FORBUSH EVENTS VS LATITUDE

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Introduction

- The detector of the EEE network have been measured different Forbush decreases

- The EEE network is spread out in all Italy:
  - We can see a latitude dependence of the Forbush decrease?
  - Or the latitude range is too narrow and no conclusion can be drawn?

- Today, first results are shown
- Other elements to be considered (and discussed): altitude, enviromental condition, shielding ... --> not treated today (to be implemented later)
- Use of POLA-R detector --> not treated today, to be implemented later

Analysis routine

- Started the analysis looking at the Forbush decrease of the 19 January 2026 using the EEE MRPC

- New results, only reported a preliminary plot on SIF Prima Pagina with two telescopes + two POLA and on Run Coordination Meeting

- Some implementation on the code has been done:
  - Add of statistical uncertainty and correct error propagation in the resampling
  - Search of the minimum value of the decrease
  - Magnitude estimation
  - Minimum and magnitude vs latitude (and, actually, longitude!)

Thanks to Ombretta & Annalisa for the code!

Telescopes active during the Forbush event

Telescope	Latitude	Longitude
AREZ-01	43.464650	11.874020
BARI-01 *	41.119220	16.871950
BOLO-01 *	44.500670	11.356800
BOLO-02 *	44.484620	11.372350
BOLO-05 **	44.488630	11.347920
CARI-01 *	39.489350	16.956250
FERM-01 ****	41.89736	12.49258
FRAS-01	41.794520	12.664730
LAQU-01	42.356680	13.414030
LNLE-01	45.351830	13.414030
PISA-01	43.720490	10.407970
RECA-01 ****	38.095337	16.659853
REND-01 ***	39.36	16.12
SALE-03 ***, #	40.77	14.79
VIC-01	45.558150	11.533380
VIC-02 ##	45.552300	11.556270

Some notes:

- *: Latitude and longitude values taken from ~2020 files and not from the day of the measurements files
- **: Latitude and longitude same as BOLO-03 (same school according to the logbook)
- ***: no latitude and longitude info found on data files, taken from Forbush 2024 paper
- ****: no latitude and longitude info found, taken from Google Maps

- #: pressure taken from METAR
- ##: pressure taken from VIC-01 telescope

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Even if different telescopes have been taking data during the Forbush period, not all of them have a good response

Some telescopes have been discarded from the beginning, some others have been analyzed and discarded once the differential corrected rate was calculated (see backup slides)

Statistical uncertainties

To each measurement of rate, a statitstical uncertainty is associated according to the Poisson distribution of the counts

$$\Delta R = \frac{\Delta N}{t} = \frac{\sqrt{N}}{t} = \frac{\sqrt{Rt}}{t} = \sqrt{\frac{R}{t}}$$

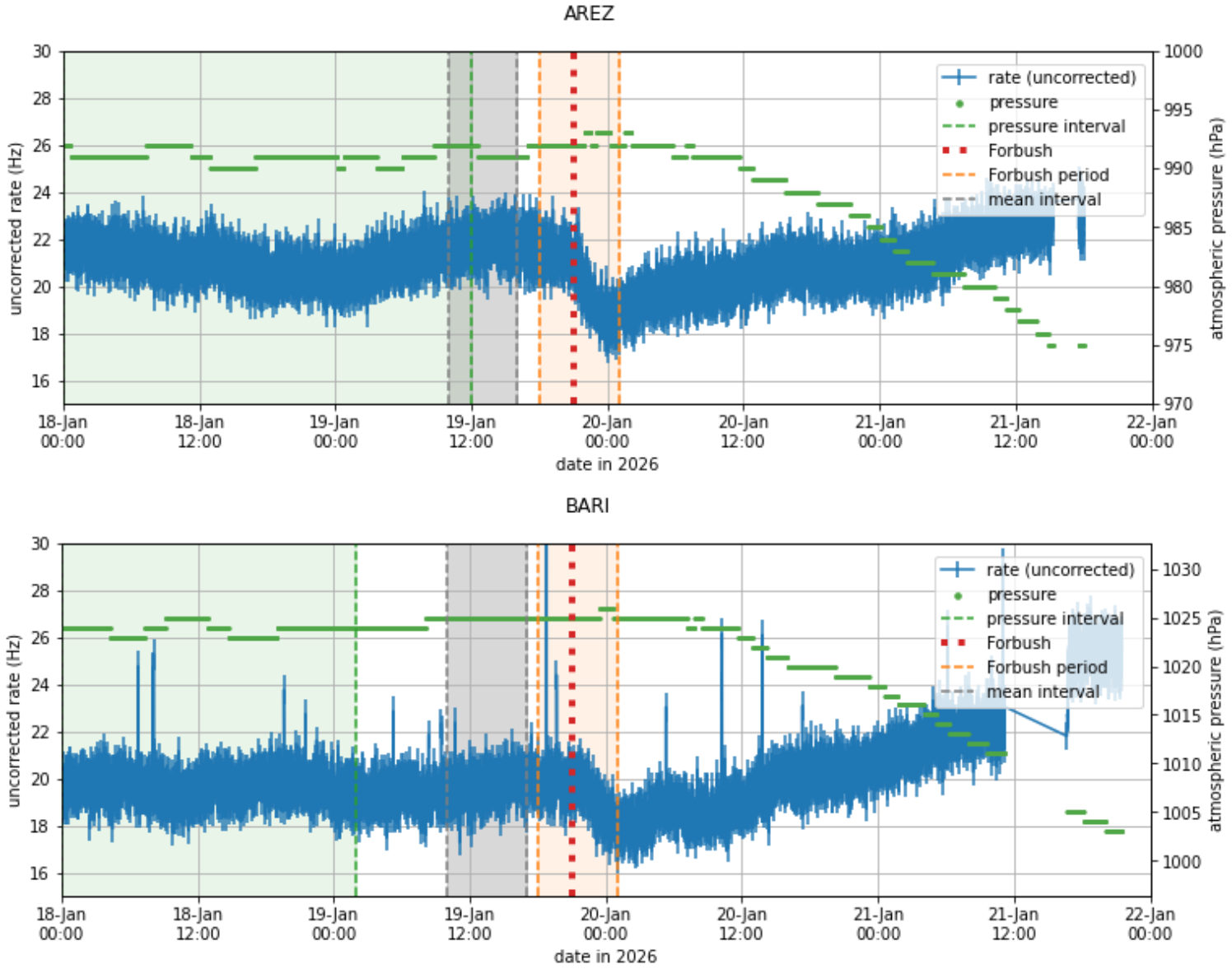
When resampled (--> mean) or a mean value is calculated error propagated as:

$$\overline{x} = \frac{1}{N}\sum_i x_i \qquad \sigma_{\overline{x}} = \frac{1}{N}\sum_i \sigma_{x_i}^2$$

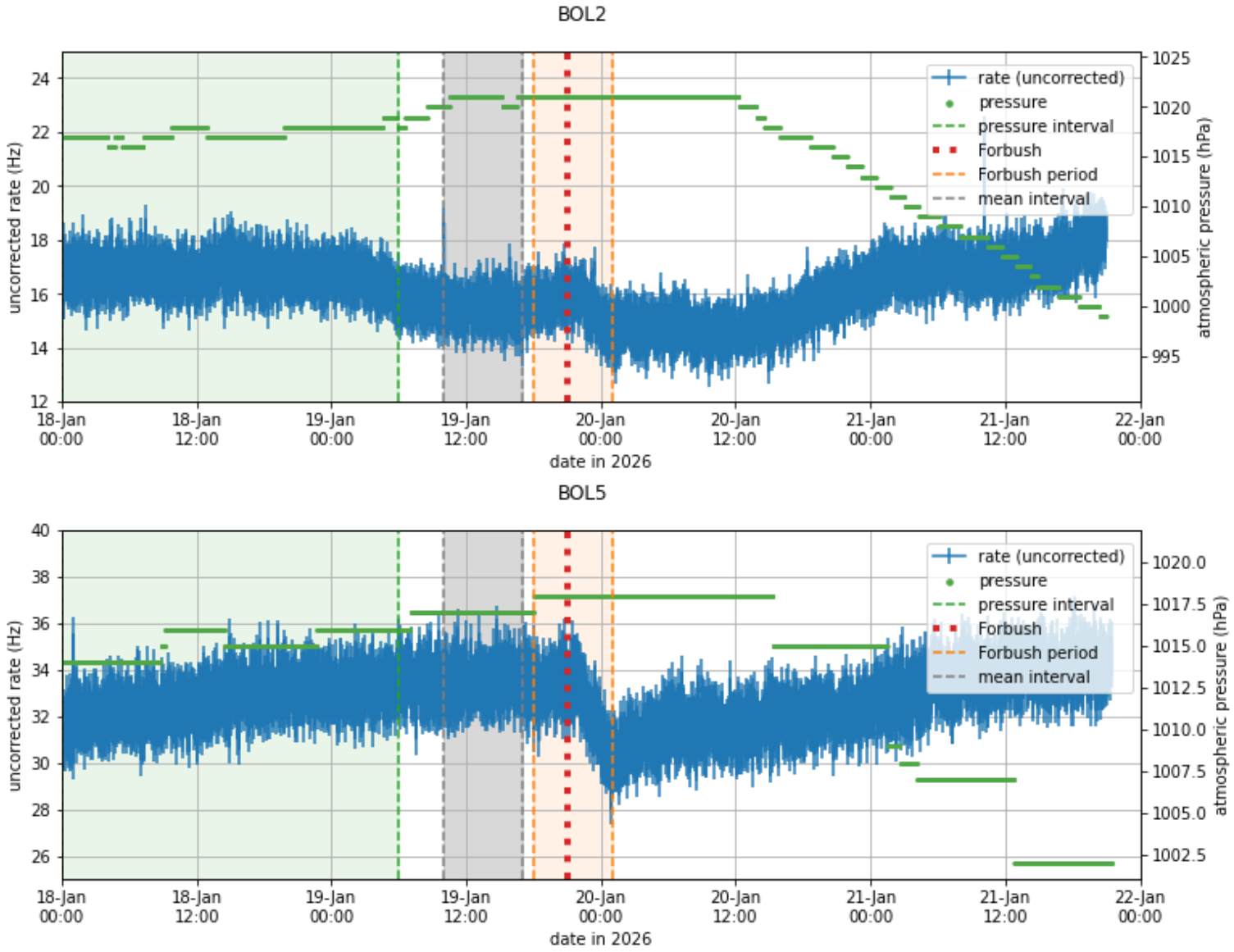
For the corrected differential rate (%):

$$R_{diff} = \frac{R_c - \overline{R}_c}{\overline{R}_c} \times 100 \qquad \Delta R_{diff} = \frac{100}{\overline{R}_c}\sqrt{\Delta R_c^2 + \left(\frac{R_c}{\overline{R}_c}\right)^2 \Delta \overline{R}_c^2}$$

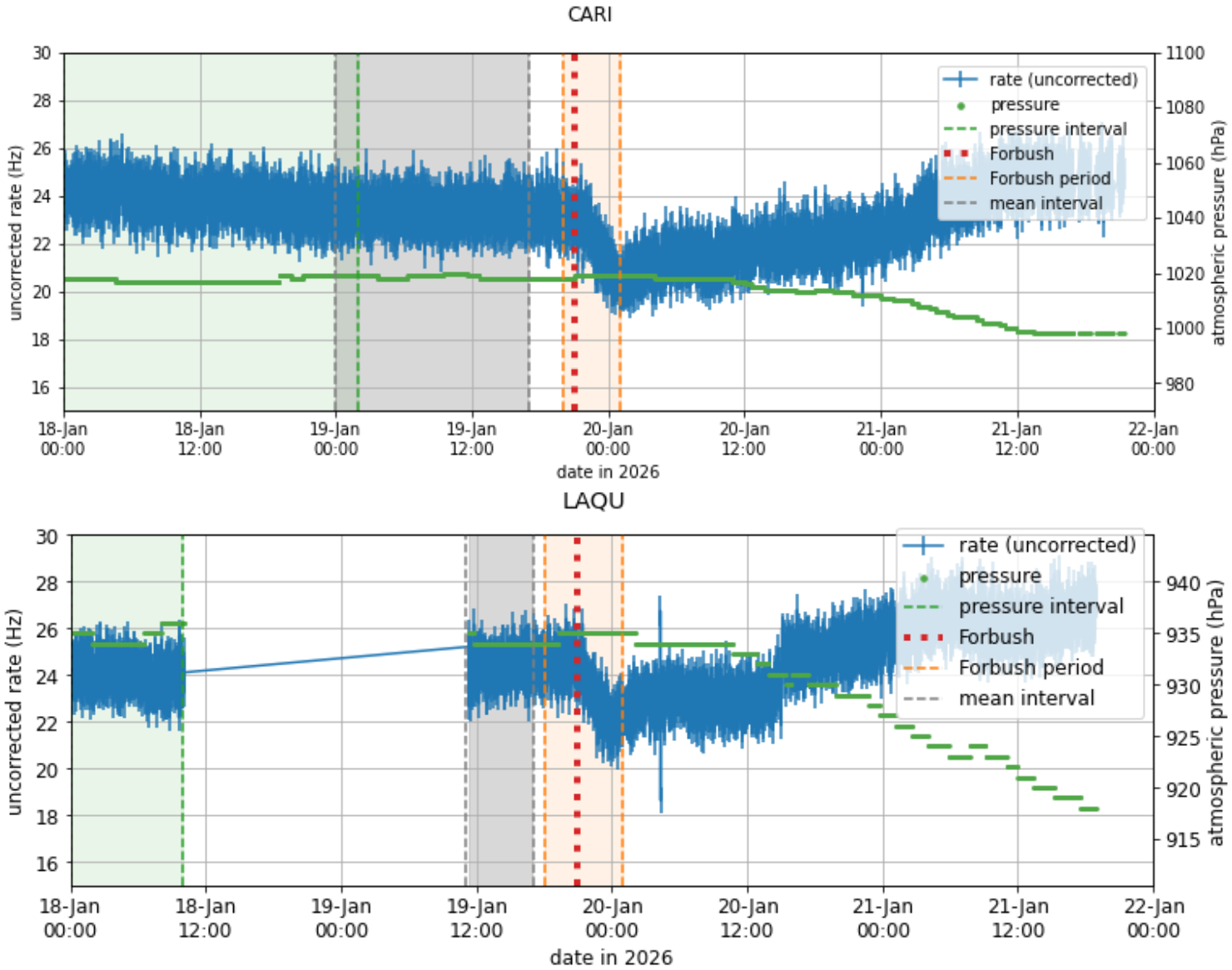
Measured rate and pressure



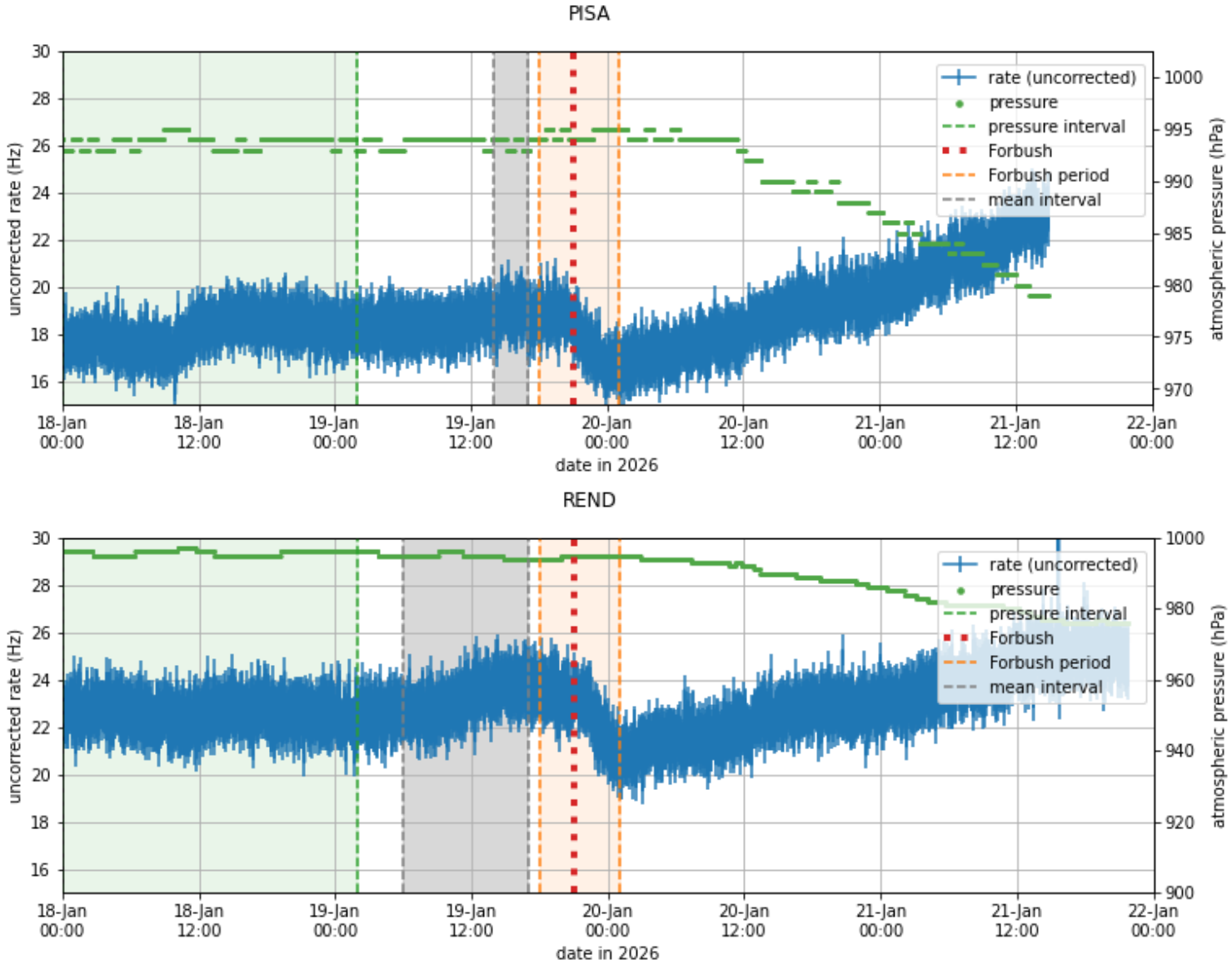
Measured rate and pressure



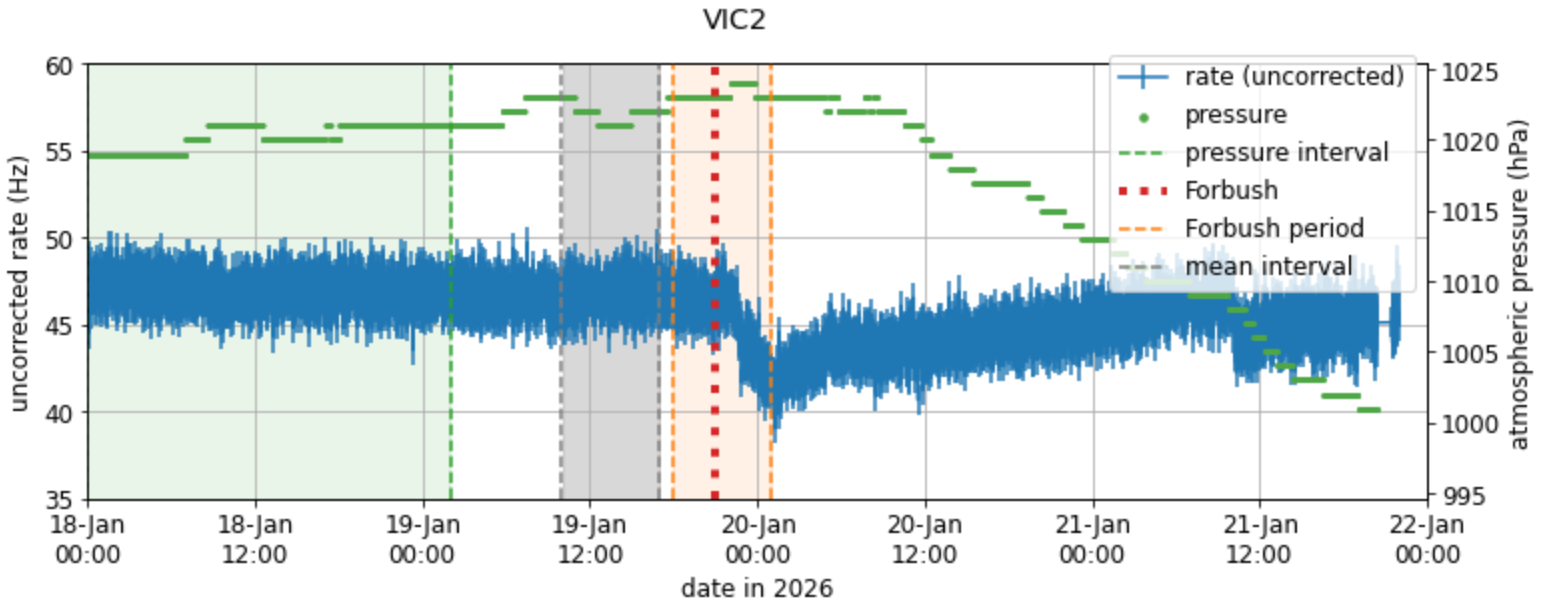
Measured rate and pressure



Measured rate and pressure



Measured rate and pressure



Barometric correction

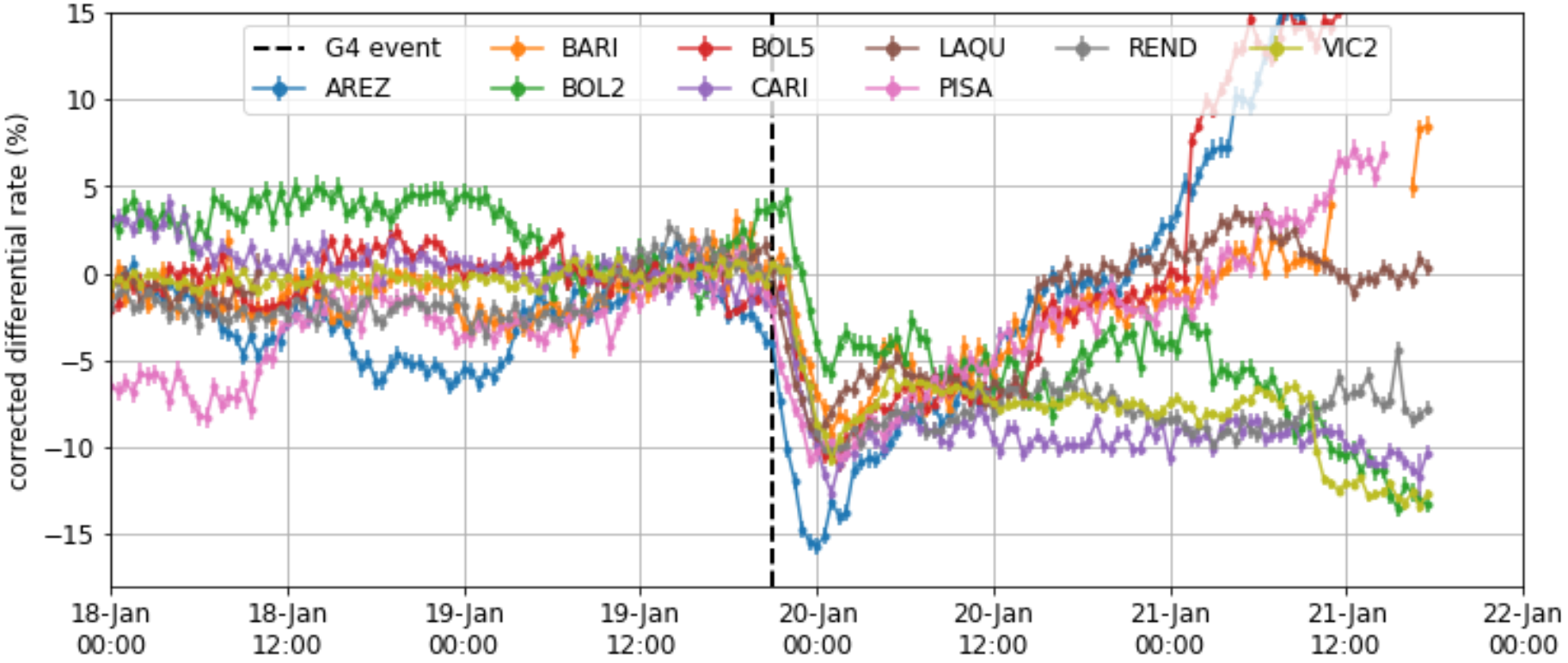
Barometric coefficient beta evaluated as the slope coefficient of the simple linear regression between log(Delta I/<I>) and DeltaP = P - <P>

As expected, Pearson coefficient between corrected rate and pressure is ~ 0

Barometric correction: parameters

tele	presMean[i]	P.std()	P.max()-P.min()	beta[i]	parA	pearsonBefore[i]	pearsonAfter[i]
AREZ	991.03	0.64	2.00	0.0109	-0.0239	0.3226	0.0000
BARI	1023.87	0.65	2.00	-0.0085	-0.0065	-0.4841	0.0005
BOL1	1019.81	0.55	2.00	-0.0025	-0.0012	-0.2779	0.0003
BOL2	1017.40	0.71	3.00	-0.0130	-0.0099	-0.6562	0.0032
BOL5	1015.13	0.85	2.00	0.0126	-0.0132	0.6536	0.0014
CARI	1017.67	0.83	2.00	-0.0083	-0.0083	-0.5307	0.0009
FERM	1013.77	0.82	2.00	-0.0230	-0.0277	-0.8049	0.0031
LAQU	934.75	0.77	2.00	-0.0055	-0.0023	-0.6200	0.0005
LNLE	1020.75	0.62	3.00	-0.0174	-0.0108	-0.7285	-0.0003
PISA	993.73	0.59	2.00	-0.0089	-0.0305	-0.2131	0.0002
REND	995.69	0.57	2.00	-0.0086	-0.0036	-0.5828	-0.0004
SAL3	1018.93	0.32	1.03	0.0079	-0.0037	0.2979	-0.0011
VIC1	1020.21	0.84	2.00	-0.0241	-0.0339	-0.7791	-0.0030
VIC2	1020.21	0.84	2.00	-0.0053	-0.0017	-0.7481	0.0001

Forbush event – cumulative plot



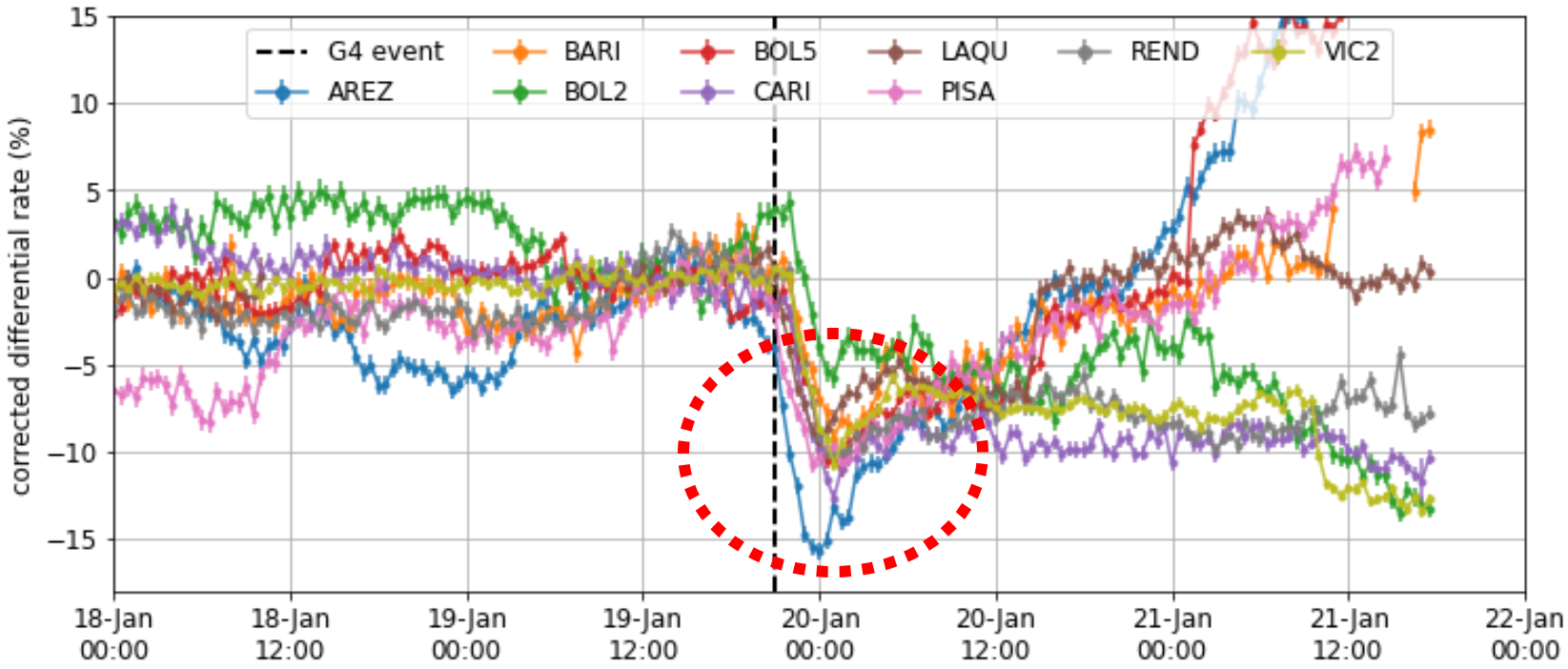
Even with the selected telescopes, there is a spread on the corrected differential rate ***before*** the Forbush decrease

Recovery phase for some telescope is not the best

Forbush vs latitude

In order to estimate the behaviour as a function of the latitude, two approaches are used:

- Minimum of the Forbush decrease



Forbush vs latitude

In order to estimate the behaviour as a function of the latitude, two approaches are used:

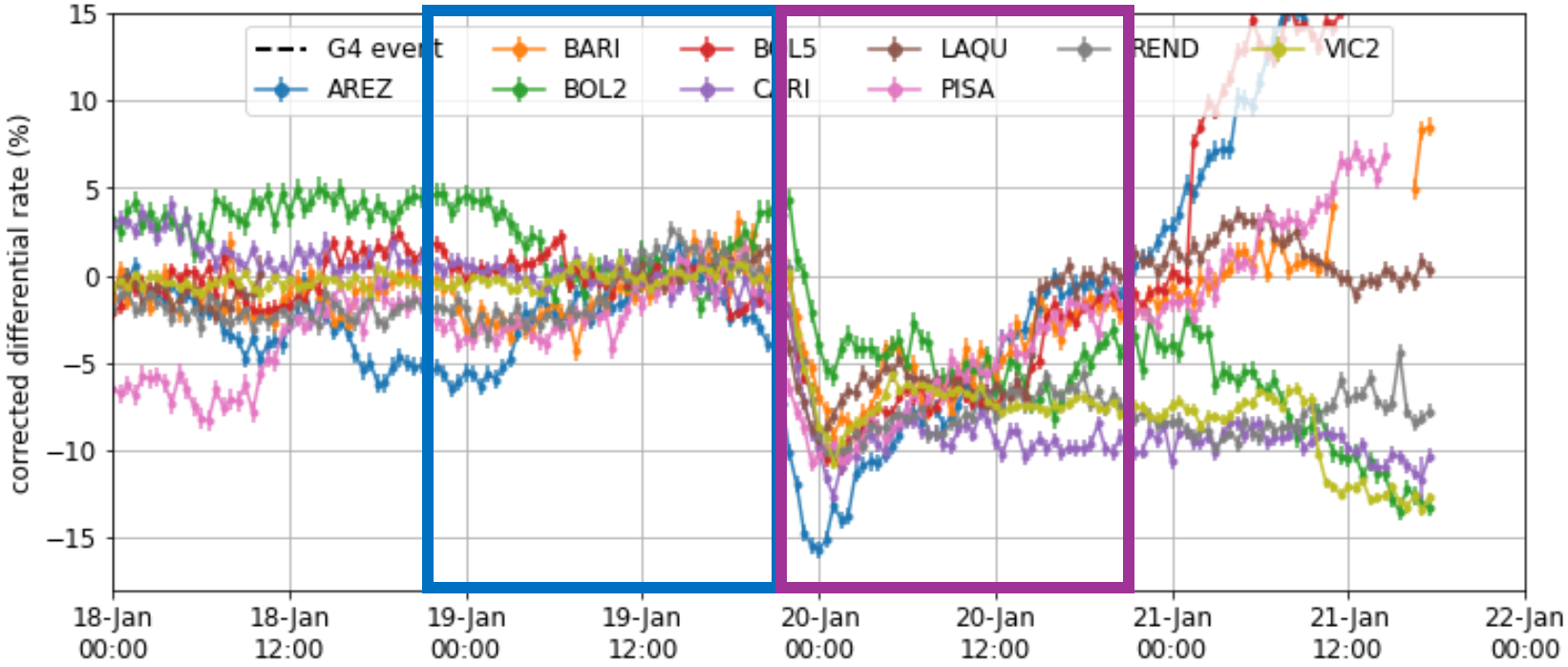
- Minimum of the Forbush decrease
- Calculate the magnitude, defined as:

$$Magnitude = \frac{Max - Min}{Max}$$

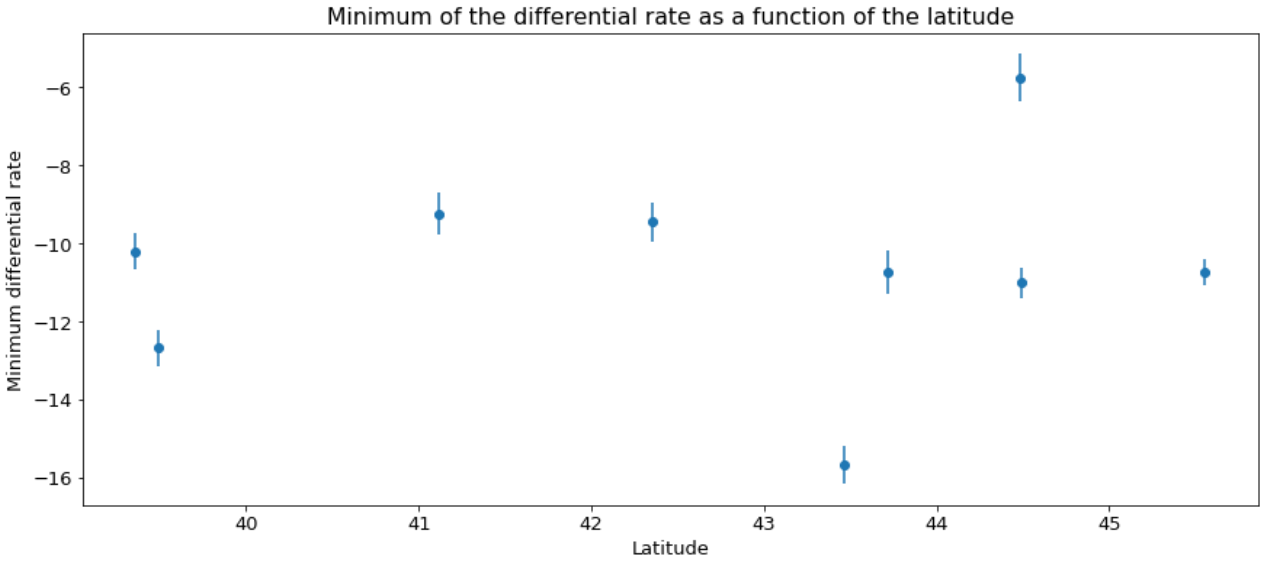
$$\sigma_{Mag} = \sqrt{\left(\frac{Min}{Max^2}\sigma_{Max}\right)^2 + \left(\frac{1}{Max}\sigma_{Min}\right)^2}$$

With:

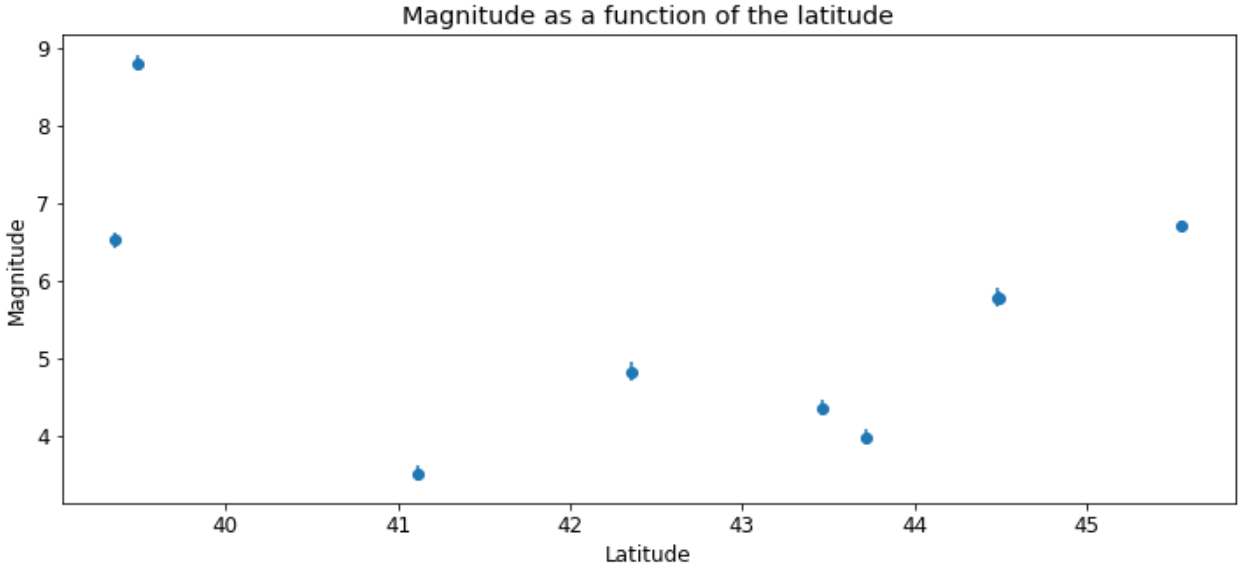
- **Max** = Mean of the corrected rate in the 24h before the Forbush decrease
- **Min** = Mean of the corrected rate in the 24h after the Forbush decrease



Forbush vs latitude

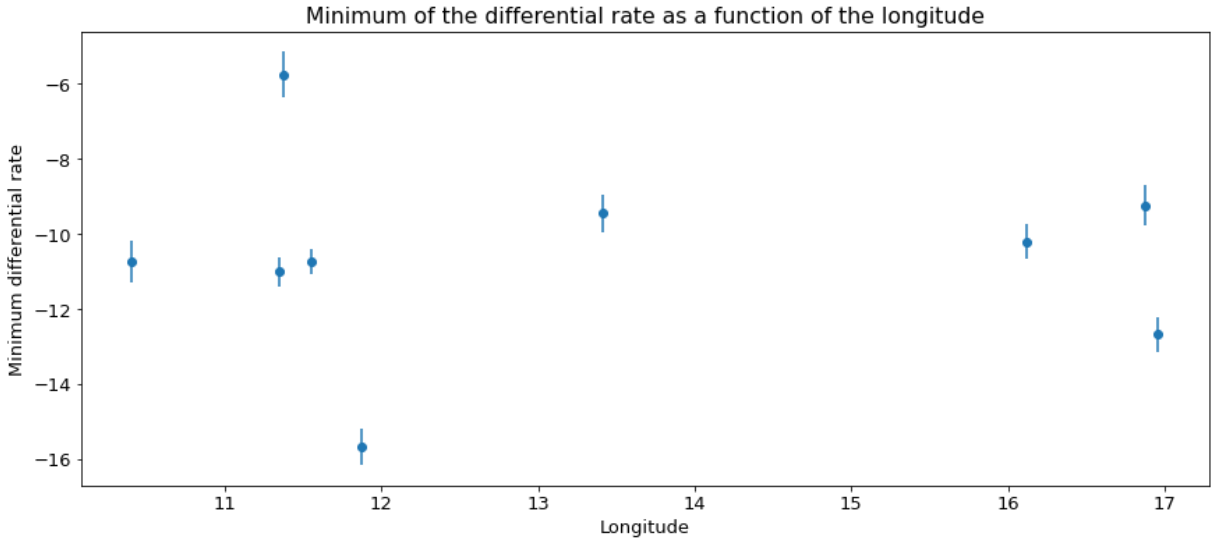


Pearson coefficient:
0.13190233432096005

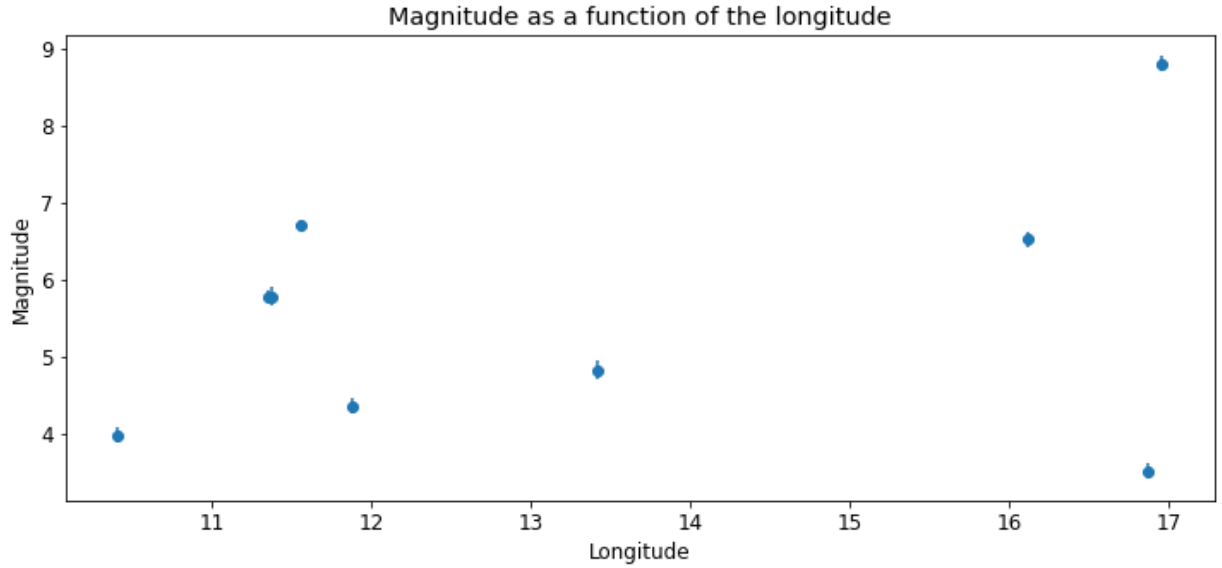


Pearson coefficient:
-0.29269134180317413

BONUS: Forbush vs longitude

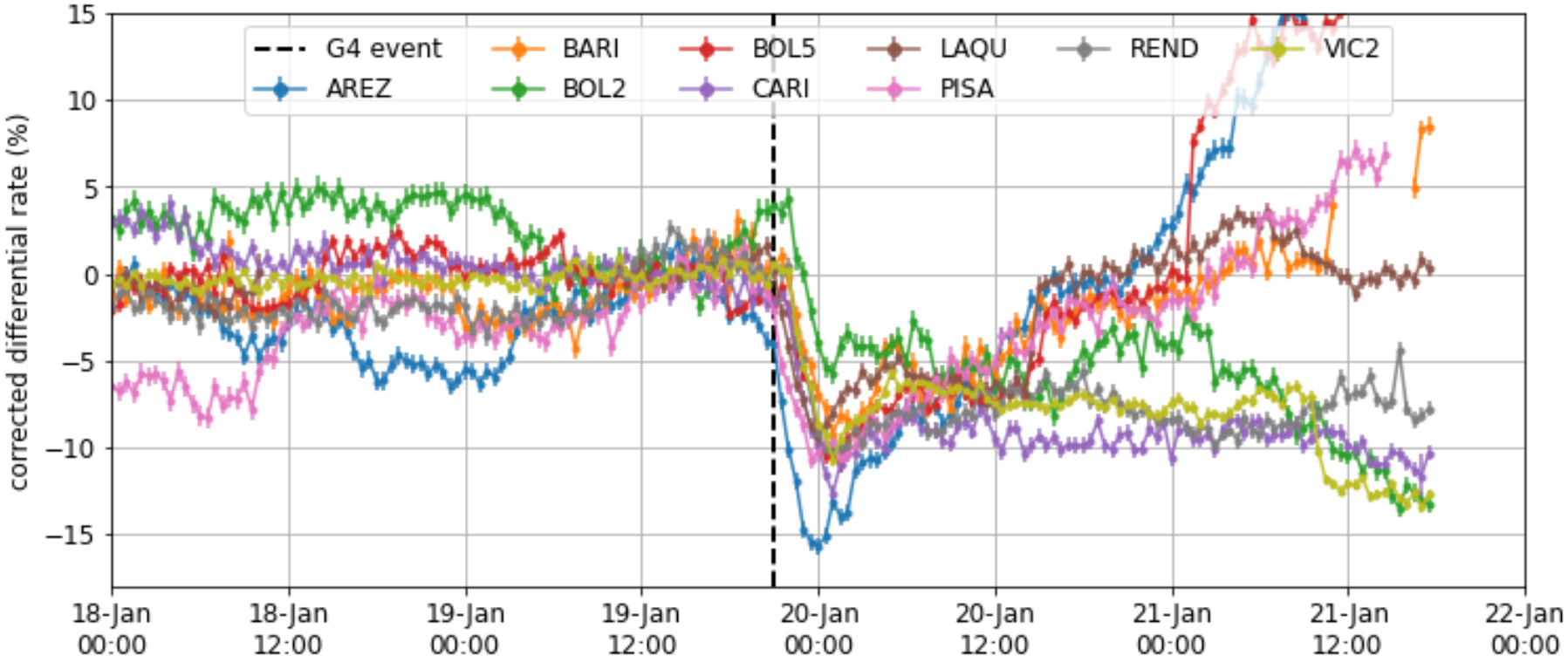


Pearson coefficient: -0.0393381049984671 5



Pearson coefficient: 0.3077862425450763 6

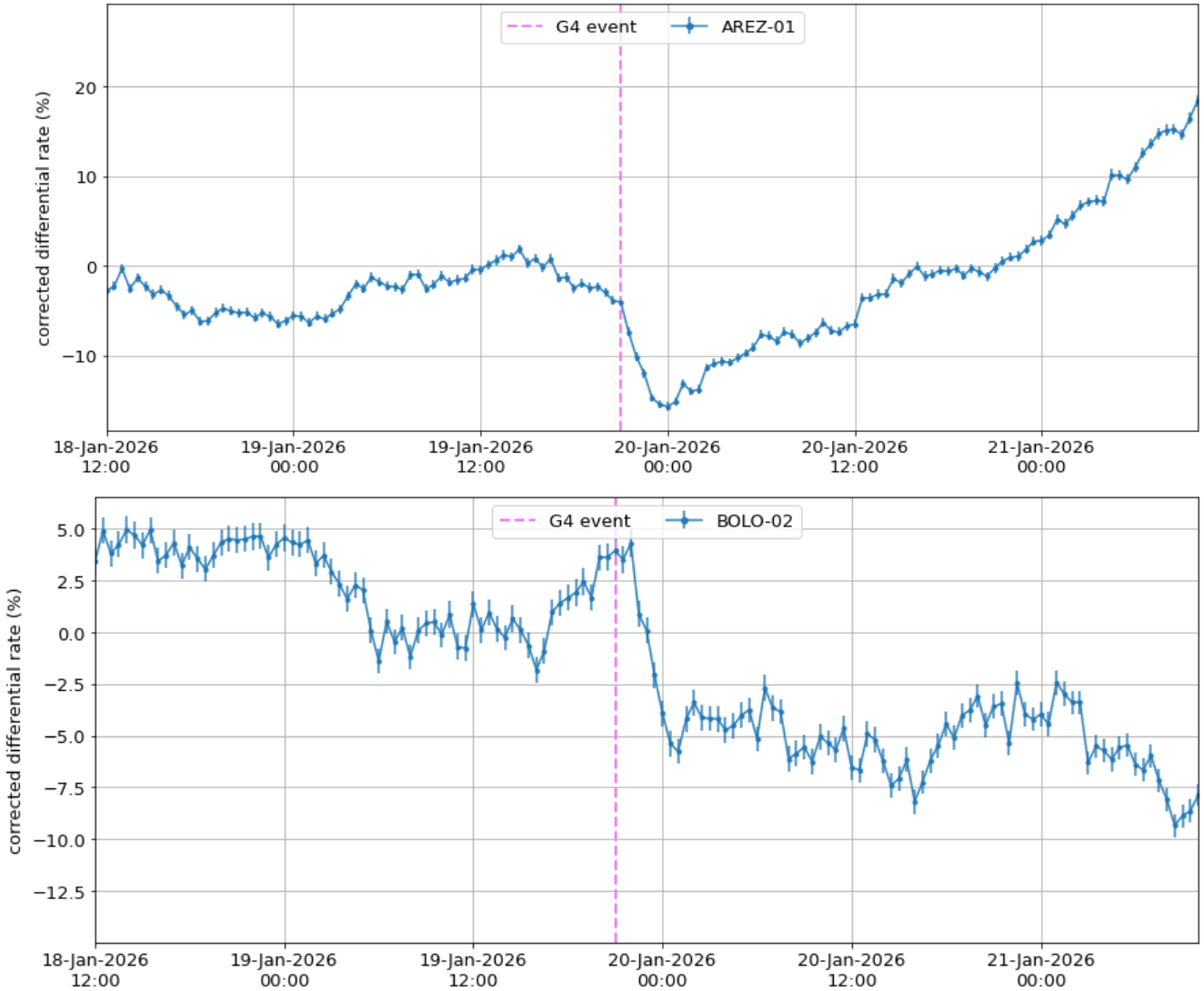
We can polish the telescope selection?



Even with the selected telescopes, there is a spread on the corrected differential rate ***before*** the Forbush decrease

Which are the problematic telescopes?

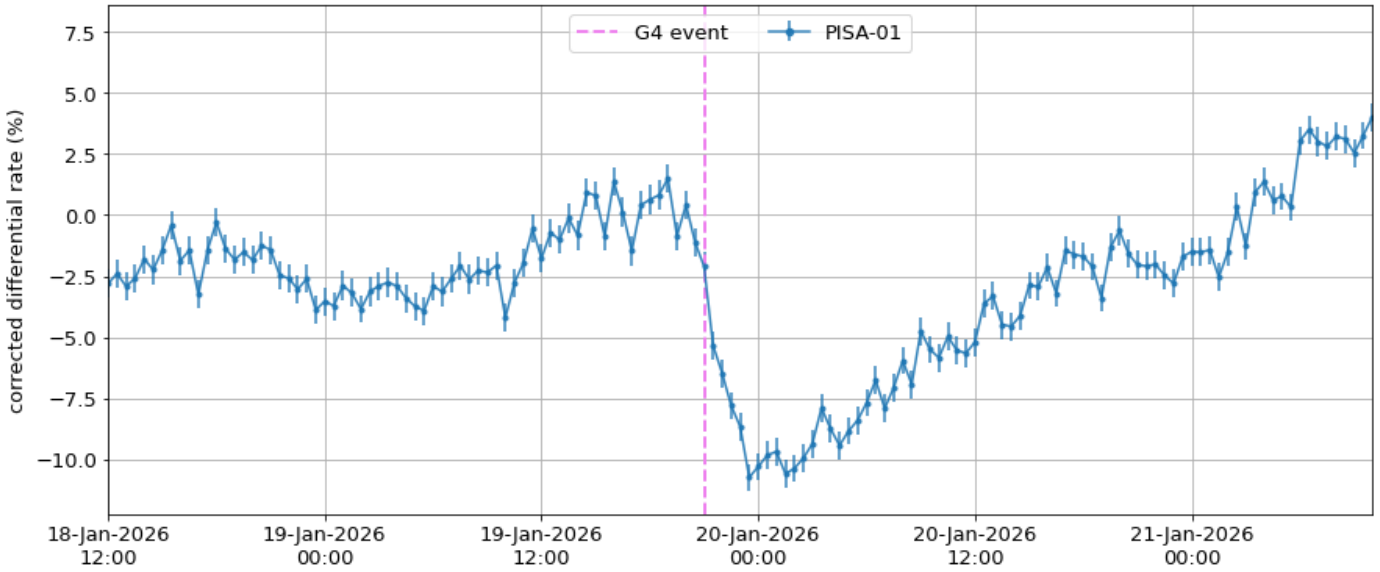
We can polish the telescope selection?



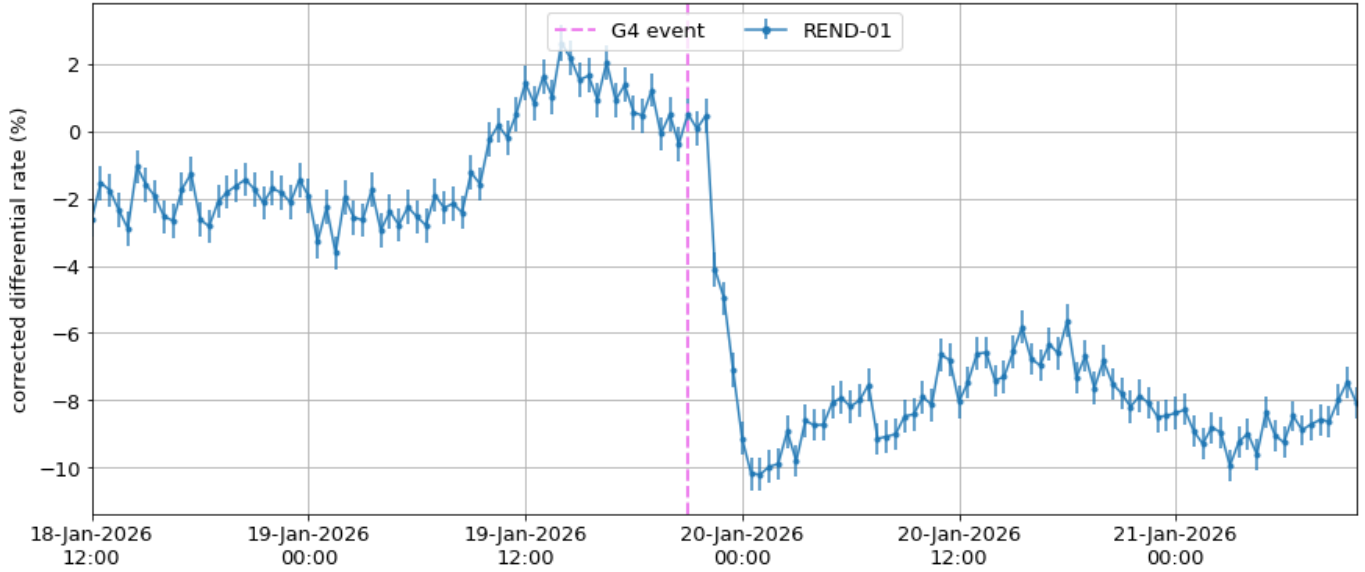
AREZ-01 shows a dip in the pre-Forbush rate up to –5% in the 24h before the Forbush event

BOLO-02 shows an unusual high differential rate before the Forbush

Can we polish the telescope selection?

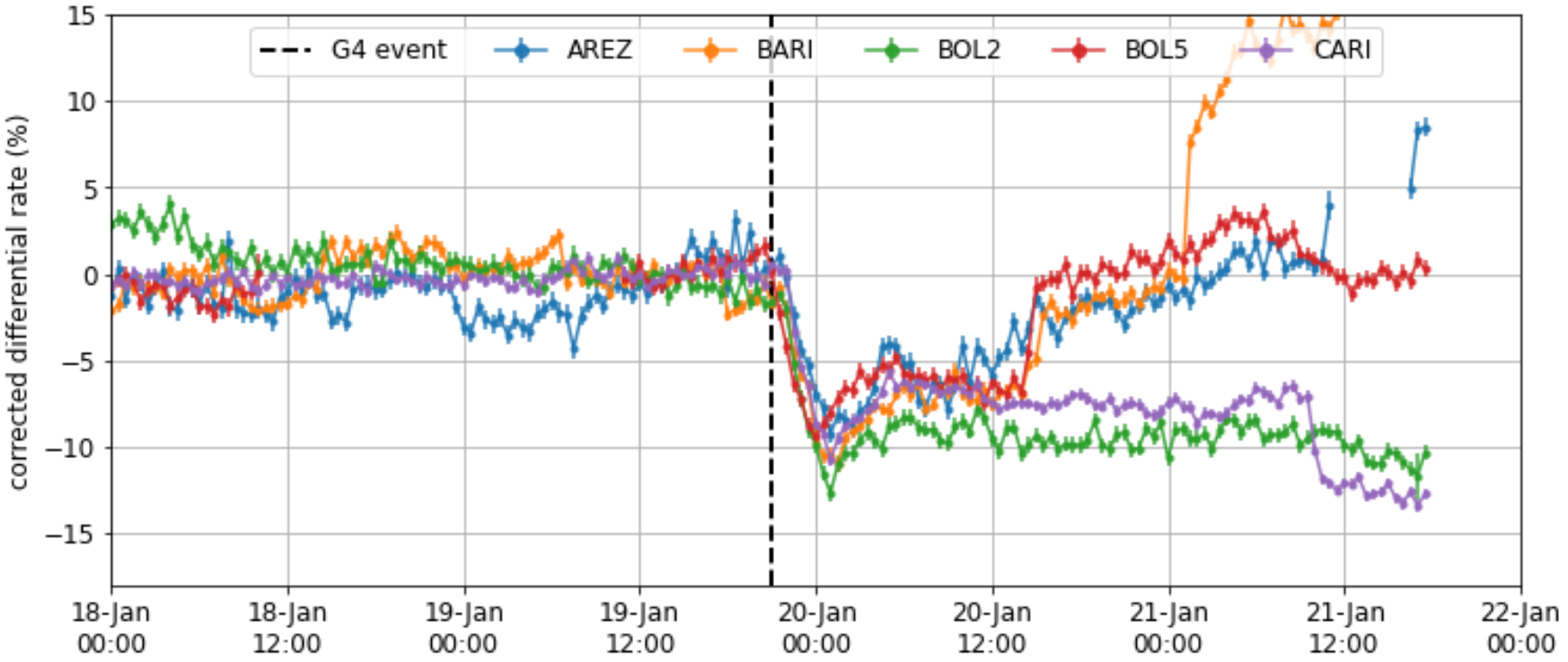


PISA-01 shows a low pre-forbush differential rate



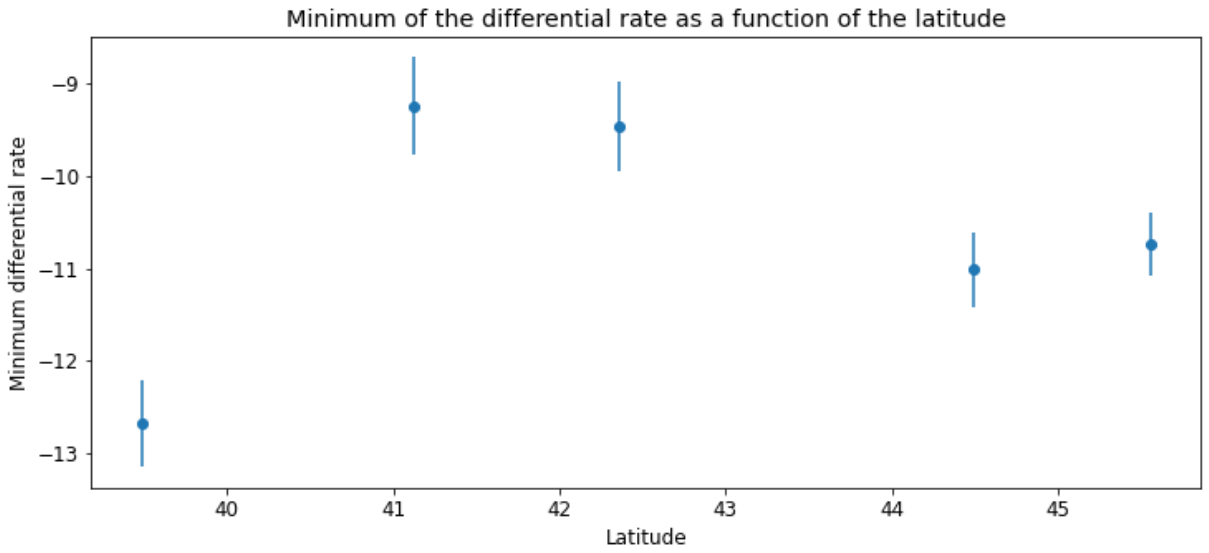
REND-01 shoys a bump before the forbush decrease

Forbush event – cumulative "less" plot

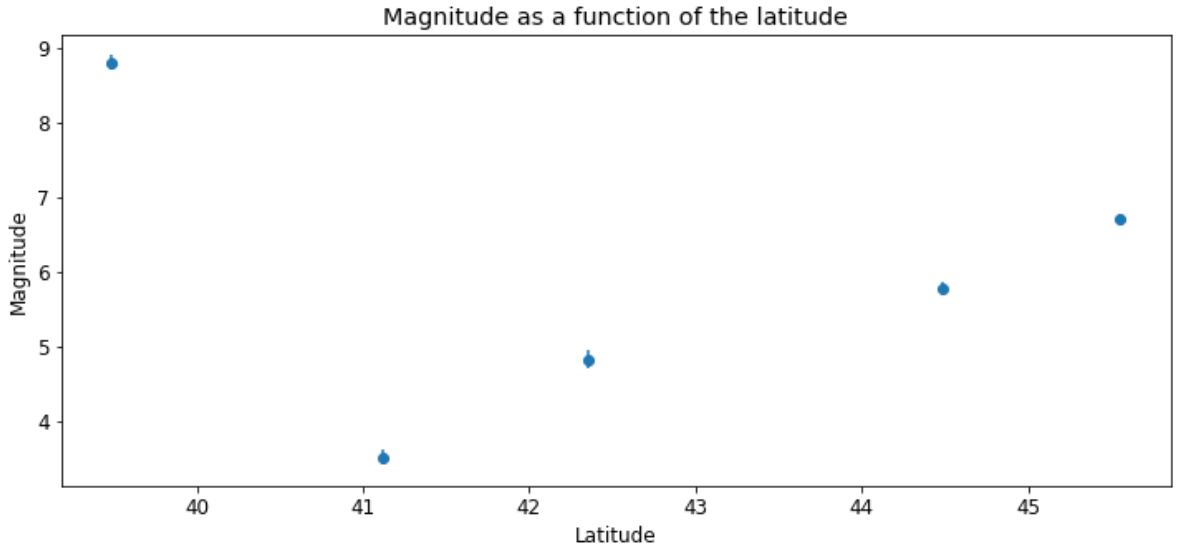


Removing these 4 telescopes give us only 5 telescopes with a "neat" pre-Forbush rate – too low statistics?

Forbush vs latitude – less telescopes

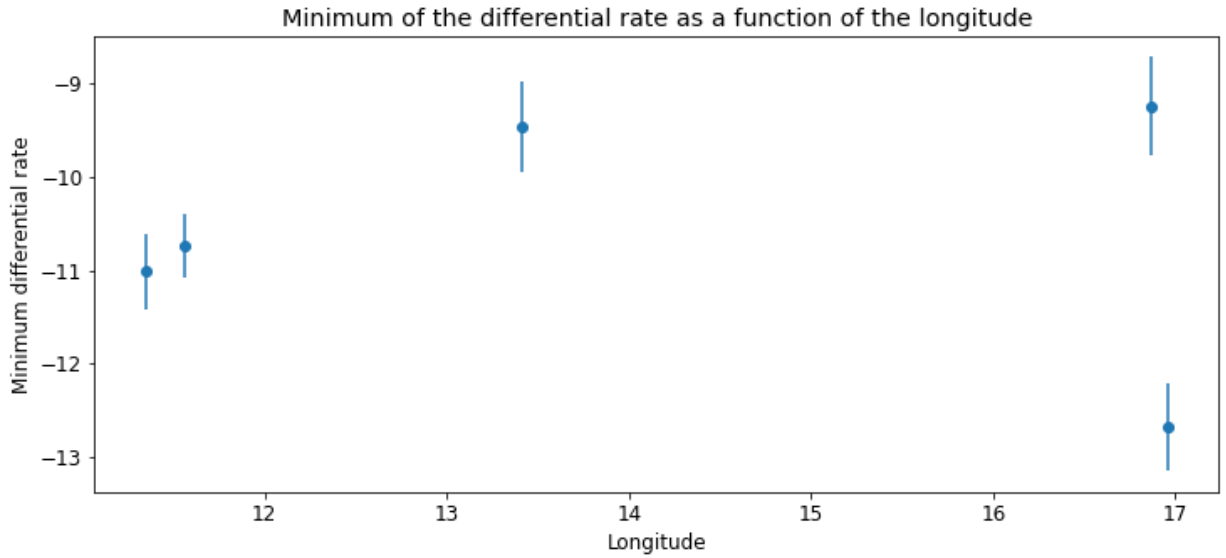


Pearson coefficient:
0.220665252188271

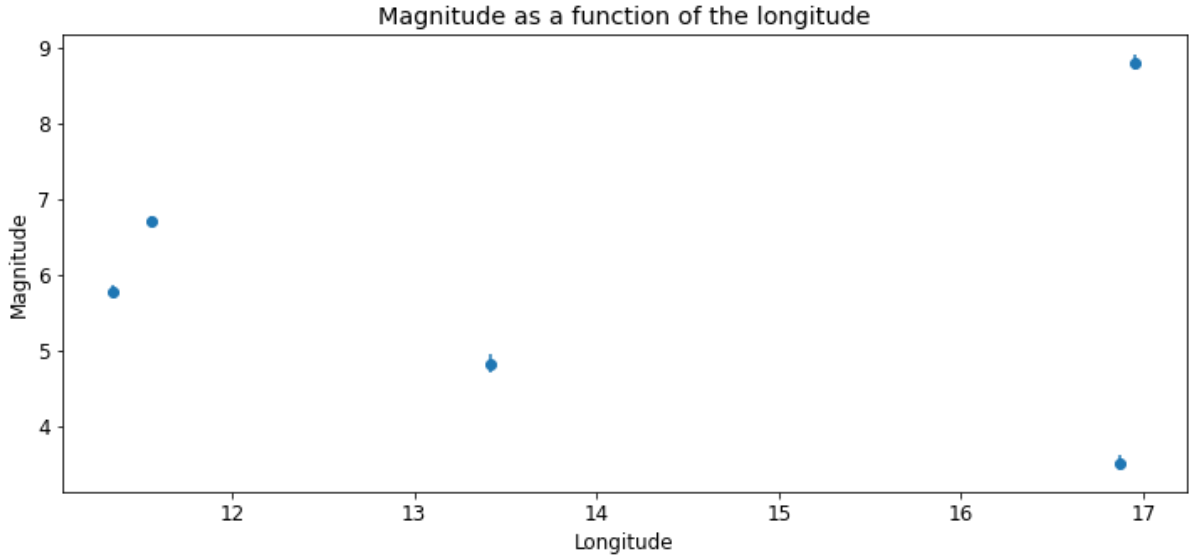


Pearson coefficient:
-0.15785776756517111

BONUS: Forbush vs longitude – less telescopes

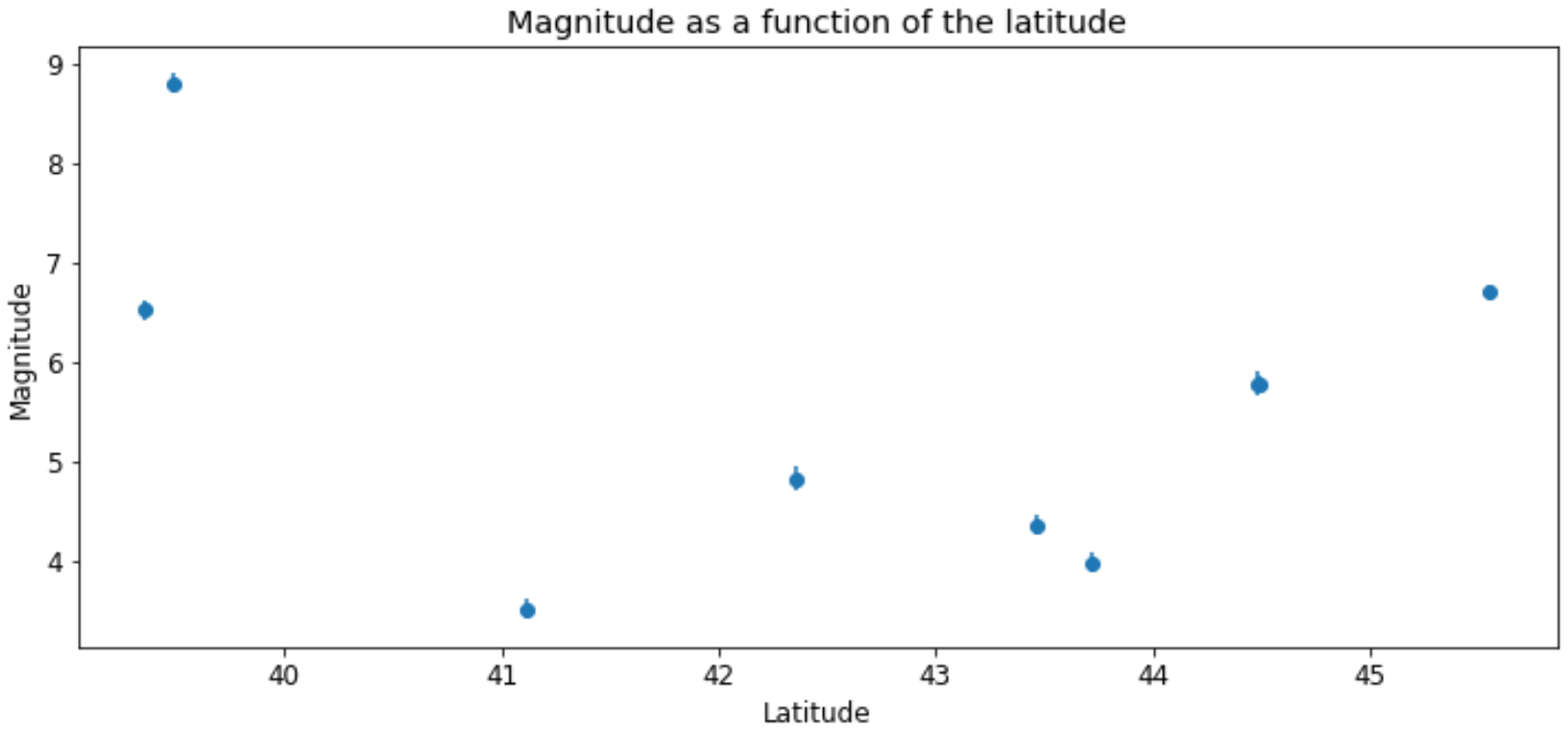


Pearson coefficient: -0.098028677565819 3



Pearson coefficient: 0.032653754083136 83

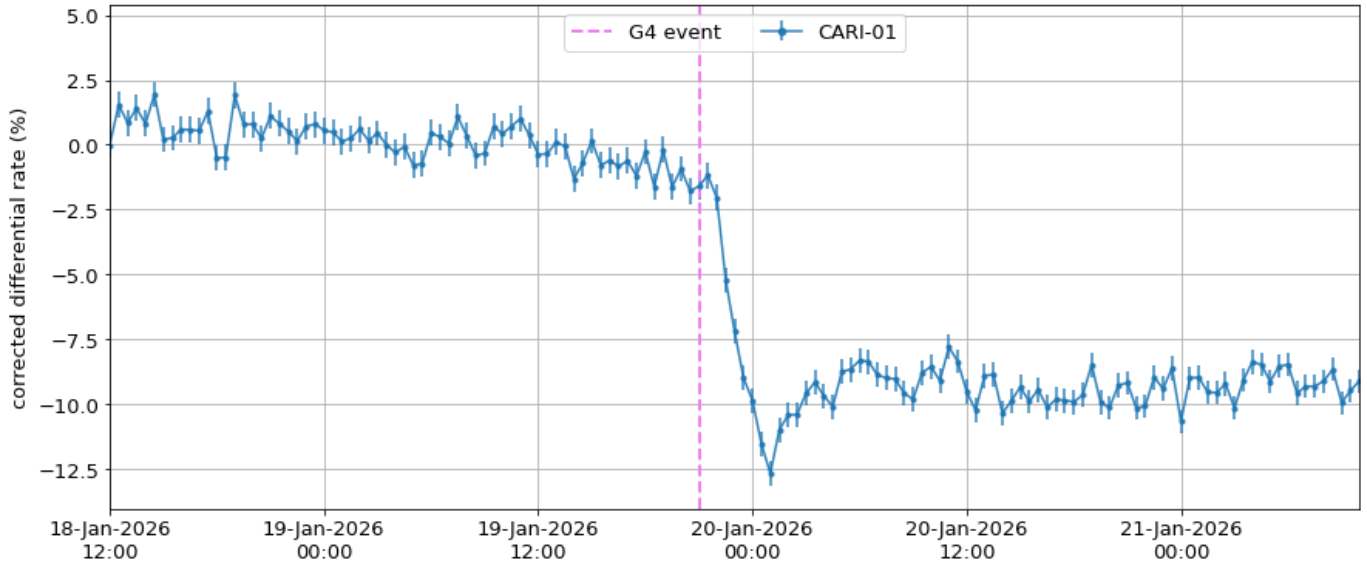
A step back...



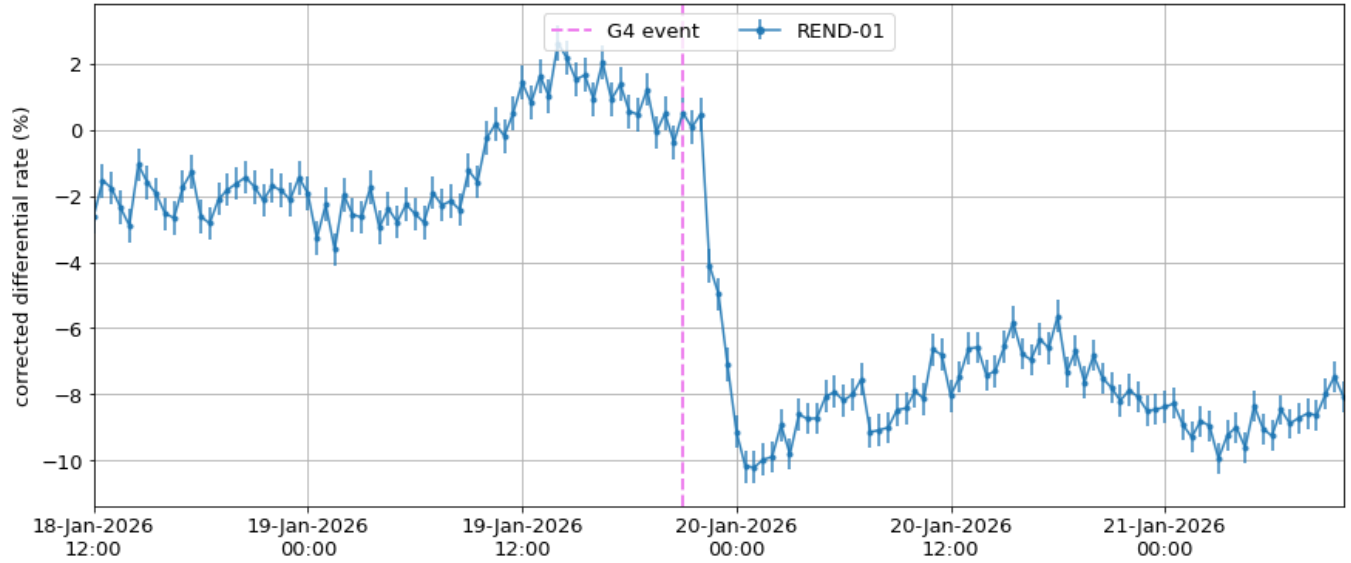
It seems that, if we discard the first two telescopes at low latitude, a more clear trend with the latitude is present

The two telescopes are CARI-01 and REND-01. What is their differential rate?

A step back...

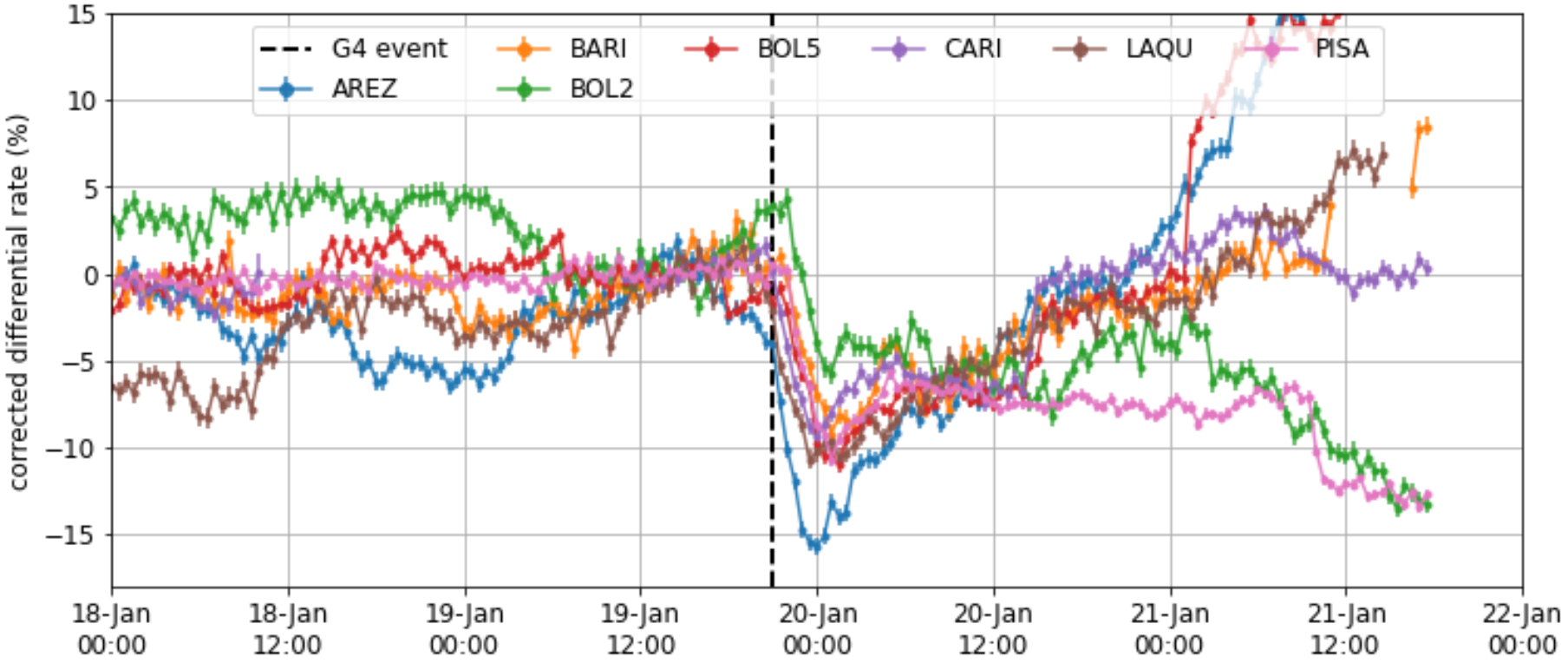


CARI-01 is really good

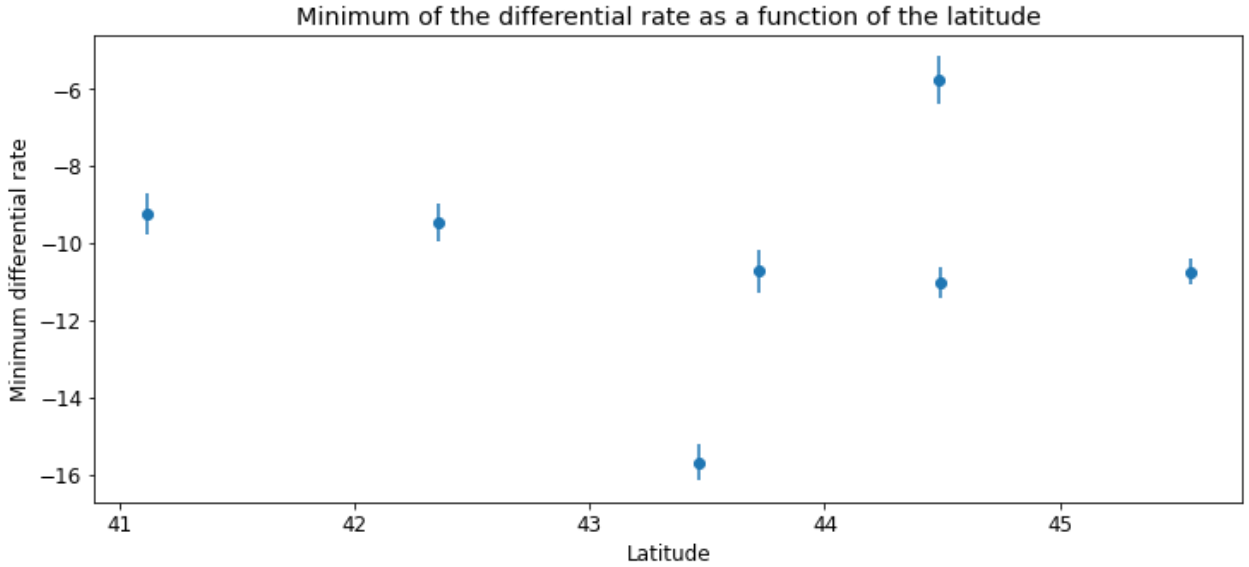


REND-01 has a bump just before the FD – differential rate the days before ~ -2%

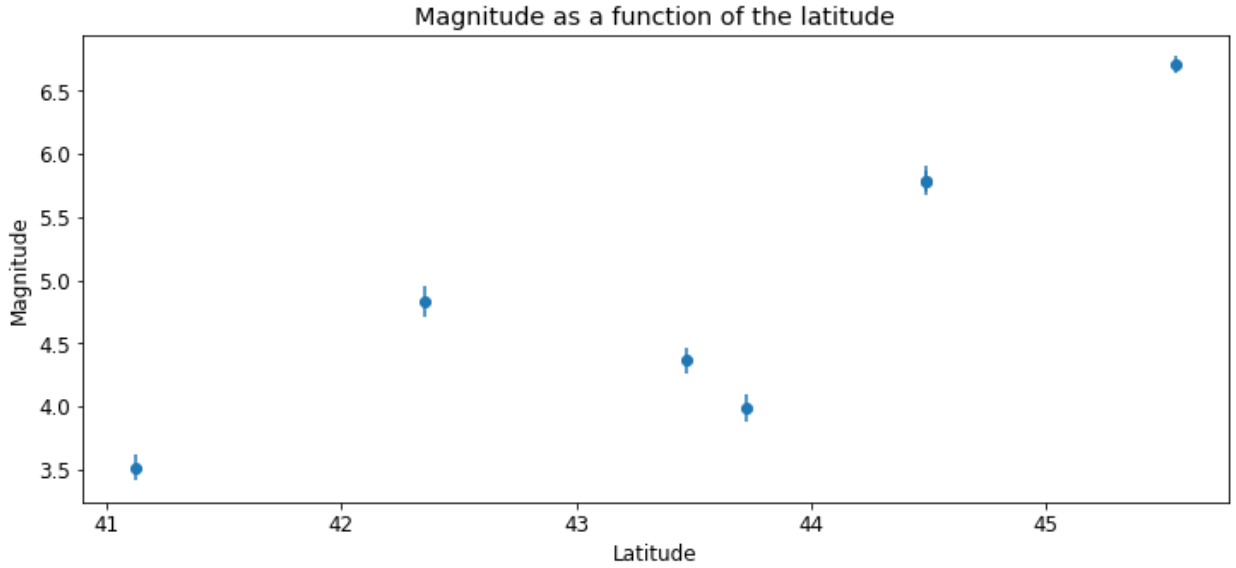
Forbush event – cumulative no low latitude



Forbush vs latitude – no low latitude

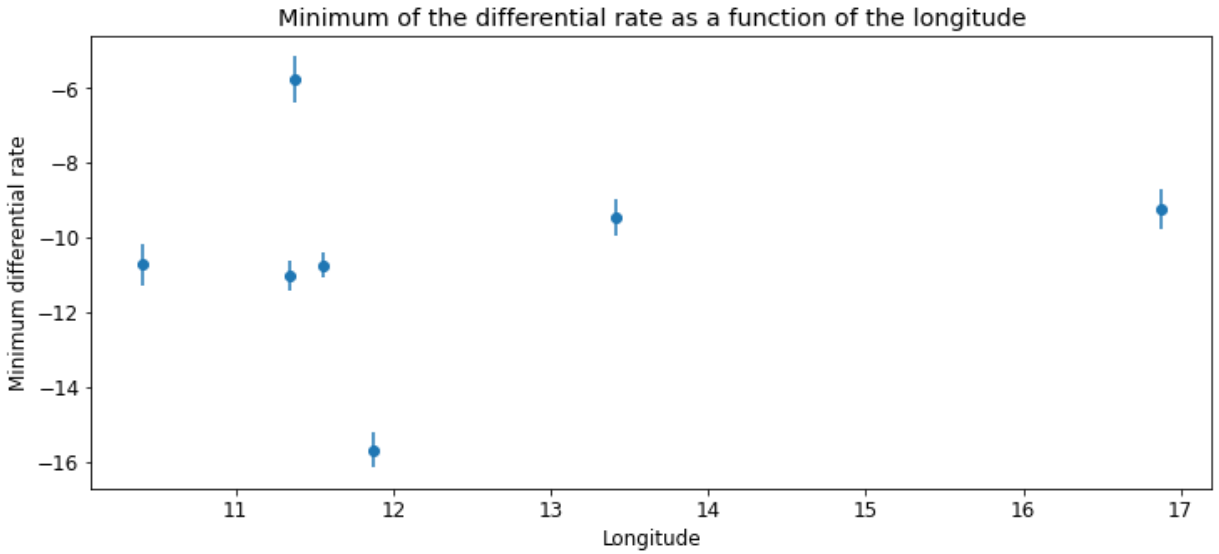


Pearson -
0.018053588283464515

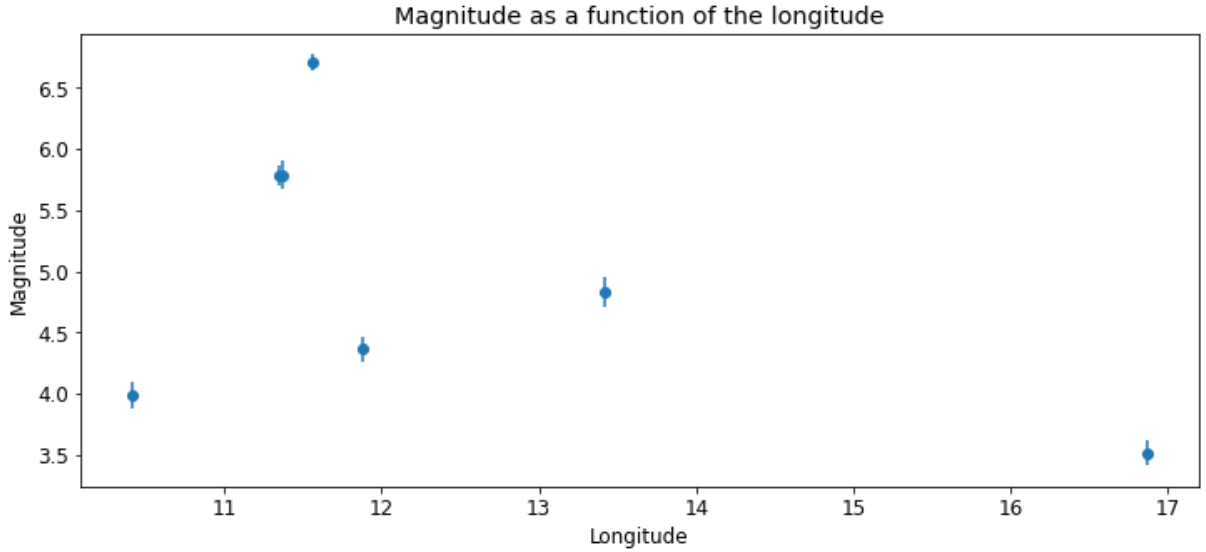


Pearson
0.8481140279263688

BONUS: Forbush vs longitude – no low latitude



Pearson
0.14917257723545965



Pearson -
0.5080399241592779

Recap

Latitude

Number of telescopes	Minimum Pearson	Magnitude Pearson
9	0.13	-0.29
7	-0.02	0.85
5	0.22	-0.15

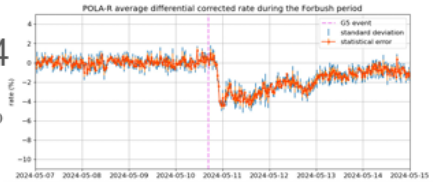
Longitude

Number of telescopes	Minimum Pearson	Magnitude Pearson
9	-0.04	0.31
7	0.15	-0.51
5	-0.10	0.04

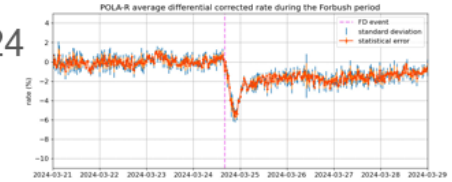
Next analysis step

- Analyze other Forbush decreases
  - Best candidate at the moment is the May 2024 one --> we also have papers on that
  - Take into account other effects (altitude? Shielding?)
  - Extend the latitude range using the POLA-R data

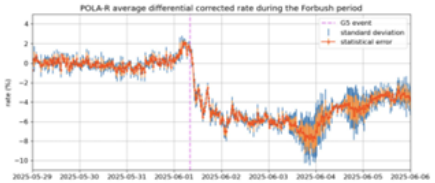
10/5/2024
G5
Neutrons 15.7%
DST=-419 nT



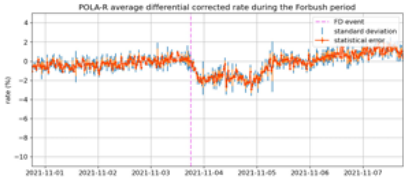
23/3/2024
G4
Neutrons 15%
DST=-130 nT
Fast recovery



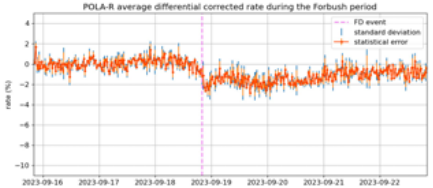
1/6/2025
G4
Neutrons ~18%
DST~-122 nT



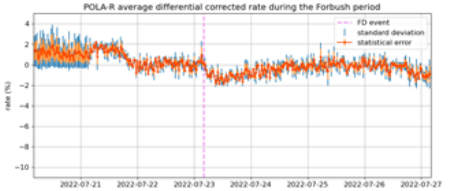
3/11/2021
G3
Neutrons 5-10%
DST=-118 nT



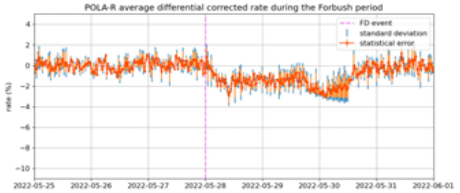
18/9/2023
G2
Neutrons 4%
DST=-85 nT



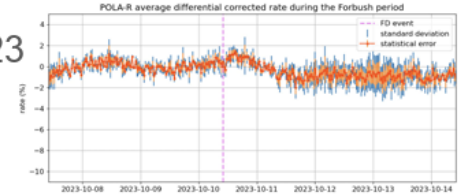
23/7/2022
G2
Neutrons 4%
DST=-80 nT



28/5/2022
G1
Neutrons 3%
DST=-65 nT



10/10/2023
G1
Neutrons 2%
DST=-13 nT



9

Plan for conferences

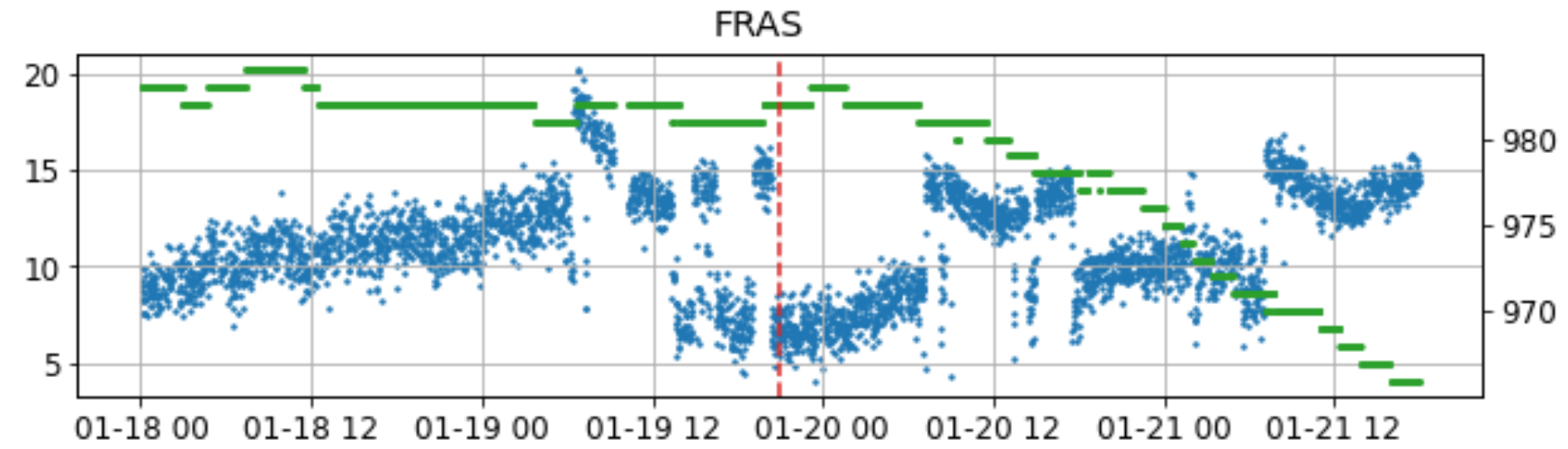
We have presented an abstract for this study for next conferences (poster in CRIS-MAC, talk in ICHEP)

We would like to present some of these results, but some question arises:

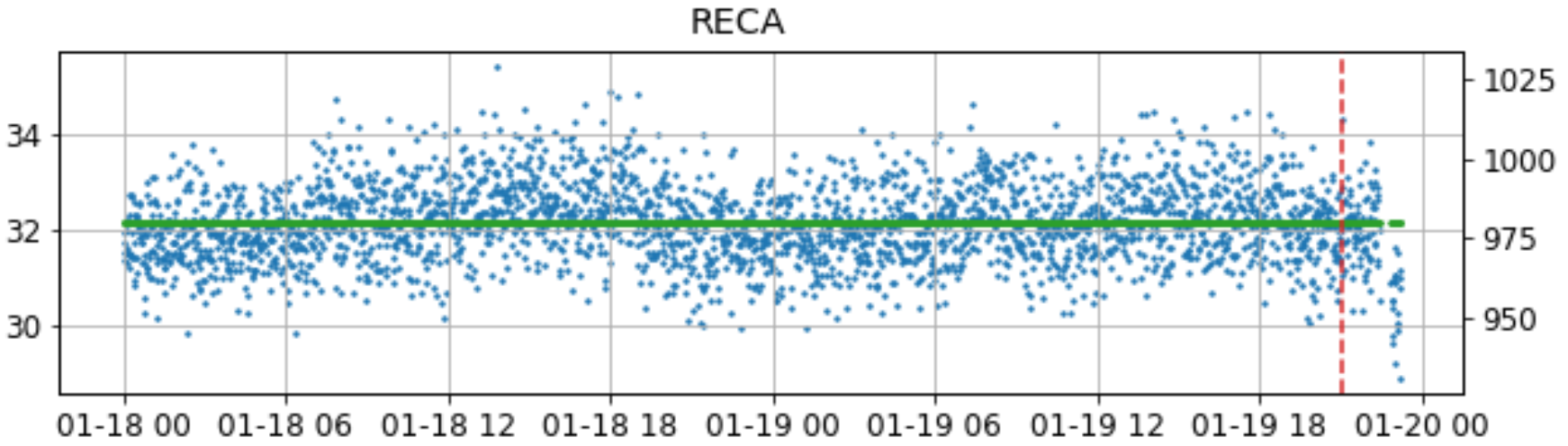
- Which telescope group we should consider?
- Show minimum or magnitude as a function on latitude ?
- Of course, the analysis is still fully ongoing, so we should specify the caveats: response of the detector is not optimal, study of other effects (altitude, different shielding of the telescopes etc etc) is not taken into account, etc etc
- Also on that, it is better that we stay conservatives: we can say that at the moment we can not draw any conclusion and studies on other recorded Forbush events is needed

Backup

Discarded telescopes

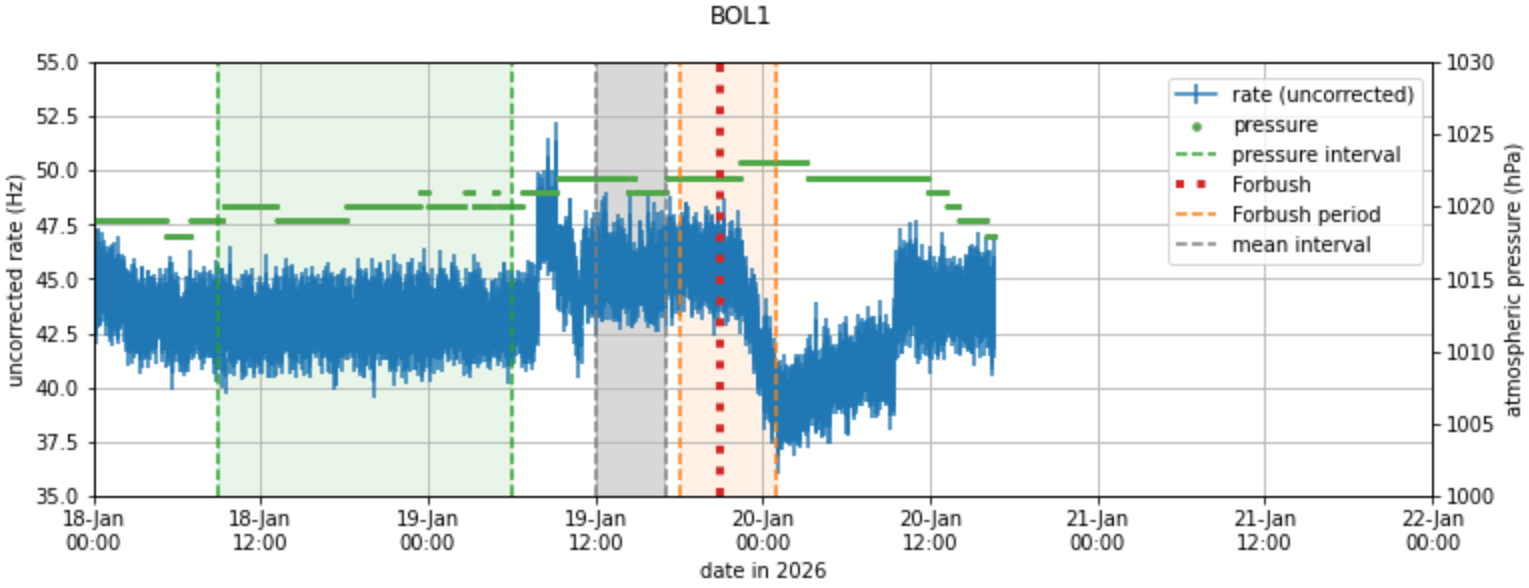


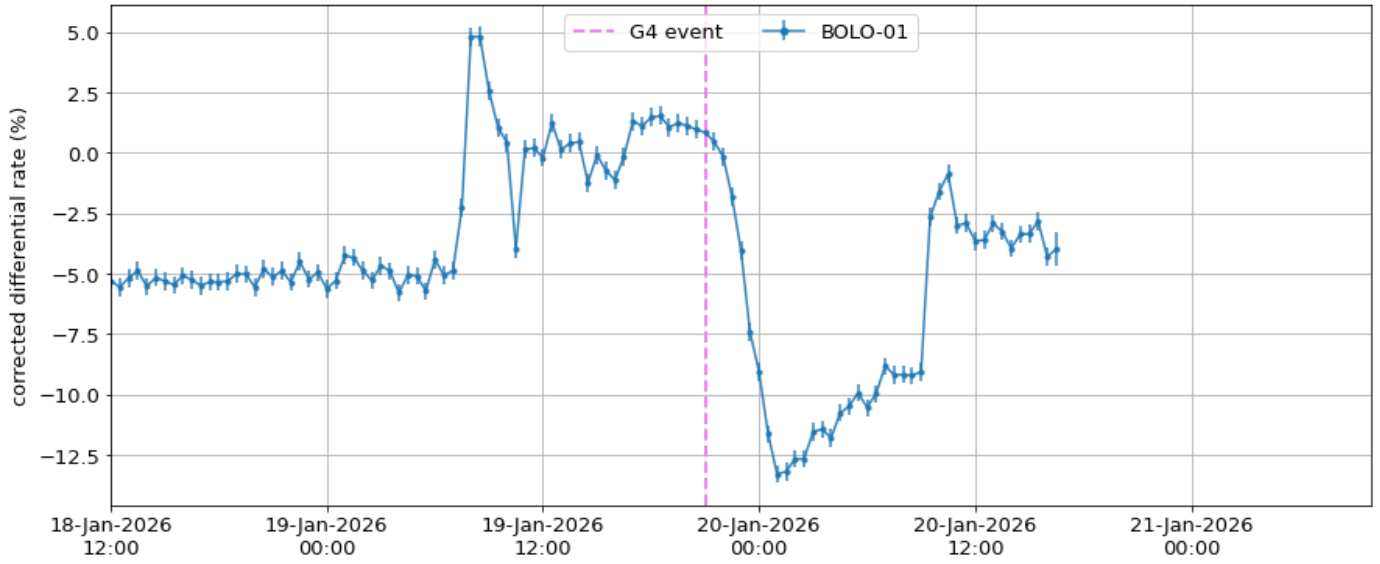
Unstable data taking



Not enough data after FD

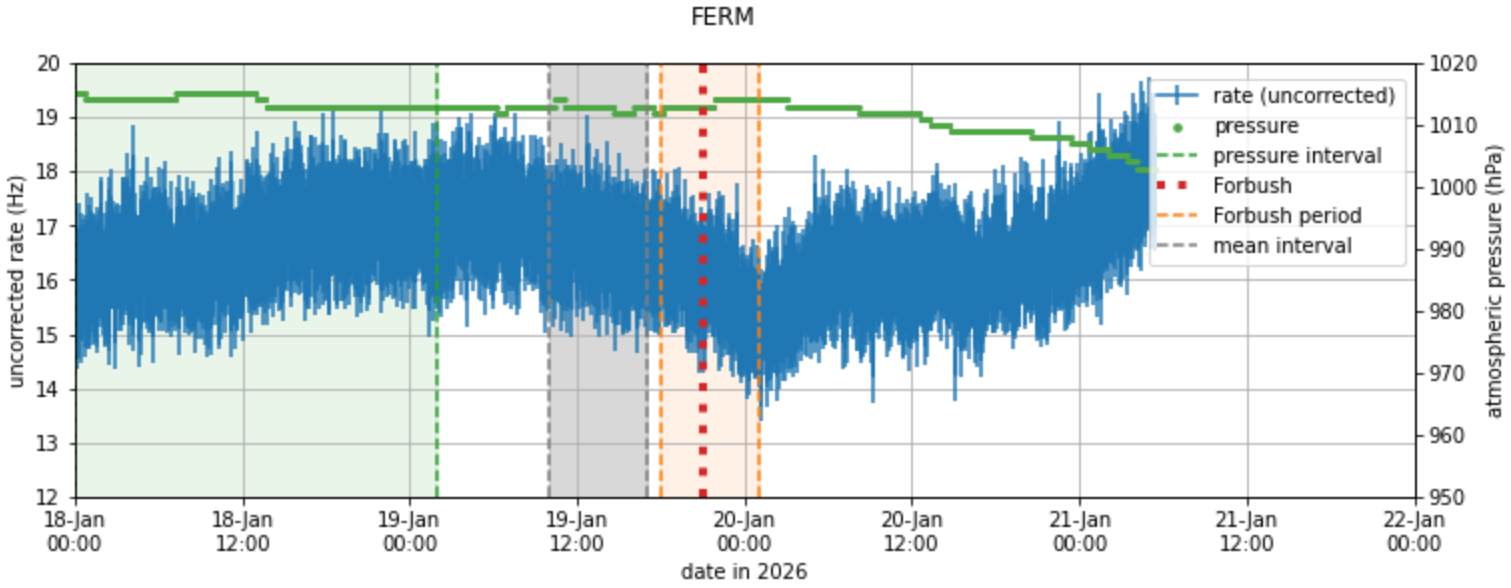
Discarded telescopes

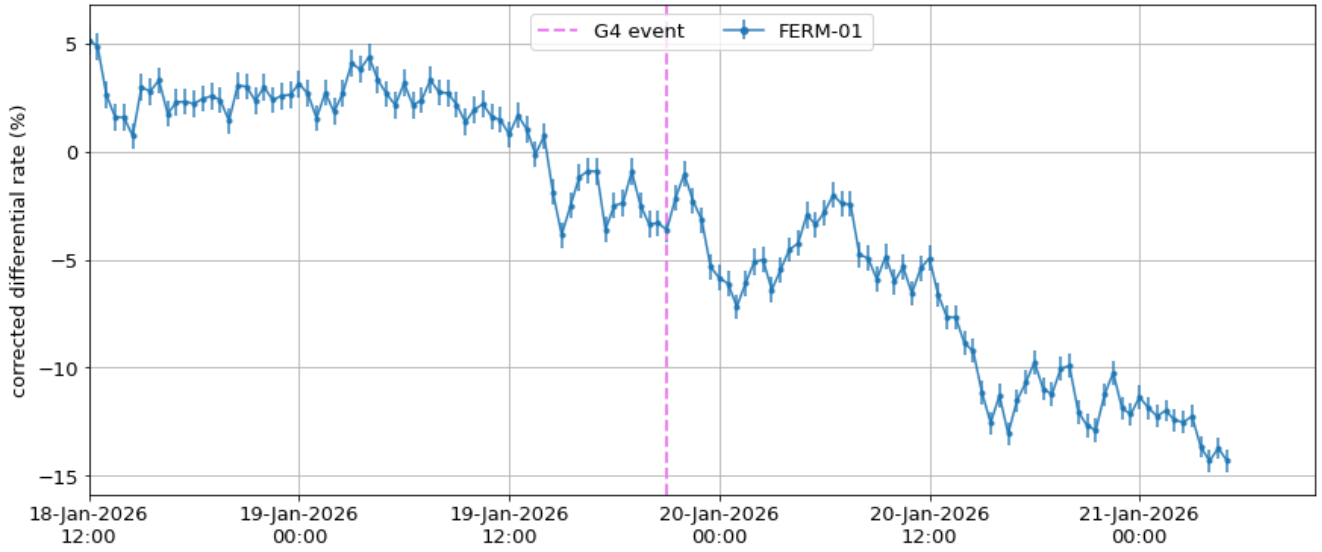




Telescope not considered due to the peak behaviour pre and post Forbush

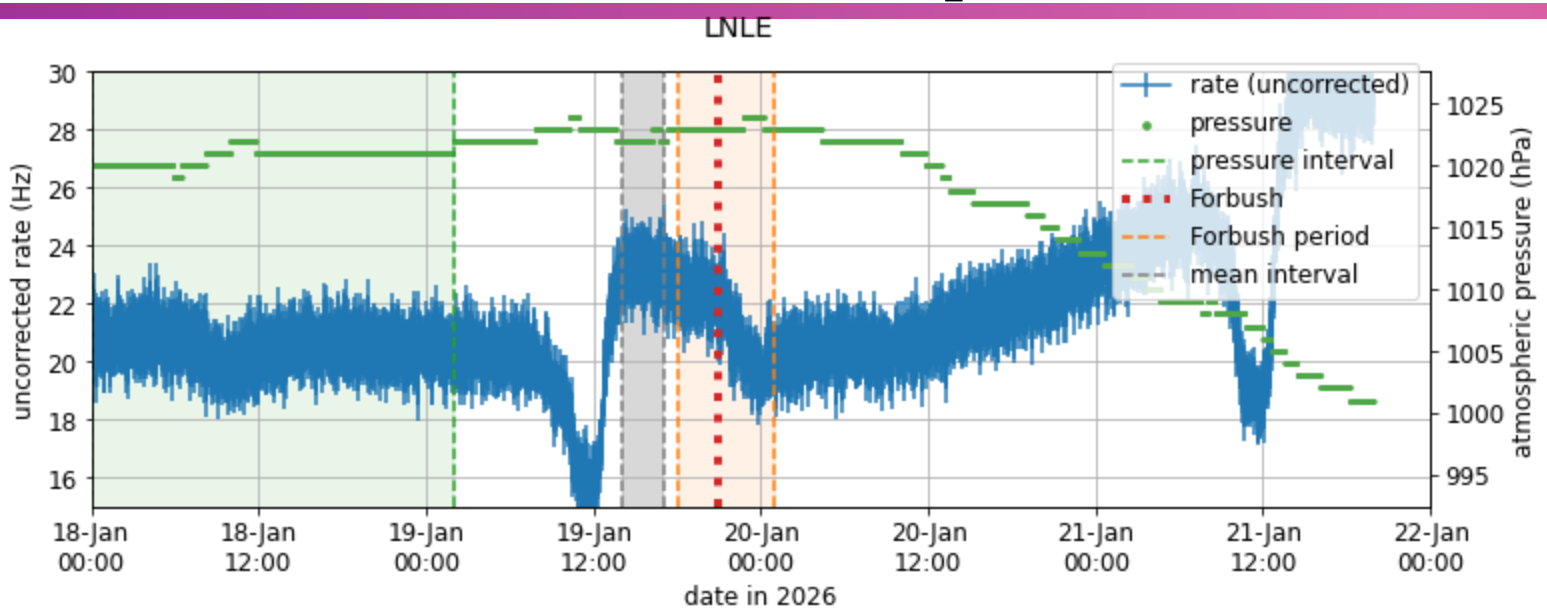
Discarded telescopes



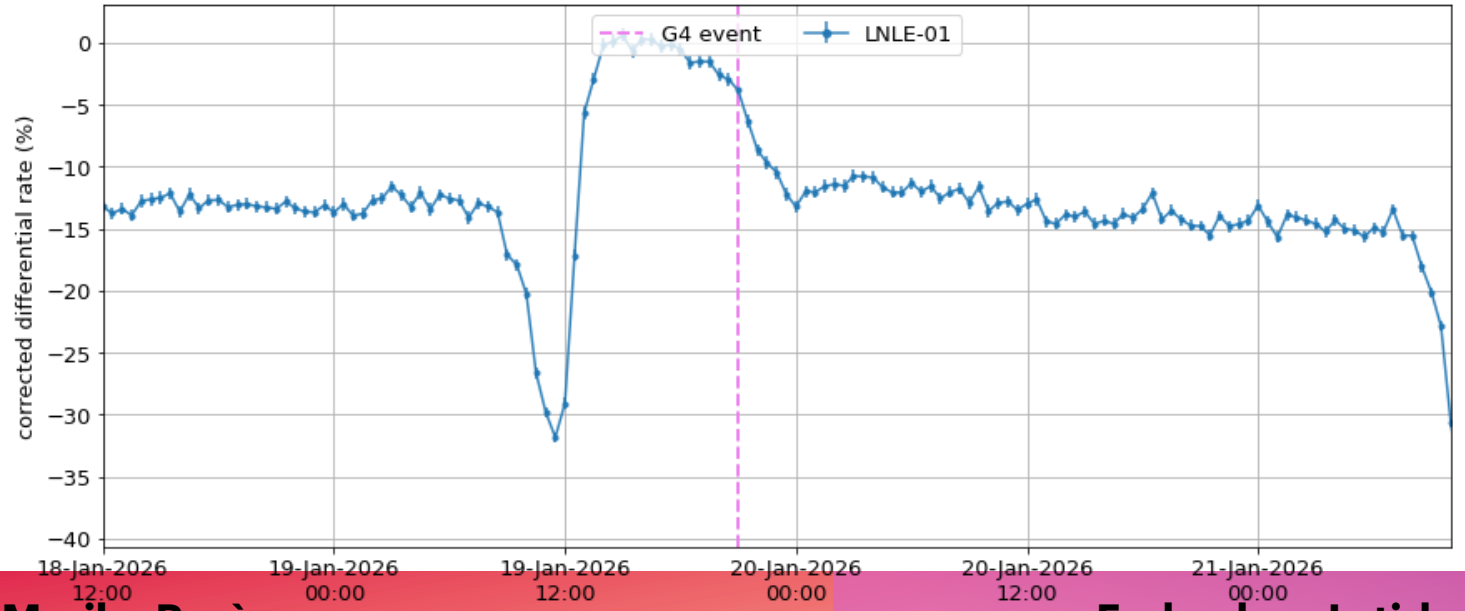


No clear Forbush decrease when calculating the corrected rate

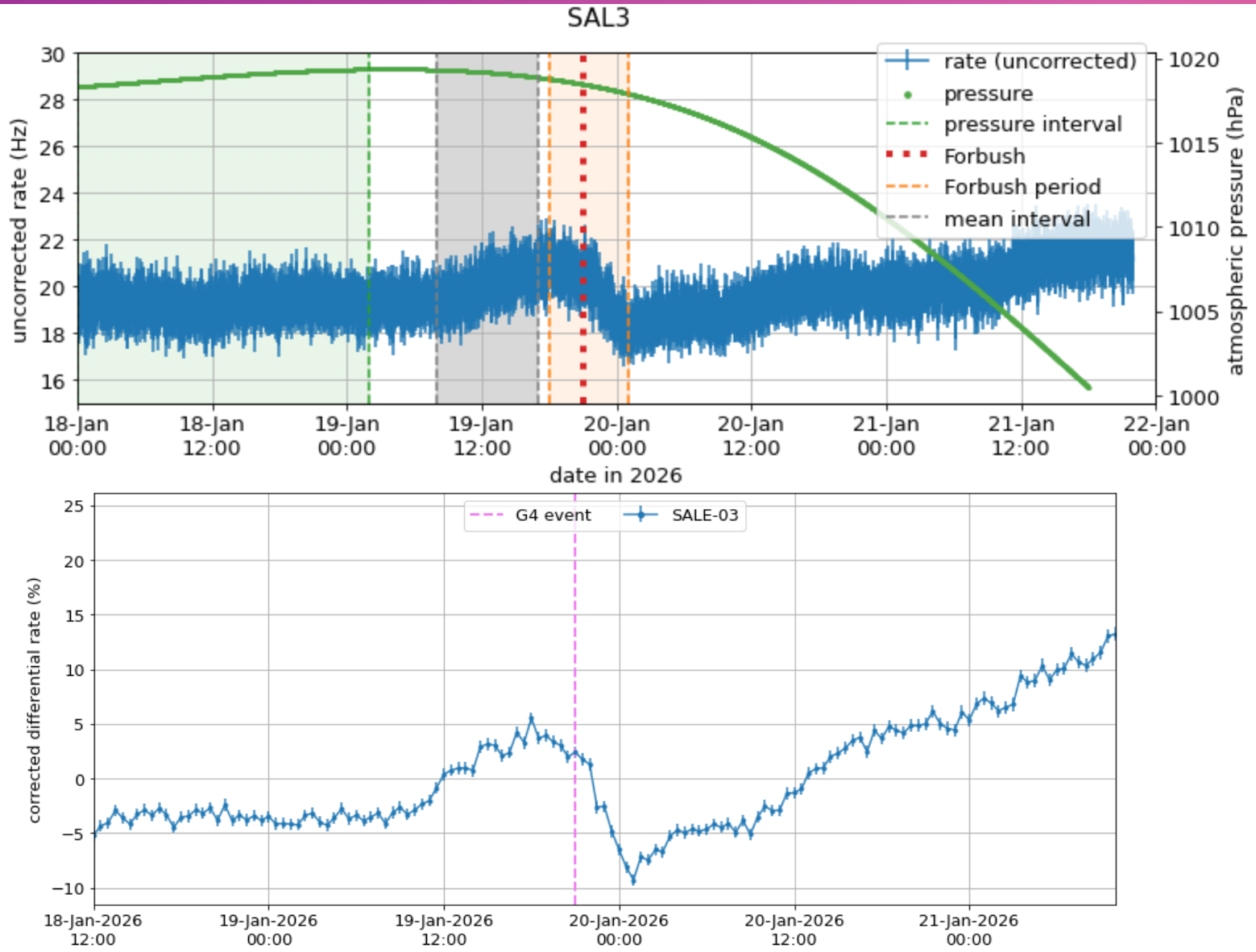
Discarded telescopes



Dip before FD

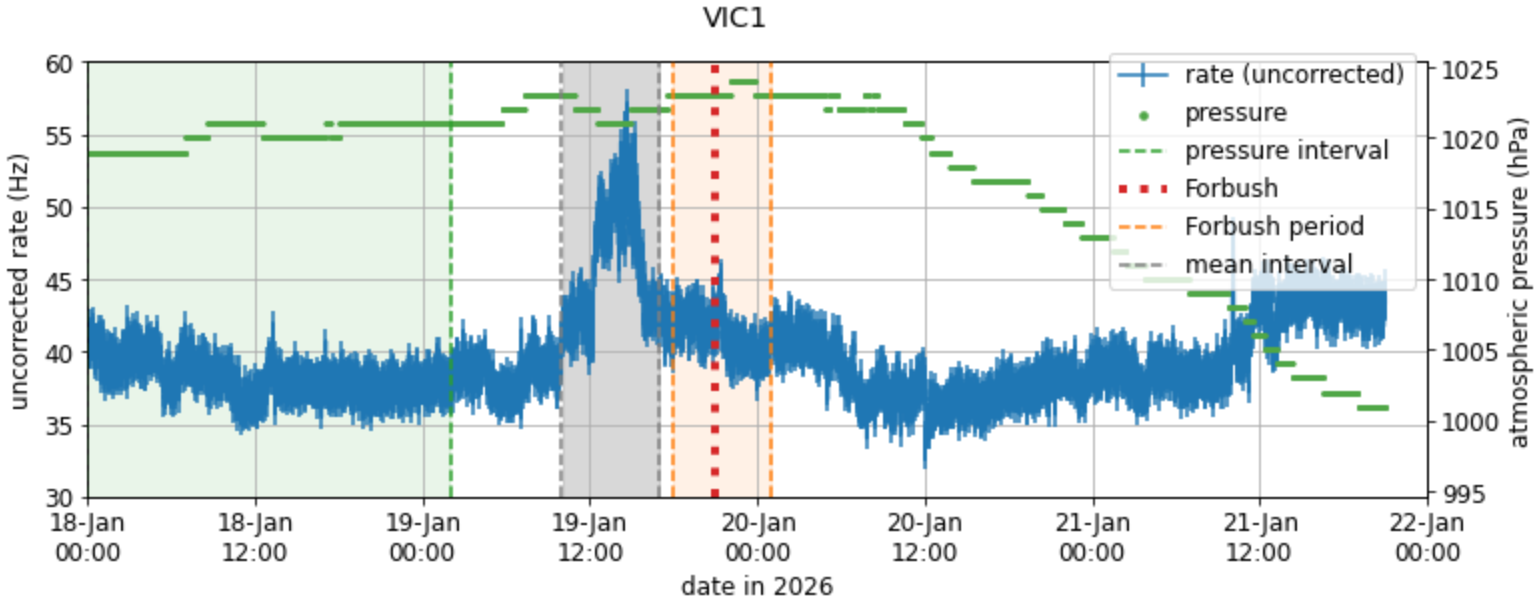


Discarded telescopes



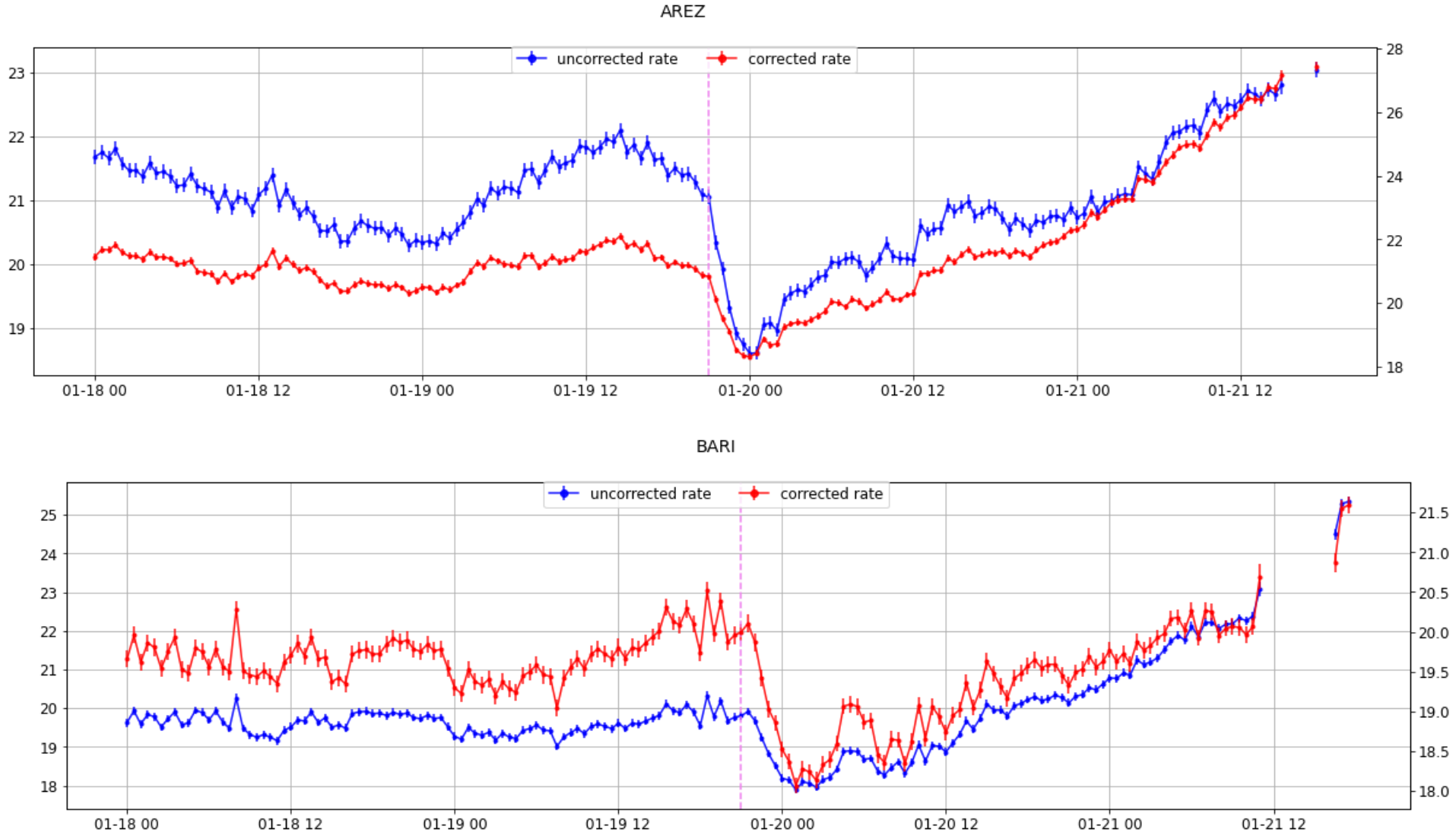
Increase of rate just before Forbush: even if the decrease is visible, the differential rate is very low at the beginning

Discarded telescopes

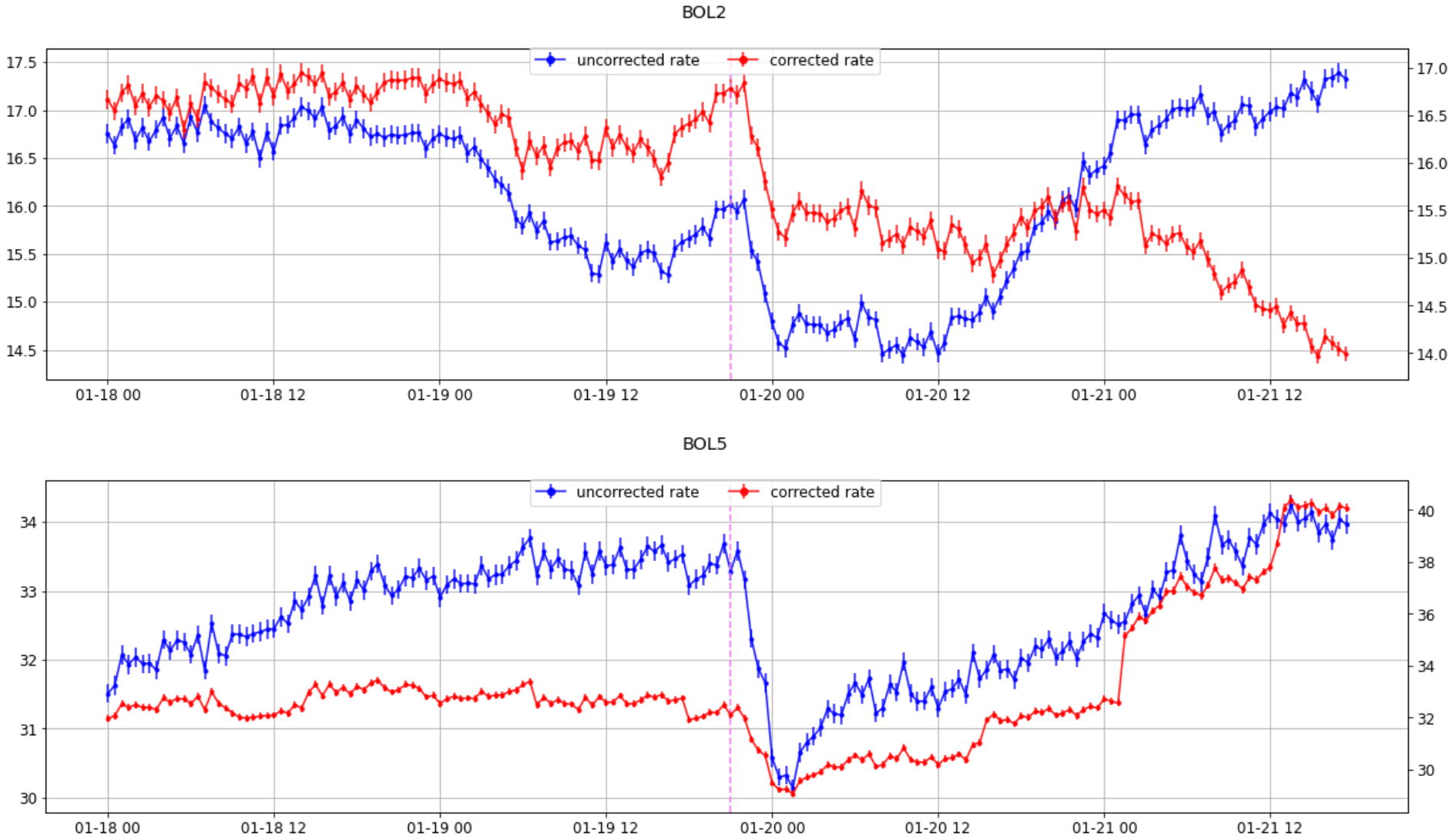


Non-stable data taking before Forbush

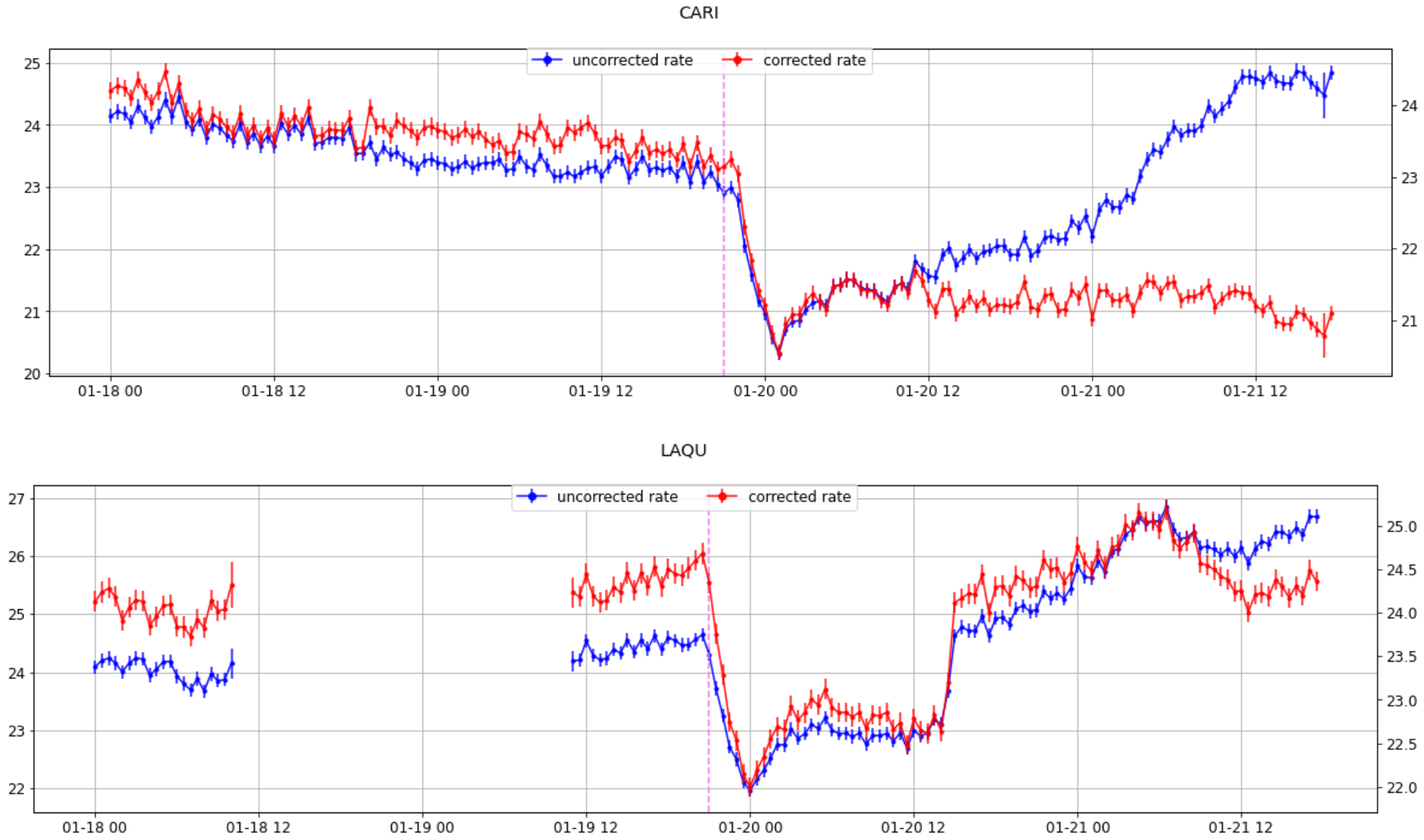
Uncorrected vs Corrected rate



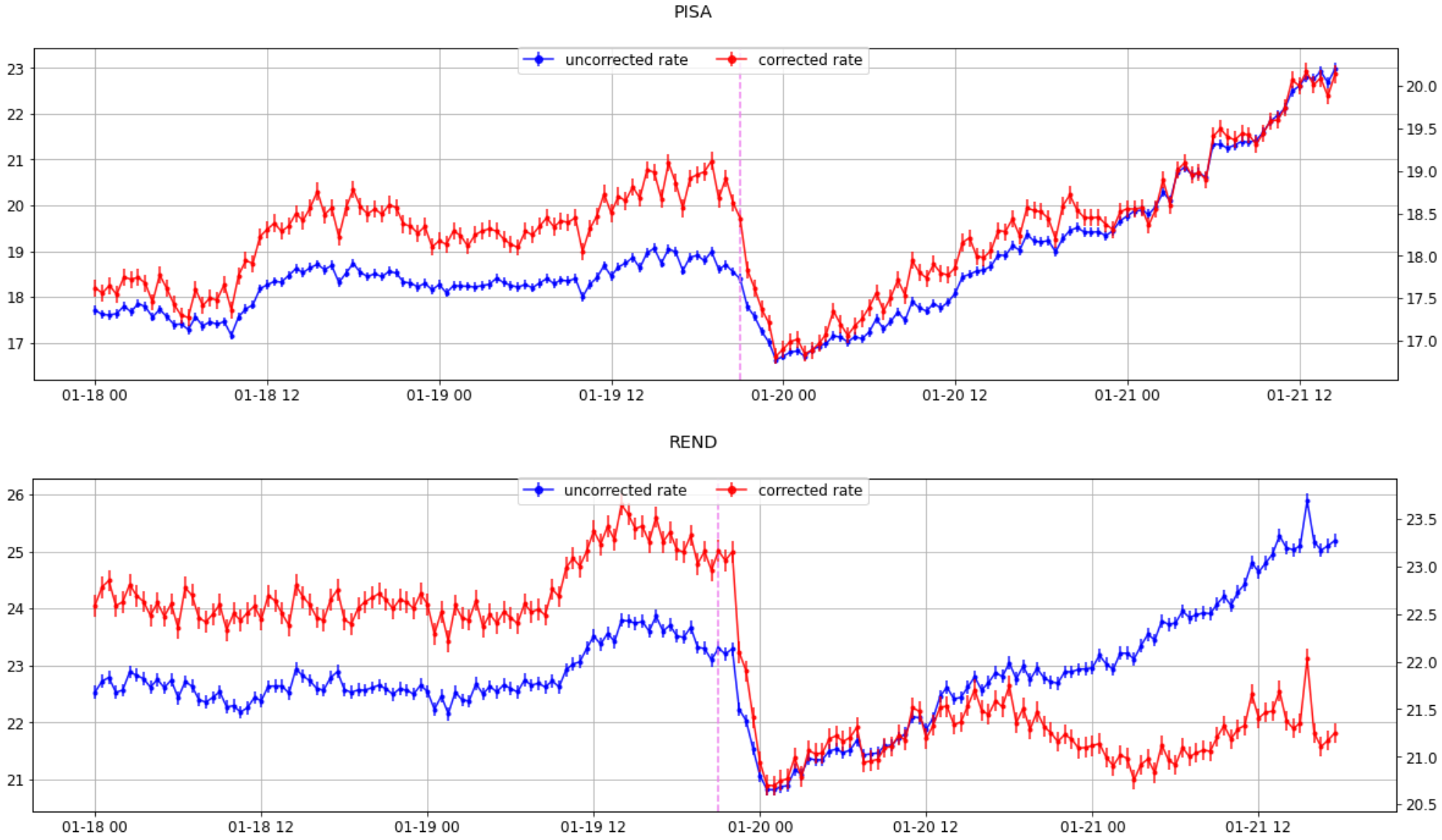
Uncorrected vs corrected rate



Uncorrected vs corrected rate



Uncorrected vs corrected rate



Uncorrected vs corrected rate