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Space weather impact on GPS positioning results in Latvia

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Overview

- Objective
- Methodology for studying the space weather impact on GPS
- Discrepancy sorting results
- Simultaneous space weather impact on many sites
- Loss-of-Lock situations
- Pearsons' correlation results
- Impact of St. Patricks' geomagnetic storm on Ranging Integrity Monitoring Stations (RIMS)
- Conclusions

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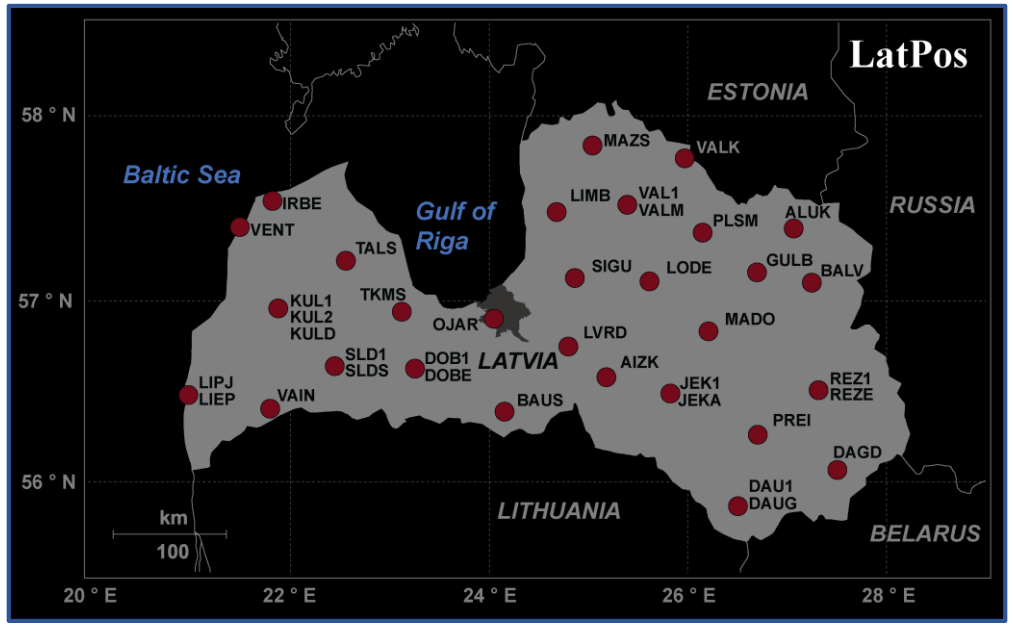
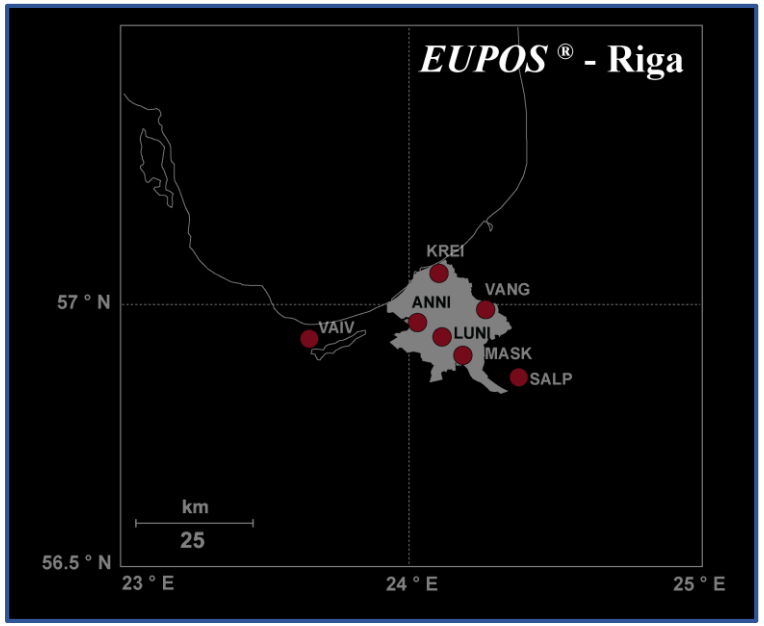
Objective

The objective is to validate the space weather impact on Latvian CORS networks over 11-year period by means of kinematic GPS positioning discrepancies analysis in relation to the ionospheric TEC and ROTI levels.





Methodology for studying the space weather impact on GPS

- The 90-s kinematic time series for each of Latvian CORS station for the 4-5 months of each year in period from 2007 to 2017 were obtained;
- Over 36 million position determination solutions of *Bernese Software v.5.2* were examined;
- Positioning discrepancies were found, statistics on frequency of simultaneously occurring faults in numerous stations were counted;
- Loss-of-Lock occurrences were identified and analyzed;
- The correlation was computed between faulty results, TEC and ROTI levels and *Bernese GNSS Software v5.2* detected cycle slips.

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Statistical analysis

- Assessment of the values of TEC and ROTI global modelling irregularities were identified on the basis of weak Pearsons' correlation;

- Additionally, an assessment of the impact of geomagnetic storm on St. Patrick's day in 2015 at three sites of the set of Ranging Integrity Monitoring Stations (RIMS) was made.

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Distribution of the size of discrepancies

#	Interval (m)		Count of faulty solutions	CSLP	% f. sol.	% CSLP
1	[0.1	1.0)	153592	3781	75.3%	78.0%
2	[1.0	5.0)	21533	473	10.6%	9.8%
3	[5.0	10.0)	8691	192	4.3%	4.0%
4	[10.0	20.0)	7163	141	3.5%	2.9%
5	[20.0	30.0)	4196	57	2.1%	1.2%
6	[30.0	40.0)	2694	42	1.3%	0.9%
7	[40.0	50.0)	1478	33	0.7%	0.7%
8	[50.0	100.0)	3401	87	1.7%	1.8%
9	[100.0	150.0)	806	26	0.4%	0.5%
10	[150.0	200.0)	259	10	0.1%	0.2%
11	[200.0	500.0)	204	7	0.1%	0.1%
12	[500.0	900.0]	5	0	0.0%	0.0%
Total	[0.1	900.0]	204022	4849	100.0%	100.0%

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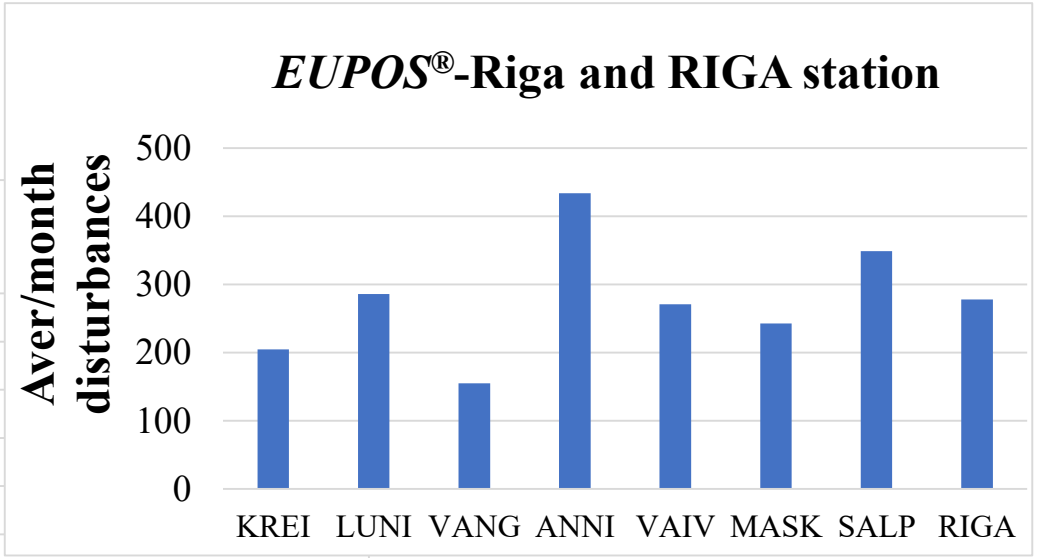
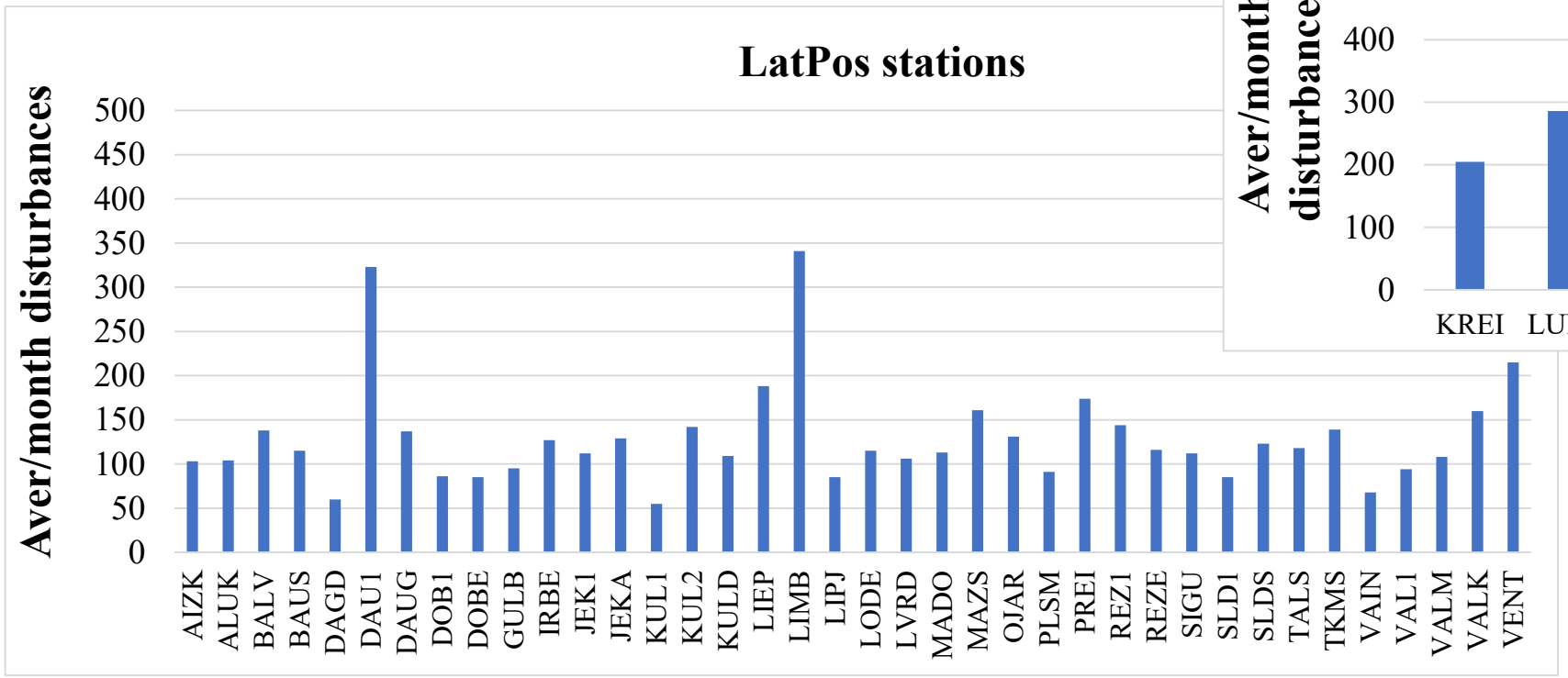
Average per month disturbances in LatPos stations, *EUPOS*®- Riga stations and station RIGA





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List of stations of simultaneously occured faulty solutions on 17 March 2015

Date	Time UT	Station
2015 MAR 17	16:42: 0	TALS TKMS LIPJ BALV LIMB MAZS DAU1 SIGU REZ1 LODE VANG DOB1 SALP BAUS JEK1 VAIV KREI LUNI RIGA IRBE
2015 MAR 17	16:43:30	TALS TKMS LIPJ LIMB MAZS BALV DAU1 SIGU REZ1 LODE VANG DOB1 BAUS LUNI SALP JEK1 KREI VAIV RIGA IRBE
2015 MAR 17	16:45: 0	VAL1 TALS TKMS LIPJ LIMB MAZS BALV DAU1 SIGU REZ1 LODE VANG DOB1 BAUS LUNI JEK1 RIGA VAIV KREI SALP IRBE
2015 MAR 17	16:46:29	VAL1 TALS TKMS LIPJ LIMB MAZS DAU1 BALV SIGU REZ1 LODE VANG RIGA DOB1 BAUS JEK1 VAIV KREI LUNI SALP IRBE
2015 MAR 17	16:48: 0	PLSM TALS TKMS LIPJ MAZS LIMB DAU1 SIGU BALV REZ1 LODE VANG RIGA DOB1 BAUS VAL1 JEK1 KREI LUNI SALP VAIV IRBE
2015 MAR 17	16:49:30	TKMS TALS LIPJ OJAR LIMB MAZS SIGU REZ1 BALV LODE VANG RIGA VAL1 DOB1 BAUS DAU1 VAIV JEK1 SALP LUNI KREI IRBE
2015 MAR 17	16:51: 0	LIMB TKMS TALS LIPJ MAZS SIGU REZ1 BALV LODE VANG OJAR LUNI KREI RIGA VAIV DOB1 BAUS DAU1 JEK1 SALP IRBE
2015 MAR 17	16:52:30	TKMS TALS LIPJ MAZS SIGU REZ1 BALV LODE VANG RIGA LUNI VAIV KREI BAUS DOB1 DAU1 SALP JEK1 IRBE
2015 MAR 17	16:54: 0	TKMS TALS MAZS LIPJ SIGU BAUS REZ1 BALV LODE RIGA DAU1 VANG DOB1 VAIV SALP LUNI KREI JEK1 IRBE
2015 MAR 17	16:55:29	LIMB TKMS TALS LIPJ MAZS SIGU REZ1 BALV LODE BAUS SALP VAIV LUNI KREI DOB1 DAU1 VANG RIGA JEK1 IRBE
2015 MAR 17	16:57: 0	MADO LIMB TALS LIPJ TKMS MAZS SIGU REZ1 KREI VAIV LUNI SALP BALV LODE BAUS DAU1 DOB1 RIGA VANG JEK1 IRBE
2015 MAR 17	16:58:30	MADO TALS TKMS LIPJ MAZS SIGU REZ1 BALV LODE DAU1 VAIV KREI LUNI SALP BAUS RIGA DOB1 JEK1 VANG IRBE
2015 MAR 17	17:60: 0	LVRD TKMS TALS LIPJ MAZS SIGU REZ1 BALV LODE KREI VAIV LUNI SALP DAU1 DOB1 BAUS JEK1 RIGA VANG IRBE

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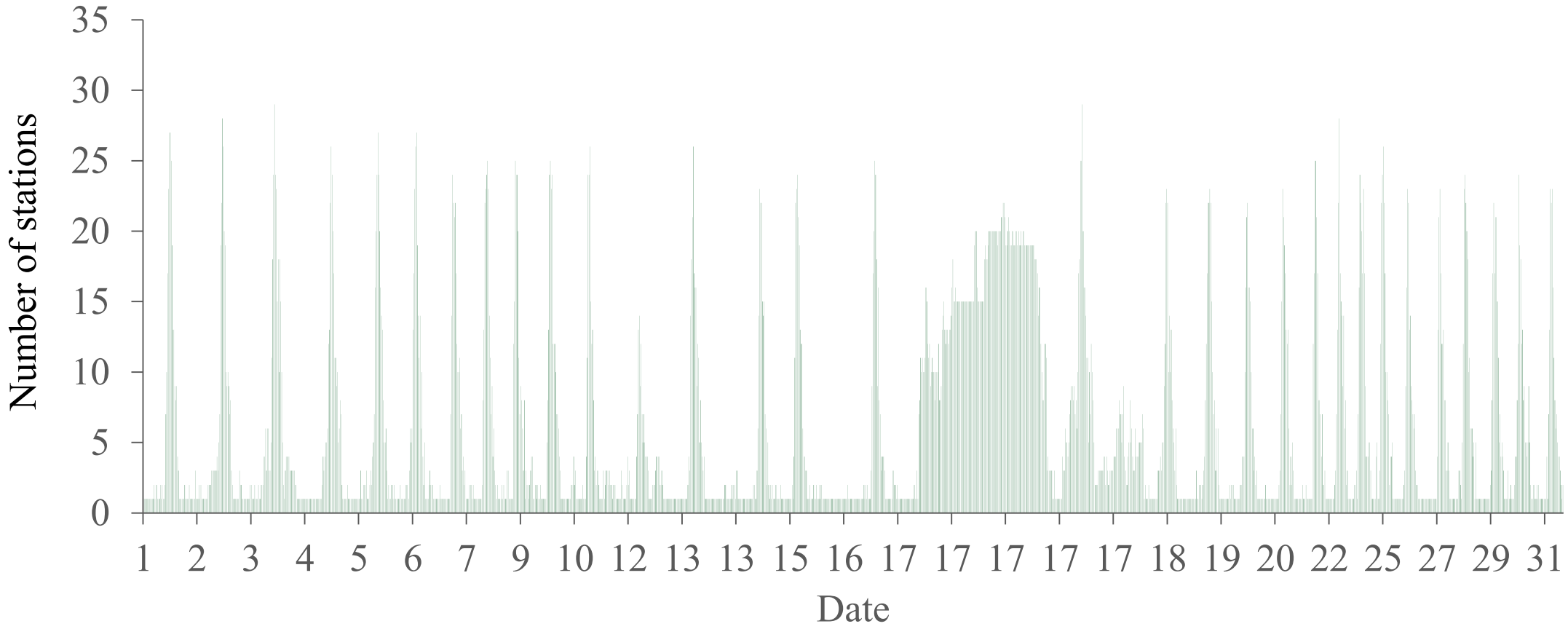
Plot of the distribution of simultaneously occurred discrepancies in multiple stations in March 2015



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The max size (m) of disturbances during geomagnetic storm in St. Patrick's day on 17 March 2015

		North	East	Up	Time (DOY)
RIGA 76 DAY	6935	40.135	-10.435	-531.428	76.714583
VANG 76 DAY	9404	40.601	-9.497	-531.624	76.714583

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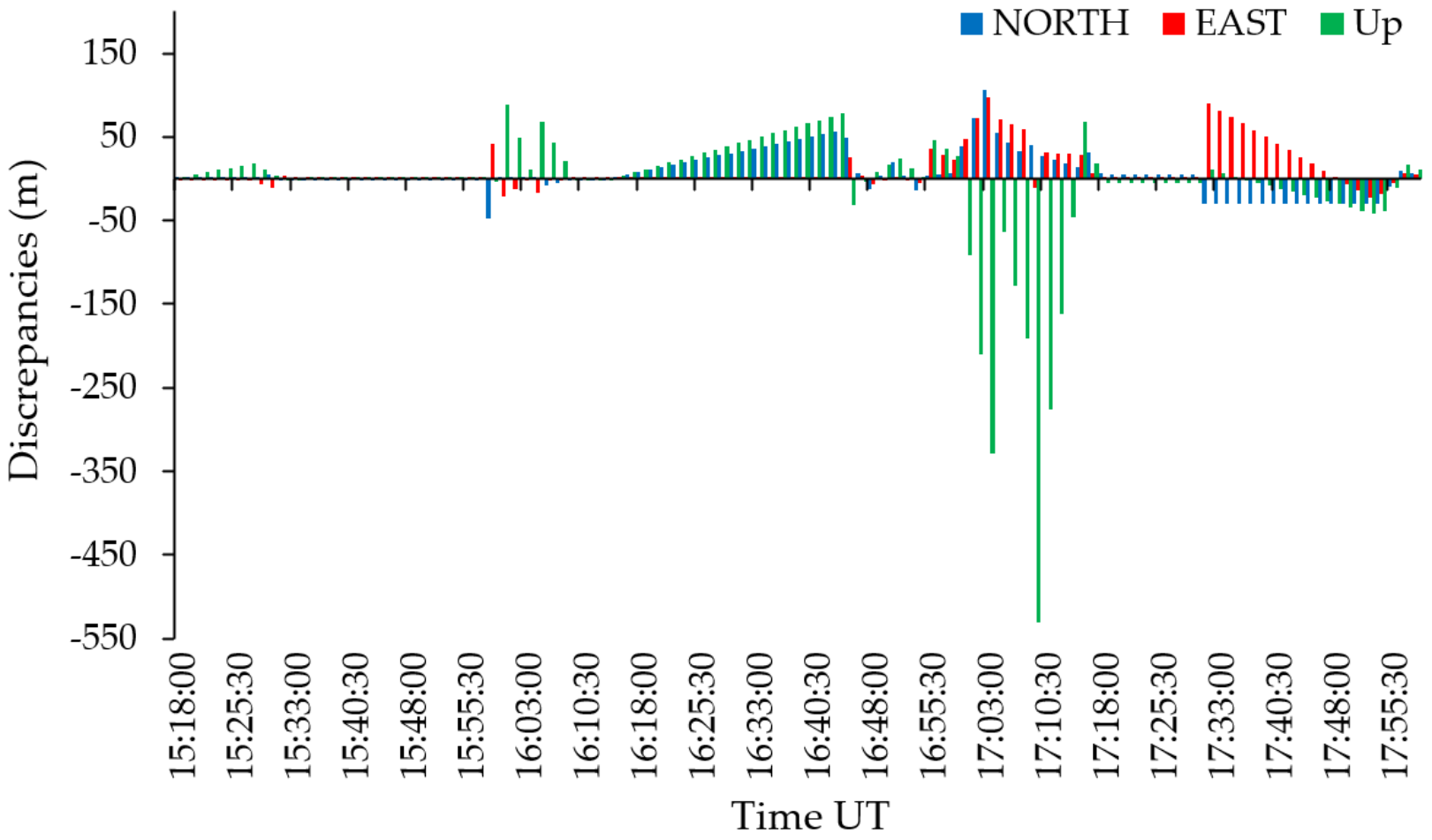
Distribution of discrepancies of station RIGA on 17 March 2015



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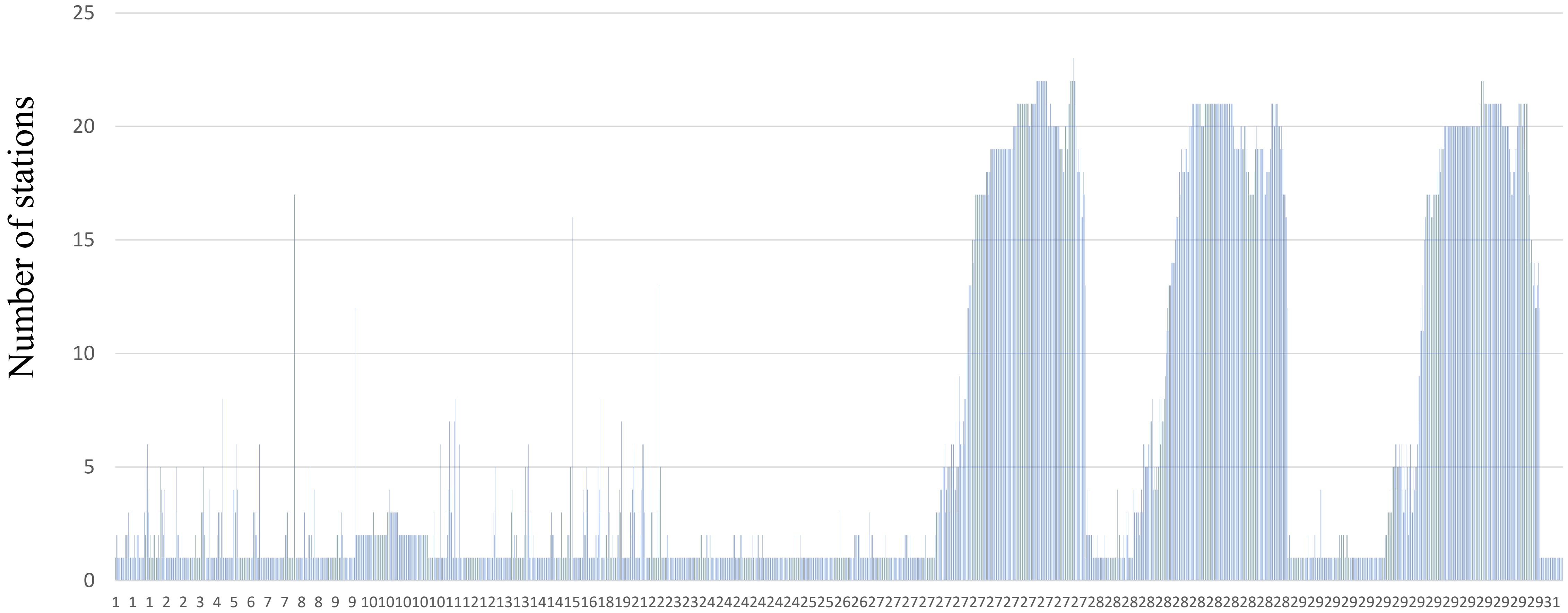
December 2009 (HALO ?)



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Loss-of-Lock fixed

2007 MAY 4 KREI 2115 after 124.867708 day repeatedly 3 times ***
2007 MAY 5 KREI 2118 after 125.864583 day repeatedly 3 times ***
2007 MAY 7 KREI 2124 after 127.859375 day repeatedly 3 times ***
2007 MAY 8 KREI 2298 after 128.235417 day repeatedly 173 times ********173********
2007 MAY 8 KREI 2351 after 128.462500 day repeatedly 53 times ******** 53********
2007 MAY 8 KREI 2354 after 128.857292 day repeatedly 2 times **
2007 MAY 9 KREI 2357 after 129.853125 day repeatedly 3 times ***
2007 MAY 10 KREI 2361 after 130.851042 day repeatedly 3 times ***
2007 MAY 11 KREI 2643 after 131.000000 day repeatedly 282 times ********282********
2007 MAY 11 KREI 2646 after 131.375000 day repeatedly 2 times **
2007 MAY 11 KREI 2650 after 131.847917 day repeatedly 3 times ***

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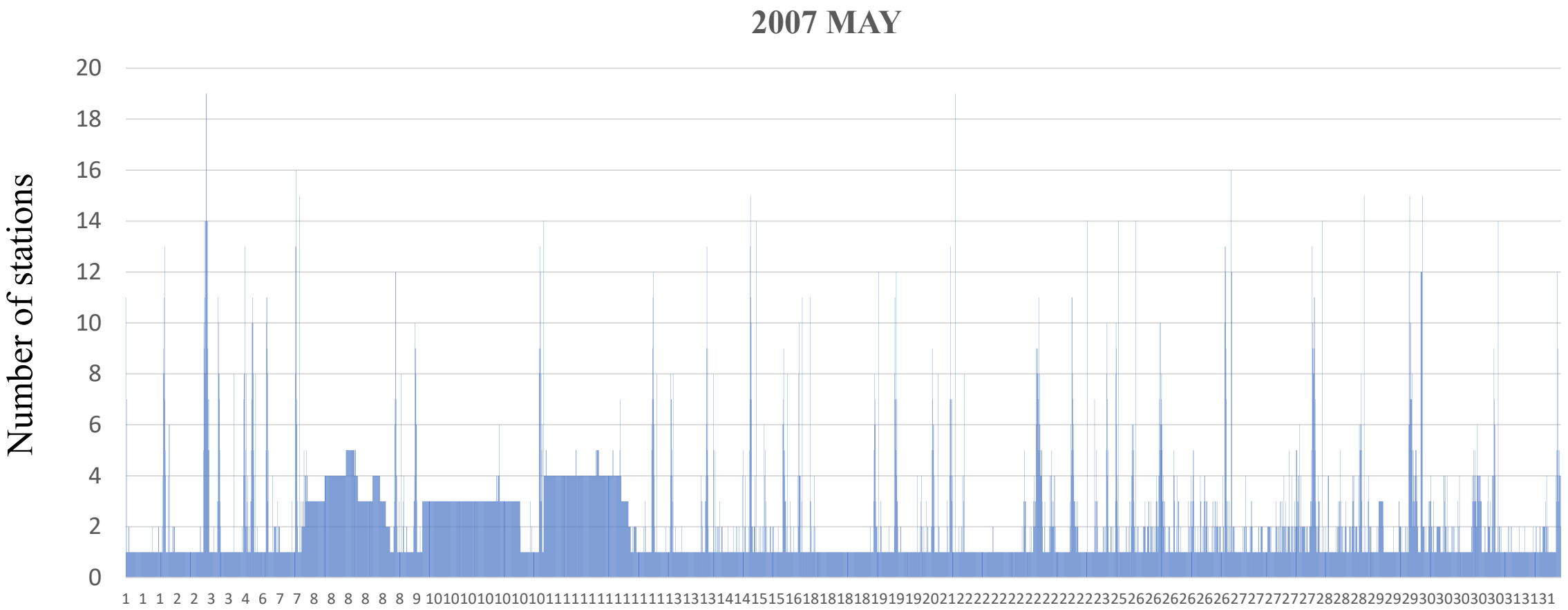
Loss-of-Lock situations



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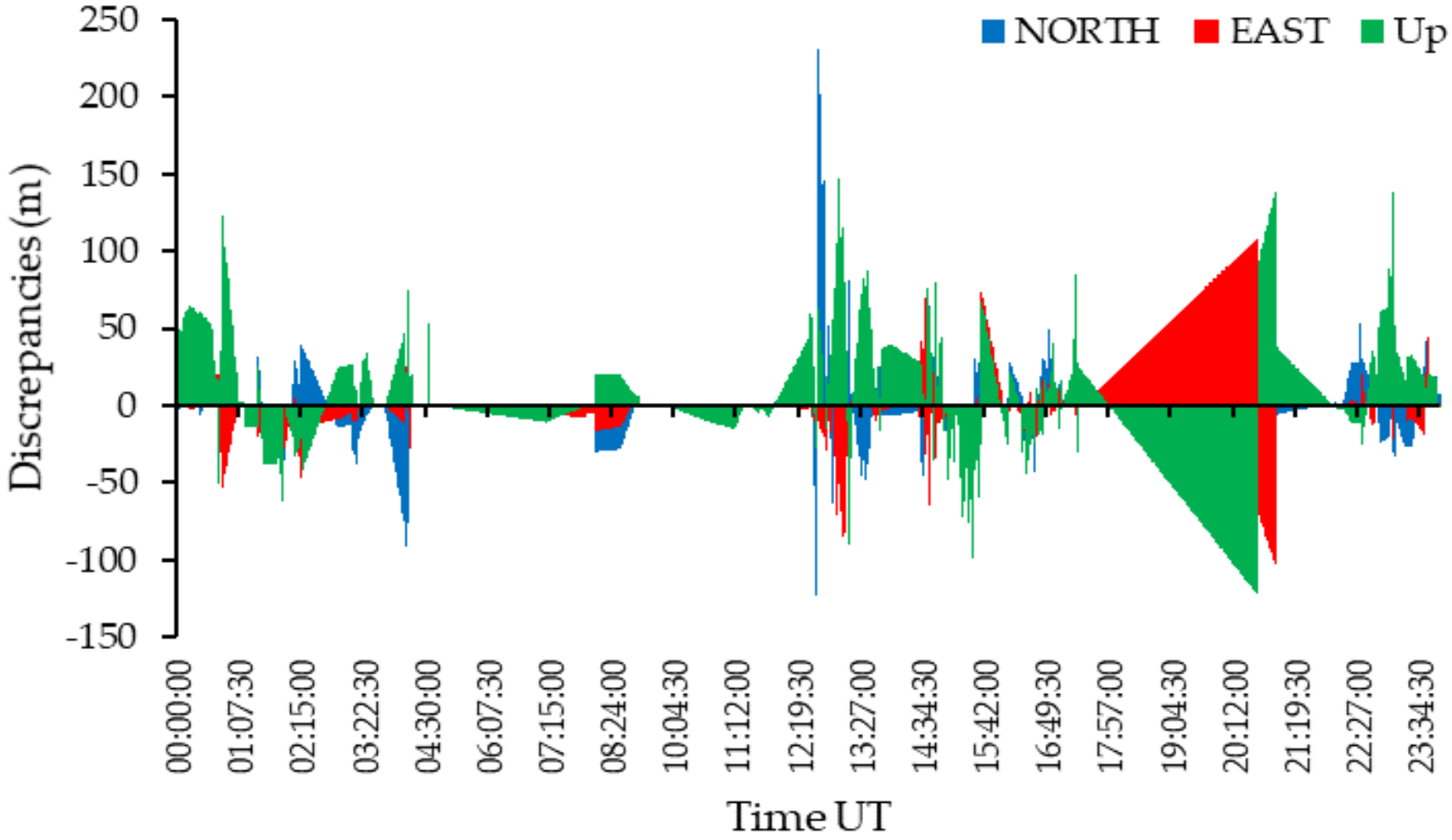
Distribution of discrepancies of station LUNI on 14 July 2017



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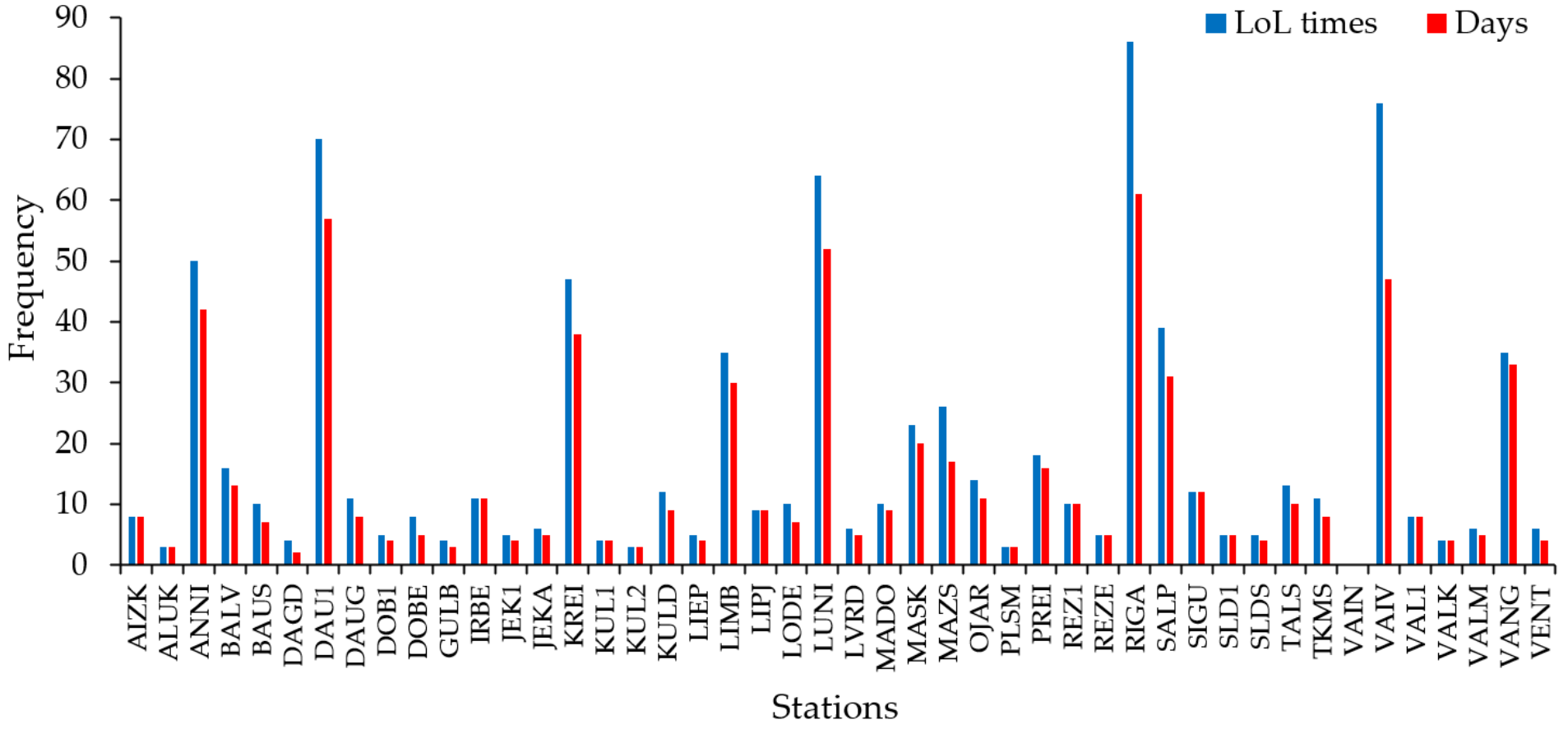
Frequency of Loss-of-Lock (LoL) in Latvian CORS stations (2007-2017)



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For correlation analysis

	Geomagnetic storms and sun flares		TEC	CSLP	>10cm	CSLP(F)
2014 DEC 1		3 C flares, M flare	34.1	472	287	2
2014 DEC 2		10 C flares	38.6	482	243	4
2014 DEC 3		7 C flares	28.6	462	252	7
2014 DEC 4		4 C flares, 3 M flares	29.8	455	339	2
2014 DEC 5		8 C flares, M flare	32.2	445	251	1
2014 DEC 6		8 C flares	36.1	469	244	2
2014 DEC 7	Kp 5-,	6 C flares	35.0	490	255	4
2014 DEC 8		3 C flares	27.5	449	261	2
2014 DEC 9		11 C flares	27.5	415	214	3
2014 DEC 10		4 C flares	26.3	491	233	4
2014 DEC 11		7 C flares	25.0	459	322	6
2014 DEC 12		6 C flares	32.8	474	304	2
2014 DEC 13		7 C flares, M flare	26.7	536	275	4
2014 DEC 14		15 C flares, M flare	31.1	505	252	6
2014 DEC 15		12 C flares	35.8	466	255	3
2014 DEC 16		4 C flares	33.2	463	264	3

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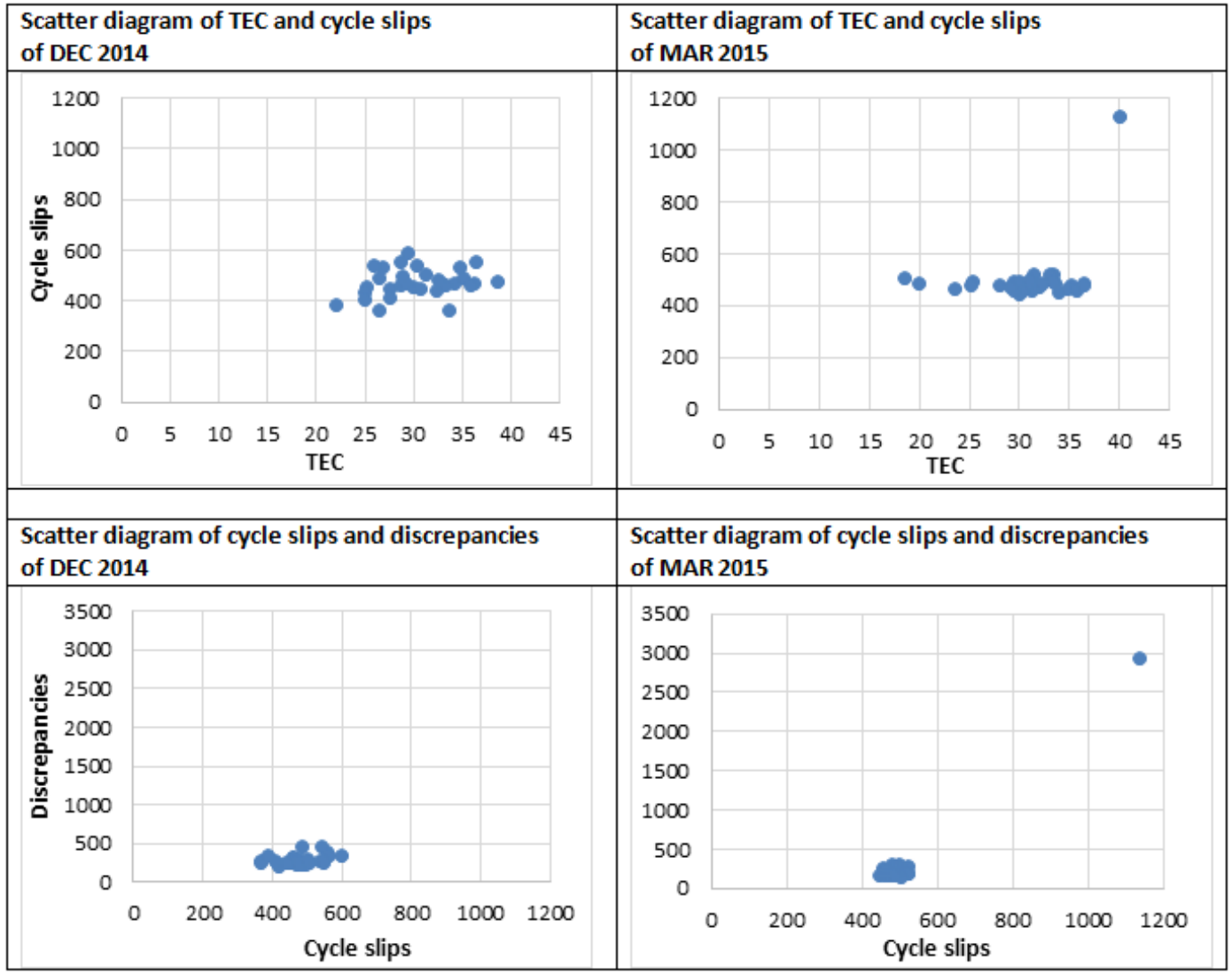
Correlation between identified cycle slips and extreme ionosphere conditions

Pearson coor.coeff. Rxy=0.2345
Cov=51.5549
Student dist. t=1.2993

Pearson coor.coeff. Rxy=0.3455
Cov=184.1497
Student dist. t=1.9829

Pearson coor.coeff. Rxy=0.3526
Cov=1187.5213
Student dist. t=2.0293

Pearson coor.coeff. Rxy=0.8062
Cov=57160.8966
Student dist. t=7.3378



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Count of Pearson's correlation coefficients before the removal of the Loss-of-Lock (1st row) and after the removal ofthe Loss-of-Lock (2nd row)

TEC and cycle slips				TEC and faulty solutions				TEC and cycle slips from faulty solutions				Cycle slips and faulty solutions			
[0 ; 0.4)	[0.4; 0.7)	[0.7; 1]	[0 ; -1]	[0 ; 0.4)	[0.4; 0.7)	[0.7; 1]	[0 ; -1]	[0 ; 0.4)	[0.4; 0.7)	[0.7; 1]	[0 ; -1]	[0 ; 0.4)	[0.4; 0.7)	[0.7; 1]	[0 ; -1]
18	5	0	23	18	4	0	24	25	4	0	17	25	1	2	18
19	5	0	22	16	6	0	24	26	3	0	17	21	0	2	23

Count of Pearson's correlation coefficients between ROTI and faulty solutions

ROTI and cycle slips				ROTI and faulty solutions				ROTI and cycle slips from faulty solutions				ROTI and TEC			
[0 ; 0.4)	[0.4; 0.7)	[0.7; 1]	[0 ; -1]	[0 ; 0.4)	[0.4; 0.7)	[0.7; 1]	[0 ; -1]	[0 ; 0.4)	[0.4; 0.7)	[0.7; 1]	[0 ; -1]	[0 ; 0.4)	[0.4; 0.7)	[0.7; 1]	[0 ; -1]
18	5	3	8	13	6	1	14	15	4	1	14	18	7	0	9

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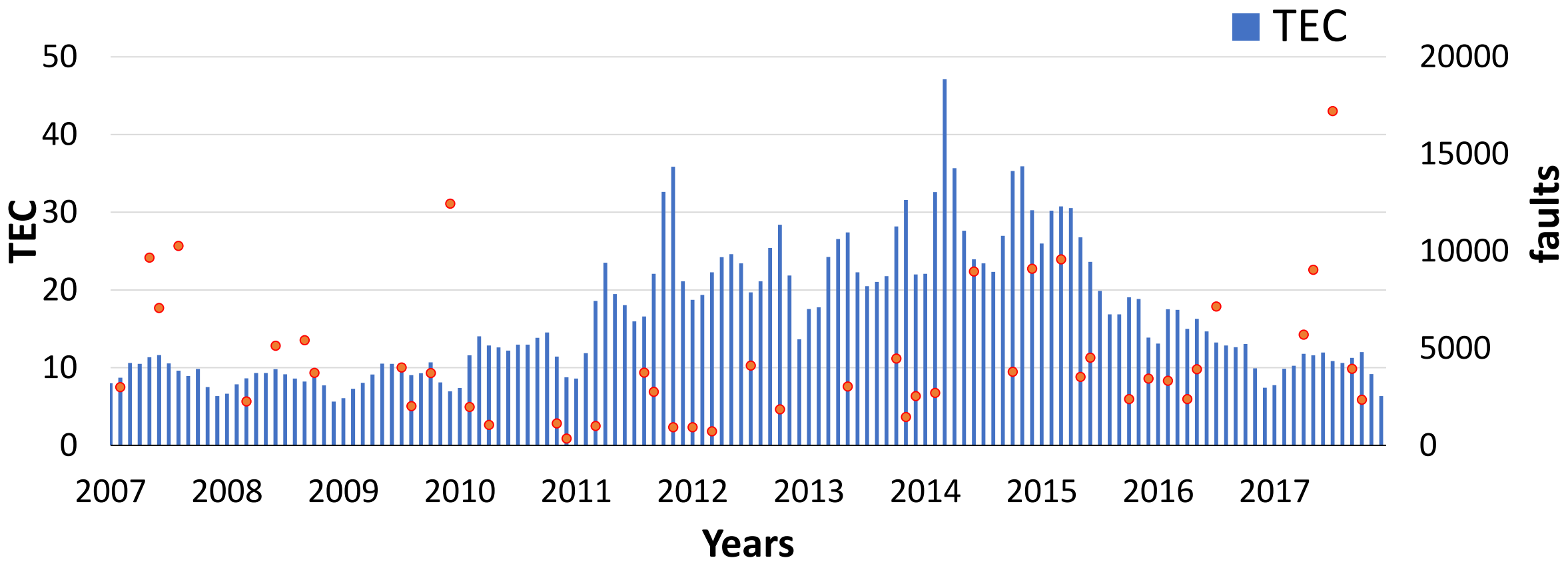
Monthly average of daily maximum TECs and the average number of faults per month



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RIMS stations GVLA&B, LAPA&B and WRSA&B

[https://gssc.esa.int/navipedia/index.php/File:RIMS.png]

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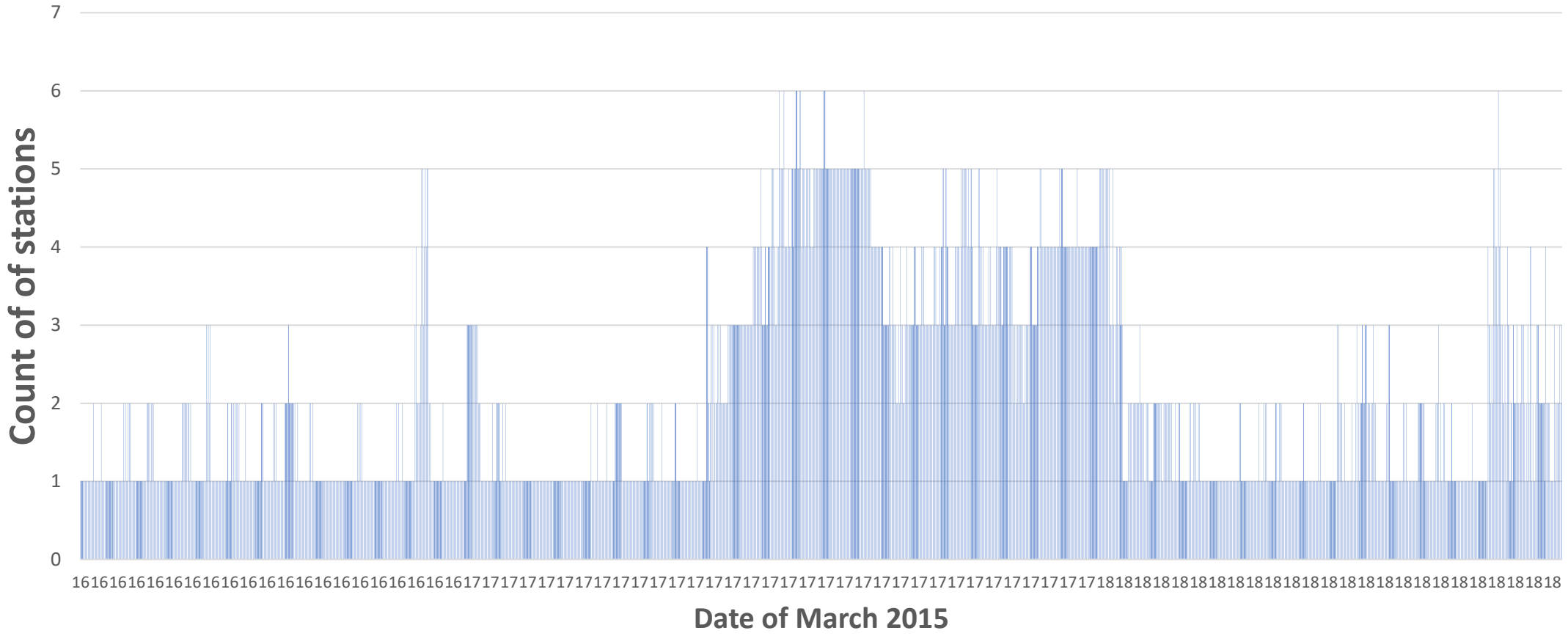
Frequency of faulty solutions in 16-18 March 2015 in the set of RIMS stations GVLA&B, LAPA&B and WRSA&B



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Discrepancies of RIMS on 17 March 2015 (m)

754 2015 MAR 17 15:28:30 UT

Station	#	North	East	Up	Dist	Az
WRSA	1101	0.000	0.009	0.120	0.120	90.0
LAPB	1100	-0.087	0.033	0.436	0.446	159.2
GVLB	1098	0.700	-1.622	-0.649	1.882	-66.7
GVLA	1097	-53.826	-19.559	-12.408	58.598	-160.0
LAPA	1099	-16.684	46.905	-199.657	205.770	109.6

755 2015 MAR 17 15:30: 0 UT

WRSA	1106	-0.012	0.012	0.106	0.107	135.0
LAPB	1105	-0.083	0.025	0.539	0.546	163.2
GVLB	1103	0.715	-1.655	-0.653	1.917	-66.6
GVLA	1102	-53.469	-18.643	-15.603	58.736	-160.8
LAPA	1104	-16.844	47.730	-203.047	209.261	109.4

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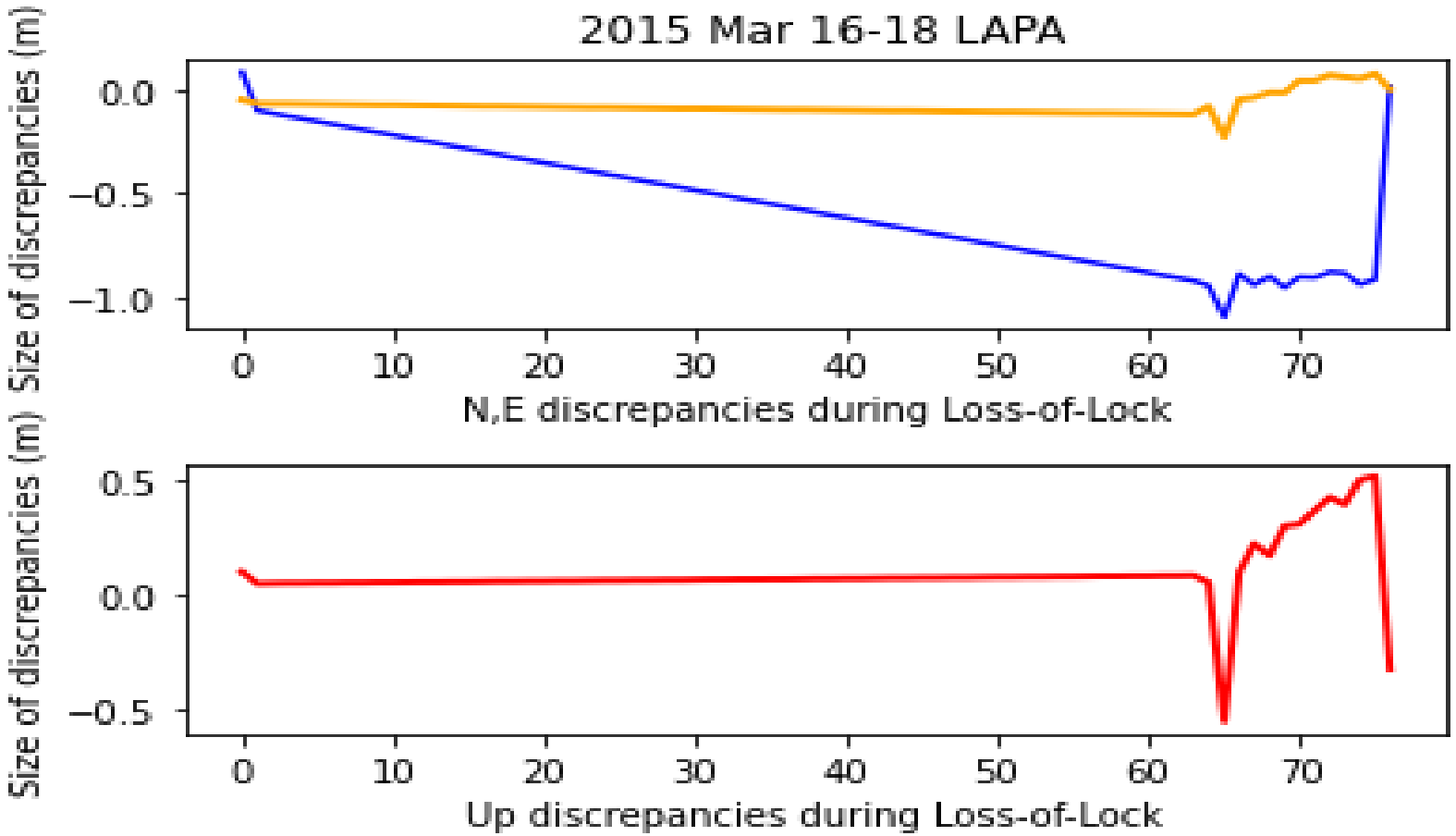
Loss-of-Lock: RIMS station LAPA 17 mar 2015 (North – blue, East – orange, Up – red)



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Conclusions

- Pearsons' coefficient statistical analysis on the coverage of discrepancies over Latvia in relation to ionospheric Total Electron Content (TEC) and Rate of change of TEC index (ROTI) values discovers significant irregularities due to weak correlation.

- The assessed suitability of the global TEC and ROTI approximation models for the local Latvian CORS stations in 2007-2017 confirm the local ionospheric anomaly irregularities. In case of 96.6% of discovered discrepancies are not identified by Bernese 5.2 software as cycle slips.

- It is assumed the eventual dependency between the frequency on Loss-of-Lock and the GNSS receivers' network geometry and size of the territorial coverage.

- The monthly discrepancy diagrams revealed simultaneous discrepancies at numerous individual stations. Therefore, this enables to characterize the waveform movement of space weather influence in time span 2007-2017. The strongest impact of space weather was observed on 17 March 2015.

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THANK YOU!

APPRECIATE!