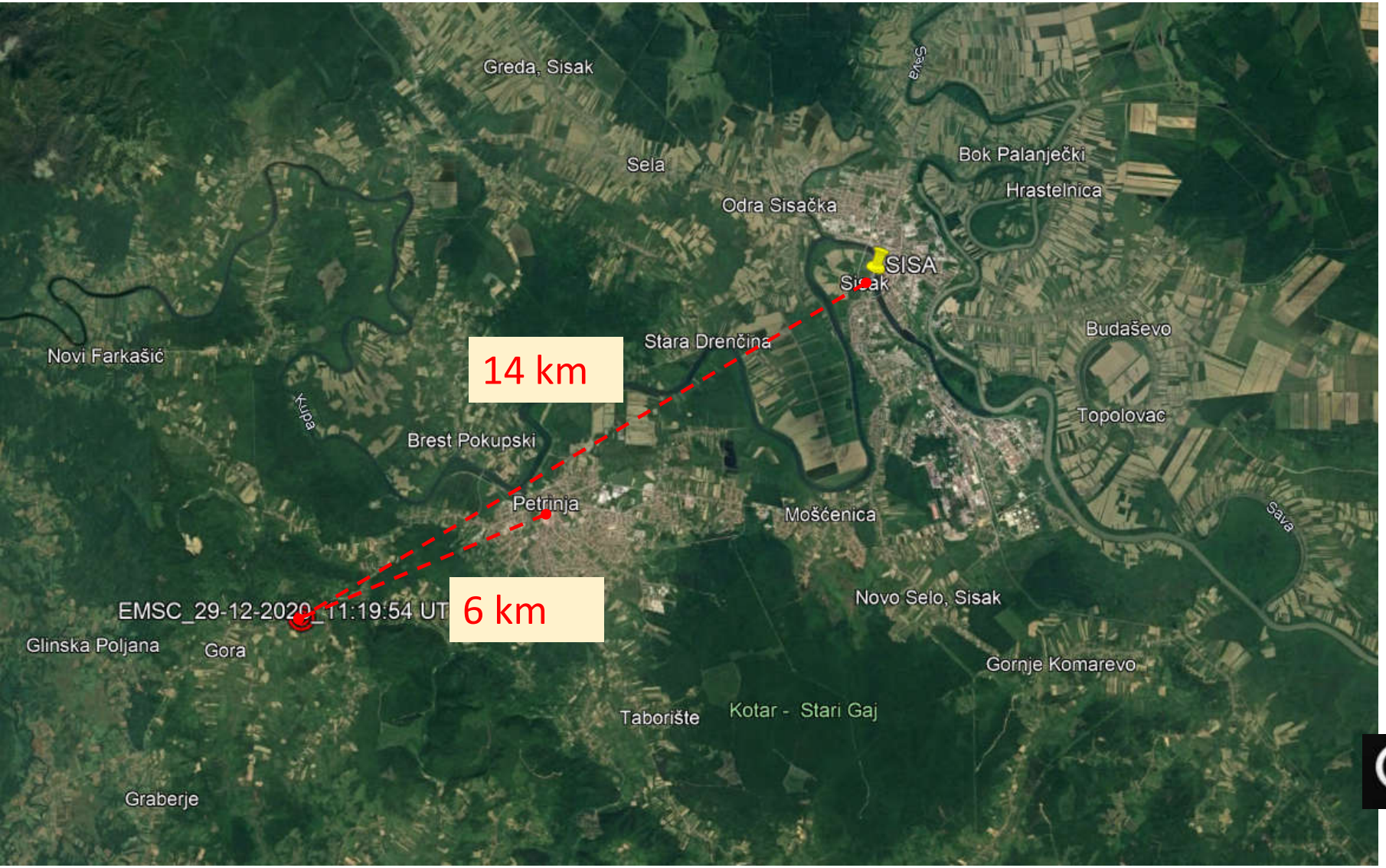
Petrinja earthquake on 29th December 2020

M 6.4 - CROATIA - 2020-12-29 11:19:54 UTC

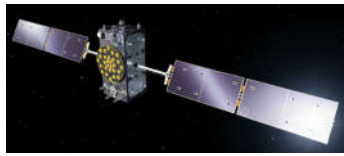
https://www.youtube.com/watch?v=phbc5Lhnu30

Petrinja, 29th December 2020

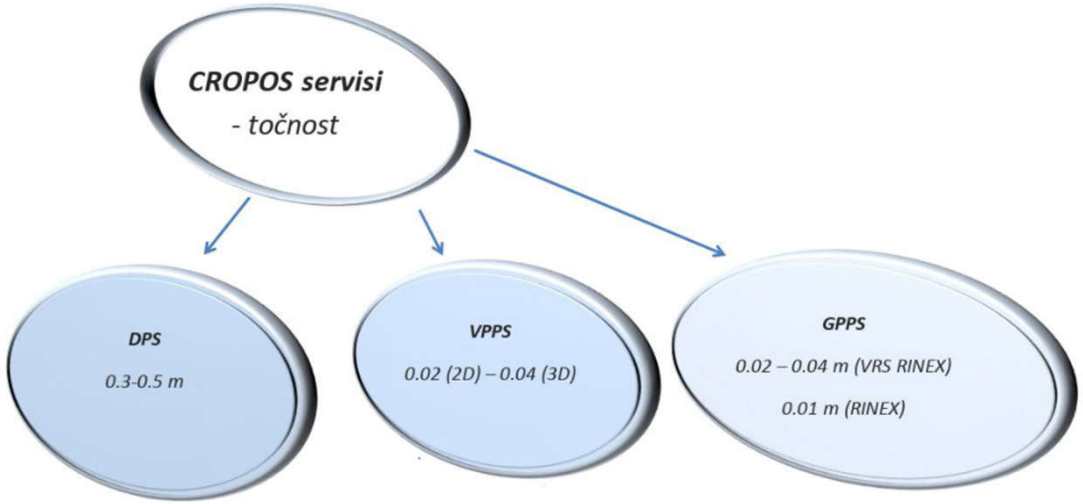
Petrinja earthquake on 29th December 2020

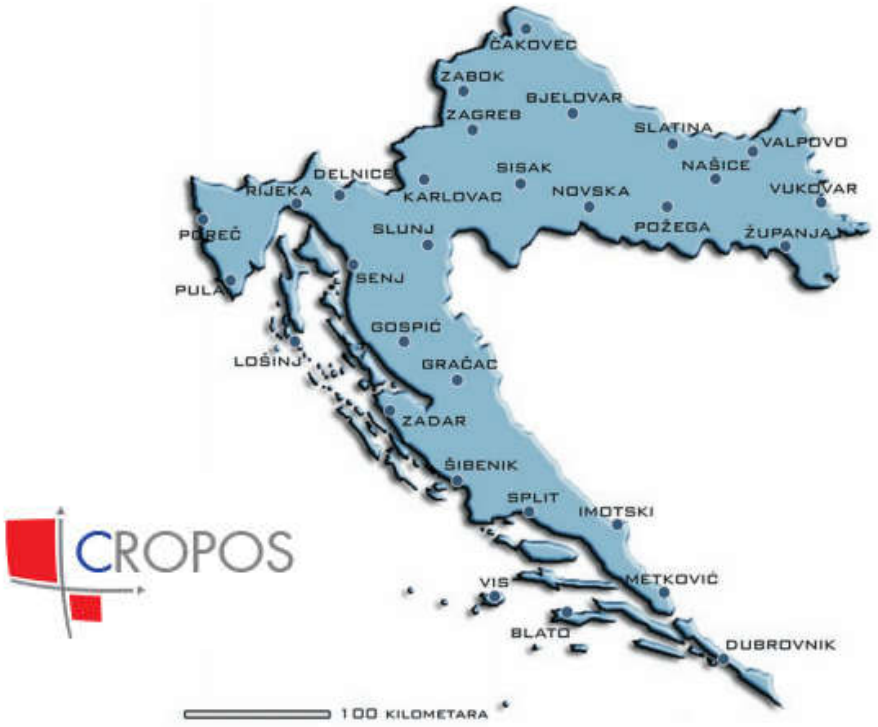


CROPOS:



- National permanent GNSS network of Croatia
- Established in 2008 (30 stations)
- ETRF00 (R05), e = 2008.83
- services: DSP, VPPS, GPPS

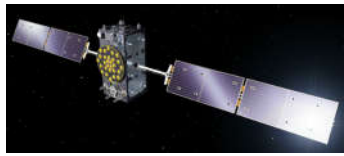




CROPOS:

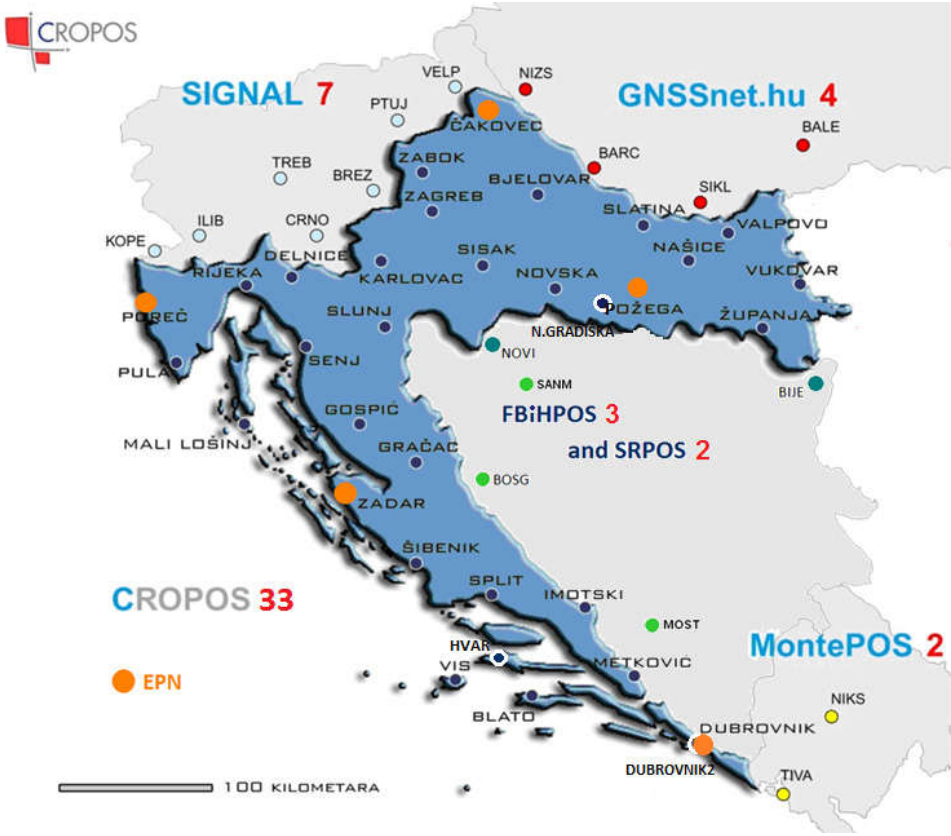
EUROPSKI STRUKTURNI I INVESTICIJSKI FONDOVI

Europska unija
Zajedno do fondova EU



- Network enlargement:
  (HR 30 + 3) + (SLO 7 + HU 6 + BiH 5 + MNE 2) = 51
- EPN: 5 stations
- modernization: 2019
- Trimble Alloy &
  Zephyr Geodetic 3 (TZGD)
- GPS + GLO + GAL + BSD

CROPOS &GALILEO



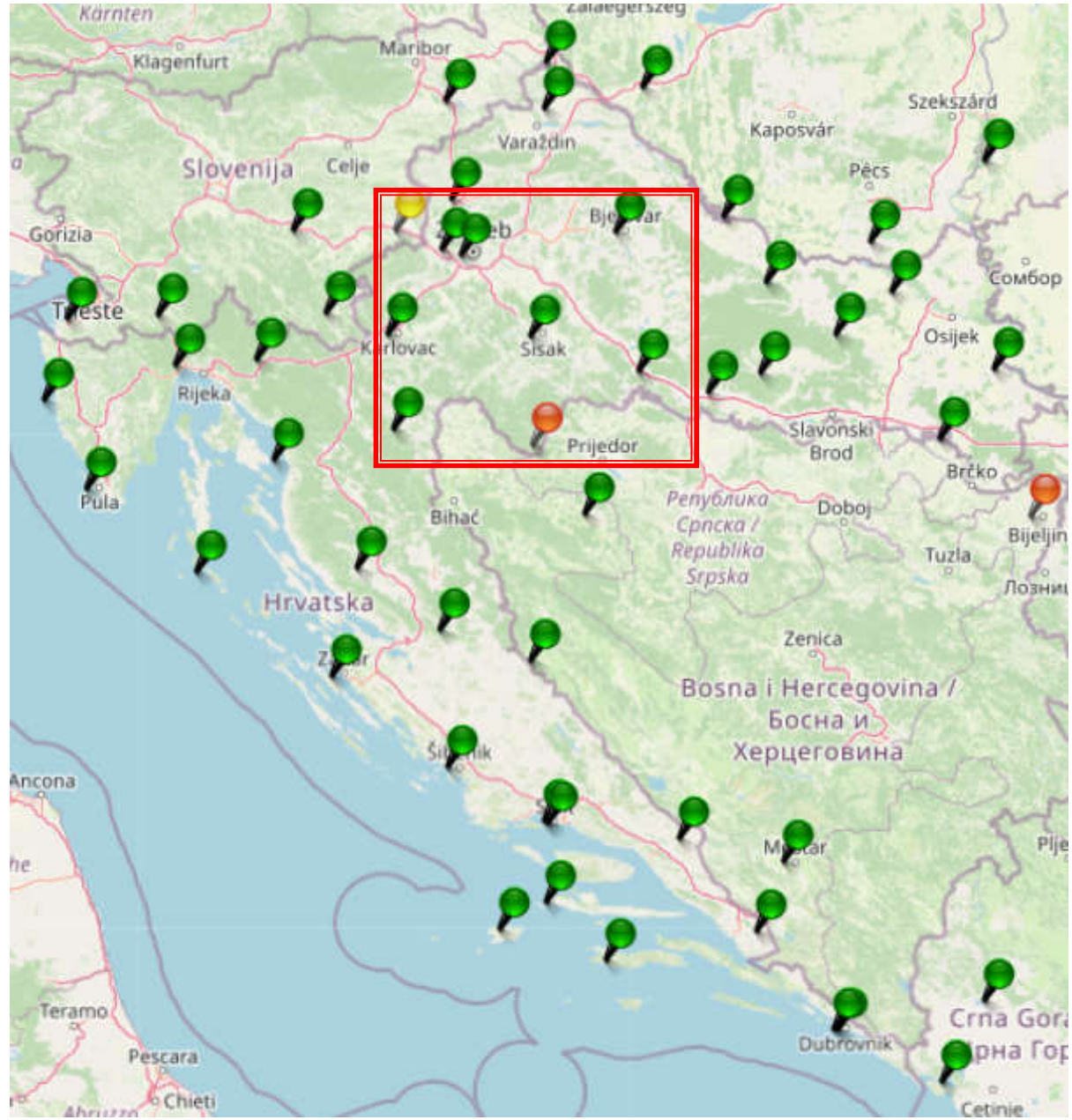
CROPOS:

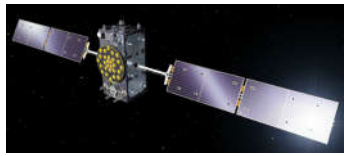
- GPPS -

  Geodetic Precise Positioning System

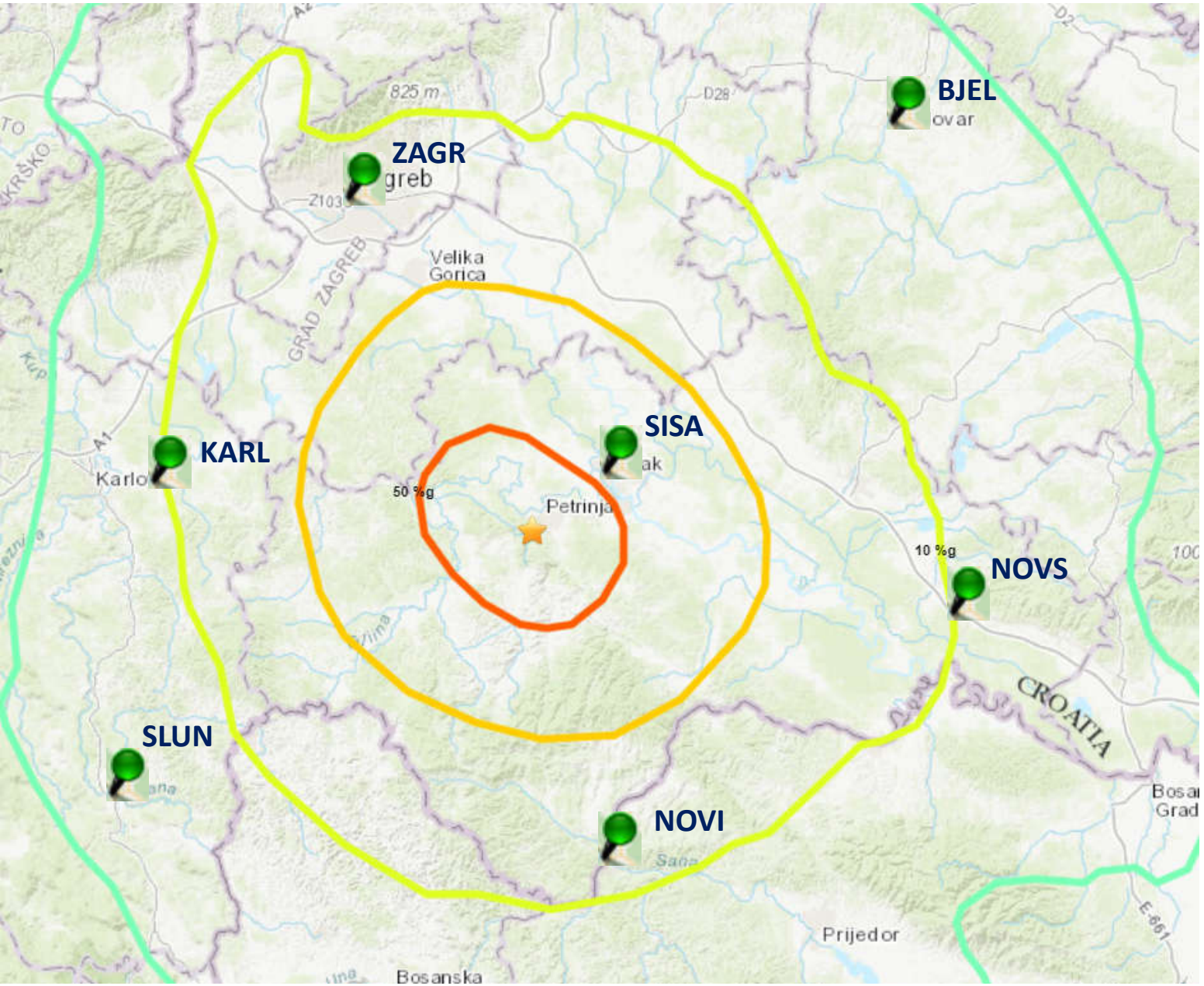
Trimble® Pivot Web

http://195.29.198.194/Map/SensorMap.aspx





CROPOS



Observation data set:

- SISA, BJEL, NOVS, NOVI, SLUN, KARL, ZAGR
- 23 – 27 December 2020
- **28 & 29 December 2020**
- 30 December 2020 – 3 January 2021

- T02
- logging interval 15 s
- RINEX 3.04

Precise Point Positioning (PPP):

Kouba et al. (2017): „The PPP approach uses undifferenced, dual-frequency, pseudorange and carrier-phase observations along with precise satellite orbit and clock products, for standalone static or kinematic geodetic point positioning with centimeter precision.”

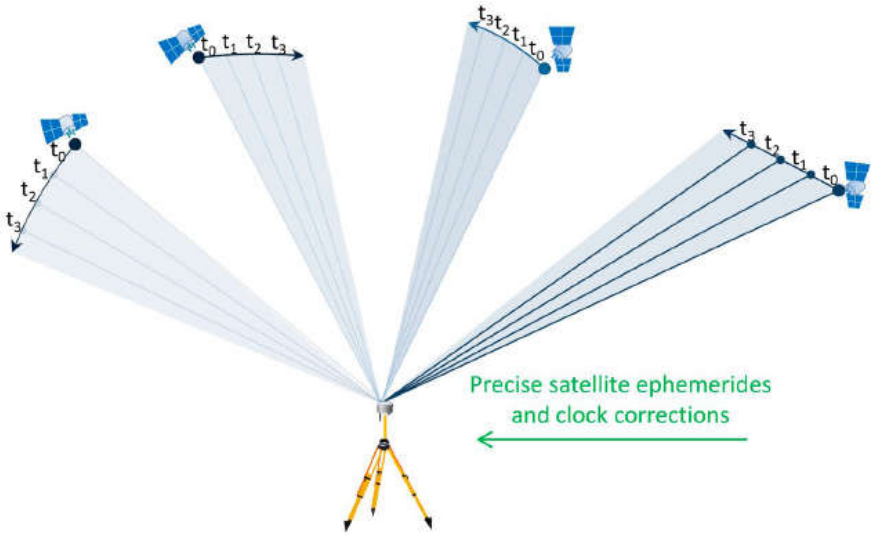


Figure 3.2: *Precise Point Positioning.*

Kouba, J., Lahaye, F. & Tétreault, P. (2017): Precise Point Positioning, pp. 723-751, in Springer Handbook of Global Navigation Satellite Systems, Peter J.G. Teunissen, Oliver Montenbruck (Eds.), Springer International Publishing AG.

Lipatnikov, L.A. and Shevchuk, S.O. (2019): Cost Effective Precise Positioning with GNSS, FIG Report Commission 5, International Federation of Surveyors (FIG).

Precise Point Positioning (PPP):

- PPP is able to provide position solutions at cm-level: accuracy performance can be even better, e.g., sub-centimeter level, in post-processing and in static mode

PPP Fundamentals

esa navipedia

https://gssc.esa.int/navipedia/index.php/PPP_Fundamentals

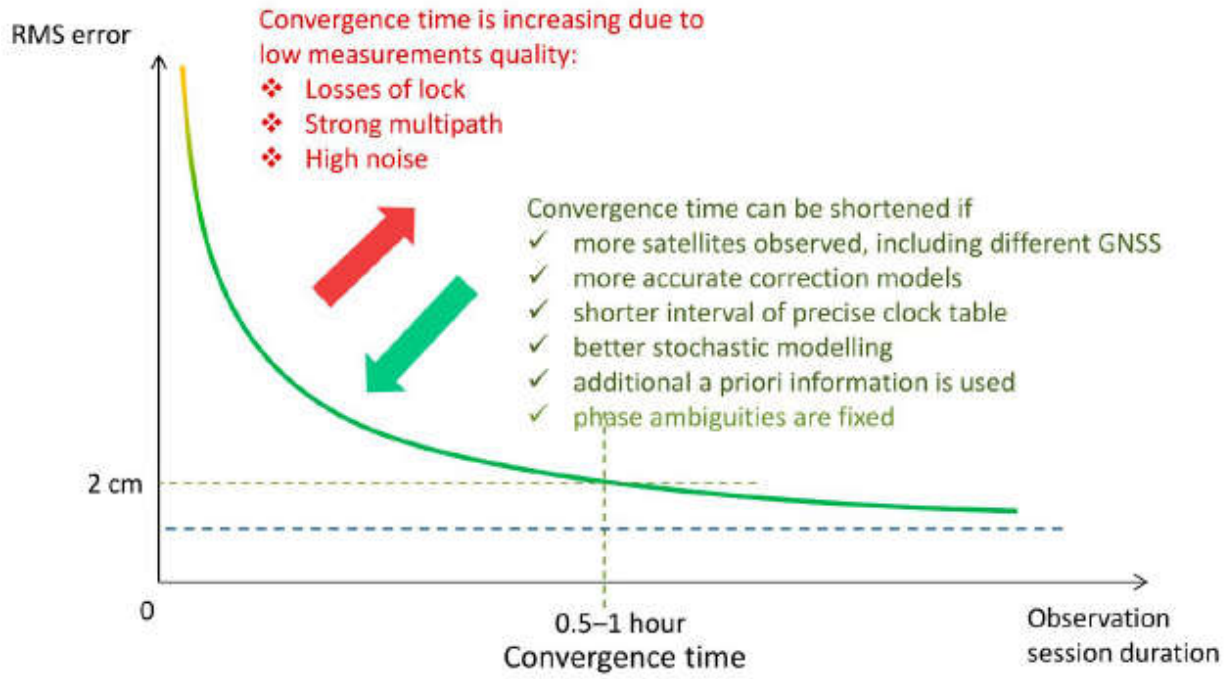
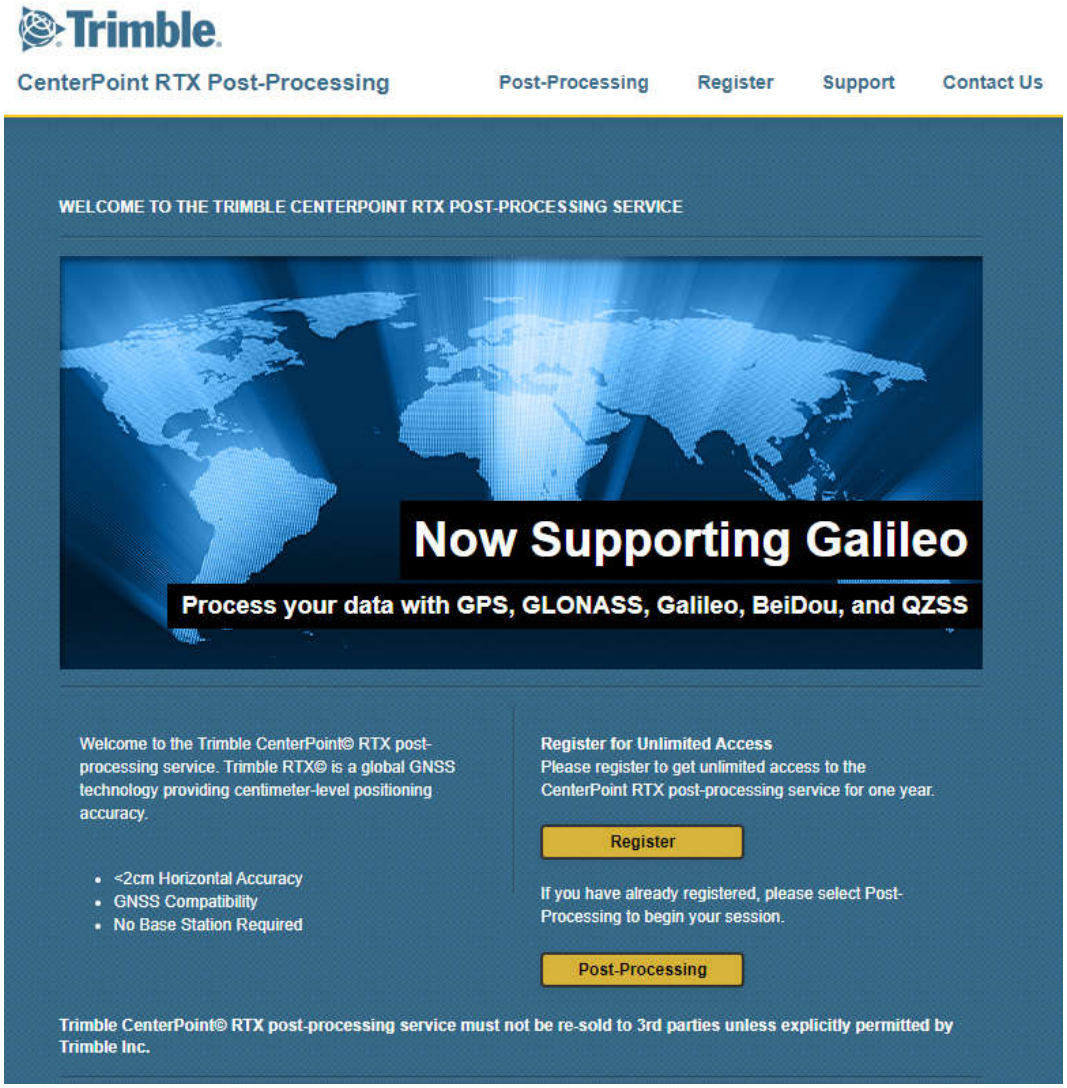
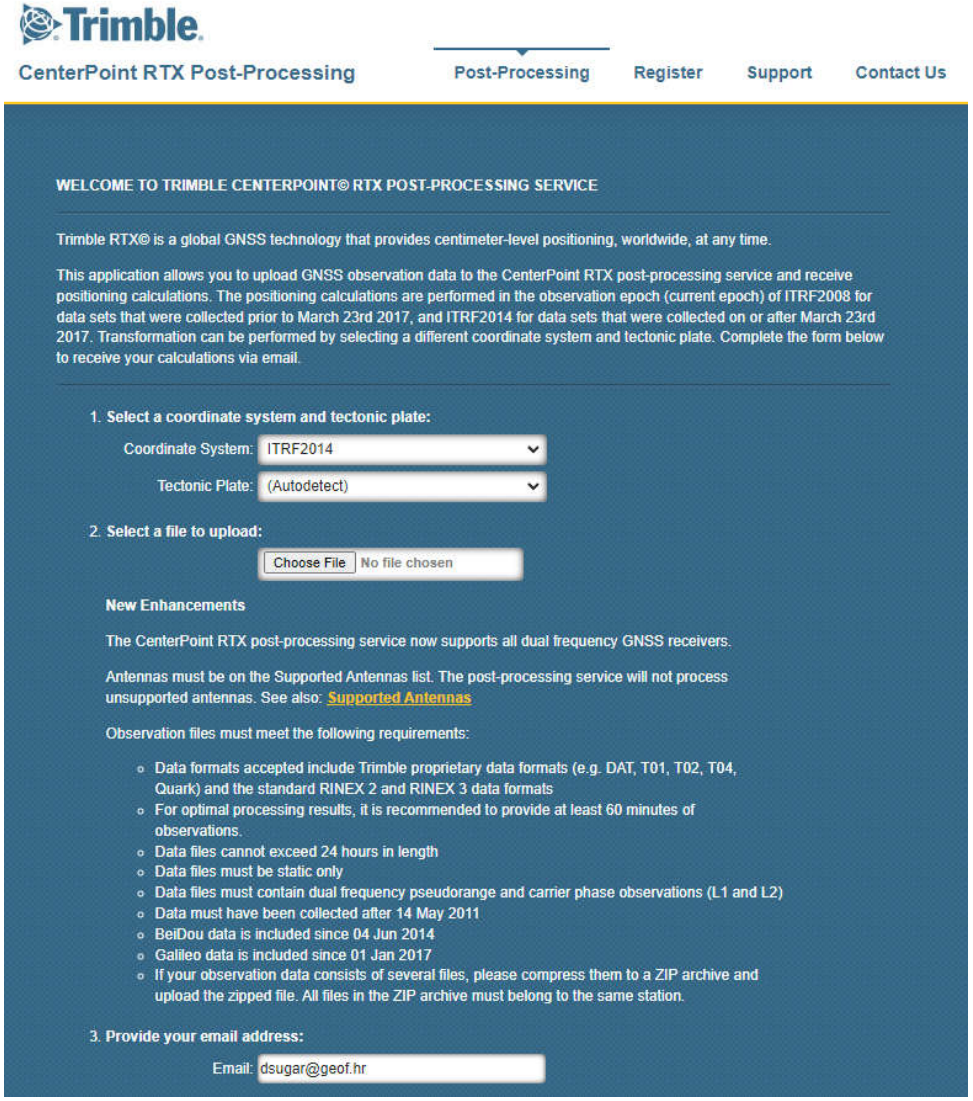


Figure 3.3: *PPP convergence time.*

Lipatnikov, L.A. and Shevchuk, S.O. (2019): Cost Effective Precise Positioning with GNSS, FIG Report Commission 5, International Federation of Surveyors (FIG).

PPP-PP services: CenterPoint RTX Post-Processing





Trimble

Post-Processing Service Based on RTX Technology

TrimbleRTX.com

Contributor: blagus.luka@gmail.com
Reference Name: BJEL3580.t02
Upload Date: 12/16/2022 21:09:15 UTC

Report Time Frame:
Start Time: 12/23/2020 00:00:00 UTC
End Time: 12/23/2020 23:59:45 UTC
Observation File Type(s): T02
Observation File(s): BJEL3580.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

Used Satellites

# Total Satellites:	80
GPS:	G01 G02 G03 G04 G05 G06 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 C08 C09 C10 C11 C12 C13 C14

Processing Results

ITRF2014 at Epoch 2010.0		
Coordinate	**Value**	**σ**
X	4255938.302 m	0.003 m
Y	1288569.454 m	0.003 m
Z	4557372.026 m	0.003 m
Latitude	45° 53' 46.84501" N	0.002 m
Longitude	16° 50' 41.01255" E	0.002 m
El. Height	188.377 m	0.004 m

ITRF2014 at Epoch 2020.98		
Coordinate	**Value**	**σ**
X	4255938.138 m	0.003 m
Y	1288569.627 m	0.003 m
Z	4557372.131 m	0.003 m
Latitude	45° 53' 46.84985" N	0.002 m
Longitude	16° 50' 41.02245" E	0.002 m
El. Height	188.378 m	0.004 m

PPP-PP services:

CenterPoint RTX Post-Processing

ITRF2014 at Epoch 2020.98		
Coordinate	**Value**	**σ**
X	4255938.138 m	0.003 m
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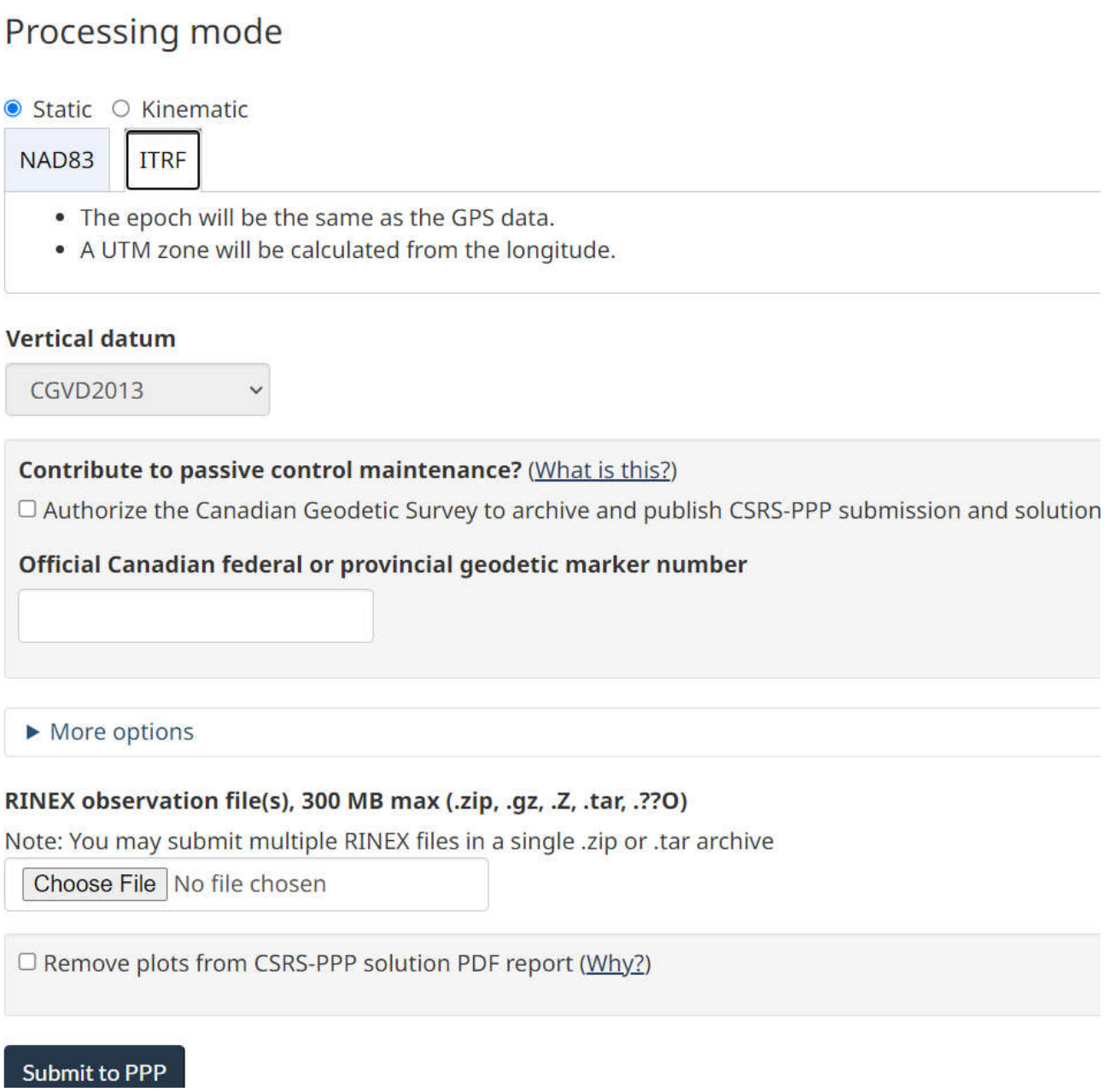
Z	4557372.131 m	0.003 m
Latitude	45° 53' 46.84985" N	0.002 m
Longitude	16° 50' 41.02245" E	0.002 m
El. Height	188.378 m	0.004 m

(Fi, La) → UTM 33 North → (E, N)

Government of Canada | Gouvernement du Canada

PPP-PP services:
Canadian Spatial Reference System CSRS - PPP

https://webapp.csrs-scrs.nrcan-rncan.gc.ca/



Government of Canada | Gouvernement du Canada

PPP-PP services:
Canadian Spatial Reference System
CSRS - PPP

CSRS-PPP 3.54.2 (2022-11-10)

BJEL3580.20o
BJEL

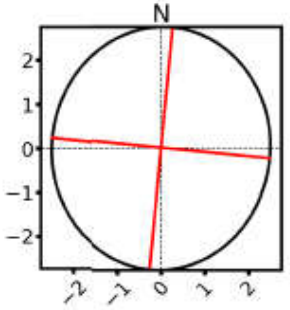
Data Start	Data End	Duration of Observations
2020-12-23 00:00:00.00	2020-12-23 23:59:30.00	23:59:30
Processing Time		**Product Type**
12:57:23 UTC 2022/12/17		NRCan/IGS Final
Observations	**Frequency**	**Mode**
Phase and Code	Double	Static

Elevation Cut-Off	Rejected Epochs	Fixed Ambiguities	Estimation Steps
7.5 degrees	0.00 %	98.98 %	30.00 sec

Antenna Model	APC to ARP	ARP to Marker
TRM115000.00 TZGD	L1 = 0.064 m L2 = 0.057 m	H:0.000m / E:0.000m / N:0.000m

(APC = antenna phase center; ARP = antenna reference point)

95% Error Ellipse (mm)
semi-major: 3 mm
semi-minor: 2 mm
semi-major azimuth: 5° 30' 47.38"



UTM (North)
Zone 33

5084185.645 m (N)
643107.348 m (E)

Scale Factors
0.99985177 (point)
0.99982225 (combined)

Estimated Position for BJEL3580.20o

	Latitude (+n)	Longitude (+e)	Ell. Height
ITRF14 (2021.0)	45° 53' 46.84982"	16° 50' 41.02260"	188.367 m
Sigmas(95%)	0.002 m	0.002 m	0.007 m
A priori*	45° 53' 46.83159"	16° 50' 40.99114"	188.374 m
Estimated – A priori	0.563 m	0.678 m	-0.007 m

Comparison of results (daily solutions): 23.12.2020. – 03.01.2021.

Trimble

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Trimble RTX-PP vs. CSRS - PPP

	Range E [m]	Range N [m]	Range el. H [m]
BJEL	0,001	0,002	0,008
KARL	0,002	0,002	0,008
NOVI	0,004	0,007	0,014
NOVS	0,002	0,003	0,009
SISA	0,010	0,005	0,008
SLUN	0,002	0,002	0,009
ZAGR	0,002	0,003	0,010

Comparison of results (daily solutions): 23.12.2020. – 03.01.2021.

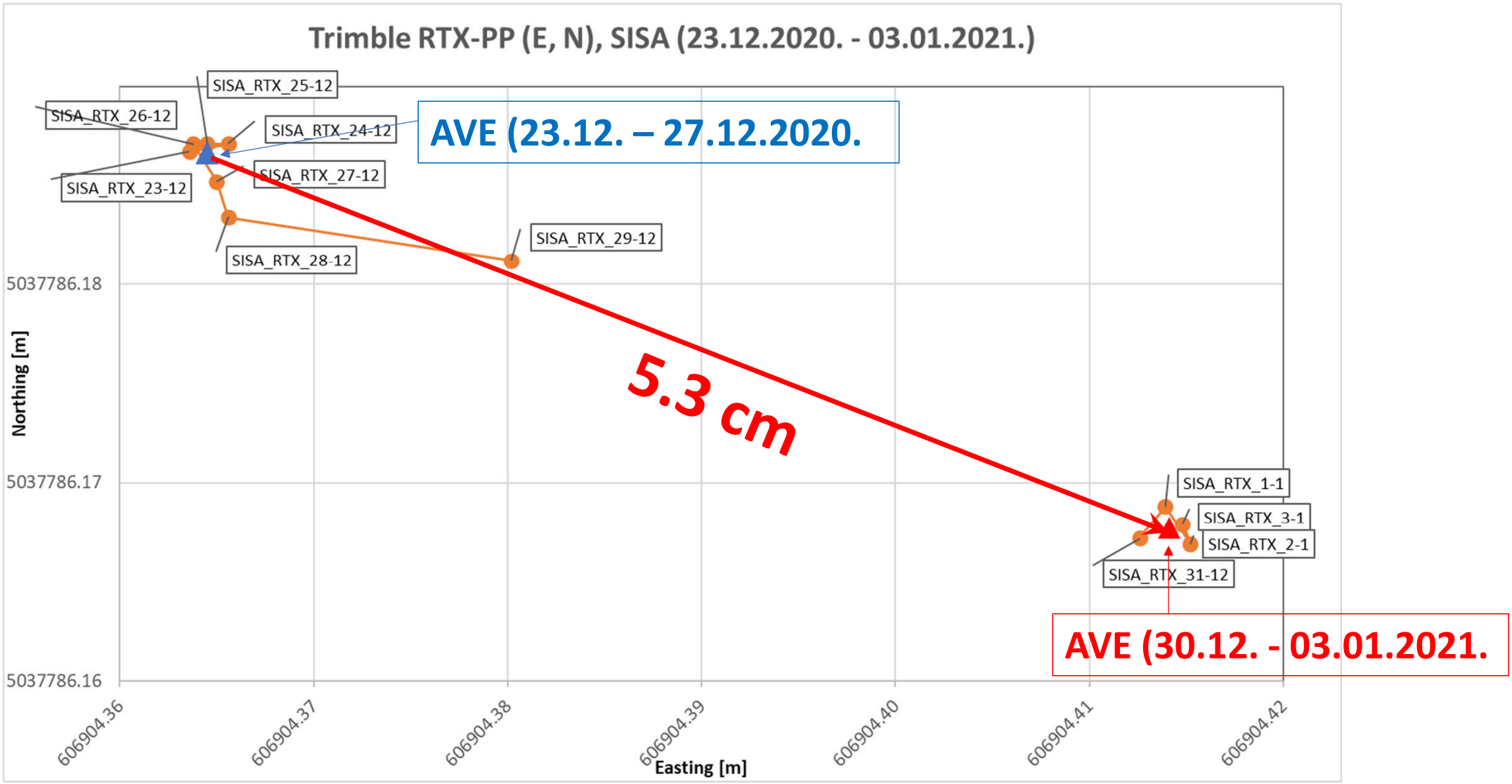
Trimble

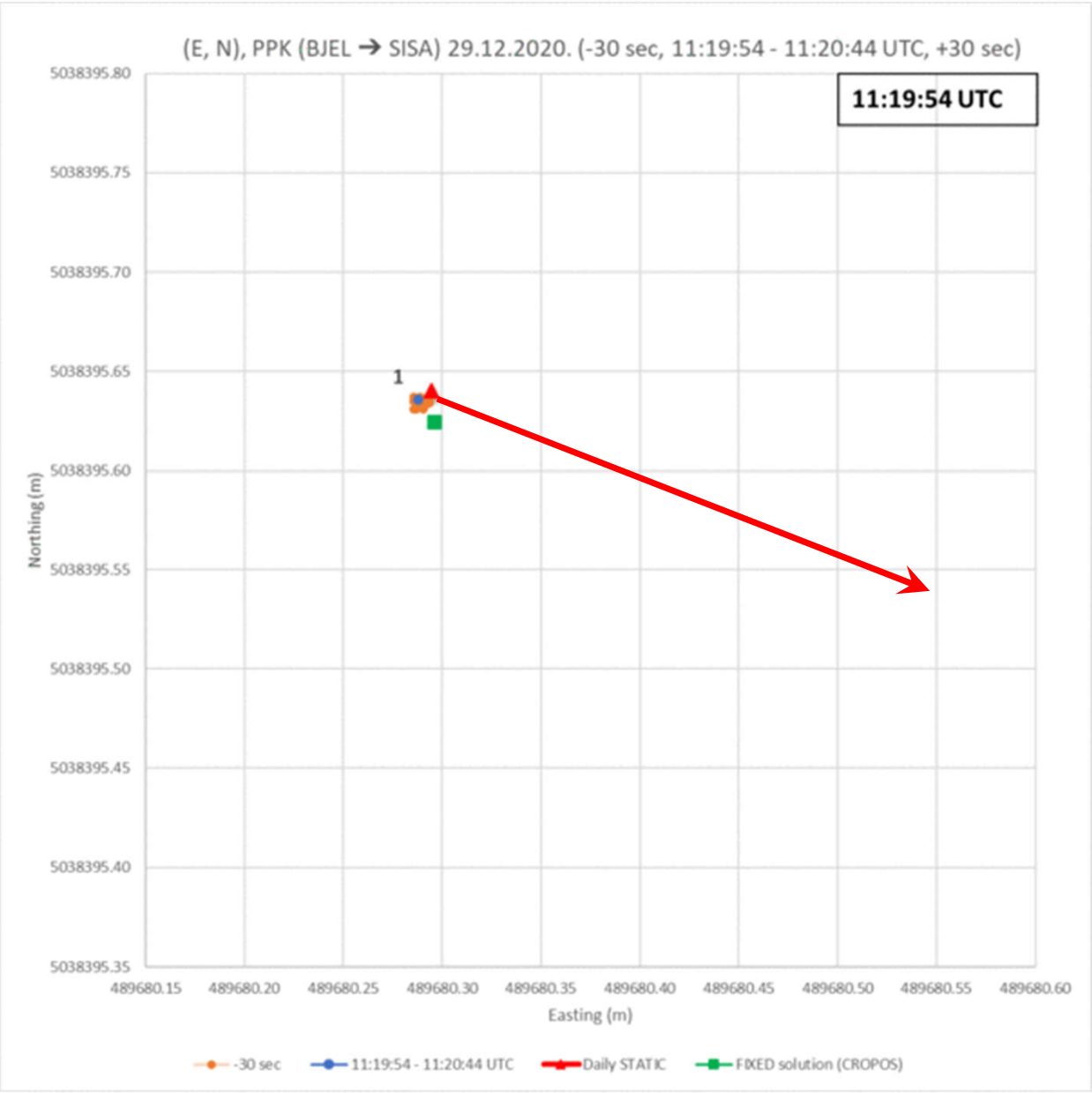
Government of Canada / Gouvernement du Canada

Trimble RTX-PP vs. CSRS - PPP

	max σE [m]	max σN [m]	max σ(el. H) [m]
BJEL	0,003	0,003	0,008
KARL	0,003	0,003	0,008
NOVI	0,009	0,005	0,011
NOVS	0,003	0,003	0,008
SISA	0,014	0,007	0,020
SLUN	0,003	0,003	0,008
ZAGR	0,003	0,004	0,008

SISA: daily solutions (RTX-PP), 23.12.2020. – 03.01.2021.





Kinematic motion M6.4

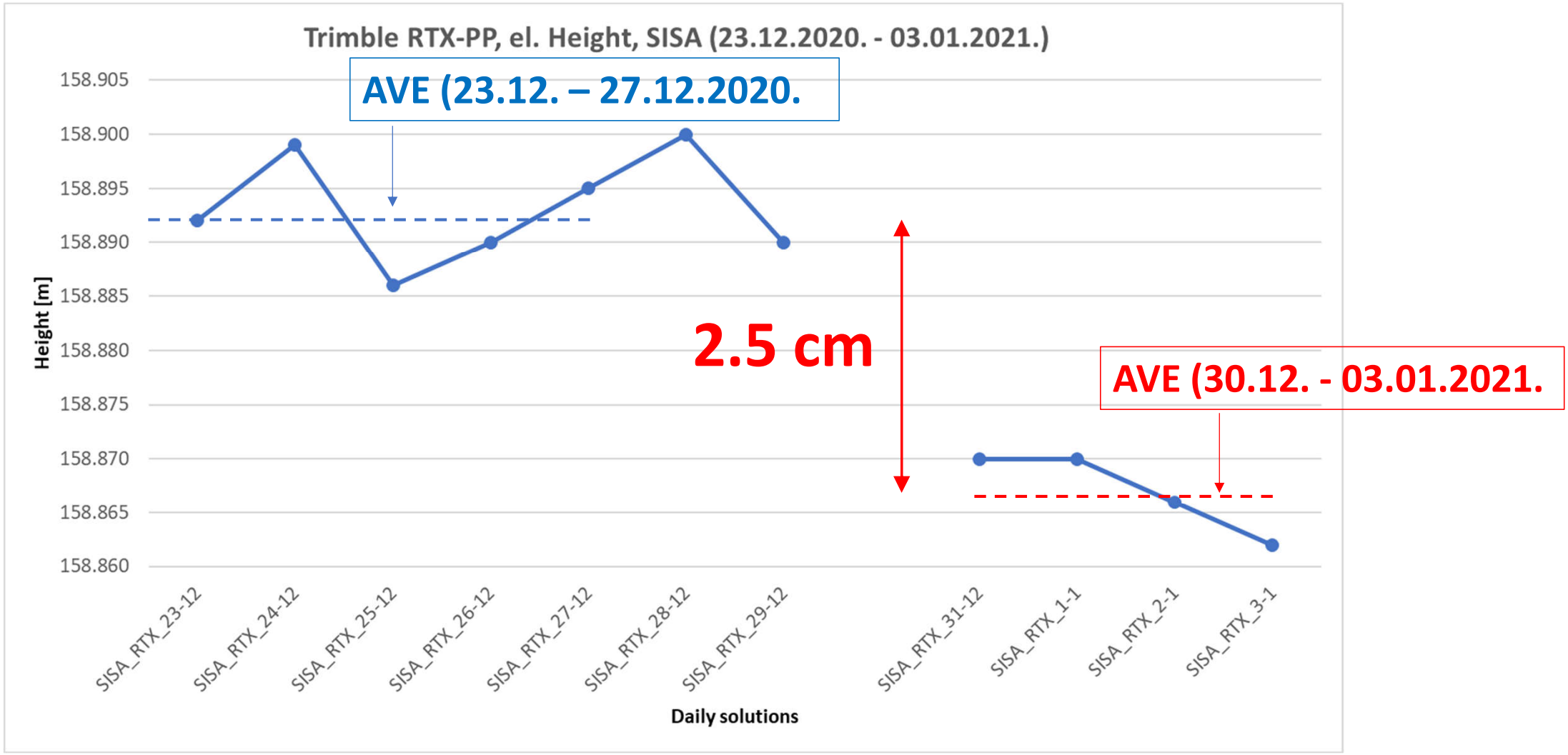
SISA, 29.12.2020.

- **30 sec**
- **11:19:54 – 11:20:44 UTC**
- **+30 sec**

MAX dist: 11→ 12: 0.273 m

MAX dist: 11→ 14: 0.497 m

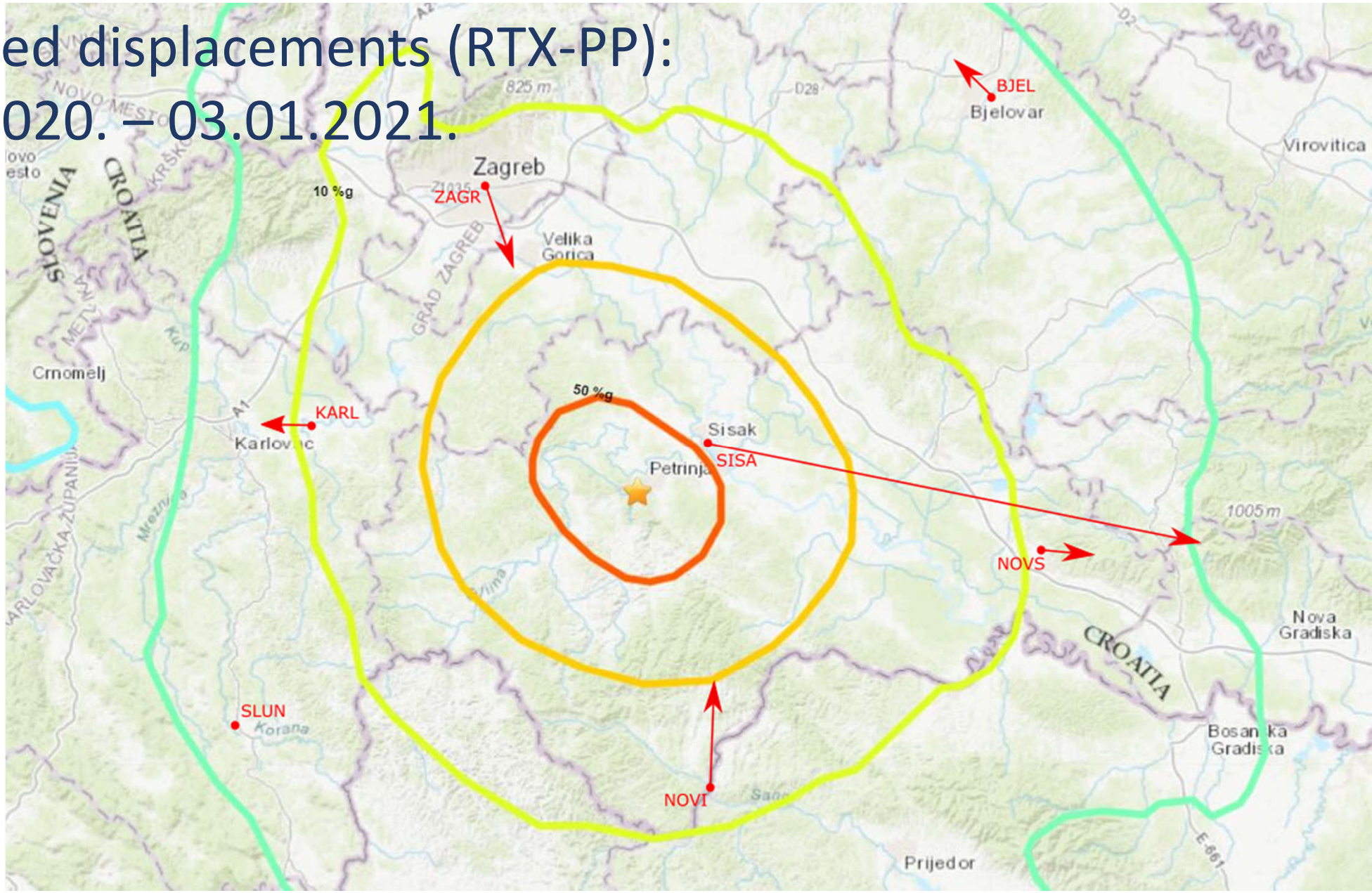
SISA: daily solutions (RTX-PP), 23.12.2020. – 03.01.2021.

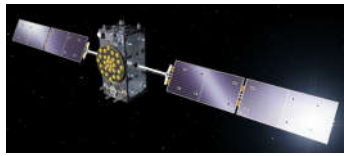


Estimated displacements (RTX-PP): 23.12.2020. – 03.01.2021.

	ΔE [m]	ΔN [m]	Δ ell. H [m]	Planar displ. [m]	Dist (epcn. – CORS) [km]
BJEL	-0,003	0,004	-0,004	0,006	71
KARL	-0,005	0,000	-0,005	0,005	54
NOVI	0,000	0,011	-0,001	0,011	43
NOVS	0,006	0,000	-0,007	0,006	59
SISA	0,050	-0,019	-0,025	0,053	14
SLUN	-0,002	0,000	-0,004	0,002	62
ZAGR	0,002	-0,009	-0,006	0,009	48

Estimated displacements (RTX-PP): 23.12.2020. – 03.01.2021.





Conclusions:

- PPP-PP daily solutions have revealed (indicated) the presence of permanent displacements
- PPP-PP has provided an estimation of displacements magnitude and direction
- all stations have shown a subsidence
- it is not possible to discern whether a permanent displacements come from a man-made building displacement or soil displacement. Or both.
- Scientific SW, e.g. Bernese

CROPOS

Danijel Šugar, Luka Blagus, Željko Bačić

Assessment of CROPOS GNSS stations stability after the Petrinja 2020-2021 earthquake series

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GNSS SEMINÁŘ 2023

Brno, 2nd February 2023