

The Critical Role of GNSS Metadata in Ensuring Homogeneous Time Series for Geophysical Applications

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What is GNSS station metadata and why is it critical?

Station metadata	Usage
Station ID and country code	• Identify a station • Find observation files (RINEX) on data repositories
Approximate station position	Extract correction models for: • tidal effect (solid earth, ocean, atmosphere) • tropospheric delays (mapping function, zhd...)
Antenna and radome types	• Correct antenna/radome PCO and PCV
Eccentricity	• Correct 3D offset from ARP to monument marker

- Some information can be found in RINEX headers, but experience shows that this is often not reliable ⚠
- Station metadata has been standardized by IGS in so-called “sitelog files”.

Example of sitelog for station CCJM: ccjm_20181227.log

```
1 .....CCJM00JPN.Site.Information.Form.(site.log)
2 .....International.GNSS.Service
3 .....See.Instructions.at:
4 .....ftp://igs.org/pub/station/general/sitelog_instr.txt
5
6 0....Form
7
8 .....Prepared.by.(full.name)::Tomoaki.Furuya/Kazuki.Sakai/Motor
9 .....Date.Prepared.....:2018-12-27
10 .....Report.Type.....:UPDATE
11 .....If.Update:
12 .....Previous.Site.Log.....:ccjm_20130311.log
13 .....Modified/Added.Sections::11
14
15
16 1....Site.Identification.of.the.GNSS.Monument
17
18 .....Site.Name.....:CHICHIJIMA
19 .....Four.Character.ID.....:CCJM
20 .....Monument.Inscription::
21 .....IERS.DONES.Number.....:217328003
22 .....CDP.Number.....:
23 .....Monument.Description.....:STAINLESS-STEEL-MAST
24 .....Height.of.the.Monument::5.25-m
25 .....Monument.Foundation.....:CONCRETE-BLOCK
26 .....Foundation.Depth.....:1.5-m
27 .....Marker.Description.....:none
28 .....Date.Installed.....:1995-03-13T00:00Z
29 .....Geologic.Characteristic::BEDROCK
30 .....Bedrock.Type.....:IGNEOUS
31 .....Bedrock.Condition.....:FINE
32 .....Fracture.Spacing.....:0-cm
33 .....Fault.zones.nearby::
34 .....Distance/activity::
35 .....Additional.Information::
36
37
38 2....Site.Location.Information
39
40 .....City.or.Town.....:Ogasawara
41 .....State.or.Province.....:Tokyo
42 .....Country.....:Japan
43 .....Tectonic.Plate.....:PHILIPPINE
44 .....Approximate.Position.(ITRF)
45 .....X.coordinate.(m).....:-4488925.724
46 .....Y.coordinate.(m).....:3483903.122
47 .....Z.coordinate.(m).....:2887743.274
48 .....Latitude.(N.is.+).....:+270544.10
49 .....Longitude.(E.is.+).....:+1421104.49
50 .....Elevation.(m,ellips.)::208.83
51 .....Additional.Information::ITRF2000
52
```

General information sections

```
54 3....GNSS.Receiver.Information
55
56 3.1.Receiver.Type.....:TOPCON-GP-R1DY
57 .....Satellite.System.....:GPS
58 .....Serial.Number.....:214
59 .....Firmware.Version.....:1E051C3
60 .....Elevation.Cutoff.Setting::15-deg
61 .....Date.Installed.....:1995-03-13T06:30Z
62 .....Date.Removed.....:1996-03-15T23:59Z
63 .....Temperature.Stabiliz.....:
64 .....Additional.Information::
65
66 3.2.Receiver.Type.....:TOPCON-GP-R1DY
67 .....Satellite.System.....:GPS
68 .....Serial.Number.....:118
69 .....Firmware.Version.....:1E861D0
70 .....Elevation.Cutoff.Setting::15-deg
71 .....Date.Installed.....:1996-03-17T00:00Z
72 .....Date.Removed.....:1996-04-02T23:59Z
73 .....Temperature.Stabiliz.....:
74 .....Additional.Information::
75
76 ...
77
78 3.9.Receiver.Type.....:TOPCON-GP-R1DY
79 .....Satellite.System.....:GPS
80 .....Serial.Number.....:118
81 .....Firmware.Version.....:1F701D0
82 .....Elevation.Cutoff.Setting::15-deg
83 .....Date.Installed.....:2000-01-01T00:00Z
84 .....Date.Removed.....:2001-02-24T23:59Z
85 .....Temperature.Stabiliz.....:
86 .....Additional.Information::
87
88 3.10.Receiver.Type.....:TRIMBLE-4000SSI
89 .....Satellite.System.....:GPS
90 .....Serial.Number.....:13734
91 .....Firmware.Version.....:7.19
92 .....Elevation.Cutoff.Setting::15-deg
93 .....Date.Installed.....:2001-02-25T23:21Z
94 .....Date.Removed.....:2003-02-23T14:59Z
95 .....Temperature.Stabiliz.....:
96 .....Additional.Information::
97
98 3.11.Receiver.Type.....:TRIMBLE-5700
99 .....Satellite.System.....:GPS
100 .....Serial.Number.....:21296
101 .....Firmware.Version.....:1.24
102 .....Elevation.Cutoff.Setting::5-deg
103 .....Date.Installed.....:2003-02-27T00:47Z
104 .....Date.Removed.....:2011-03-08T23:59Z
105 .....Temperature.Stabiliz.....:
106 .....Additional.Information::
107
```

Receiver section

```
177 4....GNSS.Antenna.Information
178
179 4.1.Antenna.Type.....:TOP700779A.....:DOME
180 .....Serial.Number.....:10121
181 .....Antenna.Reference.Point::BPA
182 .....Marker->ARP.Up.Ecc.(m)::0.0
183 .....Marker->ARP.North.Ecc(m)::0.0
184 .....Marker->ARP.East.Ecc(m)::0.0
185 .....Alignment.from.True.N.....:0-deg
186 .....Antenna.Radome.Type.....:DOME
187 .....Radome.Serial.Number.....:
188 .....Antenna.Cable.Type.....:
189 .....Antenna.Cable.Length.....:50-m
190 .....Date.Installed.....:1995-03-13T06:30Z
191 .....Date.Removed.....:2001-02-24T23:59Z
192 .....Additional.Information::Spherical.radome
193
194 4.2.Antenna.Type.....:TRM29659.00.....:DOME
195 .....Serial.Number.....:60651
196 .....Antenna.Reference.Point::BPA
197 .....Marker->ARP.Up.Ecc.(m)::0.0
198 .....Marker->ARP.North.Ecc(m)::0.0
199 .....Marker->ARP.East.Ecc(m)::0.0
200 .....Alignment.from.True.N.....:0-deg
201 .....Antenna.Radome.Type.....:DOME
202 .....Radome.Serial.Number.....:
203 .....Antenna.Cable.Type.....:Trimble-N-minilemo
204 .....Antenna.Cable.Length.....:50-m
205 .....Date.Installed.....:2001-02-25T23:21Z
206 .....Date.Removed.....:2011-03-08T23:59Z
207 .....Additional.Information::Spherical.radome
208
209 4.x.Antenna.Type.....:(A20,from.rcvr_ant.tab;see.instructions)
210 .....Serial.Number.....:(A*,but.note.the.first-A5.is.used.in.SINEX)
211 .....Antenna.Reference.Point::(BPA/BCR/XXX.from."antenna.gra";see.instr.)
212 .....Marker->ARP.Up.Ecc.(m)::(F8.4)
213 .....Marker->ARP.North.Ecc(m)::(F8.4)
214 .....Marker->ARP.East.Ecc(m)::(F8.4)
215 .....Alignment.from.True.N.....:(deg;+is.clockwise/east)
216 .....Antenna.Radome.Type.....:(A4.from.rcvr_ant.tab;see.instructions)
217 .....Radome.Serial.Number.....:
218 .....Antenna.Cable.Type.....:(vendor.&.type.number)
219 .....Antenna.Cable.Length.....:(m)
220 .....Date.Installed.....:(CCYY-MM-DDThh:mmZ)
221 .....Date.Removed.....:(CCYY-MM-DDThh:mmZ)
222 .....Additional.Information:::(multiple.lines)
223
```

Antenna section

How are inhomogeneities in GNSS time series related to station metadata?

- **Jumps in time series are often associated with:**

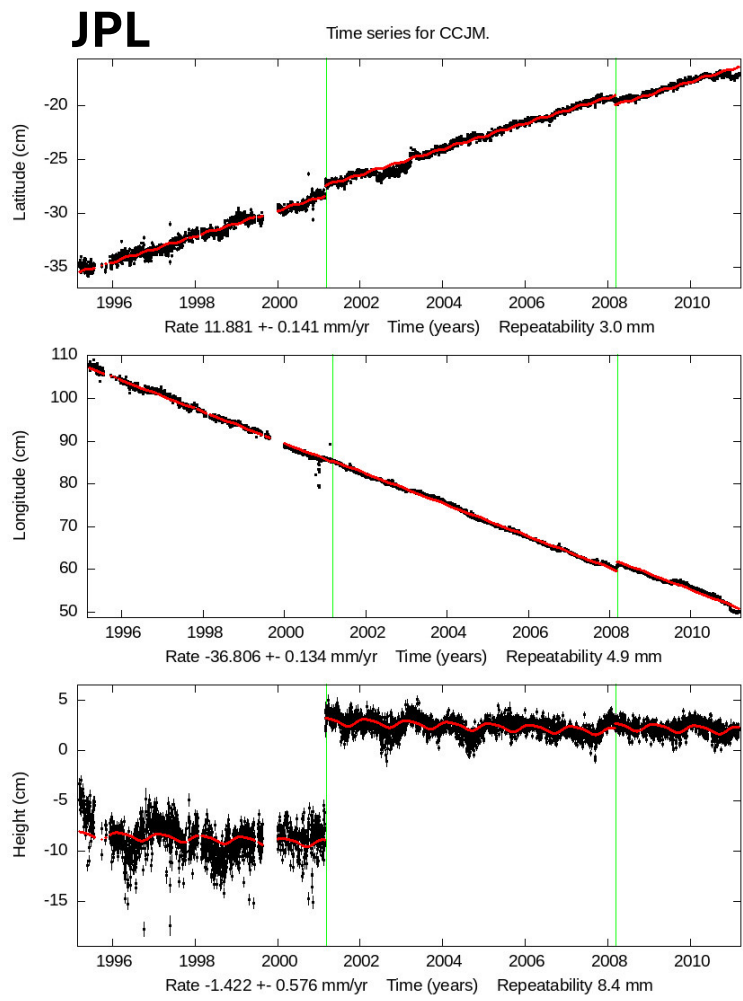
- Equipment changes (antenna, radome, receiver)
- Earthquakes (primarily seen in positions)
- Changes in the station's environment (urbanization, vegetation growth or removal)

=> These changes can hardly be avoided but ...
they should be reported in the data product's metadata

- **Other causes that could be avoided:**

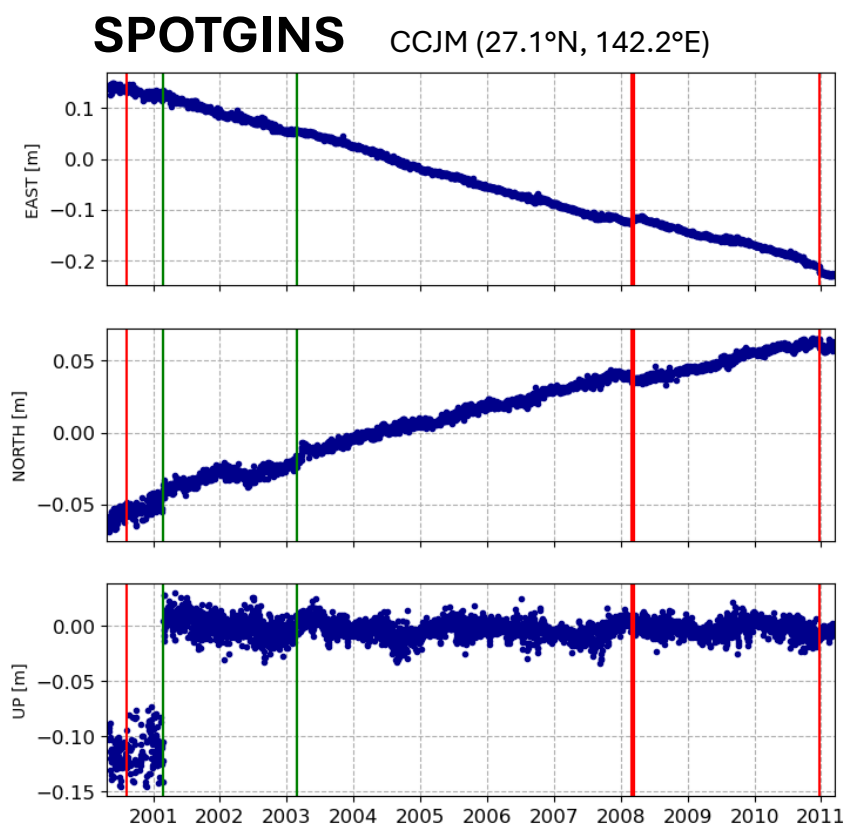
- ⚠ Using wrong information during data processing (antenna & radome type, eccentricity)
- ⚠ Concatenating time series from different stations (unless documented)
- ⚠ Changing the data processing procedure over time (unless documented)

Example of inhomogeneities observed in position time series: station CCJM



Detected change-points

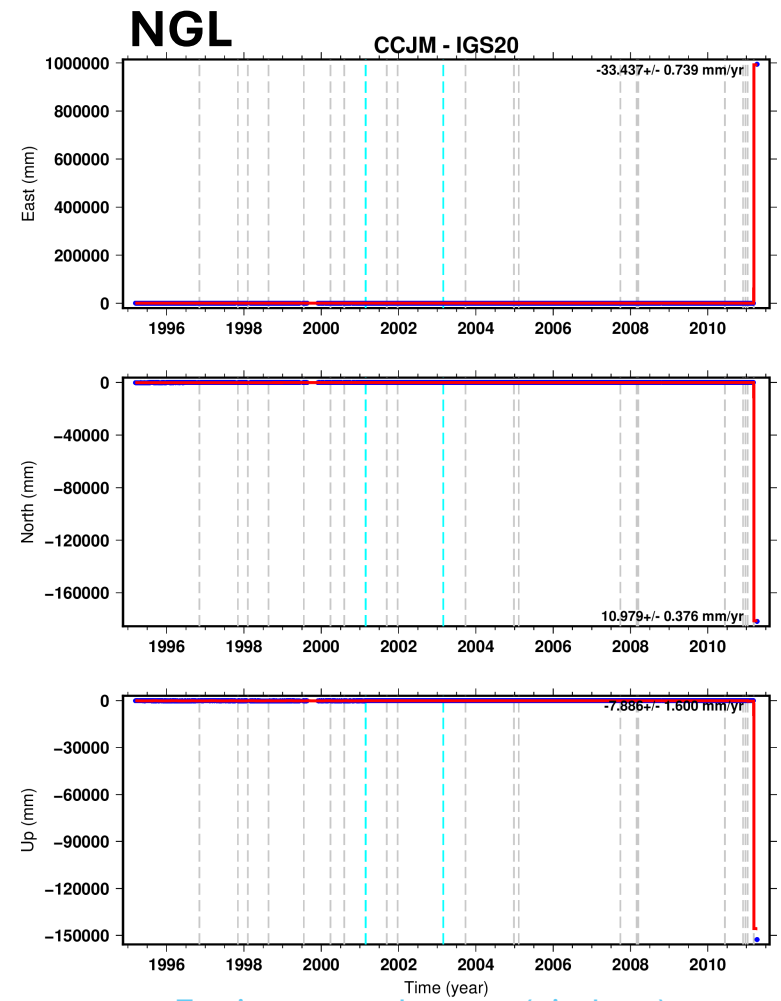
<https://sideshow.jpl.nasa.gov/>
2000+ receivers, analyzed with GipsyX



Equipment changes (site logs)

Earthquakes

<https://www.poleterresolide.fr/geodesy-plotter/>
5000+ receivers, analyzed with GINS PPP-AR

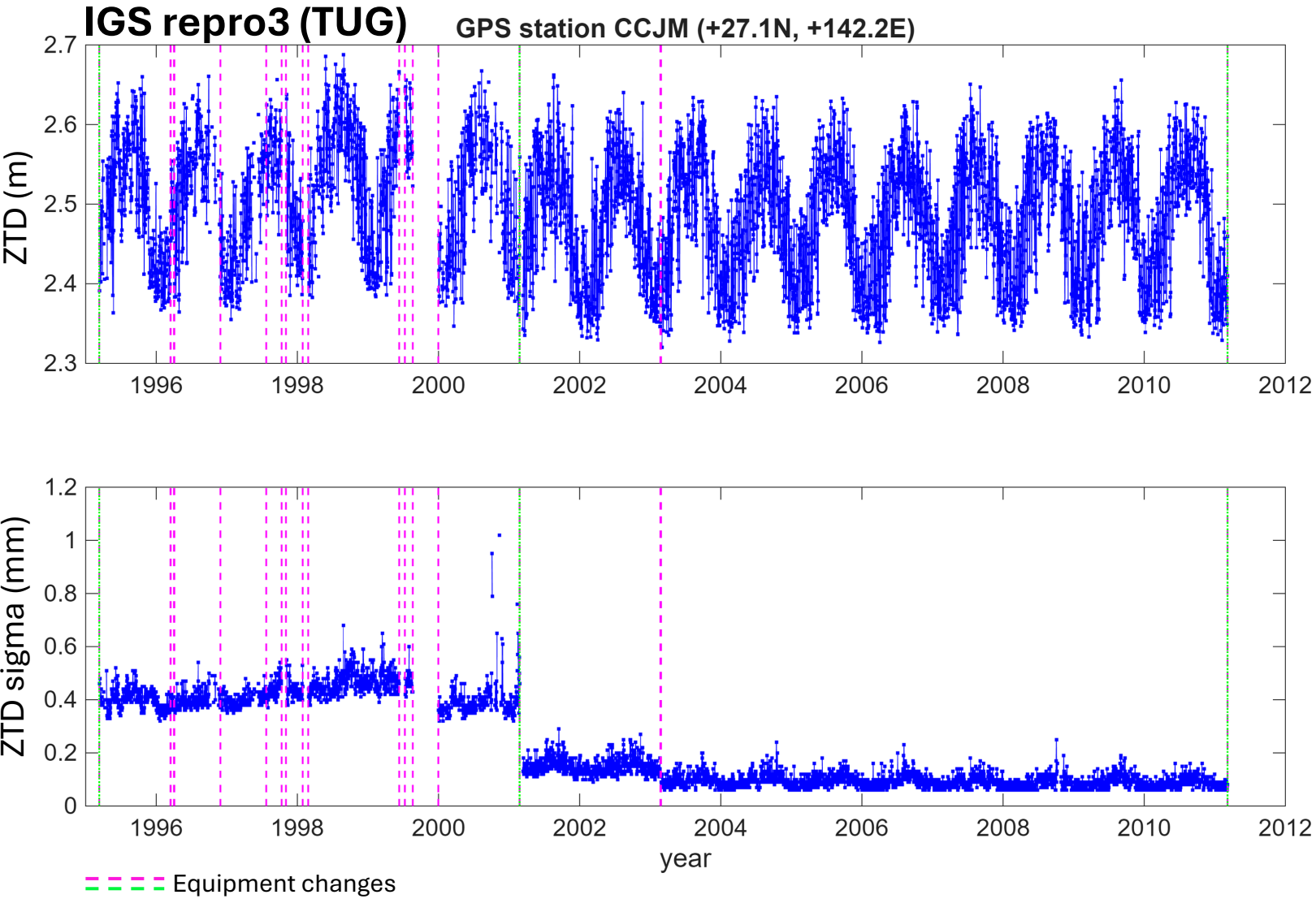


Equipment changes (site logs)

Earthquakes

https://geodesy.unr.edu/gps_timeseries/
20000+ receivers, analyzed with GipsyX PPP-AR

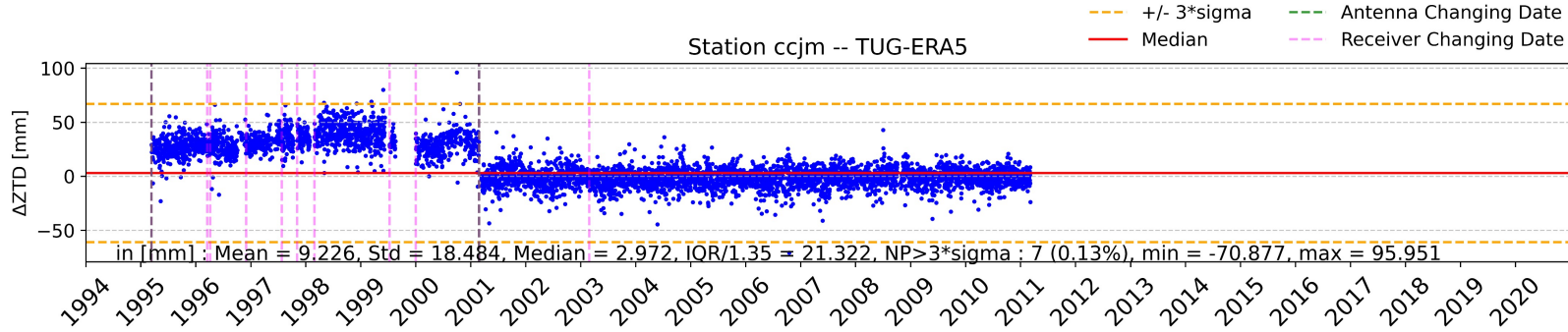
Example of inhomogeneities observed in ZTD time series: station CCJM



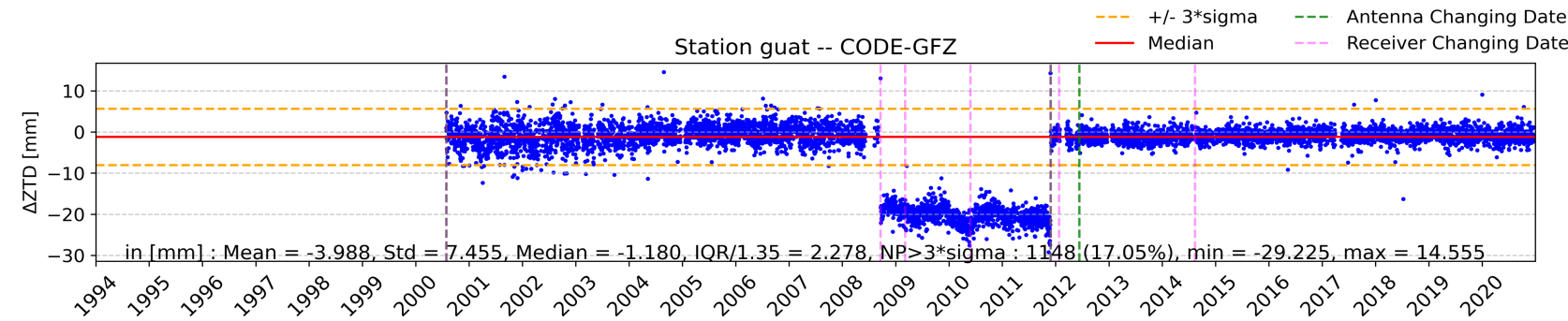
Eq changes summary from sitelog

CCJM00JPN	1996 075	1996-03-15	SF
CCJM00JPN	1996 093	1996-04-02	SF
CCJM00JPN	1996 334	1996-11-29	SF
CCJM00JPN	1997 205	1997-07-24	SF
CCJM00JPN	1997 285	1997-10-12	S
CCJM00JPN	1998 029	1998-01-29	S
CCJM00JPN	1999 163	1999-06-12	S
CCJM00JPN	1999 233	1999-08-21	SF
CCJM00JPN	2001 055	2001-02-24	RSFAs
CCJM00JPN	2003 054	2003-02-23	RSFC

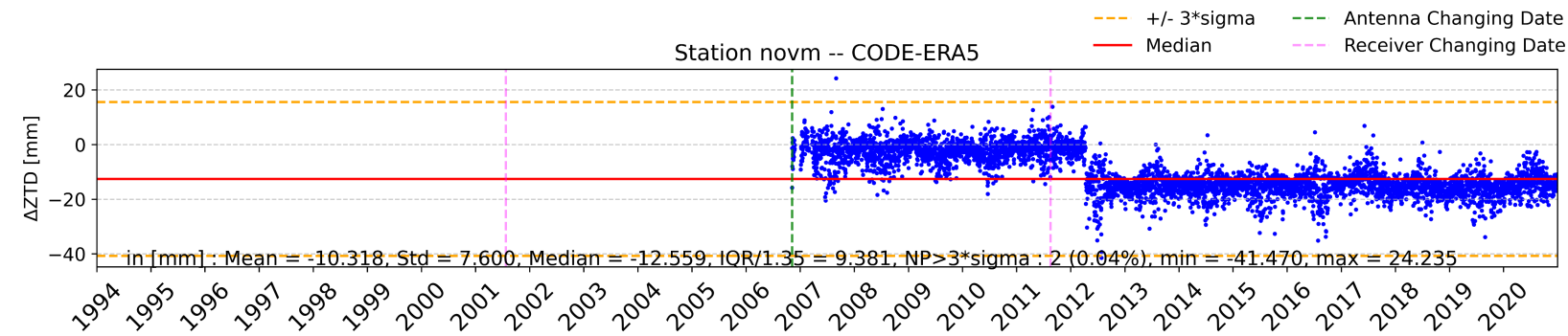
Inhomogeneities observed in ZTD difference time series: IGS repro3



- antenna+radome in use before 2001
does not have a model in igs.atx
=> 30 mm bias ($\sim 4.5 \text{ kg m}^{-2}$)



- antenna change applied in 2008
instead of 2011
=> 20 mm bias ($\sim 3 \text{ kg m}^{-2}$)



- sitelog info wrong or incomplete
=> 12 mm bias ($\sim 2 \text{ kg m}^{-2}$)

Equipment changes

How reliable is the information found in sitelogs?

⚠ Global, regional, and national repositories are not always consistent:

- Mix of station IDs: 4-char vs. 9-char
 - CCJM (ucsd, apref) vs. CCJM00JPN (igs_api, sonel)
- Sitelog file names and update version
 - ccjm_20181227.log vs. ccjm00jpn_20181227.log (igs_api, sonel) vs. ccjm_20130311.log (igs former)
- Mix of country names and codes:
 - Japan vs. JPN
- Station coordinates rounded to different digits and zero-padding...

⚠ More problematic situations:

- Inconsistencies in XYZ and LLH coordinates
 - Differences up to thousands of km !
- Typos and formatting errors:
 - Lat/Lon given in degrees without warning (non-standard)
 - Lat/Lon given in DDMMSS.X but '(deg)' is indicated
 - Units added (°, E, N, m...)
 - Non-standard country names (e.g. P.R.C instead of CHN)

A comprehensive assessment of the IGS repository can be found here:

<https://docs.google.com/presentation/d/1z07pg2bDZx-c7L356jltU6S0wzNOkzfDQL8uU9ehlQw>

```
1 .....CCJ000JPN.Site.Information.Form.(site.log)
2 .....International.GNSS.Service
3 .....See.Instructions.at:
4 .....https://files.igs.org/pub/station/general/sitelog\_instr\_v2.0.txt
```

```
6 0...Form
```

```

8 .....Prepared by: (full name).....Tomoaki Furuya/Kazuki Sakai/Motomu Mandokoro
9 .....Date Prepared.....: 2018-12-27
10 .....Report Type.....: UPDATE
11 .....If Update:
12 .....Previous Site Log.....: ccjrm_20130311.log
13 .....Modified/Added Sections.....: 11

```

16 1... Site Identification of the GNSS Monument

```

18 ..... Site Name ..... CHICHIJIMA
19 ..... Nine Character ID ..... CCJM00JPN
20 ..... Monument Inscription .....
21 ..... IERS DOME Number ..... 21732S003
22 ..... CDP Number .....
23 ..... Monument Description ..... STAINLESS STEEL MAST
24 ..... Height of the Monument ..... 5.25 m
25 ..... Monument Foundation ..... CONCRETE BLOCK
26 ..... Foundation Depth ..... 1.5 m
27 ..... Marker Description ..... none
28 ..... Date Installed ..... 1995-03-13T00:00Z
29 ..... Geologic Characteristic ..... BEDROCK
30 ..... Bedrock Type ..... IGNEOUS
31 ..... Bedrock Condition ..... FINE
32 ..... Fracture Spacing ..... 0 cm
33 ..... Fault zones nearby .....
34 ..... Distance/activity .....
35 ..... Additional Information .....

```

```
38 2....Site.Location.Information
```

```

40      City or Town ..... :Ogasawara
41      State or Province ..... :Tokyo
42      Country or Region ..... :JPN
43      Tectonic Plate ..... :PHILIPPINE
44      Approximate Position (ITRF)
45      X coordinate (m) ..... : -4488925.72
46      Y coordinate (m) ..... : 3483903.12
47      Z coordinate (m) ..... : 2887743.27
48      Latitude (N is +) ..... : +270544.10
49      Longitude (E is +) ..... : +1421104.45
50      Elevation (m,ellips.) ..... : 208.8
51      Additional Information ..... : ITRF2000

```

```
54 3...GNSS.Receiver.Information
```

```

56 3.1. Receiver Type . . . . . : TOPCON_GP-R1DY
57 . . . . . Satellite System . . . . . : GPS
58 . . . . . Serial Number . . . . . : 214
59 . . . . . Firmware Version . . . . . : 1E051C3
60 . . . . . Elevation Cutoff Setting : 15 deg
61 . . . . . Date Installed . . . . . : 1995-03-13T06:30Z
62 . . . . . Date Removed . . . . . : 1996-03-15T23:59Z
63 . . . . . Temperature Stabiliz. . . . . :
64 . . . . . Additional Information . . . . . :

```

```

66 3.2.Receiver.Type.....:TOPCON.GP-R1DY
67 .....Satellite.System.....:GPS
68 .....Serial.Number.....:118
69 .....Firmware.Version.....:1E861D0
70 .....Elevation.Cutoff.Setting.....:15 deg
71 .....Date.Installed.....:1996-03-17T00:00Z

```

```
1 .....CCJMO0JPN.Site.Information.Form.(site.log)
2 .....International.GNSS.Service
3 .....See.Instructions.at:
4 .....ftp://igs.org/pub/station/general/sitelog inst
```

0...Form

```

8 .....Prepared by:(full.name)::Tomoaki.Furuya/Kazuki.Sakai/Motomu.Mandokoro
9 .....Date.Prepared::2018-12-27
10 .....Report.Type::UPDATE
11 .....If.Update:
12 .....Previous.Site.Log::ccjm_20130311.log
13 .....Modified/Added.Sections::11

```

16 1...Site Identification of the GNSS Monument

```

18 ..... Site Name ..... : CHICHIJIMA
19 ..... Four Character ID ..... : CCJM
20 ..... Monument Inscription ..... :
21 ..... IERS DONES Number ..... : 21732S003
22 ..... CDP Number ..... :
23 ..... Monument Description ..... : STAINLESS STEEL MAST
24 ..... Height of the Monument ..... : 5.25 m
25 ..... Monument Foundation ..... : CONCRETE BLOCK
26 ..... Foundation Depth ..... : 1.5 m
27 ..... Marker Description ..... : none
28 ..... Date Installed ..... : 1995-03-13T00:00Z
29 ..... Geologic Characteristic ..... : BEDROCK
30 ..... Bedrock Type ..... : IGNEOUS
31 ..... Bedrock Condition ..... : FINE
32 ..... Fracture Spacing ..... : 0 cm
33 ..... Fault zones nearby ..... :
34 ..... Distance/activity ..... :
35 ..... Additional Information ..... :

```

```
38 2....Site Location Information
```

```

40      City or Town ..... : Ogasawara
41      State or Province ..... : Tokyo
42      Country ..... : Japan
43      Tectonic Plate ..... : PHILIPPINE
44      Approximate Position (ITRF)
45      X coordinate (m) ..... : -4488925.724
46      Y coordinate (m) ..... : 3483503.122
47      Z coordinate (m) ..... : 2987743.274
48      Latitude (N is +) ..... : +270544.10
49      Longitude (E is +) ..... : +1421110.49
50      Elevation (m, ellips.) ..... : 208.83
51      Additional Information ..... : ITRF2000

```

```
54 3....GNSS.Receiver.Information
```

```

56 3.1. Receiver Type . . . . . TOPCON.GP-R1DY
57 . . . . . Satellite System . . . . . GPS
58 . . . . . Serial Number . . . . . 214
59 . . . . . Firmware Version . . . . . 1E051C3
60 . . . . . Elevation Cutoff Setting . . . . . 15_deg
61 . . . . . Date Installed . . . . . 1995-03-13T06:30Z
62 . . . . . Date Removed . . . . . 1996-03-15T23:59Z
63 . . . . . Temperature Stabiliz. . . . .
64 . . . . . Additional Information . . . . .

```

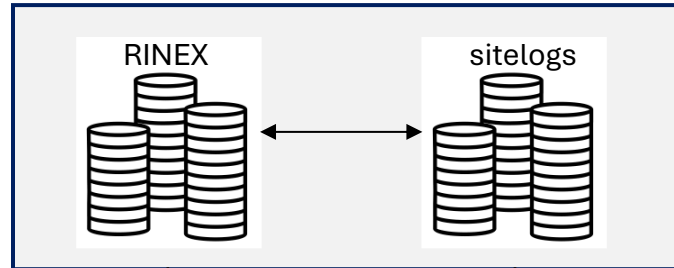
```

65 3.2. Receiver Type ..... TOPCON GP-R1DY
66 ..... Satellite System ..... GPS
67 ..... Serial Number ..... 118
68 ..... Firmware Version ..... 1E861D0
69 ..... Elevation Cutoff Setting ..... 15_deg
70 ..... Date Installed ..... 1996-03-17T00:00Z
71

```

Multisource Station Metadata DB (MSMDB)

Global, regional, national repositories



User segment

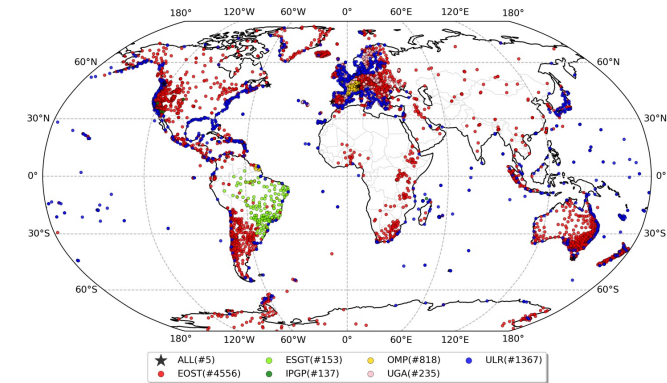
MSMDB

28,408 sitelogs

v_2026-01-24

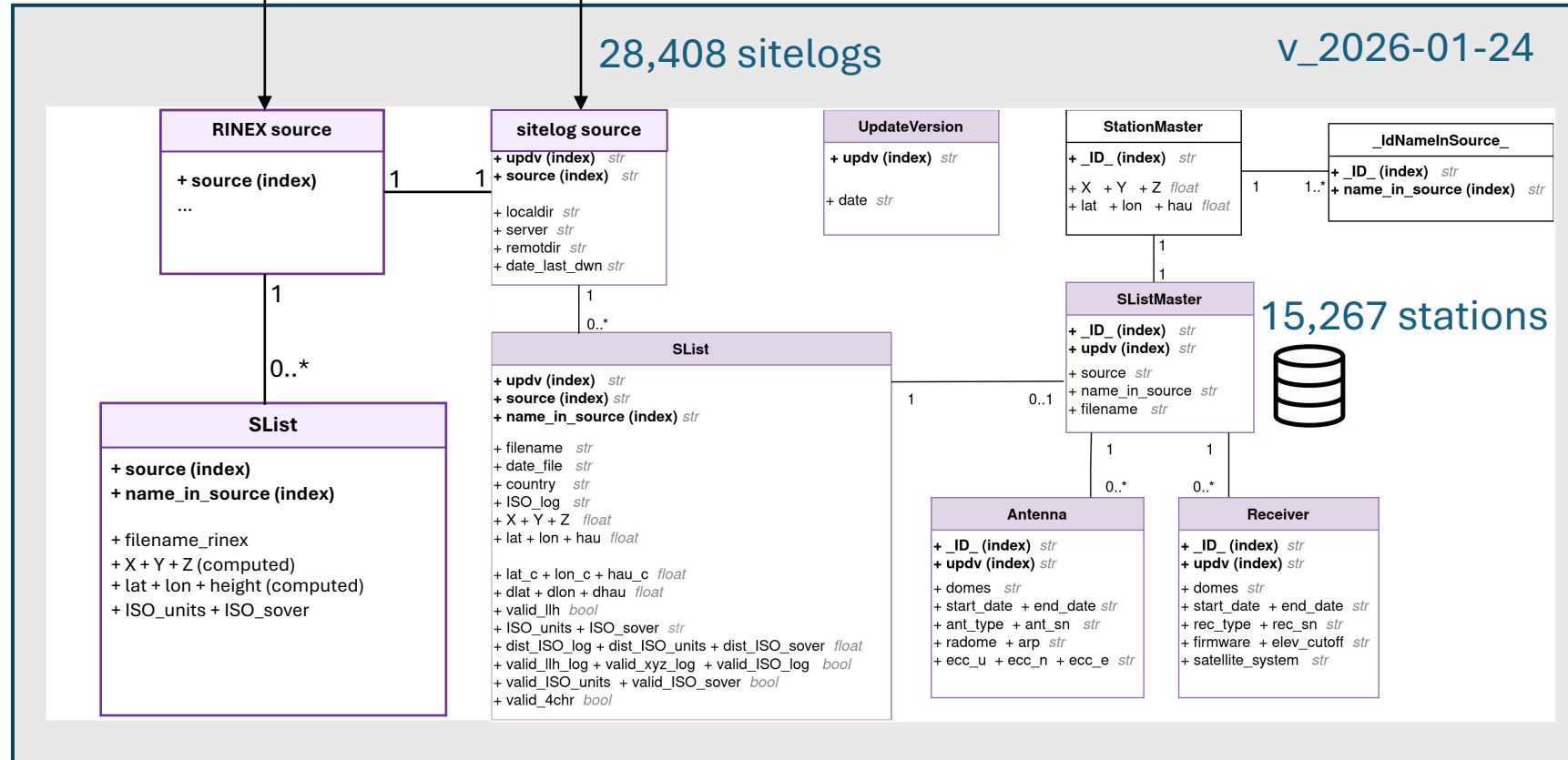
SPOTGINS (6500 stations)

Station_master.dat



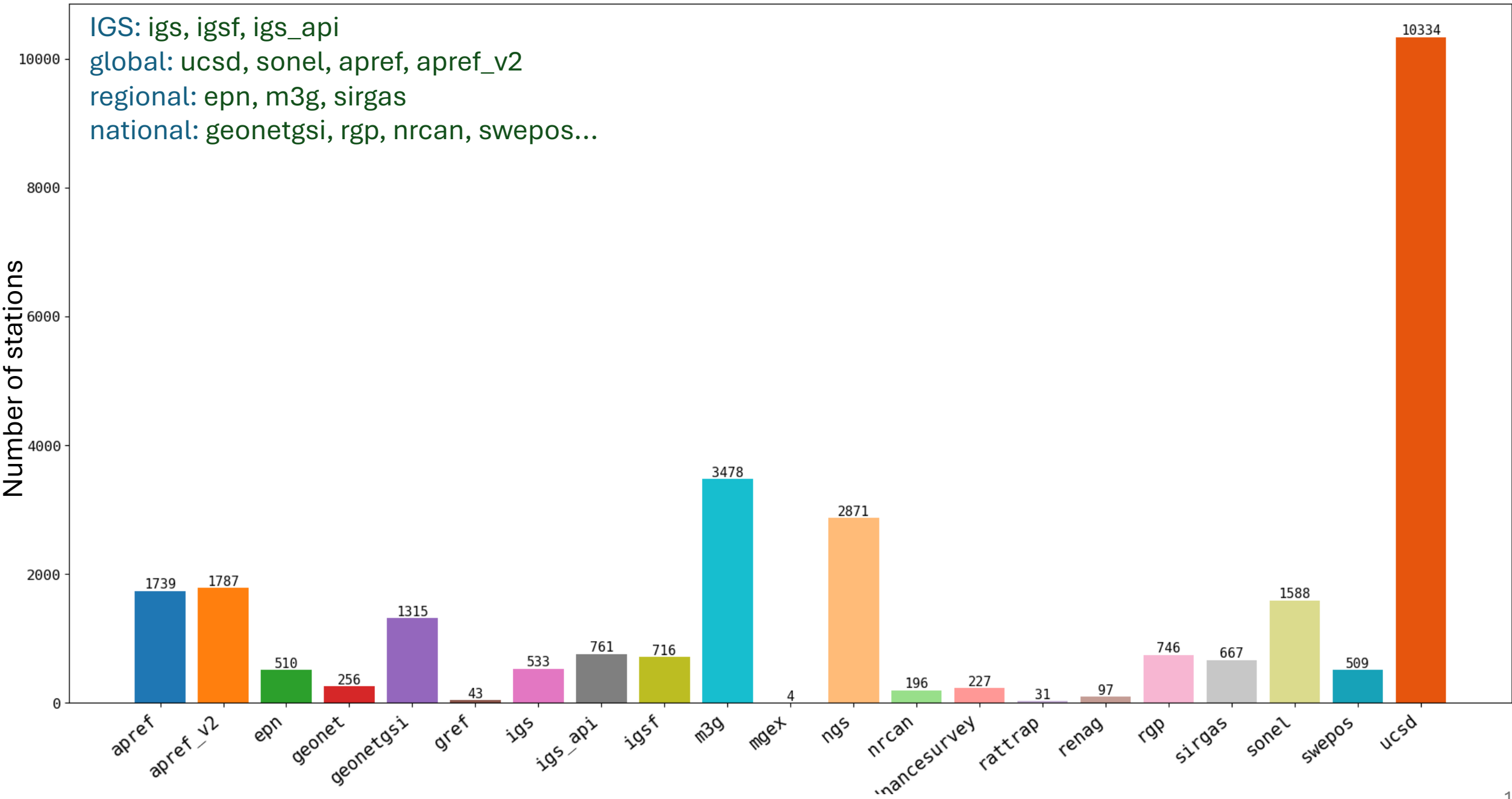
Station_info.dat

export (5710 stations)

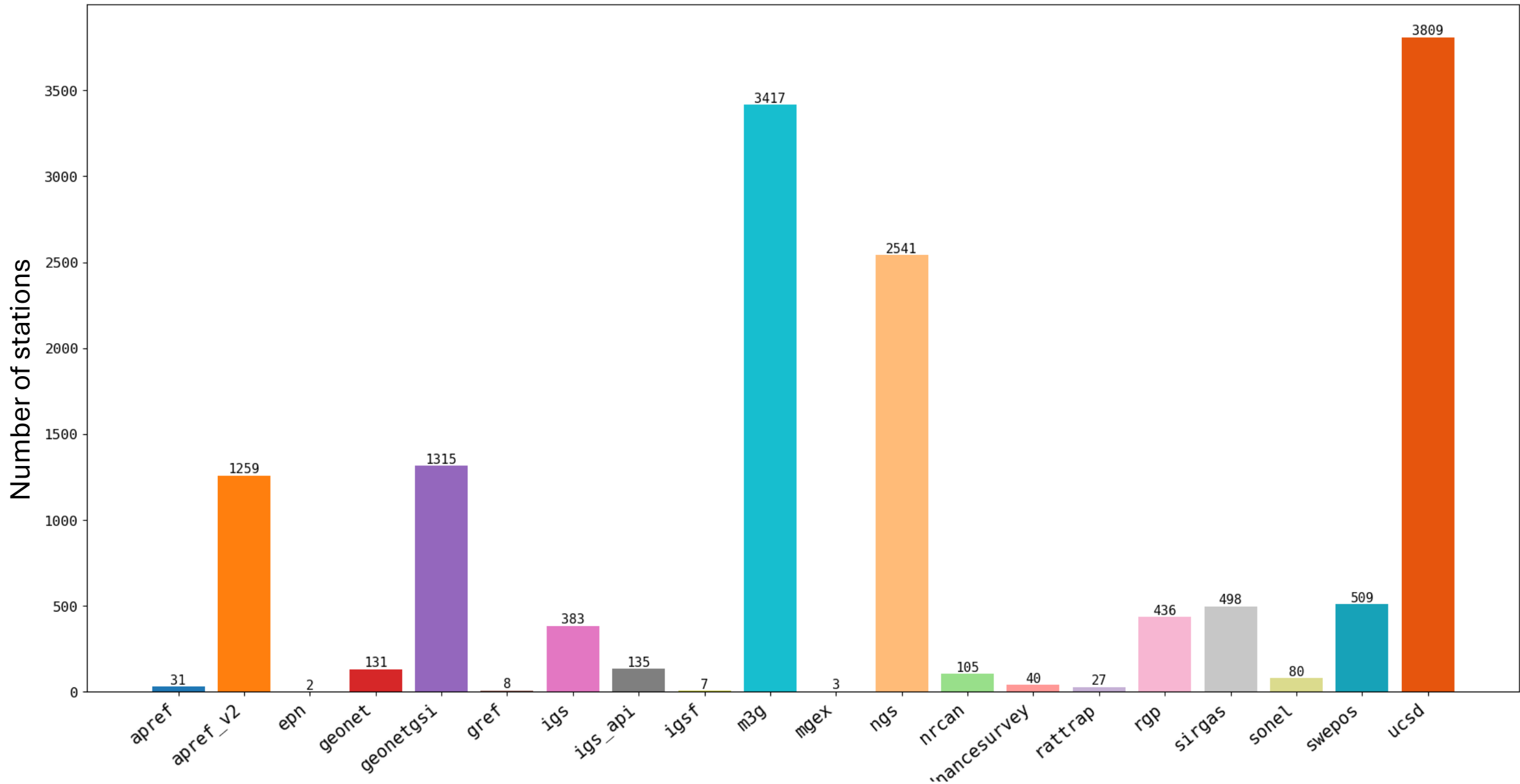


28,408 sitelogs and station info files scanned from 20 GNSS repositories

IGS: igs, igsf, igs_api
global: ucsd, sonel, apref, apref_v2
regional: epn, m3g, sirgas
national: geonetgsi, rgp, nrcan, swepos...

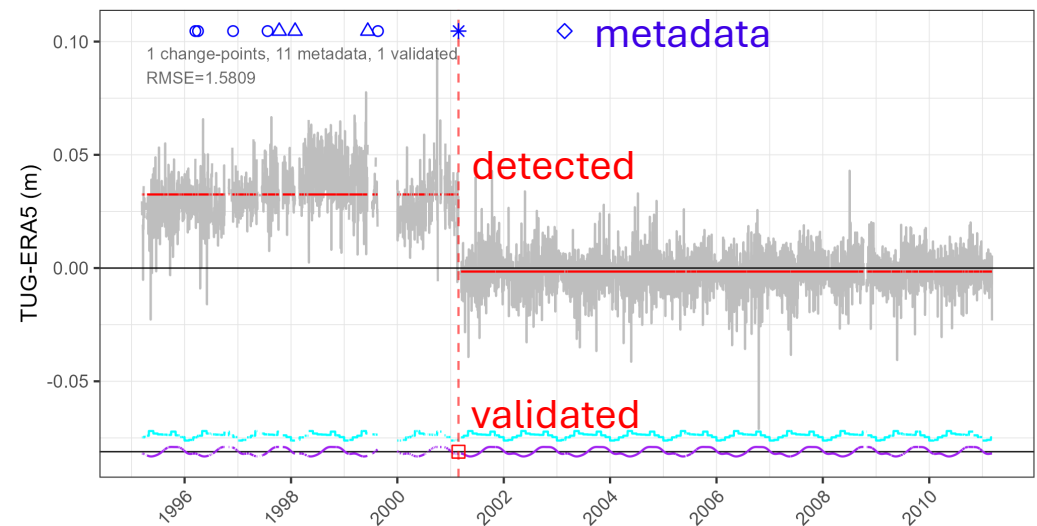


15,267 unique IDs entered the Station Master file (with qualified information)

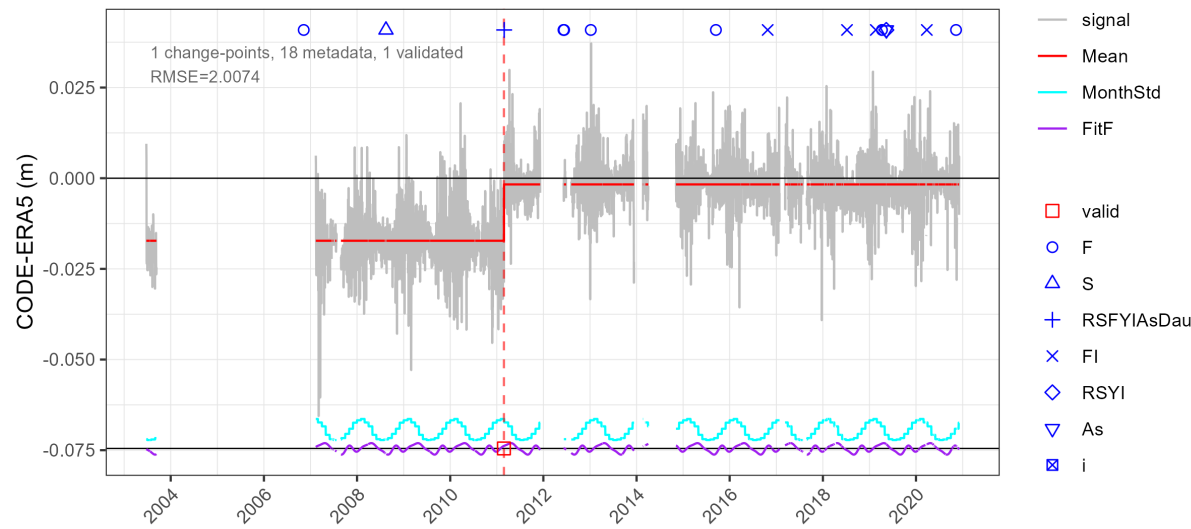


MSMDB used to validate change-points detected with the PMLseg segmentation package

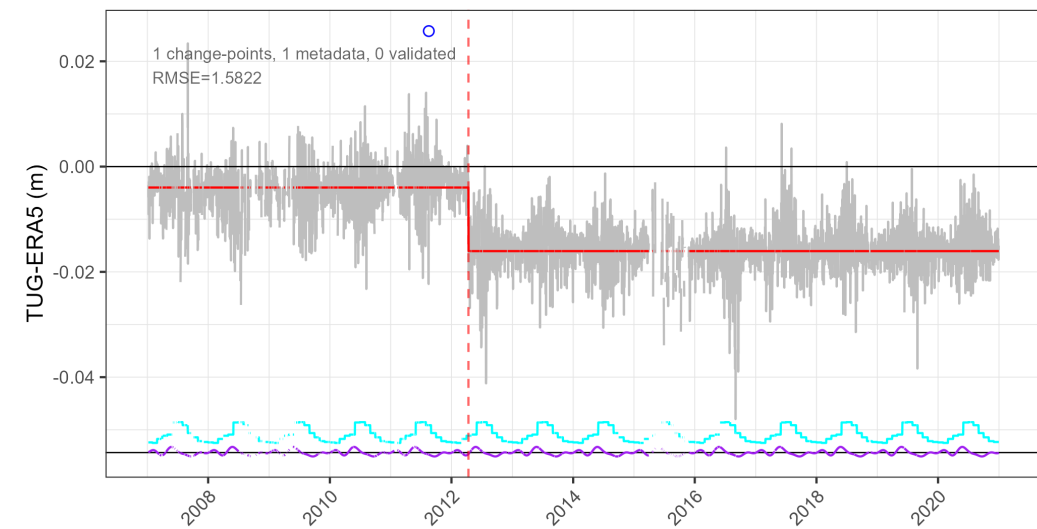
TUG-ERA5, Lav, CCJM



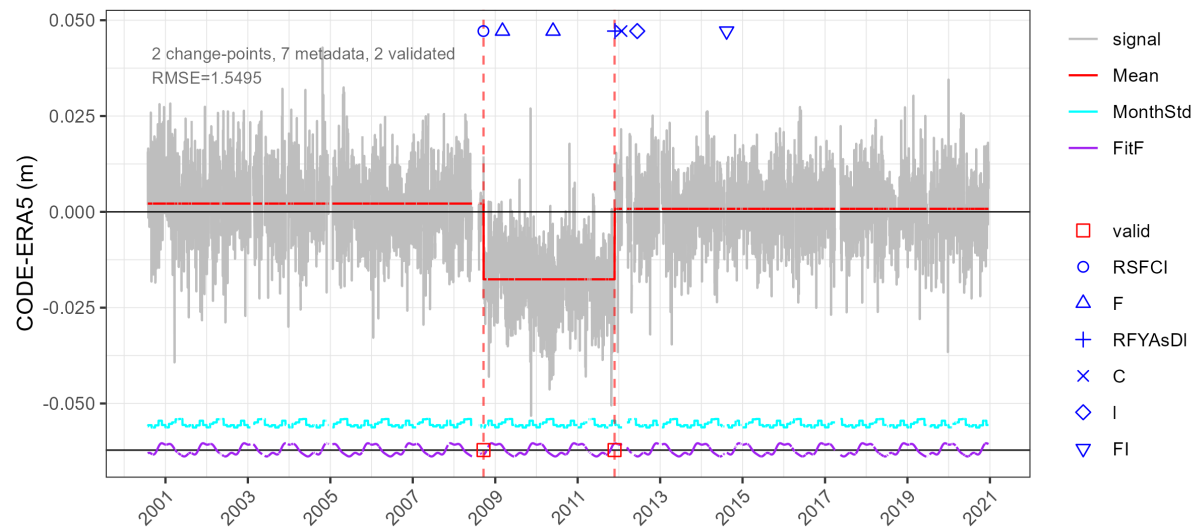
CODE-ERA5, Lav, WIND



TUG-ERA5, Lav, NOV



CODE-ERA5, Lav, GUAT



Segmentation results for various global GNSS data sets: daily ZTD differences (GNSS – ERA5)

- IGS repro1
 - JPL: 120 stations, 1995-2010 (Gipsy-Oasis, PPP)
 - IGS repro2
 - CODE REPRO2015: 81 stations, 1994-2018 (Bernese, DD)
 - IGS repro3
 - COD: 493 stations, 2000-2020 (Bernese, PPP-AR)
 - GFZ: 331 stations, 1994-2020 (EPOS, ZD)
 - GRG: 236 stations, 2000-2020 (GINS, ZD)
 - TUG: 1182 stations, 1994-2020 (Groops, ZD)
 - NGL repro3
 - 6048 stations, 1994-2022 (Gipsy-Oasis, PPP-AR)
 - SPOTGINS
 - 5735 stations, 1994-2025 (GINS, PPP-AR)
- 6% stations are homogeneous
 - Detected 1 CP / station / 5.6 yrs
 - Validated 34% with metadata
- 200 common stations (2000-2020)
 - 7-11% stations are homogeneous
 - Detected 1 CP / station / 4.5-7.1 yrs
 - Validated 31-35% with metadata
- 5.5% stations are homogeneous
 - Detected 1 CP / station / 6.7 yrs
 - Validated only 22% with metadata (33% on IGS stations)

Summary

- GNSS station metadata are critical both for data processing and interpretation of time series
- Inconsistencies in sitelogs have been observed
 - Up to 10% of the files show non-standard formats on some of the repositories
 - Most of the issues are erroneous station positions and inconsistent XYZ and LLH values
 - Some antenna and radome information is incorrect (e.g. typos), leading to biases in estimated parameters
- How to improve the FAIRness of GNSS products?
 - Use consistent and persistent IDs for station names, RINEX files, and data products
 - Provide computed station positions with RINEX and sitelog files
 - Maintain accessible version histories of RINEX and sitelog updates
 - Provide processing details with data products (software, models, RINEX source, sitelog version...)
 - Provide machine-actionable access to metadata through APIs
- How to check the (temporal) homogeneity of GNSS time series?
 - Use segmentation tool to detect change-points in multiple parameters (position, ZTD, gradients...)
 - Use data from nearby stations to attribute the origin of the jumps