UNIWERSYTET PRZYRODNICZY WE WROCŁAWIU

GNSS

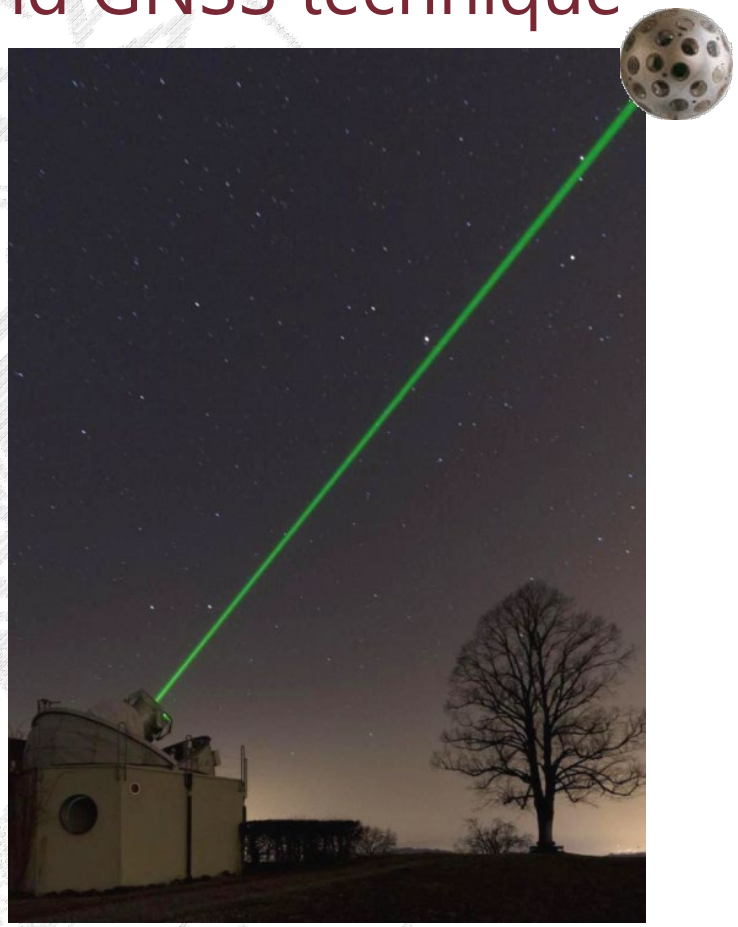
SENTINEL-3A/3B

LAGEOS 1/2

Determination of global geodetic parameters and station coordinates based on SLR measurements to reduced-dynamic Sentinel-3A/3B orbits

Dariusz Strugarek

SLR and GNSS technique



Satellite Laser Ranging (SLR)

optical technique based on registration of time-of-flight of laser signal, from station telescopes to the retroreflector mounted on a satellite, where a laser pulse is reflected back to the detector at the station.

Global Navigational Satellite Systems (GNSS)

active satellite technique based on microwave signal from satellite to receivers in positioning. GNSS use satellite signals from global and regional navigation satellite systems

Sentinel-3A/B

Sentinel info	3A	3B
Start	16-Feb-2016	25-Apr-2018
End	After 7 years	
Alititude	815 km	
Inclination	98.65°	
Weight	1150 kg	
Earth coverage	27 days	

Sentinel-3A/3B

- ESA and EUMETSAT
- active satellite
- ocean surface topography
- land and ocean temperature and color measurements
- climate and environment changes monitoring
- polar, sun-synchronous, circular orbit
- equipped with retroreflectors dedicated for SLR technique, DORIS and GNSS receivers

LAGEOS 1/2

LAGEOS, LAGEOS-2

(LAser GEOdynamics Satellite or LAser GEOdetic Satellite)

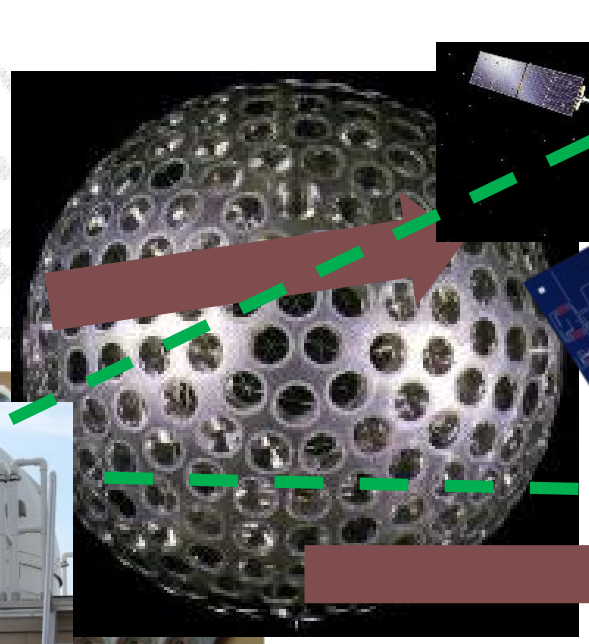
- NASA and ASI
- used for relativistic effects, gravity field, geodynamics, ERP, geocenter coordinates research by SLR measurements

LAGEOS info	1	2
Start	04-May-1976	22-Oct-1992
End	-	
Altitude	5850 km	5625 km
Inclination	109.84°	52.64°
Weight	406.965 kg	405.380 kg
Period	225 min	223 min
Orbit	circular	

- passive, spherical, geodetic satellites, with low Area-to-mass ratio
- eqiupped with 426 retroreflectors dedicated for SLR technique

Motivation

retroreflecto



LAGEOS 1/2

Sentinel 3A/B

Etalon 1/2

- ITRF
- GEOCENTER
- ERP

?

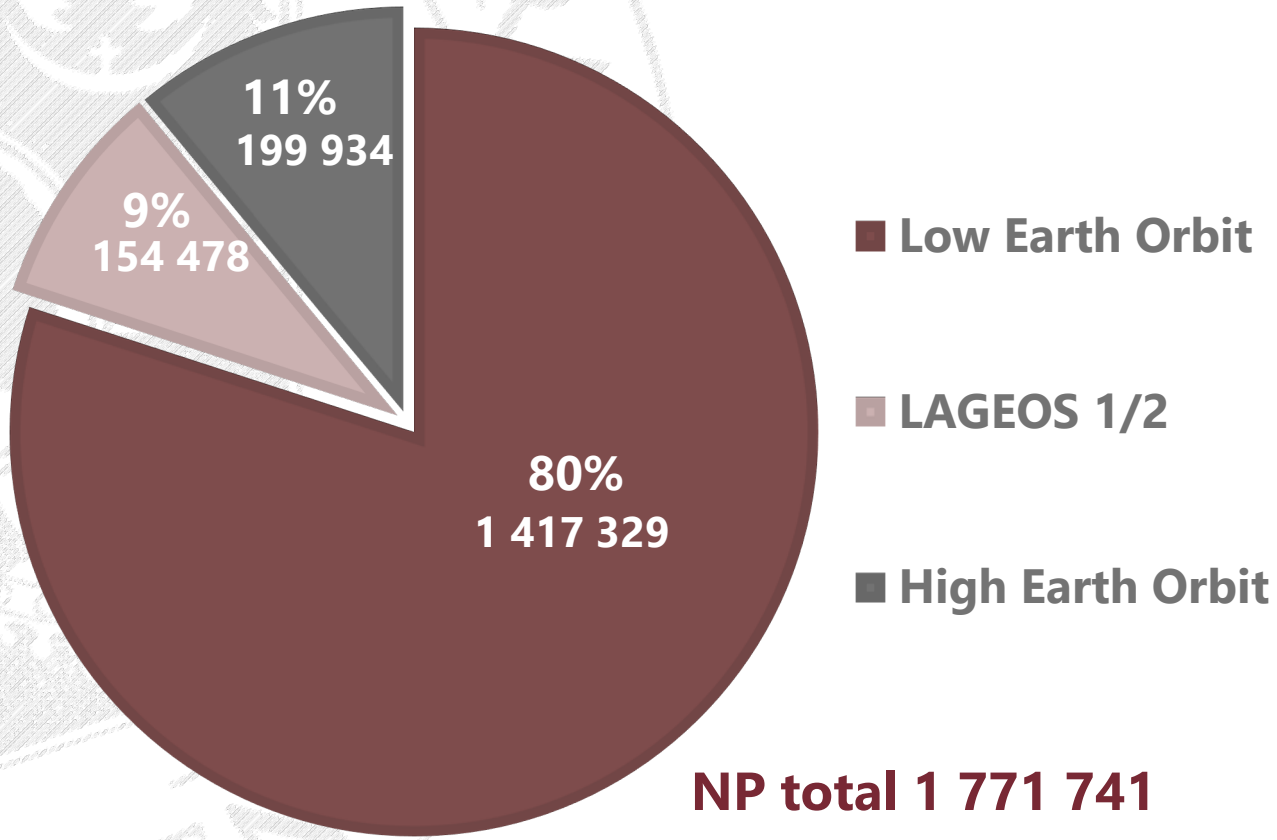
GNSS

Satellite laser ranging (SLR) and Doppler orbitography and radiopositioning integrated by satellite (DORIS) allowed (2014-2018) into the realization of the International Terrestrial Reference Frame (ITRF). SLR observations to GNSS, LEO and other satellites are used for the realization of the International Terrestrial Reference Frame (ITRF). SLR observations to GNSS, LEO and other satellites are used for the realization of the International Terrestrial Reference Frame (ITRF).

- LEO satellites
- realization of reference frames (e.g. SLRF2014)
- precise determination of station coordinates, geocenter coordinates and Earth rotation parameters

SLR observations

PERCENTAGE/NUMBER OF SLR OBSERVATIONS (NORMAL POINTS) TO PARTICULAR SATELLITE TYPE IN 2017



NP total 1 771 741

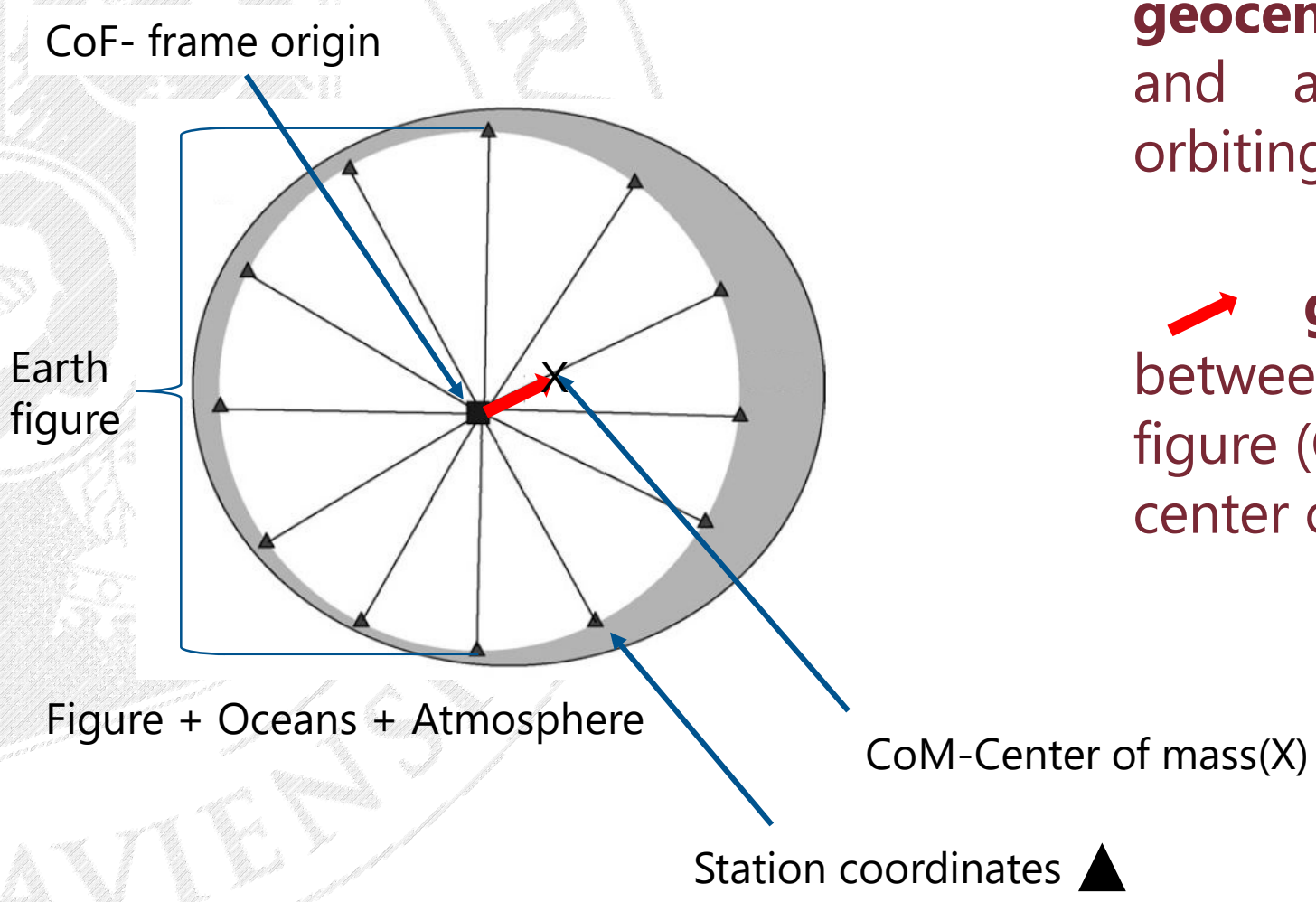
Just 9 % of all SLR measurements are used for reference frames realization, determination of Earth rotation parameters, geocenter coordinates

HEO = GNSS (MEO+IGSO+GEO)

https://ilrs.cddis.eosdis.nasa.gov/network/system_performance/global_report_cards/perf_2017q4_wLLR.html

Parameters

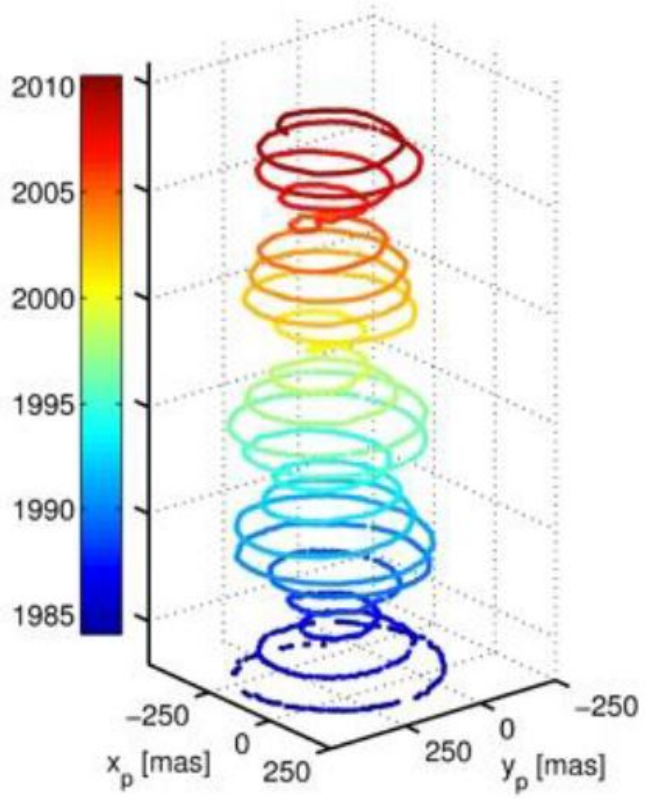
SLR sites coordinates (XYZ for e.g. ITRF2014, SLRF2014; North, East, Up dla IGS14)



geocenter- center of Earth mass with oceant and atmosphere layers, CoM), satellites orbiting point

geocenter movement - vector between frame origin-Center of the Earth figure (CoF, based on station coordinates) and center of mass

Parameters



Pole coordinates

Pole coordinates (X,Y)

difference between the Earth rotation axis orientation and reference coordinates (based on IERS Reference Pole (IRP) conventions)

Length of day, UT1-UTC parameter,

difference between universal time (mean solar time on the Prime Meridian at Greenwich) and Uniwersal Time Coordinated (time scale consistent with TAI-International Atomic Tme), first deteriative of UT1-UTC = Length of day (LoD)

SLR measurements

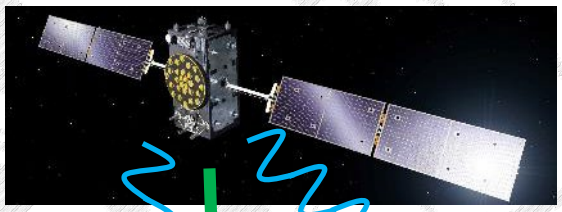
Active satellites: own power source, communication devices, solar panels different shape, weight, equipment, eg. SENTINEL 3A/B

SLR → **GNSS, LEO orbits validation**

Passive satellites: no power source, communication, research devices, weight, shape and surface dedicated for orbit perturbation reduction, e.g. LAGEOS 1/2

SLR → **Station coordinates, geocenter coordinates, ERP, scale, relativistic effects determination**

Sentinel 3A/B GNSS- and SLR- based analysis

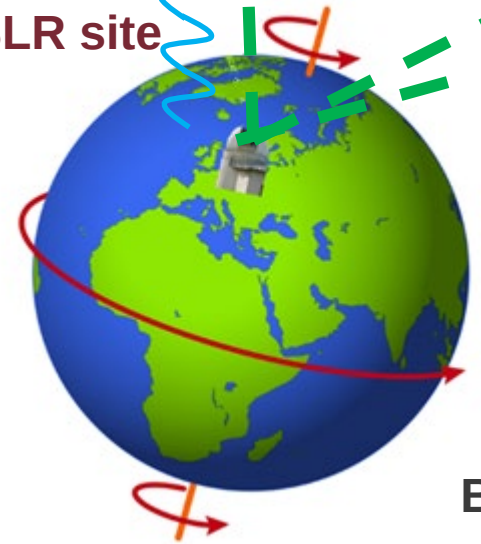


GNSS

Sentinel 3A/B

LAGEOS

SLR site



laser

microwave

SLR normal points

+

High-quality GNSS orbit and orientation data (ambiguity solution, orbit correction by AIUB)

geodetic satellites likewise approach

Station CRD

Geocenter CRD

ERP's

Station errors (biases)

Combined Sentinel 3A +LAGEOS Solution „SLR-PPP"

Bernese GNSS Software modified 5.3 Version

Solution tests– SLR to Sentinel-3A/B

Sentinel-3A/3B
(fixed GPS-based orbits)

Solution tests: different network and parameters constraining and different number of accumulated 1-day orbit combination

Test1: network constraining: no-net-translation (NNT) no-net-rotation(NNR) with estimation of parameters → Station coordinates, Geocenter coordinates, ERP

Test2: network constraining: no-net-translation (NNT) no-net-rotation(NNR) without estimation of parameters → Station coordinates

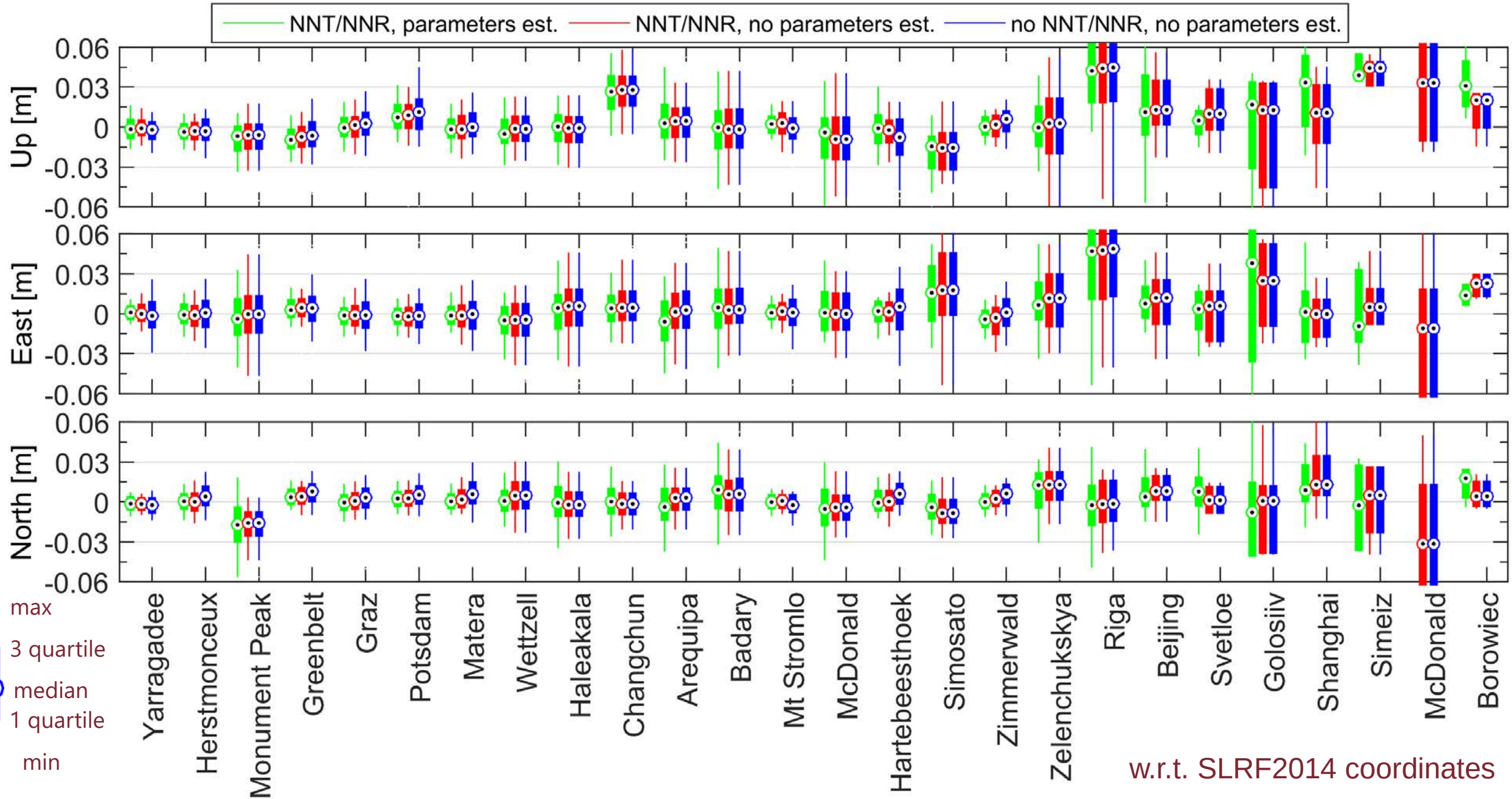
Test3: no network constraining and without estimation of parameters → Station coordinates ‚SLR-PPP'

Solution tests– SLR to Sentinel-3A/B

Solution tests: different network and parameters constraining and different number of accumulated 1-day orbit combination

- Station coordinates 1-, 3-, 7-, 15- accumulation of 1-day orbits
- Geeocenter coordinates: 3-, 5-, 7- accumulation of 1-day orbits
- ERP : 3-, 5-, 7- accumulation of 1-day orbits

Constraining tests– Sentinel-3A/B



Different number of accumulated 1-day orbit

Coordinates	Up [mm]				North [mm]				East [mm]			
1-orbit No.	1	3	7	15	1	3	7	15	1	3	7	15
IQR	31.3	17.8	**16.3**	**14.7**	15.6	12.1	**11.7**	**9.4**	24.9	14.6	**13.4**	**11.0**
Median	0.7	-0.5	**-0.7**	**-0.9**	0.2	-0.4	**0.0**	**0.1**	0.4	0.1	**0.2**	**0.2**

Station CRD

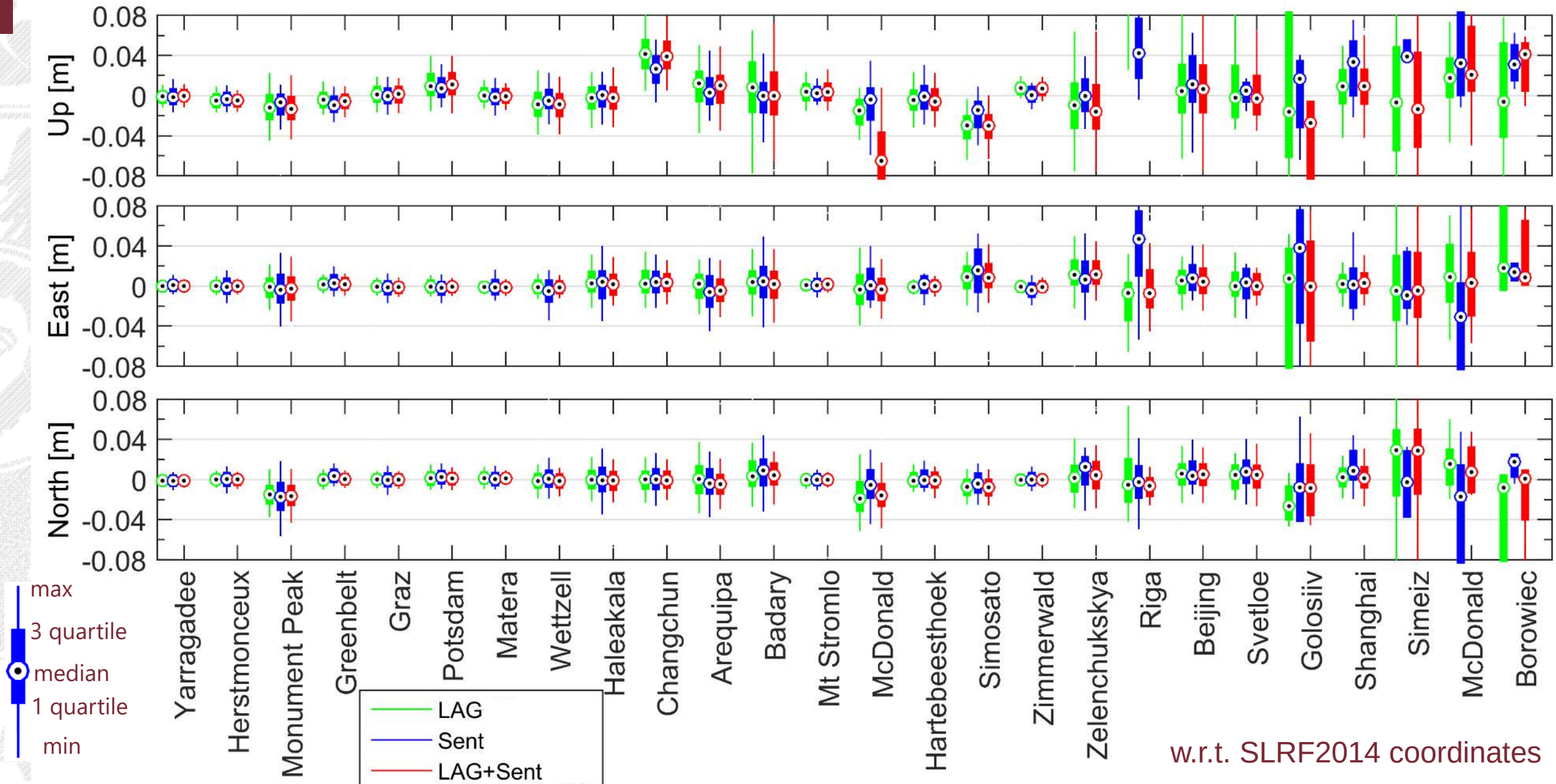
Coordinates	X [mm]			Y [mm]			Z [mm]		
1-orbit No.	3	5	7	3	5	7	3	5	7
RMS	16.4	14.4	**6.5**	10.2	9.5	**4.2**	16.7	14.6	**6.0**
Mean	-1.9	-1.5	**-1.2**	1.8	0.5	**0.5**	-4.1	-5.6	**-1.3**

Geocenter CRD

Parameters	X pole [mas]			Y pole [mas]			dT [ms/day]		
1-orbit No.	3	5	7	3	5	7	3	5	7
RMS	0.80	0.56	**0.32**	1.14	0.83	**0.32**	0.10	0.07	**0.06**
Mean	0.06	0.06	**0.11**	0.20	0.16	**0.04**	-0.0020	0.0022	**-0.0023**

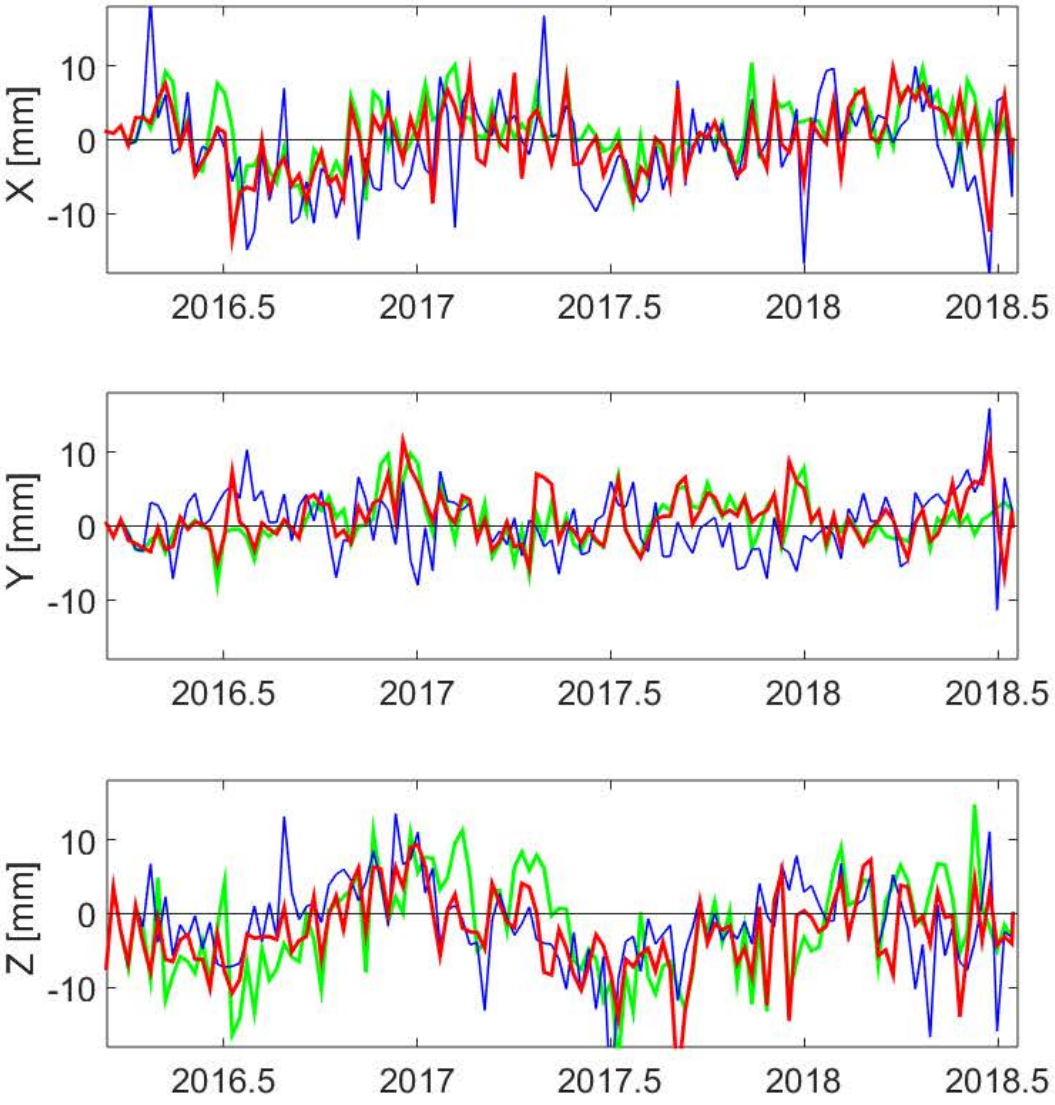
Pole CRD i LoD

Combined Sentinels-3A/B+LAGEOS solution



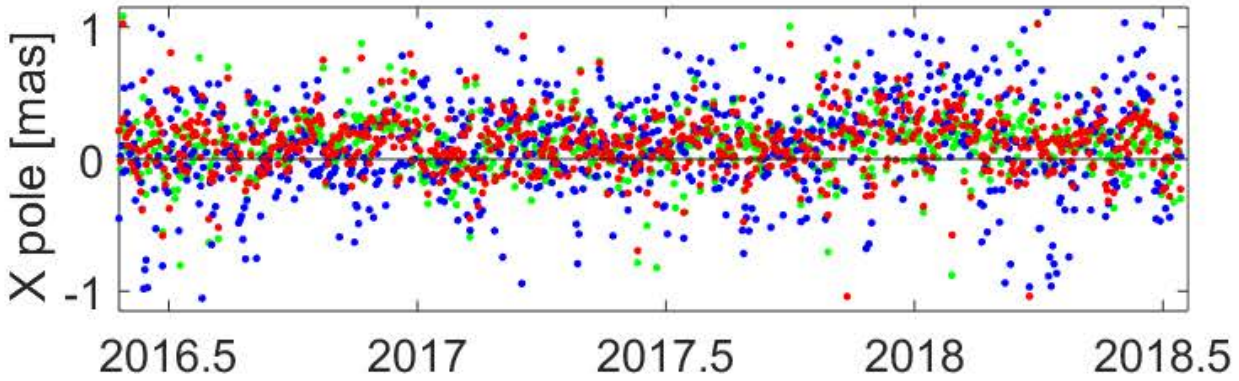
w.r.t. SLRF2014 coordinates

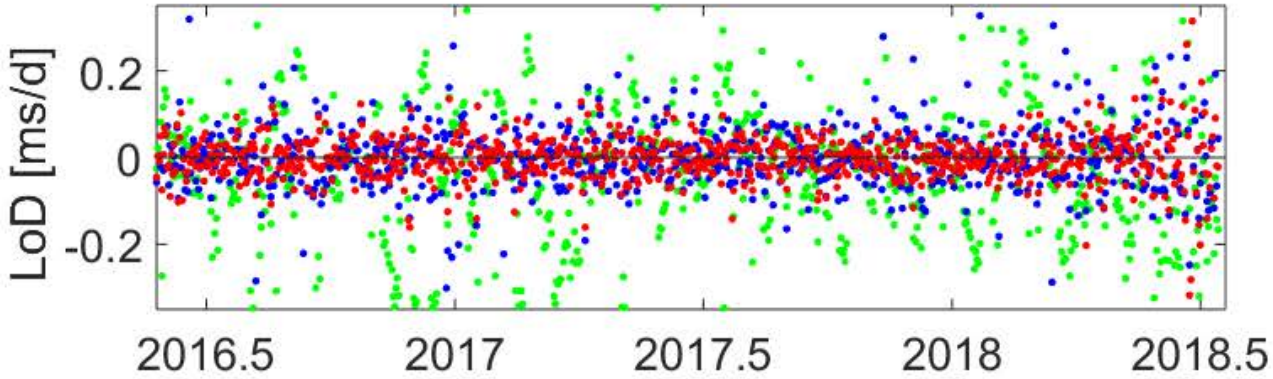
Combined Sentinels-3A/B+LAGEOS solution, geocenter

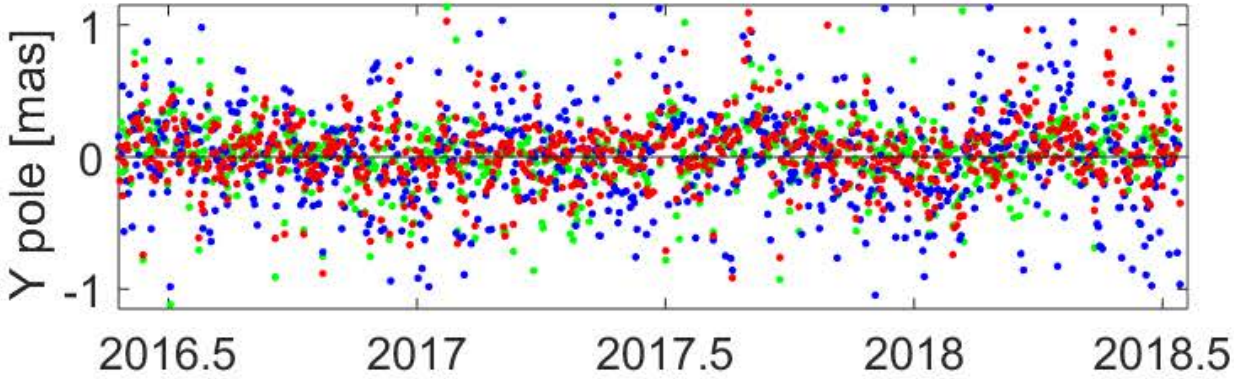


Differences	LAG-SENT	LAG-(LAG+SENT)	SENT-(LAG+SENT)
	std [mm]	std [mm]	std [mm]
X	6.2	3.6	5.1
Y	5.0	2.4	4.7
Z	7.1	4.5	5.1

Combined Sentinels-3A/B+LAGEOS solution, ERP







Solution	X pole [mas]		Y pole [mas]		LOD [ms/day]	
	mean	RMS	mean	RMS	mean	RMS
LAG	0.128	0.134	0.047	0.166	-0.098	0.107
Sent	0.109	0.320	0.040	0.314	-0.002	**0.063**
LAG+Sent	0.134	0.138	0.044	0.189	-0.011	**0.067**

w.r.t. C04 parameters (IERS data)

Summary

Use of SLR observations to Sentinel-3A/B satellites allows for determination of station coordinates at level of 10 mm (best sites), geocenter coordinates at level of 6 mm, pole X,Y at level of 0.3 mas and Lod 0.06ms/day

Reference frame determination based of SLR measurements to Sentinels-3A/B can be delivered on SLR station reference frame

„SLR PPP" free network solution is possible based on SLR data and GPS orbits of LEO satellites at level of 10-mm

Station coordinates shows the best consistency w.r.t. SLRF2014 while imposing **NNT/NNR** constraints with **parameter estimation and without network constraints and parameter estimation** („SLR-PPP")

SLR station coordinates shows the best consistency w.r.t. SLRF2014 for **7 and 15 accumulated 1-day orbits**, whereas ERP and geocenter coordinates for 7 accumulated 1-day orbits

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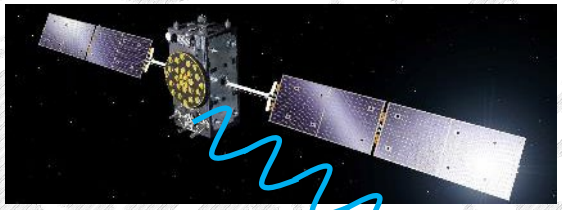
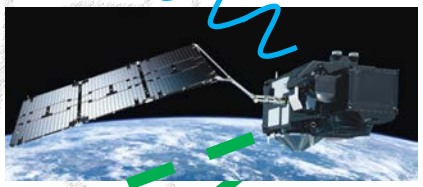
BACK UP

The issue of the reference frame differences

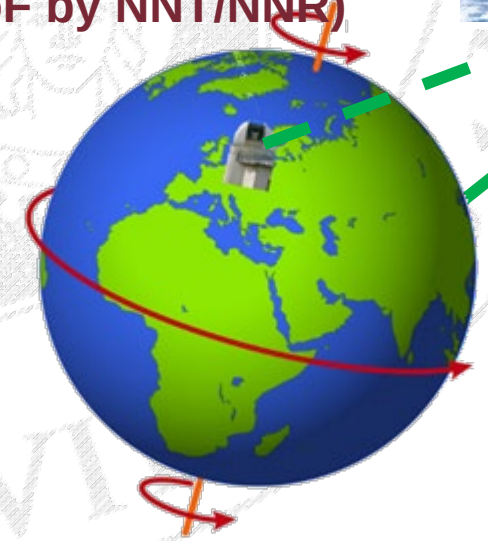
Test 1 with NNT/NNR constraints



GNSS – IGS14
integrated around
Center-of-Figure (CoF)



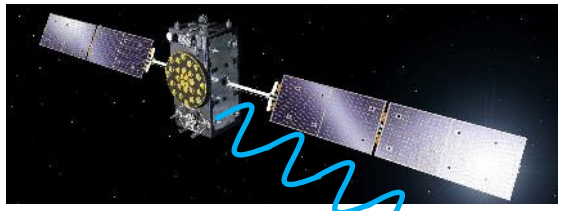
SLR sites in SLRF2014
(CoF by NNT/NNR)



LEO – IGS14, but pseudo-stochastic orbit parameters are estimated –> larger flexibility, close representation of the Earth's Center-of-Mass (CoM)

CoM vector w.r.t. CoF represents geocenter motion, but to what extent IGS14 and SLRF2014 are consistent

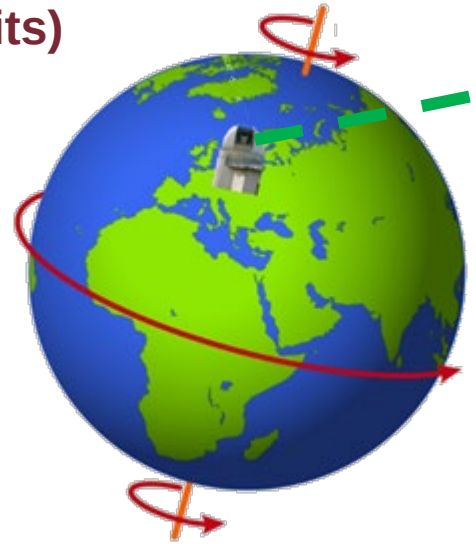
Test 3 no network constraints - SLR-PPP



GNSS – IGS14
integrated around
Center-of-Figure (CoF)

SLR sites IGS14 (reference frame transferred through LEO orbits)

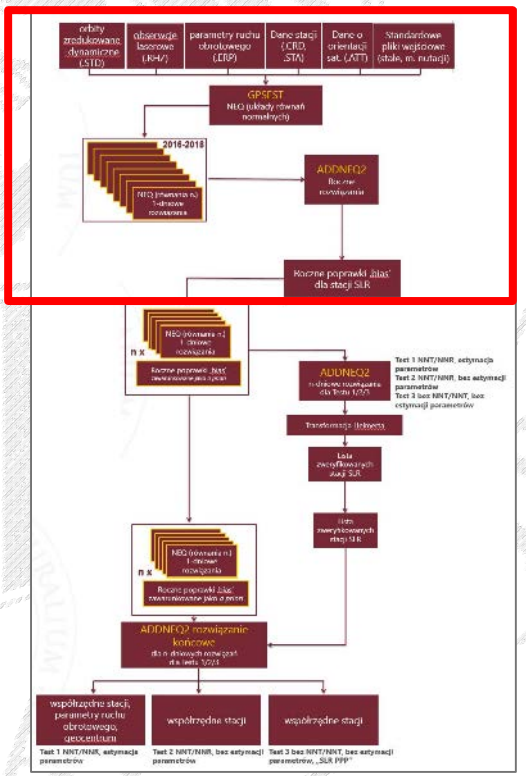
LEO – IGS14, reduced



In SLR-PPP (test3) SLR station coord. are in IGS14

Schemat obliczeń

Bernese GNSS Software modified 5.3 Version



orbity zredukowane -dynamiczne (.STD)

obserwacje laserowe (.RHZ)

parametry ruchu obrotowego (.ERP)

dane stacji (.CRD, .STA)

dane o orientacji sat. (.ATT)

standardowe pliki wejściowe (stałe, m. nutacji)

GPSEST
NEQ (układy równań normalnych)

2016-2018

NEQ (równania n.) 1-dniowe rozwiązania

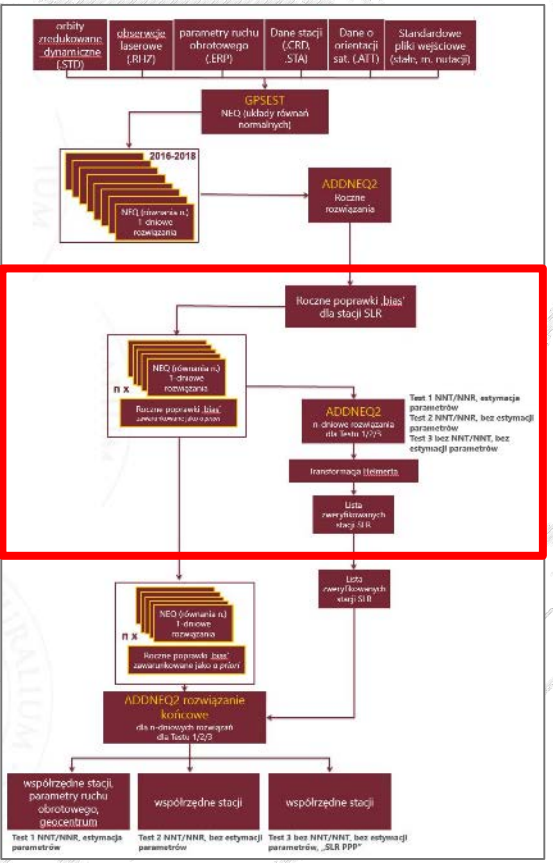
ADDNEQ2
Roczne rozwiązania

Roczne poprawki ‚bias' dla stacji SLR

...

Bernese GNSS Software

modified 5.3 Version



Roczne poprawki ‚bias' dla stacji SLR

...

n x

NEQ (równania n.) 1-dniowe rozwiązania

Roczne poprawki ‚bias' zawarunkowane jako *a priori*

...

ADDNEQ2

n-dniowe rozwiązania dla Testu 1/2/3

Test 1 NNT/NNR, estymacja parametrów globalnych
Test 2 NNT/NNR, bez estymacji parametrów globalnych
Test 3 bez NNT/NNT, bez estymacji parametrów glob.

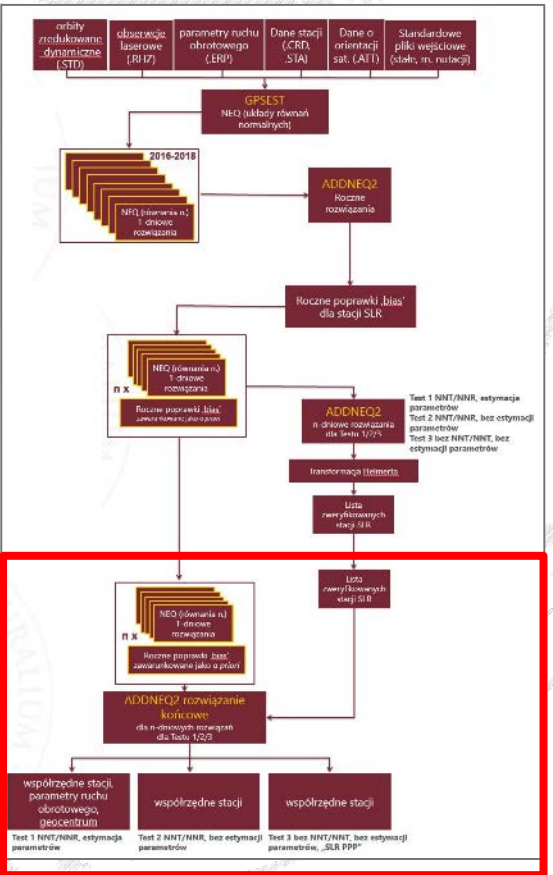
Transformacja Helmerta

Lista zweryfikowanych stacji SLR

...

Bernese GNSS Software

modified 5.3 Version



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...

Lista zweryfikowanych stacji SLR

ADDNEQ2 rozwiązanie końcowe

dla n-dniowych rozwiązań dla Testu 1/2/3

współrzędne stacji, parametry ruchu obrotowego, geocentrum

Test 1 NNT/NNR, estymacja parametrów glob.

współrzędne stacji

Test 2 NNT/NNR, bez estymacji parametrów glob.

współrzędne stacji

Test 3 bez NNT/NNT, bez estymacji parametrów glob., „SLR PPP"

Table 2 SLR residuals (RMS and mean) of reduced-dynamic orbit solutions (identifier "N") for days 001–365, 2007

Spacecraft	Solution ID	SLR residuals RMS (cm)	SLR residuals mean (cm)
GRACE A	N0	1.81	0.65
	N1 (5° × 5°)	1.81	0.65
	N4 (5° × 5°)	1.85	0.67
GRACE B	N0	2.02	0.85
	N1 (5° × 5°)	1.99	0.85
	N4 (5° × 5°)	1.95	0.83

Jäggi, A., Dach, R., Montenbruck, O., Hugentobler, U., Bock, H., Beutler, G., 2009. Phase center modeling for LEO GPS receiver antennas and its impact on precise orbit determination. J Geod 83(12):1145–1162

SLR PPP
- zegary (jeden na stacji): bez estymacji
- niewielki wpływ troposfery
- biasy (opóźnienia sprzętowe): jeden na mierzoną odległość (błąd wyznaczenia centrum optycznego, błędy kalibracji, opóźnienie syg. w kablach), ale stabilne i wyznaczane w długich okresach (1 na rok)

GNSS PPP
- zegary (osobny na stacji i osobny na sat.): estymacja dodaktowego parametru
-duży wpływ troposfery
- biasy: niestabline, estymacja 1 na dobę (różnice między systemami, między częstotliowościami, między satelitami, biasy fazy i kodu)

TOP SITES

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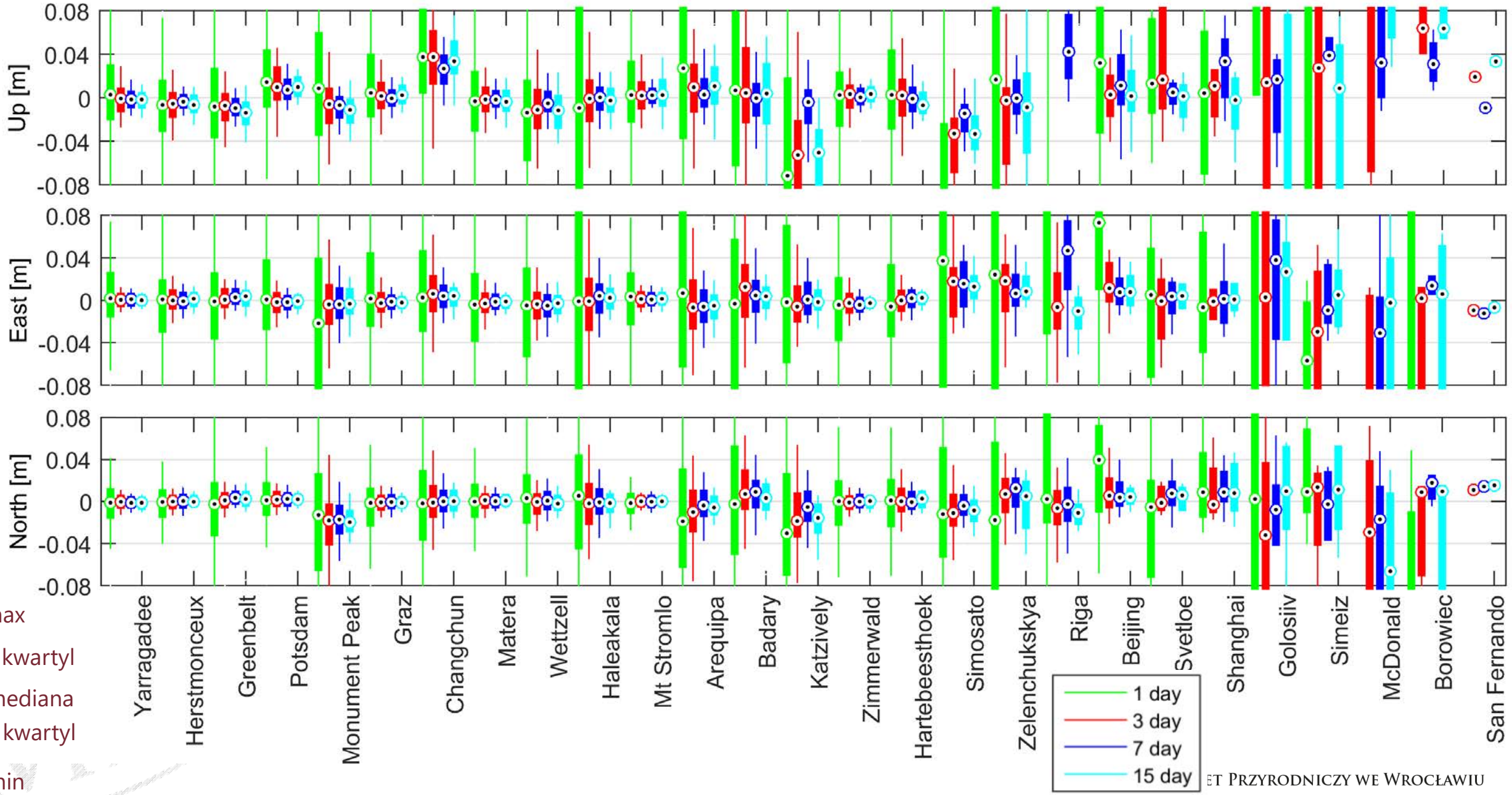
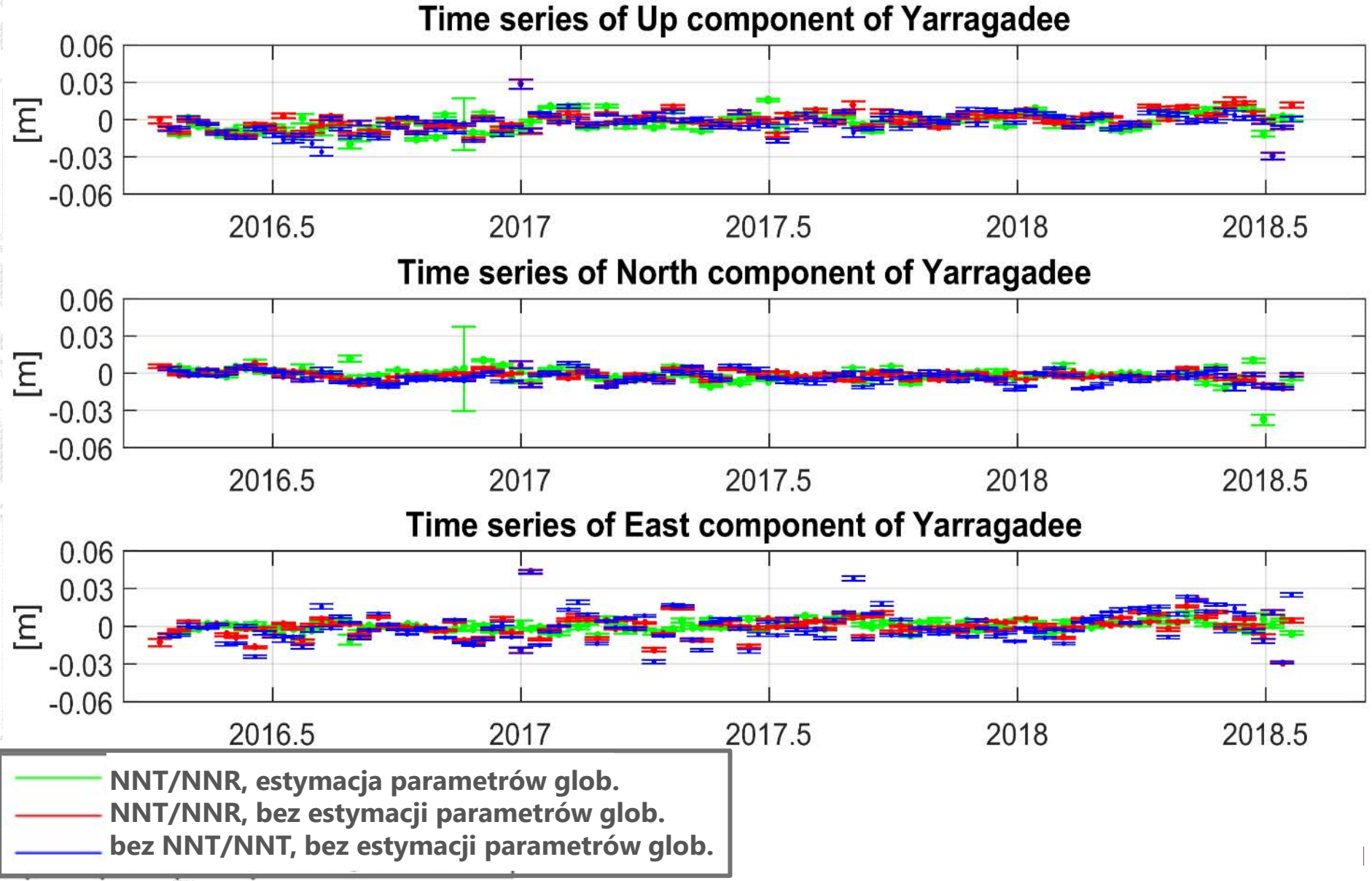
No. of sites	Solution	N [mm]		E [mm]		Up [mm]	
		median	IQR	median	IQR	median	IQR
All sites	LAG	-0.9	12.7	0.5	11.1	-0.8	24.6
	Sent	0.0	11.7	0.2	13.4	-0.8	16.3
	LAG+Sent	-1.0	12.4	0.3	11.4	-1.3	26.3
Top sites	LAG	-0.1	5.3	0.0	5.0	-0.4	12.5
	Sent	0.5	7.8	-0.4	9.1	-1.6	11.9
	LAG+Sent	-0.2	5.2	-0.1	5.2	-0.7	12.3

Yarragadee, Herstmonceux, Greenbelt, Graz, Potsdam, Matera, Wettzell, Haleakala, Mt Stromlo, Hartebeesthoek, Zimmerwald

Testy rozwiązań – różnej liczby n jednodniowych orbit w rozwiązaniach



Testy warunkowania– współrzędne stacji 7-dniowe rozwiązanie – Sentinel-3A/B

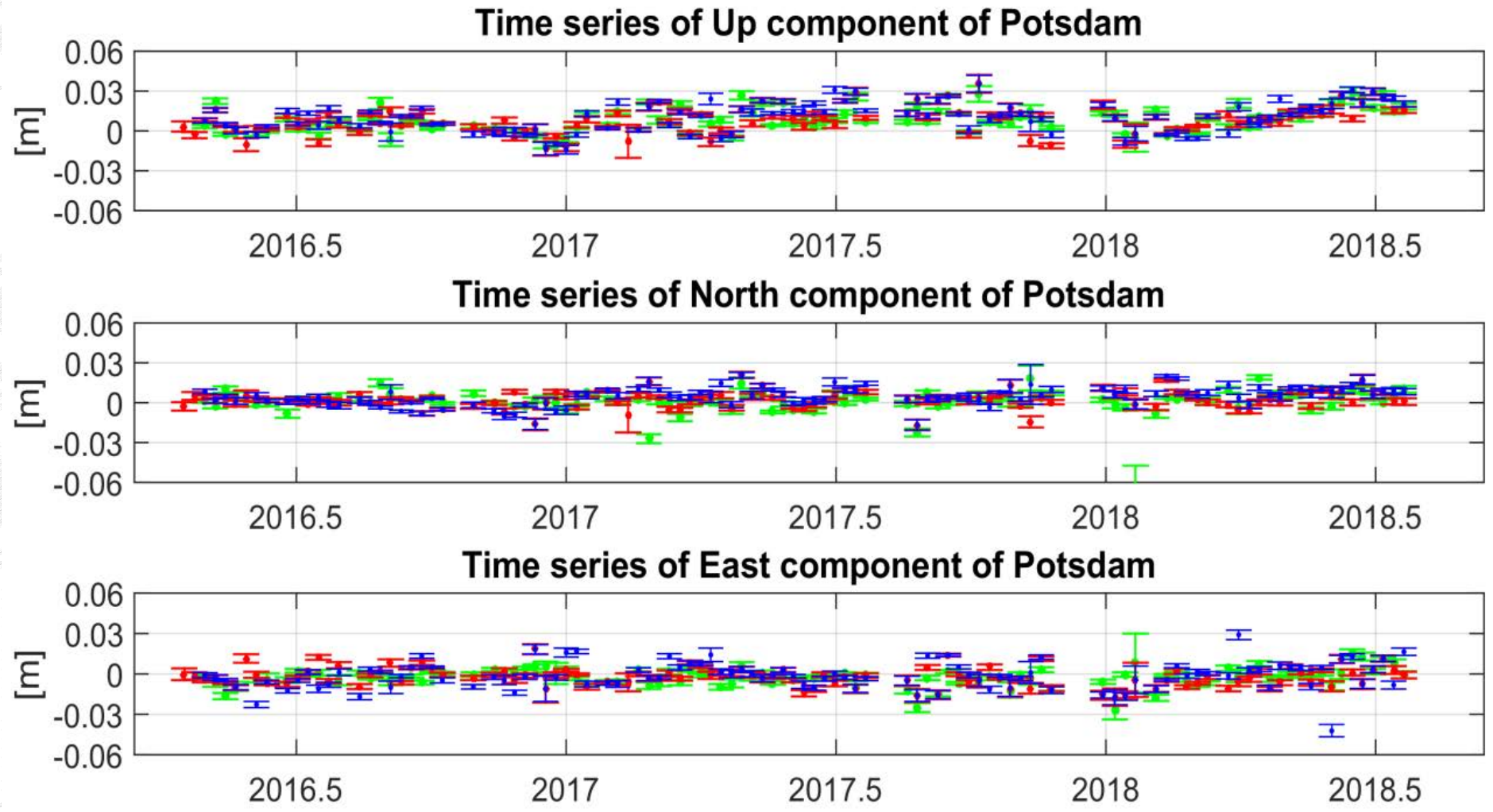


Powtarzalność stacji dla poszczególnych składowych na poziomie od 5-9 mm

Zbliżone wyniki również dla testu bez warunkowania sieci (Test 3)

Test3 można nazwać **„SLR-PPP”**, bo zależny wyłącznie od jakości orbit oraz jakości i ilość obs. SLR

Testy warunkowania– współrzędne stacji 7-dniowe rozwiązanie – Sentinel-3A/B

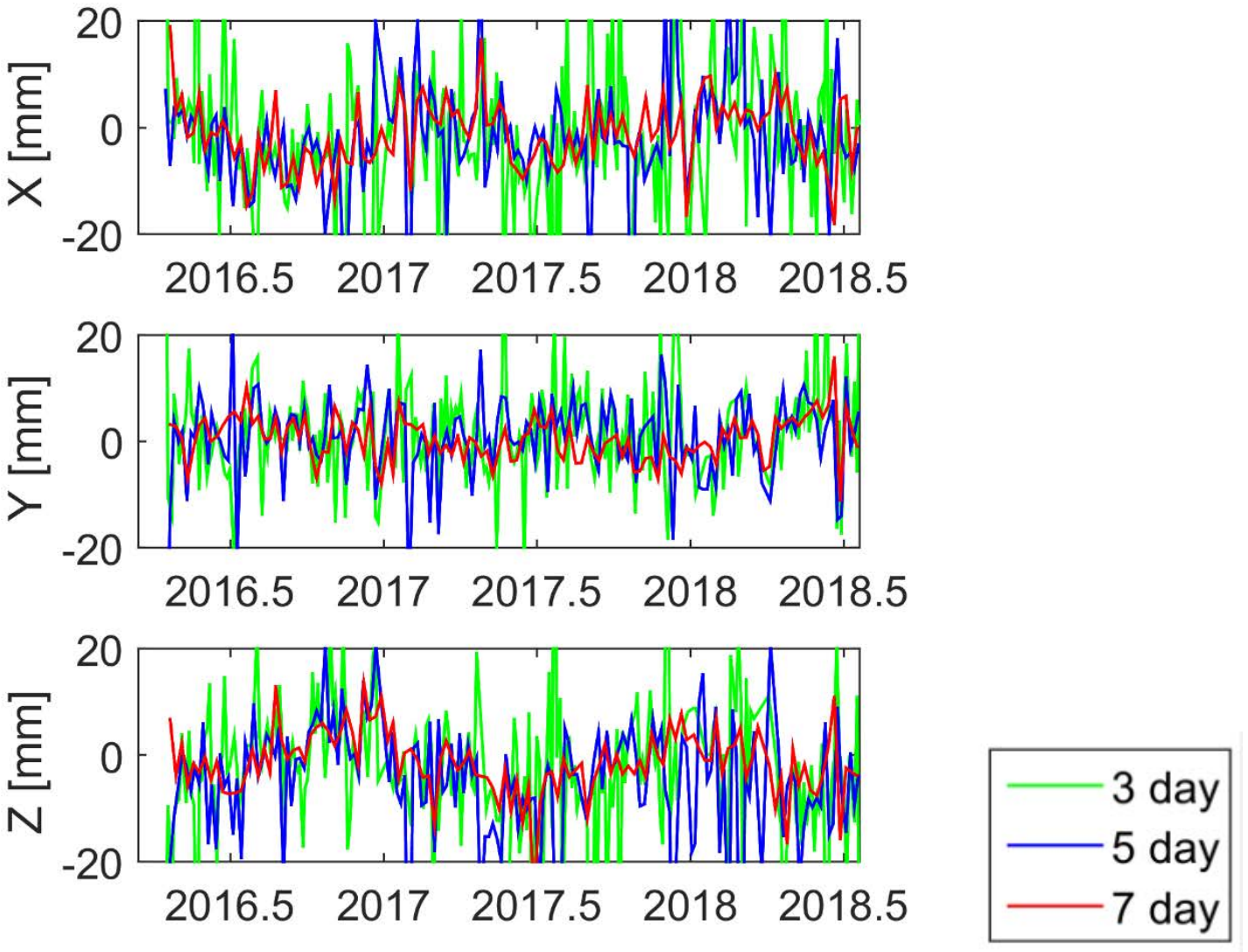


Powtarzalność stacji dla poszczególnych składowych na poziomie od 7-14 mm

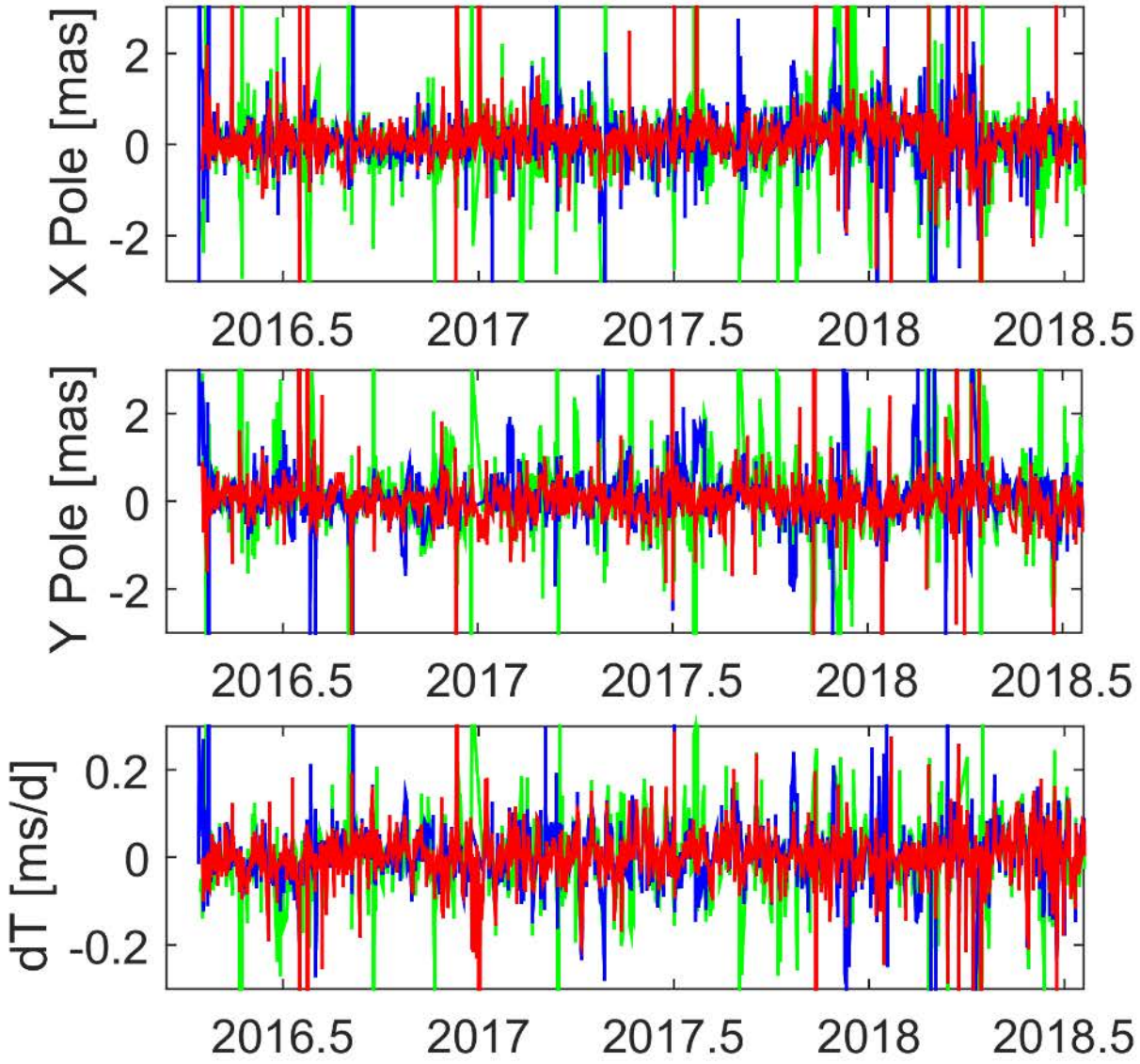
Zbliżone wyniki również dla testu bez warunkowania sieci (Test 3)

1-cm dokładność wyznaczenia współrzędnych

Testy rozwiązań – wyznaczenie współrzędnych geocentrum– Sentinel-3A/B

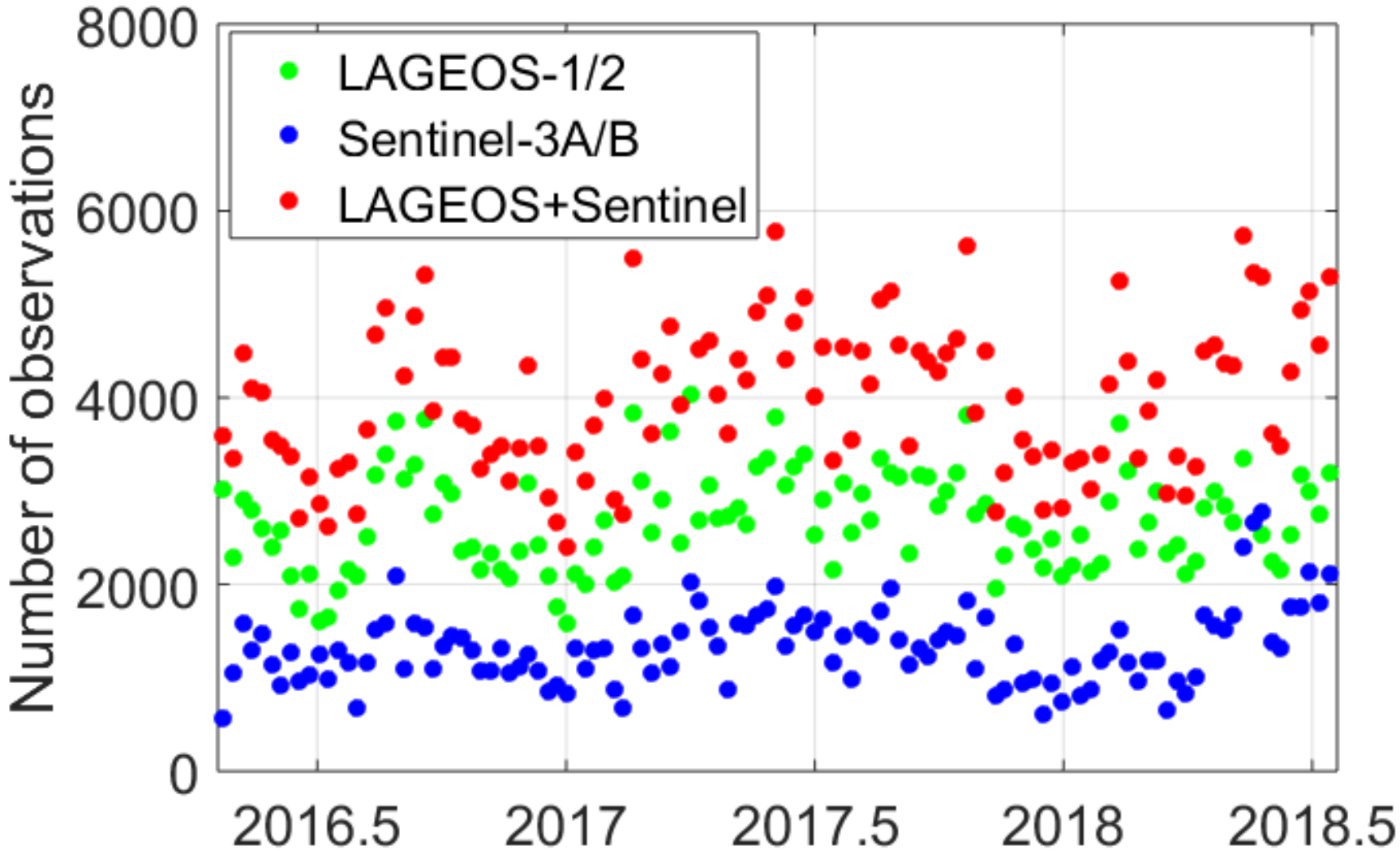


Testy rozwiązań – wyznaczenie parametrów ERP – Sentinel-3A/B



Porównanie względem produktów C04 (dane IER

Statistics



7-dniowe orbity
Rozwiązanie test 1
(NNT/NNR, estymacja parametrów glob.)

345,692 NP dla LAGEOS
157,213 NP dla Sentinel 3
502,905 NP rozwiązania łącznego

No. of obs. increase