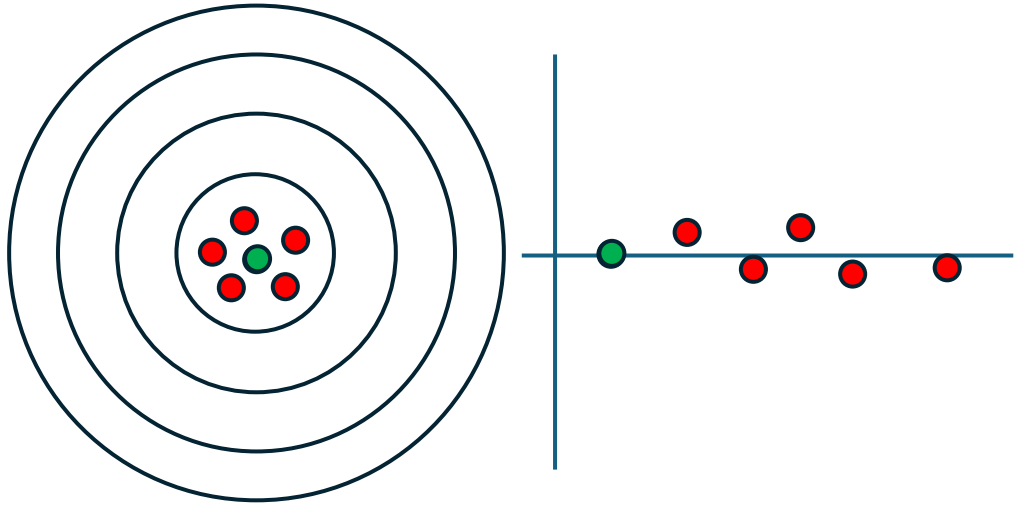
VGOS Data Quality Check

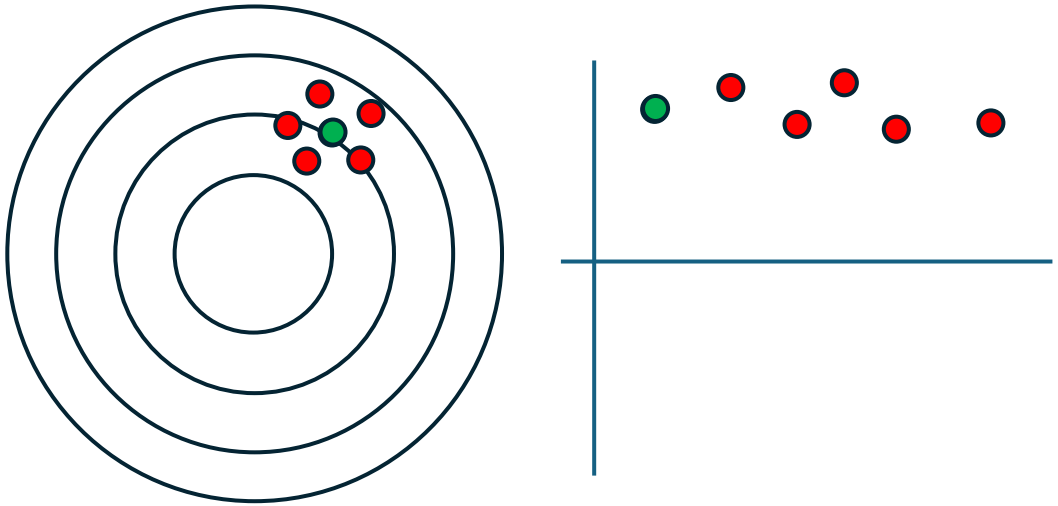
Dhiman Mondal

MIT
HAYSTACK OBSERVATORY

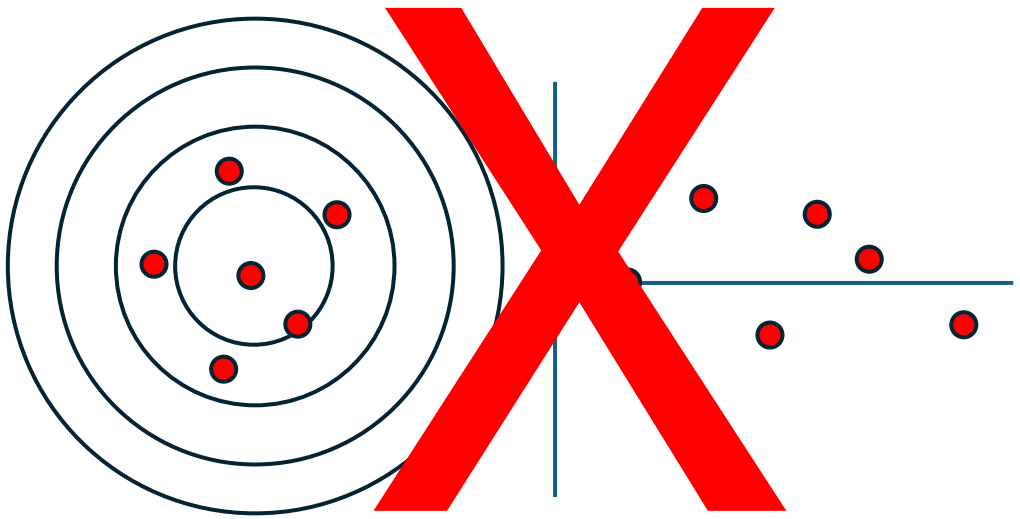
Precise and Accurate



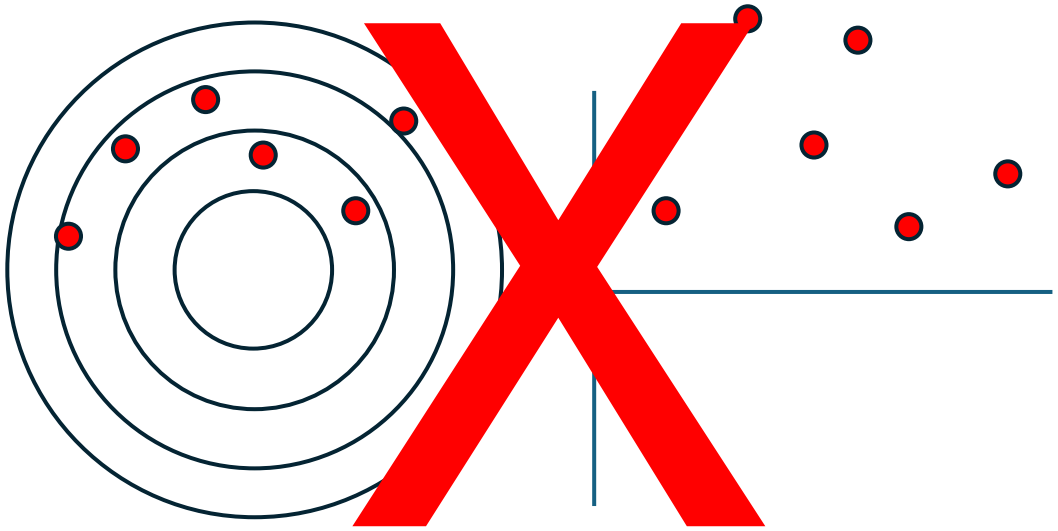
Precise, not Accurate



Not Precise, Accurate



Neither Precise nor Accurate



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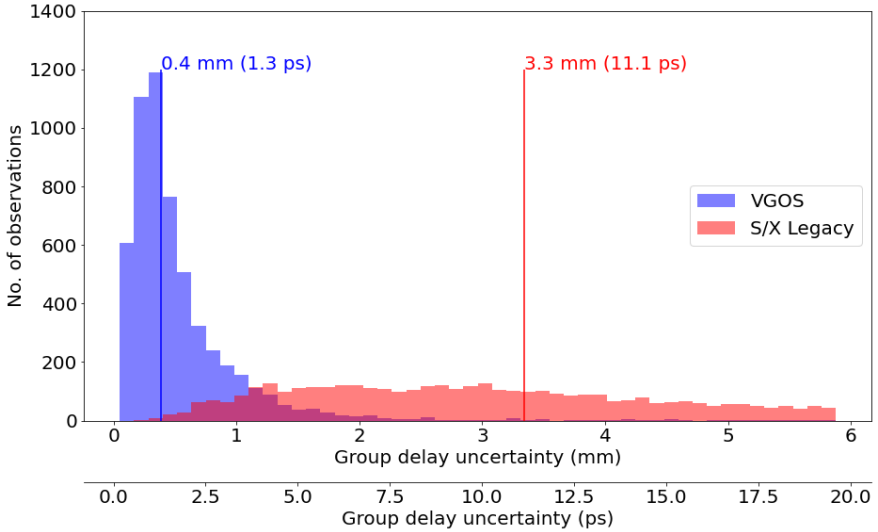
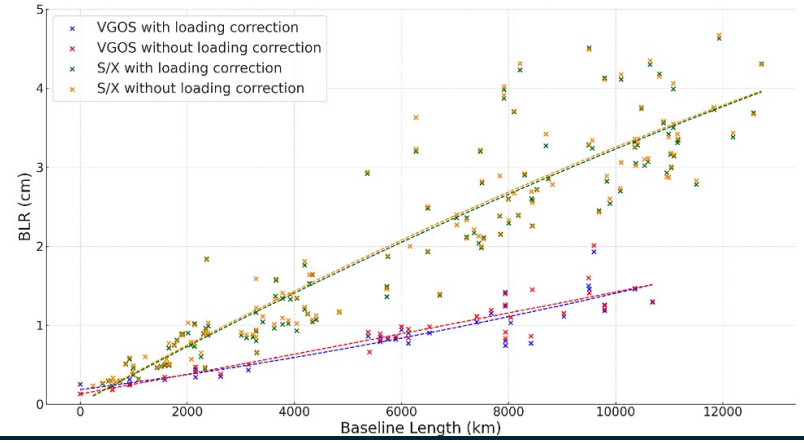
Quality of VGOS data and products

Group delay uncertainty

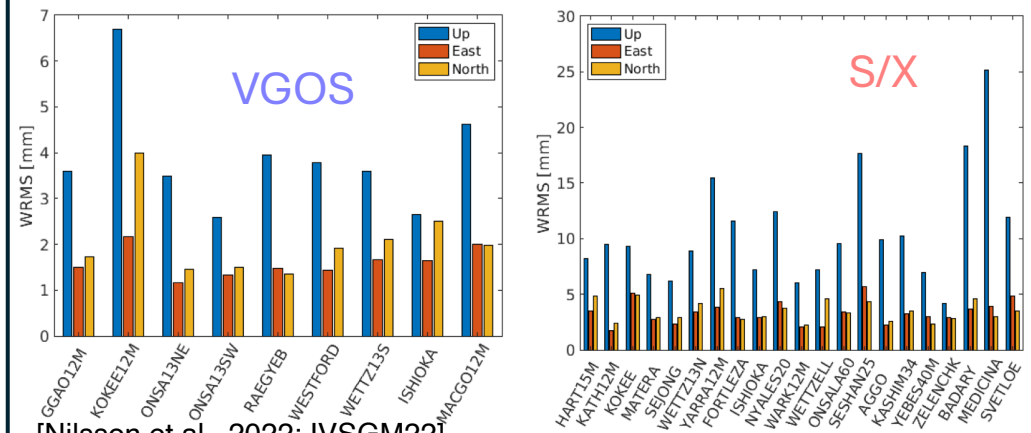


[Mondal et al., 2022]

Baseline length repeatability

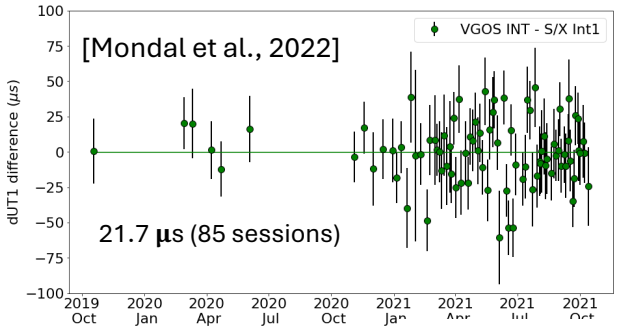


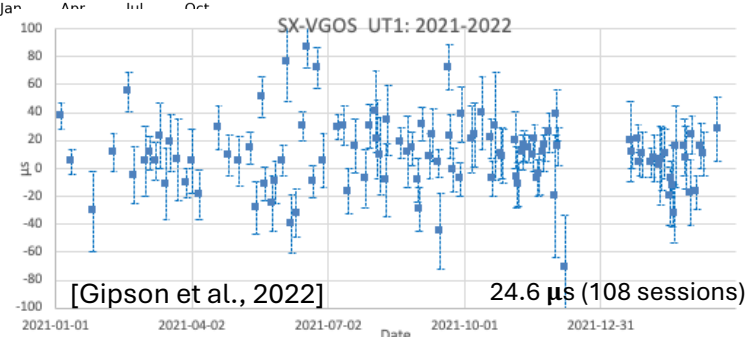
Site position estimates



[Nilsson et al., 2022; IVSGM22]

dUT1 estimates





HAYSTACK OBSERVATORY

What do the analysts see?

- Group delay per baseline
- Group delay uncertainties
- Cable calibration data
- Weather data (Met data)
- Correlator/Station Report

Measured vs Modeled

$$\tau = \tau_g + \tau_{clk} + \tau_{ins} + \tau_{ion} + \tau_{trop} + \tau_{rel} + \tau_{other} + \in$$

- **Signal** (geometry => position)
- Rest is **“noise”**
  - Clocks
  - Ionosphere
  - Troposphere
  - Electronics, etc.

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Geodetic processing of a VGOSDB

- VLBI processing software
  - VieVS *[Bohm et al., 2018]* and nuSolve *[Bolotin et al.,]*
- *GNSS* processing software
  - GAMIT/GLOBK *[Herring et al., 2010]* and GipsyX *[Bertiger et al., 2020]*
- We cross-check geodetic estimates with R1/R4 sessions and colocated GNSS stations when needed

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VGOSDB processing checklist

- Read the Correlator report and take notes about station performance
- Load the data on nuSolve to check
  - issues with VGOSDB (any warnings and errors)
  - presence of weather and cable calibration data (if missing, look for a note in the correlator report)
- Process the session with both nuSolve and VieVS
- Statistics to look at
  - Session fit (for whole session/per baseline/per station)
  - Check the parameter estimates (clock/zwd/baseline length/site position/EOP)

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Correlator Report

- What do analysts look for?
  - Antenna issues
  - Warm receiver
  - Station not operational, i.e., “down” or unreliable
  - Cable calibration is not working
  - Phase-calibration signal absent or highly variable
  - Missing proxy cc
  - No met data
  - Channel or band removed
  - Low SNR, no-detection

Analysts know what to expect

+ Which station to downweight in the analysis

+ Which station to use as a clock reference

+ Which cable-cal to use

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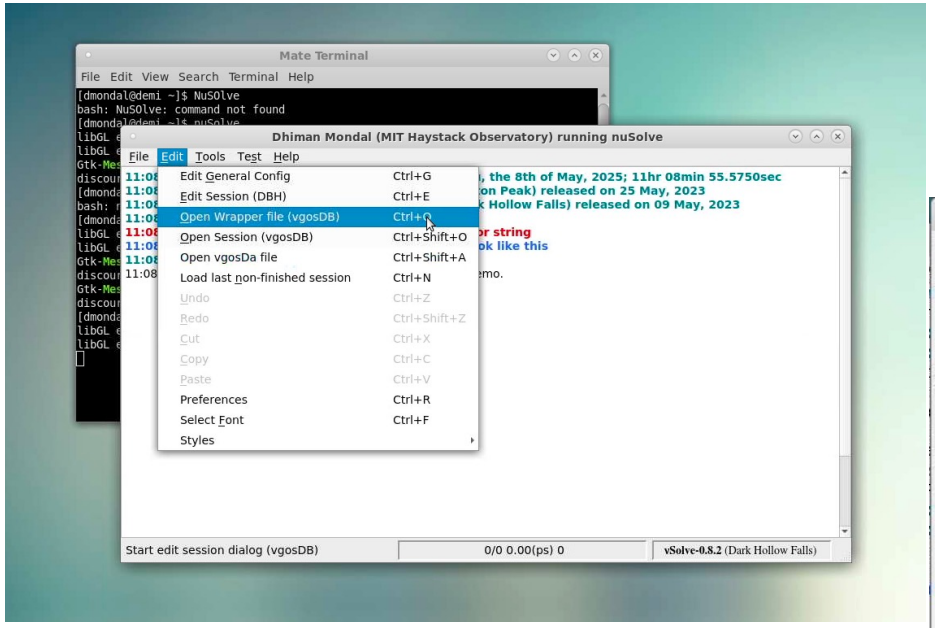
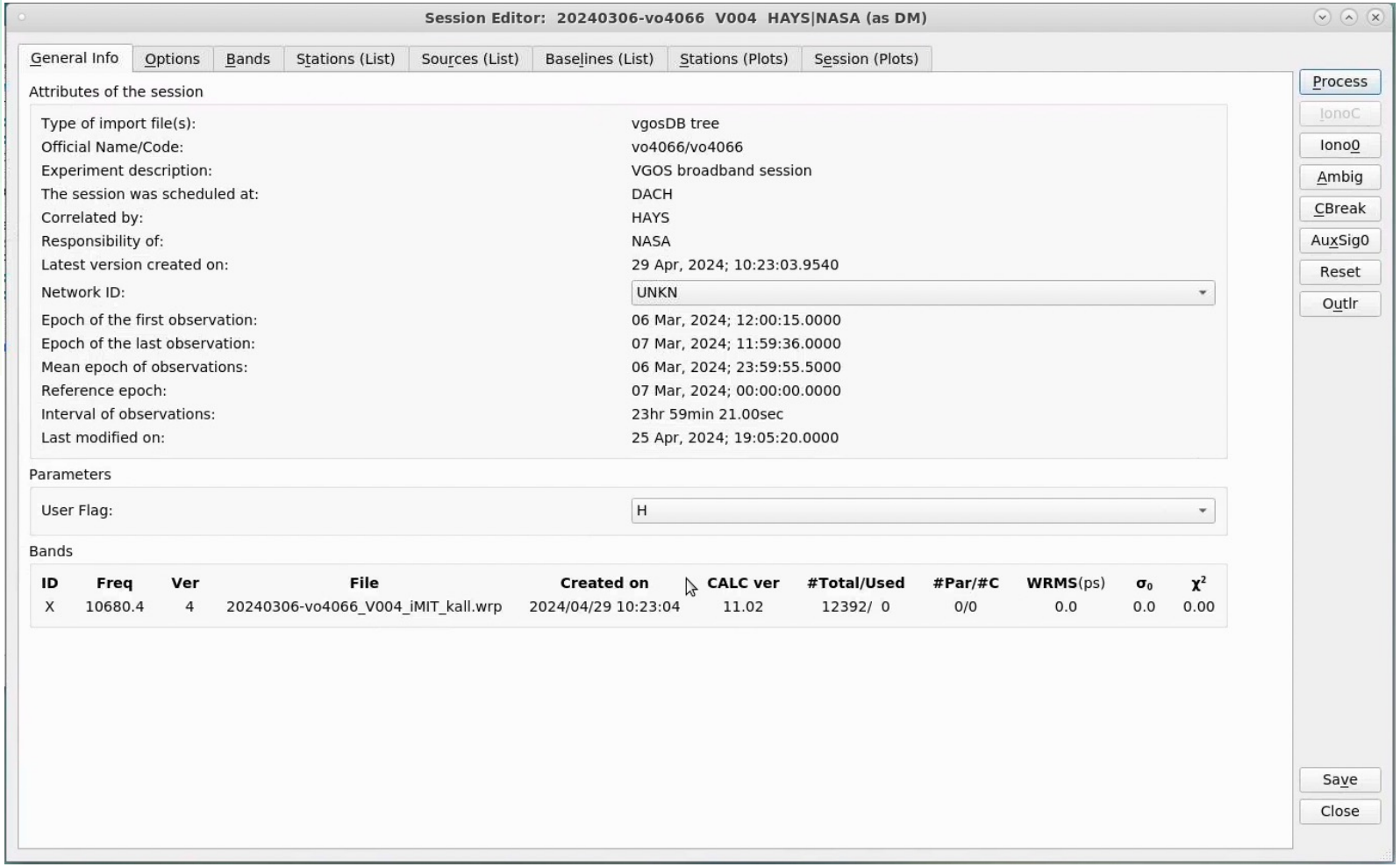
Loading data onto nuSolve (“live” demo)





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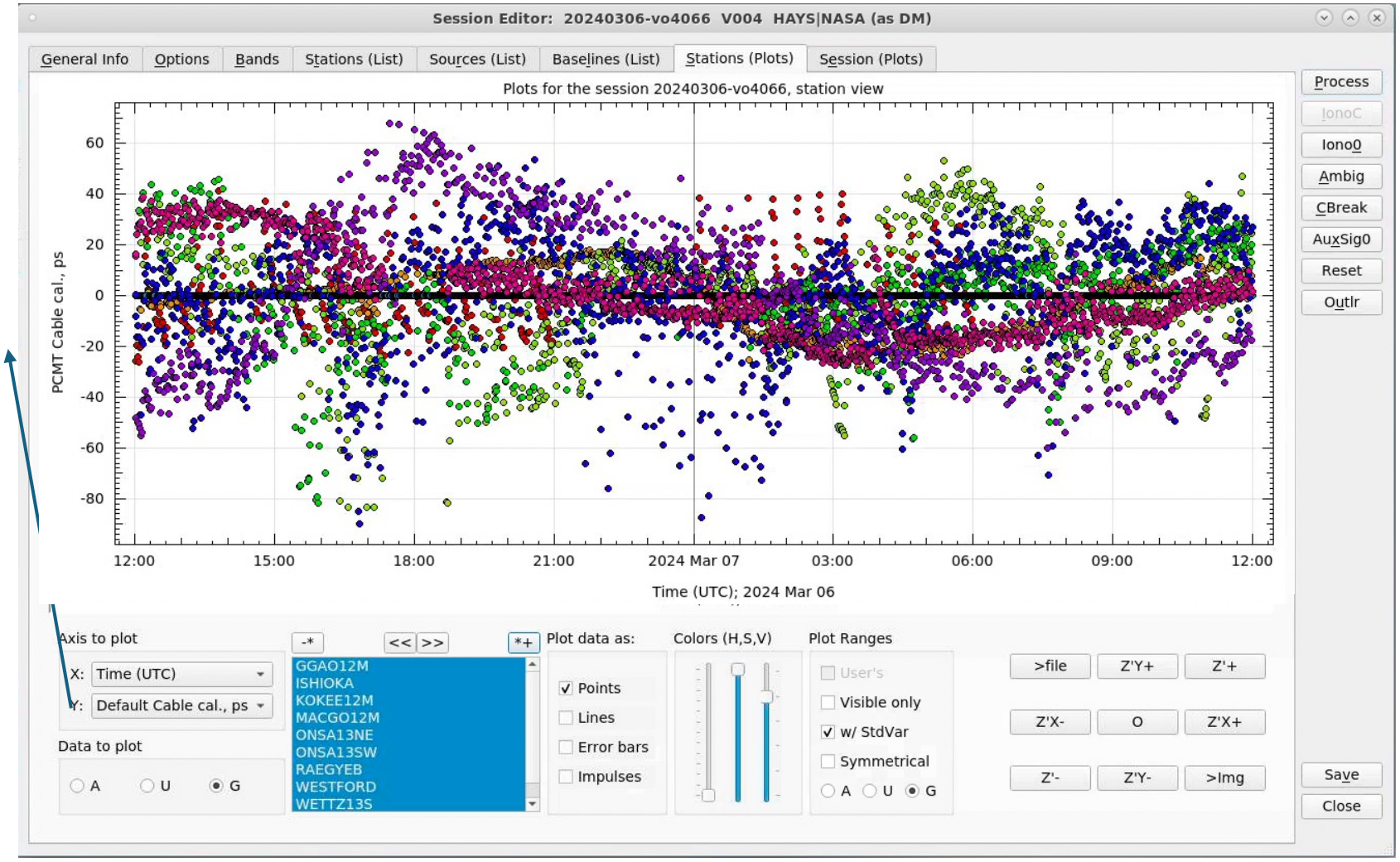
Checking cable-cal and other data

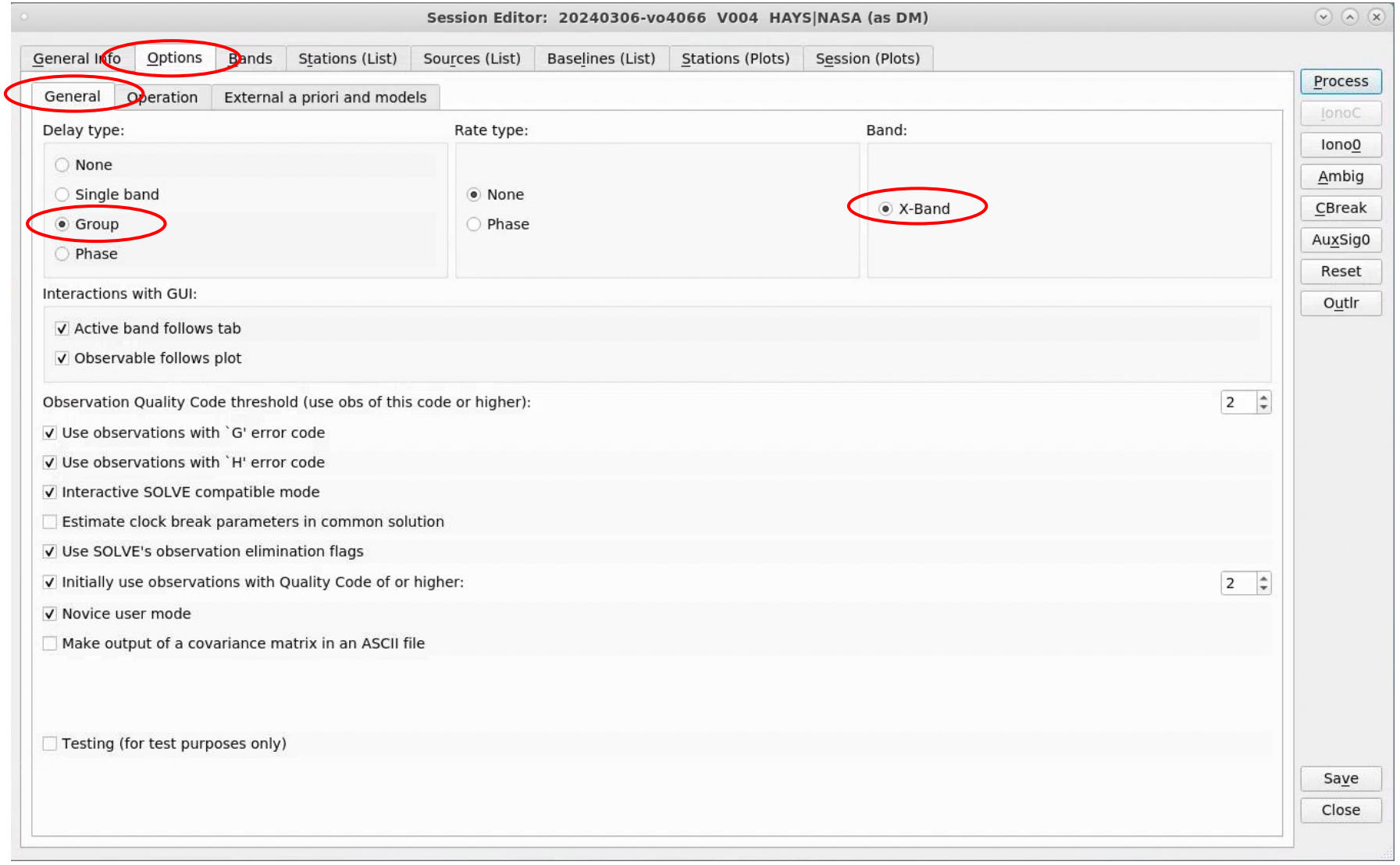
Common issues

- Proxy-cc missing
- Proxy-cc is not generated for the whole session
- Met data is missing
- Check if ERP models are included



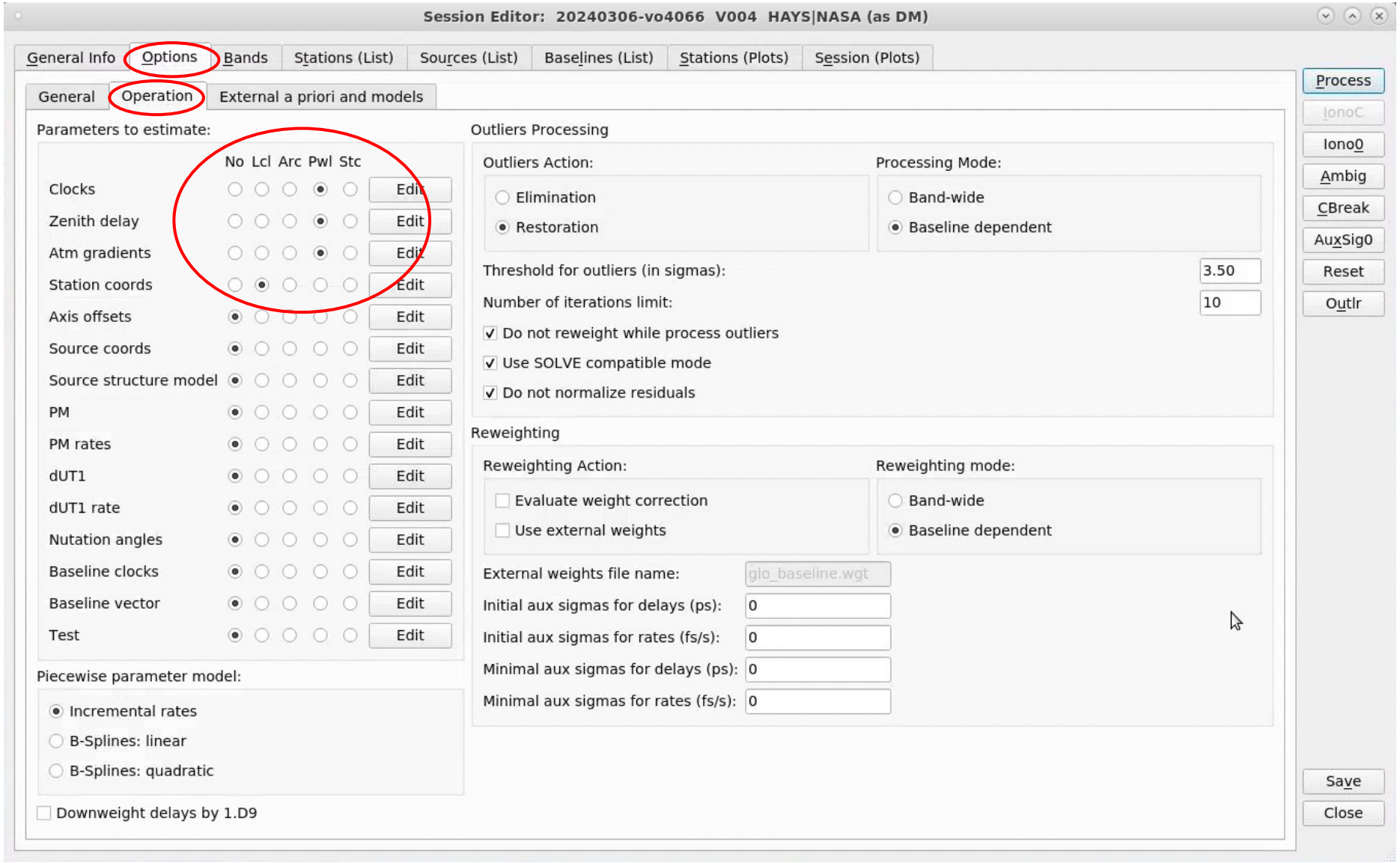
HAYSTACK OBSERVATORY

Processing VGOSDB



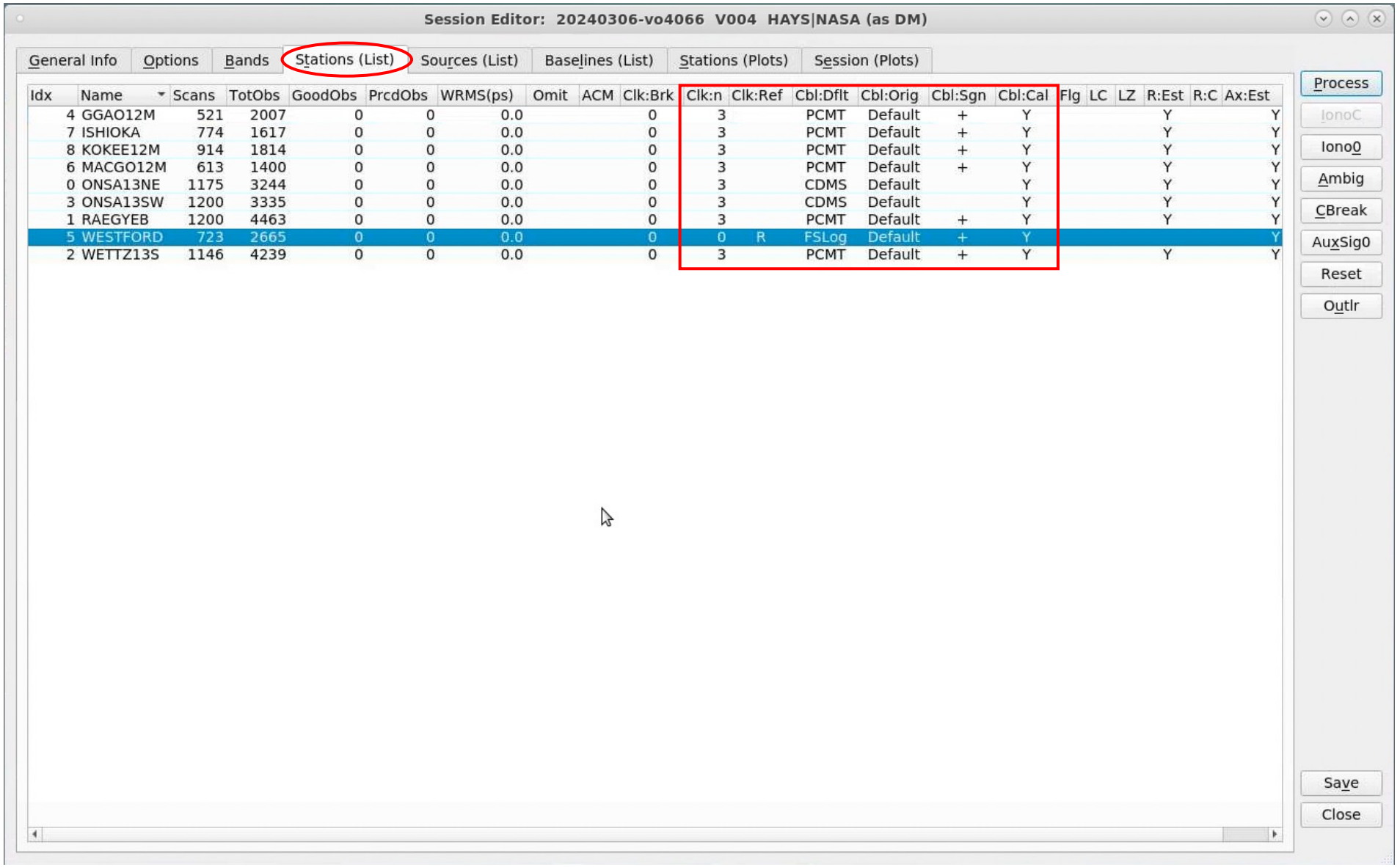
MIT HAYSTACK OBSERVATORY

Processing VGOSDB



MIT HAYSTACK OBSERVATORY

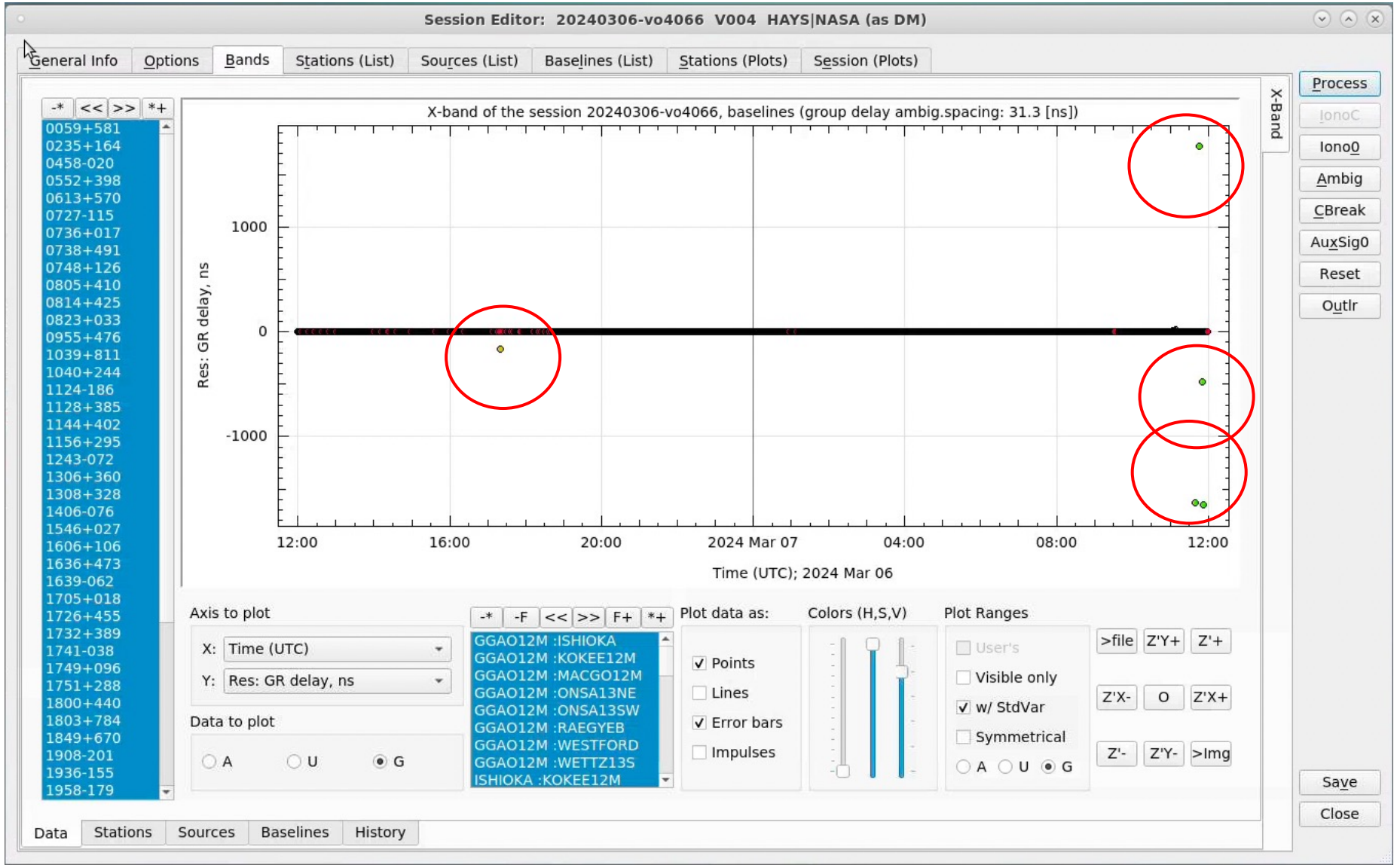
Processing VGOSDB



Idx	Name	Scans	TotObs	GoodObs	PrcdObs	WRMS(ps)	Omit	ACM	Clk:Brk	Clk:n	Clk:Ref	Cbl:Dflt	Cbl:Orig	Cbl:Sgn	Cbl:Cal	Flg	LC	LZ	R:Est	R:C	Ax:Est
4	GGAO12M	521	2007	0	0	0.0			0	3		PCMT	Default	+	Y				Y		Y
7	ISHIOKA	774	1617	0	0	0.0			0	3		PCMT	Default	+	Y				Y		Y
8	KOKEE12M	914	1814	0	0	0.0			0	3		PCMT	Default	+	Y				Y		Y
6	MACGO12M	613	1400	0	0	0.0			0	3		PCMT	Default	+	Y				Y		Y
0	ONSA13NE	1175	3244	0	0	0.0			0	3		CDMS	Default		Y				Y		Y
3	ONSA13SW	1200	3335	0	0	0.0			0	3		CDMS	Default		Y				Y		Y
1	RAEGYEB	1200	4463	0	0	0.0			0	3		PCMT	Default	+	Y				Y		Y
5	WESTFORD	723	2665	0	0	0.0			0	0	R	FSLog	Default	+	Y						Y
2	WETTZ13S	1146	4239	0	0	0.0			0	3		PCMT	Default	+	Y				Y		Y

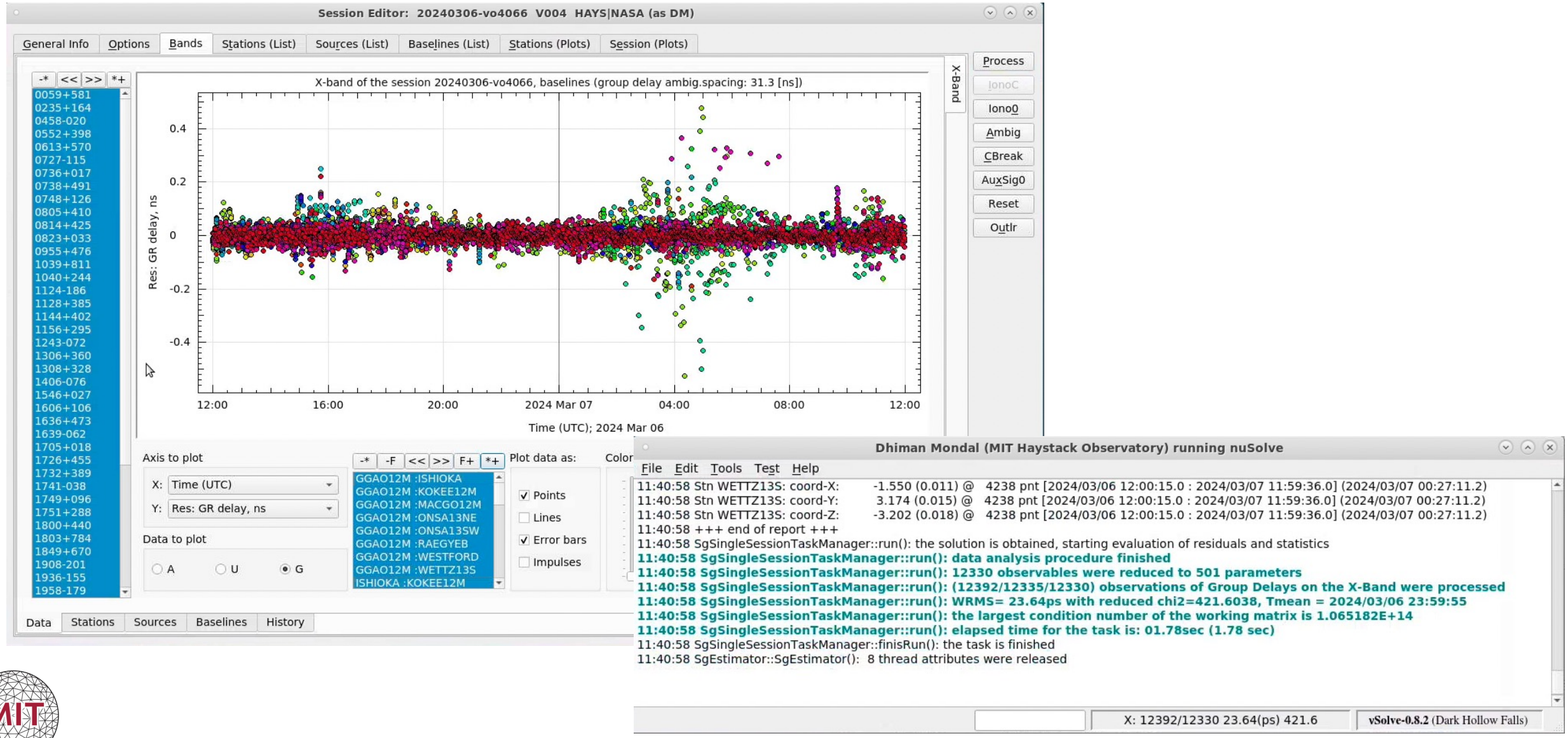
HAYSTACK OBSERVATORY

Processing VGOSDB



Ctrl+X

Initial Solution



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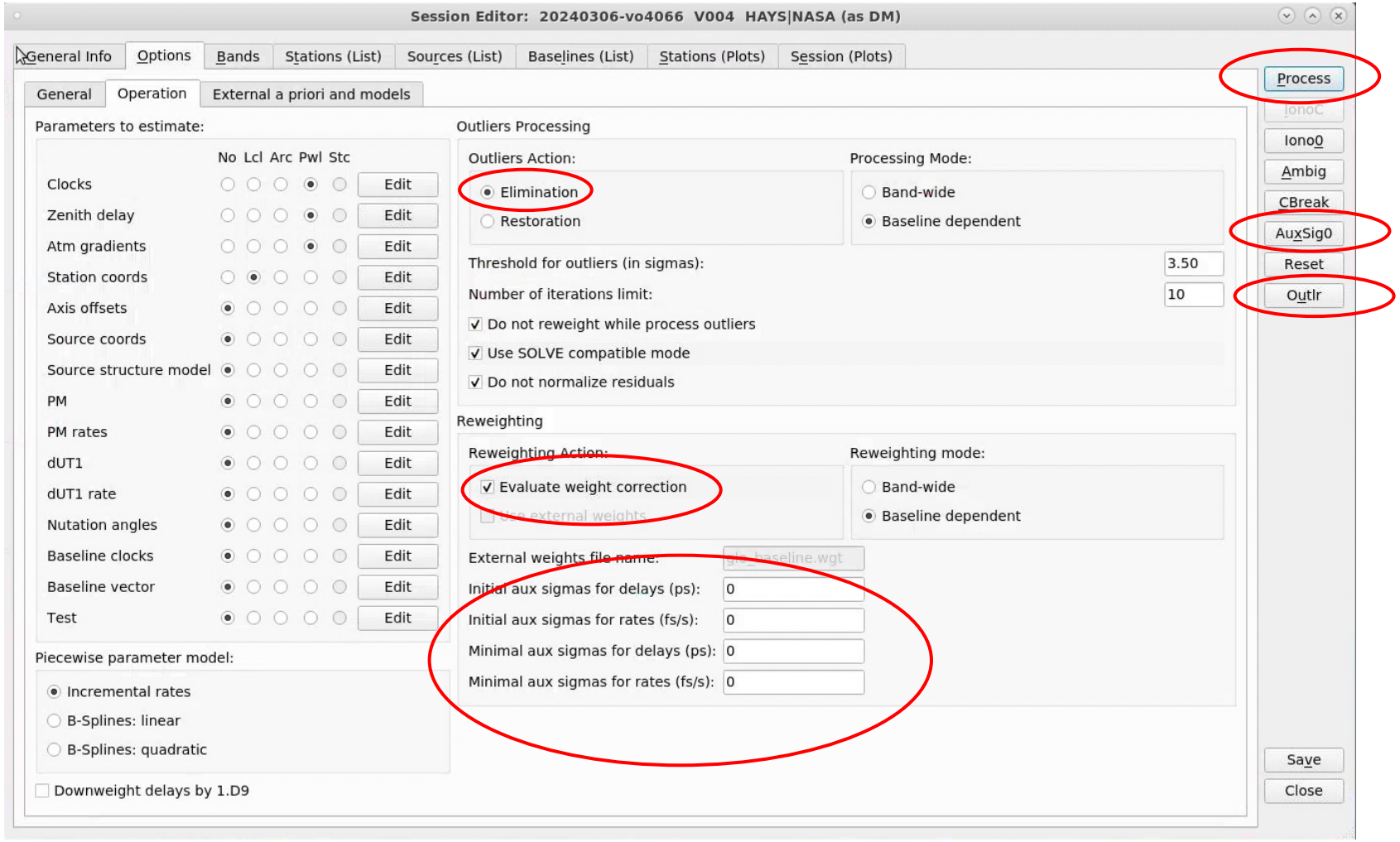
Outlier detection and re-weighting



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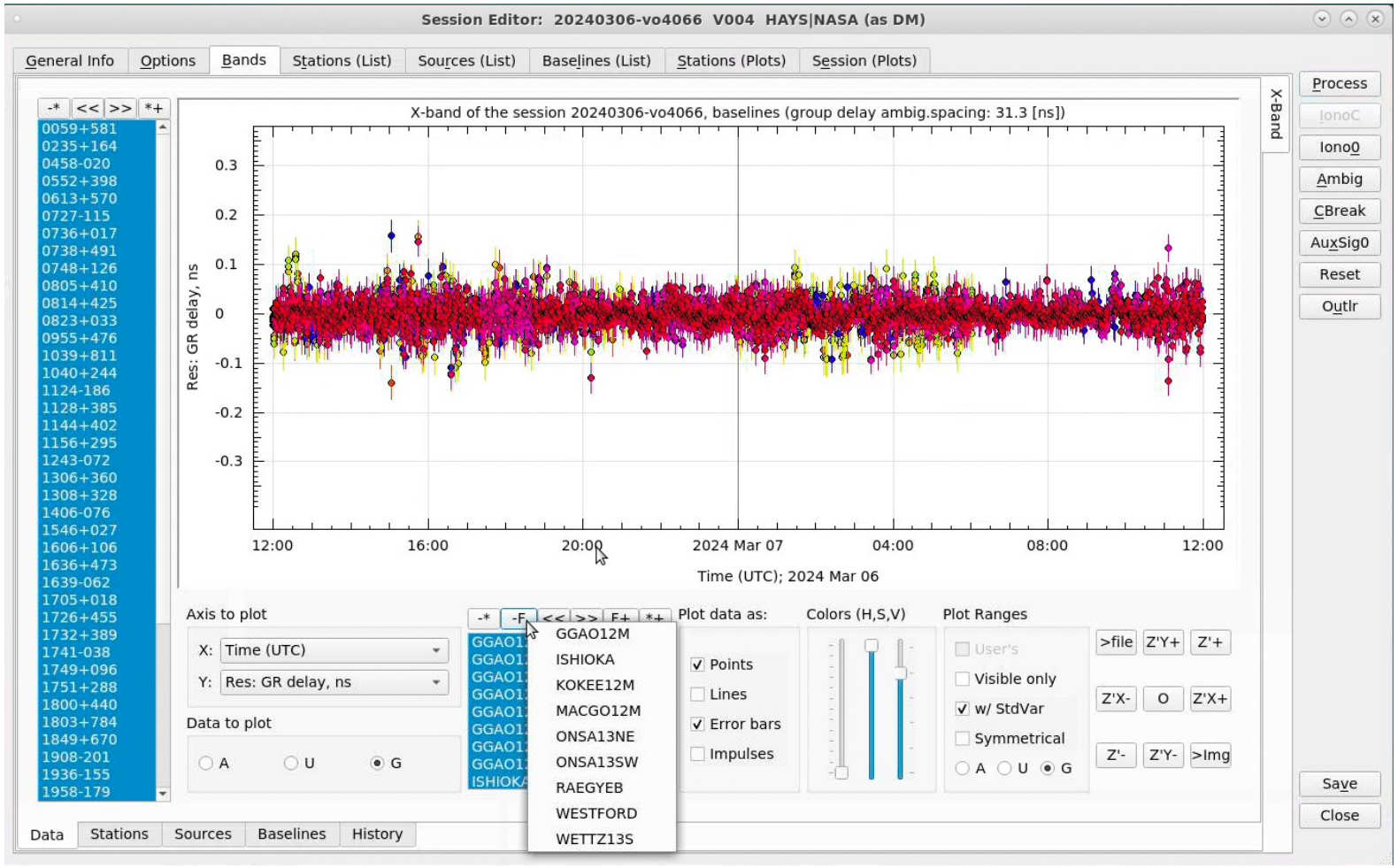
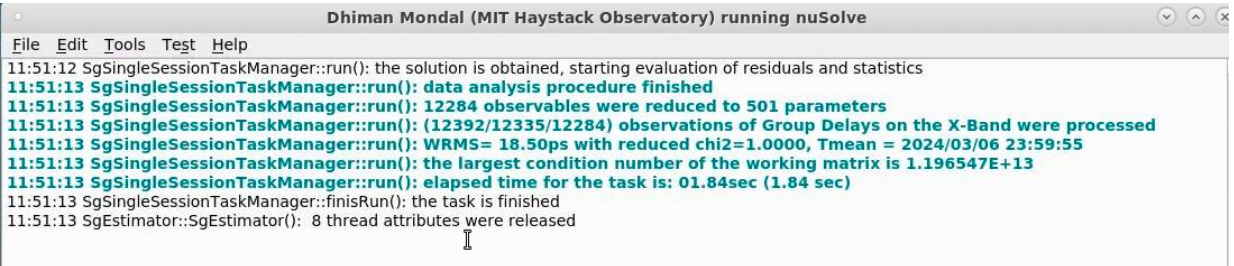
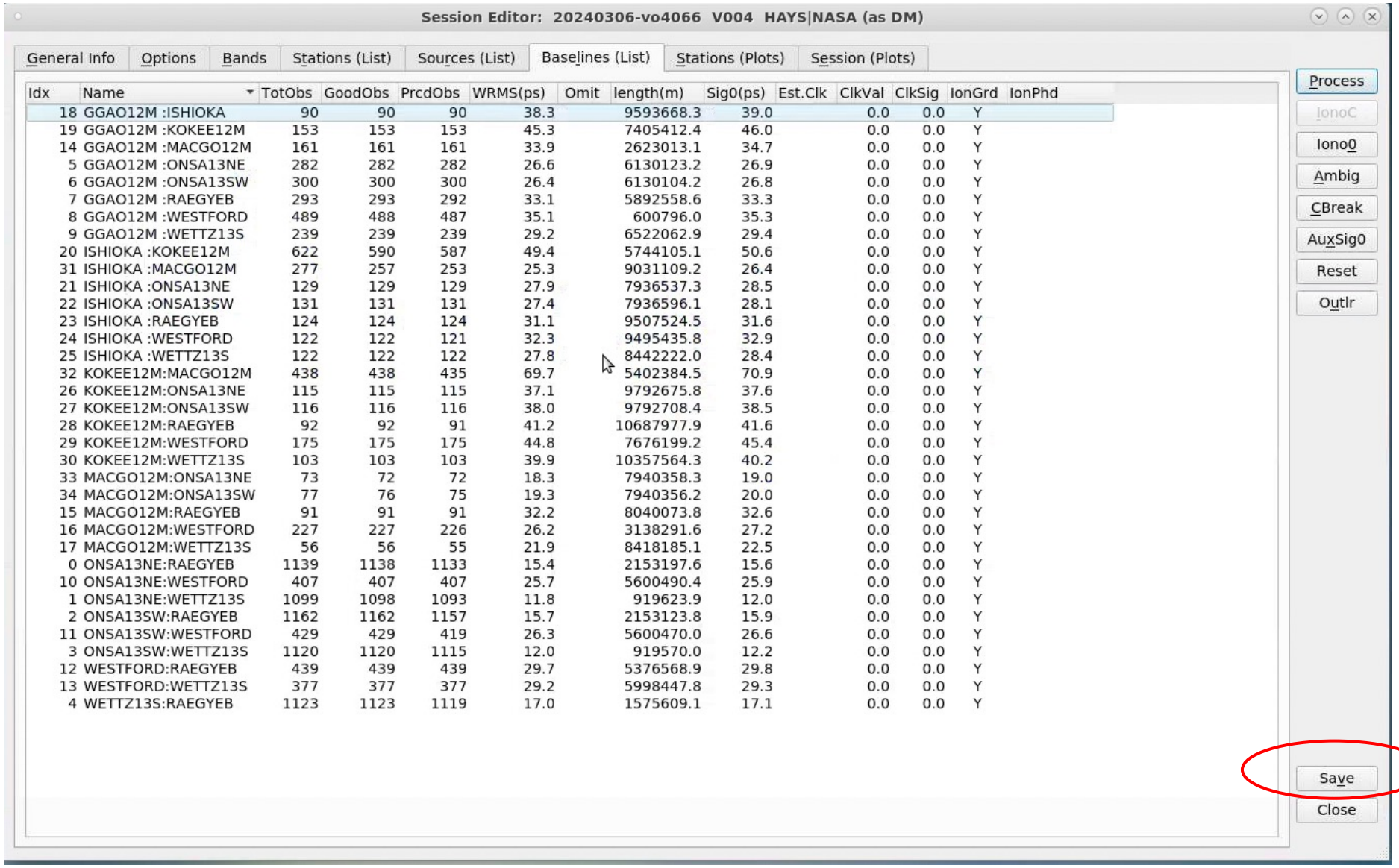
Final Solution

For plotting the parameter estimates, go to “Station (Plots)” tab





Final Solution



Idx	Name	TotObs	GoodObs	PrcdObs	WRMS(ps)	Omit	length(m)	Sig0(ps)	Est.Clk	ClkVal	ClkSig	IonGrd	IonPhd
18	GGAO12M :ISHIOKA	90	90	90	38.3		9593668.3	39.0		0.0	0.0	Y	
19	GGAO12M :KOKEE12M	153	153	153	45.3		7405412.4	46.0		0.0	0.0	Y	
14	GGAO12M :MACGO12M	161	161	161	33.9		2623013.1	34.7		0.0	0.0	Y	
5	GGAO12M :ONSA13NE	282	282	282	26.6		6130123.2	26.9		0.0	0.0	Y	
6	GGAO12M :ONSA13SW	300	300	300	26.4		6130104.2	26.8		0.0	0.0	Y	
7	GGAO12M :RAEGYEB	293	293	292	33.1		5892558.6	33.3		0.0	0.0	Y	
8	GGAO12M :WESTFORD	489	488	487	35.1		600796.0	35.3		0.0	0.0	Y	
9	GGAO12M :WETTZ13S	239	239	239	29.2		6522062.9	29.4		0.0	0.0	Y	
20	ISHIOKA :KOKEE12M	622	590	587	49.4		5744105.1	50.6		0.0	0.0	Y	
31	ISHIOKA :MACGO12M	277	257	253	25.3		9031109.2	26.4		0.0	0.0	Y	
21	ISHIOKA :ONSA13NE	129	129	129	27.9		7936537.3	28.5		0.0	0.0	Y	
22	ISHIOKA :ONSA13SW	131	131	131	27.4		7936596.1	28.1		0.0	0.0	Y	
23	ISHIOKA :RAEGYEB	124	124	124	31.1		9507524.5	31.6		0.0	0.0	Y	
24	ISHIOKA :WESTFORD	122	122	121	32.3		9495435.8	32.9		0.0	0.0	Y	
25	ISHIOKA :WETTZ13S	122	122	122	27.8		8442222.0	28.4		0.0	0.0	Y	
32	KOKEE12M:MACGO12M	438	438	435	69.7		5402384.5	70.9		0.0	0.0	Y	
26	KOKEE12M:ONSA13NE	115	115	115	37.1		9792675.8	37.6		0.0	0.0	Y	
27	KOKEE12M:ONSA13SW	116	116	116	38.0		9792708.4	38.5		0.0	0.0	Y	
28	KOKEE12M:RAEGYEB	92	92	91	41.2		10687977.9	41.6		0.0	0.0	Y	
29	KOKEE12M:WESTFORD	175	175	175	44.8		7676199.2	45.4		0.0	0.0	Y	
30	KOKEE12M:WETTZ13S	103	103	103	39.9		10357564.3	40.2		0.0	0.0	Y	
33	MACGO12M:ONSA13NE	73	72	72	18.3		7940358.3	19.0		0.0	0.0	Y	
34	MACGO12M:ONSA13SW	77	76	75	19.3		7940356.2	20.0		0.0	0.0	Y	
15	MACGO12M:RAEGYEB	91	91	91	32.2		8040073.8	32.6		0.0	0.0	Y	
16	MACGO12M:WESTFORD	227	227	226	26.2		3138291.6	27.2		0.0	0.0	Y	
17	MACGO12M:WETTZ13S	56	56	55	21.9		8418185.1	22.5		0.0	0.0	Y	
0	ONSA13NE:RAEGYEB	1139	1138	1133	15.4		2153197.6	15.6		0.0	0.0	Y	
10	ONSA13NE:WESTFORD	407	407	407	25.7		5600490.4	25.9		0.0	0.0	Y	
1	ONSA13NE:WETTZ13S	1099	1098	1093	11.8		919623.9	12.0		0.0	0.0	Y	
2	ONSA13SW:RAEGYEB	1162	1162	1157	15.7		2153123.8	15.9		0.0	0.0	Y	
11	ONSA13SW:WESTFORD	429	429	419	26.3		5600470.0	26.6		0.0	0.0	Y	
3	ONSA13SW:WETTZ13S	1120	1120	1115	12.0		919570.0	12.2		0.0	0.0	Y	
12	WESTFORD:RAEGYEB	439	439	439	29.7		5376568.9	29.8		0.0	0.0	Y	
13	WESTFORD:WETTZ13S	377	377	377	29.2		5998447.8	29.3		0.0	0.0	Y	
4	WETTZ13S:RAEGYEB	1123	1123	1119	17.0		1575609.1	17.1		0.0	0.0	Y	

Click save to write the results In the spoolfile

MIT HAYSTACK OBSERVATORY

Results

Dhiman Mondal (MIT Haystack Observatory) running nuSolve

File Edit Tools Test Help

```
ATMODM
12:00:37 SgSolutionReporter::report2spoolFile(): the estimated clock PWL-parameters have been saved in the file: /home/dmondal/nuSolve/spool_files/CLOCDM
12:00:37 NsSessionHandler::generateReport(): spoolfile output has been saved in the SPLFDM file
12:00:37 NsSessionHandler::generateReport(): spoolfile output has been copied as /home/dmondal/nuSolve/Reports/20240306-vo4066.SFF file too
```

Mate Terminal

File Edit View Search Terminal Help

```
1Run 25128-1600
 Analysis center: MIT -- MIT Haystack Observatory
 Analyst:         Dhiman Mondal ( dmondal@mit.edu )
 Machine:         demi  x86_64  Linux 3.10.0-693.21.1.el7.x86_64
 Executables:     /home/dmondal
 Solve initials:  DM
 Spool format:    SgLib-0.8.2 (Compton Peak)
 Local time:      2025.05.08-12:00:37
 Correlator type: MK4
 Mark-3 db_name:

 Data base 20240306-vo4066 Ver  4

 Matrix Condition Number =   1.196546850502721E+13

 Listing_Options:  CRES_EMULATION NO  BASELINES NO  MINIMUM NO
 Listing_Options:  MAPPED_EOP_OUTPUT NO  SEG_OUTPUT NO  APRIORI_ZENDEL NO
 Listing_Options:  NRD_TABLE YES  CHI_TABLE NO  SRC_STAT PRE2004  SEG_STYLE PRE2005
 SgLib release  :  2023 May 25

  Flyby Station Cals:    DB Station Cals:             | DB Non-station Cals: | Atmosphere Partial:
 ------------------------------------------------------------------------------------------------
    GGAO12M :NMFDRFLY    cable    GION                | Pol Tide             | NMFWTFLY
    ISHIOKA :NMFDRFLY    cable    GION                | WobXCont             |
    KOKEE12M:NMFDRFLY    cable    GION                | WobYCont             |
    MACGO12M:NMFDRFLY    cable    GION                | EarthTid             |
    ONSA13NE:NMFDRFLY    cable    GION                | Ocean                |
    ONSA13SW:NMFDRFLY    cable    GION                | UT1Ortho             |
    RAEGYEB :NMFDRFLY    cable    GION                | XpYpOrth             |
    WESTFORD:NMFDRFLY    cable    GION                | XpYpLib              |
    WETTZ13S:NMFDRFLY    cable    GION                | UT1Libra             |
                                                      | OPTLCont             |
 ------------------------------------------------------------------------------------------------
 CALC Version:  11.02  SgLib-0.8.2 (Compton Peak)

  Met Statistics:
                  Temperature      Pressure        Humidity
   Station         average   rms   average   rms   average   rms
    GGAO12M   MET     10.8     0.6 1005.9     3.0    98.2     1.6
   ISHIOKA   MET      5.1     2.5  1000.2     1.7    78.3    14.2
   KOKEE12M  MET     13.5     1.6   891.5     0.7    89.0    12.0
   MACGO12M  MET     12.7     2.2   805.9     1.4    21.7     5.1
   ONSA13NE  MET      2.4     2.7  1030.6     0.8    76.3    11.2
   ONSA13SW  MET      2.4     2.7  1030.6     0.8    76.4    11.2
   RAEGYEB   MET      7.8     2.8   909.6     2.8    64.5    13.7
   WESTFORD  MET      7.6     2.3  1002.3     2.9    95.5     7.4
   WETTZ13S  MET      3.2     2.7   948.7     0.6    84.1    13.3

 Run 25128-1600        12392 Observation Pairs Available
 Session started on:    2460376.000174   2024.03.06 12:00:15.000  UTC
 Actual duration:       86361.000  sec           00 23:59:21.000  sec
 Solution type: Group delay X combination

 Data Type     Number of   Weighted RMS    Normalized RMS   Chi Square
             Observations    Residual         Residual      (precis)
                 Used

   Delay    12284             18.495 ps             1.00       1.0000
   Rate         0                  0 fs/s           0.00       0.0000
Combined        0                                   0.00       0.0000
 ------------------------------------------------------------------------
 Used quality_code_limit:                                2
 Number of potentially recoverable observations:       12335
 Number of potentially good observations with QC 5-9:  12333
 Number of used observations:                          12284  ( 99.59%)
 Number of suppressed observations:                       51  (  0.41%)
 ------------------------------------------------------------------------



 Baseline Statistics
     Baseline       # W.Obs   W.RMS Del   N.R.D.   N.R.D. W.RMS Rate   N.R.R.  D.RW   R.RW
                                                                                    1,2
```

```
 Parameter adjustments for run 25128-1600 User=DM
 Reference epoch for polynomial models: 24/03/07 00:00
                                    Parameter              Adjustment             a-sigma             m-sigma
      WESTFORD CLCK 24/03/06 12:01 Reference
Station positions are for epoch: 2024.03.06-19:42:10
    1. GGAO12M  7622 NOAM  X Comp       1130729814.73 mm        -16.647 mm             1.293 mm             1.293 mm
    2. GGAO12M  7622 NOAM  Y Comp      -4831245951.64 mm         40.745 mm             2.715 mm             2.715 mm
    3. GGAO12M  7622 NOAM  Z Comp       3994228283.70 mm        -57.480 mm             2.707 mm             2.707 mm
       GGAO12M  7622       U Comp                -69.96 mm        -69.960 mm             3.814 mm             3.814 mm
       GGAO12M  7622       E Comp                 -6.92 mm         -6.924 mm             0.980 mm             0.980 mm
       GGAO12M  7622       N Comp                -17.29 mm        -17.289 mm             0.929 mm             0.929 mm
    4. GGAO12M  CL 0 24/03/06 12:01                          -182279.535 ns              0.235 ns             0.235 ns
    5. GGAO12M  CL 1 24/03/06 12:01                            -755.804 D-14             0.539 D-14           0.539 D-14
    6. GGAO12M  CL 2 24/03/06 12:01                               4.448 D-14/day         1.070 D-14/day       1.070 D-14/day
   31. GGAO12M  AT 0 24/03/06 12:00                             -80.319 ps              4.022 ps             4.022 ps
       GGAO12M  Atm  2024.03.06-13:20:17.900  Avg:   -29.024 ps   Rms:      71.416 ps   Tot_Rms:      71.415 ps
   56. GGAO12M  NG 24/03/06 12:00                                0.763 mm             0.275 mm             0.275 mm
   57. GGAO12M  EG 24/03/06 12:00                               -0.297 mm             0.233 mm             0.233 mm
   58. GGAO12M  NG 24/03/07 11:59                                0.763 mm             0.275 mm             0.275 mm
   59. GGAO12M  EG 24/03/07 11:59                               -0.297 mm             0.233 mm             0.233 mm

Station positions are for epoch: 2024.03.06-22:02:13
   60. ISHIOKA  7369 NOAM  X Comp      -3959636273.54 mm         12.610 mm             2.986 mm             2.986 mm
   61. ISHIOKA  7369 NOAM  Y Comp       3296825492.99 mm         40.795 mm             2.869 mm             2.869 mm
   62. ISHIOKA  7369 NOAM  Z Comp       3747042556.42 mm          4.302 mm             3.335 mm             3.335 mm
       ISHIOKA  7369       U Comp                 15.78 mm         15.784 mm             4.181 mm             4.181 mm
       ISHIOKA  7369       E Comp                -39.42 mm        -39.419 mm             1.749 mm             1.749 mm
       ISHIOKA  7369       N Comp                 -6.22 mm         -6.224 mm             2.780 mm             2.780 mm
   63. ISHIOKA  CL 0 24/03/06 12:06                          -97973.465 ns              0.234 ns             0.234 ns
   64. ISHIOKA  CL 1 24/03/06 12:06                            -265.741 D-14             0.420 D-14           0.420 D-14
   65. ISHIOKA  CL 2 24/03/06 12:06                               2.629 D-14/day         0.762 D-14/day       0.762 D-14/day
   90. ISHIOKA  AT 0 24/03/06 12:00                              62.493 ps              8.402 ps             8.402 ps
       ISHIOKA  Atm  2024.03.06-15:09:33.544  Avg:    25.736 ps   Rms:      42.477 ps   Tot_Rms:      42.476 ps
  115. ISHIOKA  NG 24/03/06 12:00                                1.998 mm             0.430 mm             0.430 mm
  116. ISHIOKA  EG 24/03/06 12:00                               -0.285 mm             0.116 mm             0.116 mm
  117. ISHIOKA  NG 24/03/07 11:59                                1.998 mm             0.430 mm             0.430 mm
  118. ISHIOKA  EG 24/03/07 11:59                               -0.285 mm             0.116 mm             0.116 mm

Station positions are for epoch: 2024.03.06-20:30:04
  119. KOKEE12M 7623 PCFC  X Comp      -5543831838.93 mm        -44.808 mm             7.103 mm             7.102 mm
  120. KOKEE12M 7623 PCFC  Y Comp      -2054585364.38 mm         26.957 mm             3.871 mm             3.871 mm
  121. KOKEE12M 7623 PCFC  Z Comp       2387829086.48 mm         15.116 mm             4.601 mm             4.601 mm
       KOKEE12M 7623       U Comp                 35.94 mm         35.937 mm             8.284 mm             8.284 mm
       KOKEE12M 7623       E Comp                -40.85 mm        -40.848 mm             3.043 mm             3.043 mm
       KOKEE12M 7623       N Comp                  1.71 mm          1.706 mm             2.953 mm             2.953 mm
  122. KOKEE12M CL 0 24/03/06 12:06                          -88923.847 ns              0.237 ns             0.237 ns
  123. KOKEE12M CL 1 24/03/06 12:06                            -287.530 D-14             0.419 D-14           0.419 D-14
  124. KOKEE12M CL 2 24/03/06 12:06                               4.760 D-14/day         0.759 D-14/day       0.759 D-14/day
  149. KOKEE12M AT 0 24/03/06 12:00                            -327.000 ps             19.962 ps            19.962 ps
       KOKEE12M Atm  2024.03.06-15:25:33.029  Avg:  -271.106 ps   Rms:      42.880 ps   Tot_Rms:      42.879 ps
  174. KOKEE12M NG 24/03/06 12:00                               -1.771 mm             1.219 mm             1.219 mm
  175. KOKEE12M EG 24/03/06 12:00                               -4.210 mm             1.086 mm             1.086 mm
  176. KOKEE12M NG 24/03/07 11:59                               -1.771 mm             1.219 mm             1.219 mm
  177. KOKEE12M EG 24/03/07 11:59                               -4.210 mm             1.086 mm             1.086 mm

Station positions are for epoch: 2024.03.06-20:23:25
  178. MACGO12M -001 NOAM  X Comp      -1330788525.59 mm       -1382.332 mm             1.778 mm             1.778 mm
  179. MACGO12M -001 NOAM  Y Comp      -5328106547.85 mm       -5766.917 mm             4.806 mm             4.806 mm
  180. MACGO12M -001 NOAM  Z Comp       3236427440.61 mm        3535.507 mm             3.833 mm             3.833 mm
       MACGO12M -001       U Comp               6903.95 mm        6903.955 mm             5.952 mm             5.952 mm
       MACGO12M -001       E Comp                 56.33 mm          56.327 mm             1.857 mm             1.857 mm
       MACGO12M -001       N Comp                 14.86 mm          14.861 mm             1.442 mm             1.442 mm
  181. MACGO12M CL 0 24/03/06 12:04                          -37288.312 ns              0.235 ns             0.235 ns
  182. MACGO12M CL 1 24/03/06 12:04                            -374.586 D-14             0.417 D-14           0.417 D-14
  183. MACGO12M CL 2 24/03/06 12:04                               2.541 D-14/day         0.748 D-14/day       0.748 D-14/day
  208. MACGO12M AT 0 24/03/06 12:00                              47.154 ps              9.857 ps             9.857 ps
       MACGO12M Atm  2024.03.06-14:23:12.968  Avg:    49.490 ps   Rms:      18.230 ps   Tot_Rms:      18.229 ps
  233. MACGO12M NG 24/03/06 12:00                               -2.045 mm             0.776 mm             0.776 mm
  234. MACGO12M EG 24/03/06 12:00                                0.554 mm             0.556 mm             0.556 mm
  235. MACGO12M NG 24/03/07 11:59                               -2.045 mm             0.776 mm             0.776 mm
  236. MACGO12M EG 24/03/07 11:59                                0.554 mm             0.556 mm             0.556 mm
                                                                                                      267,2         54%
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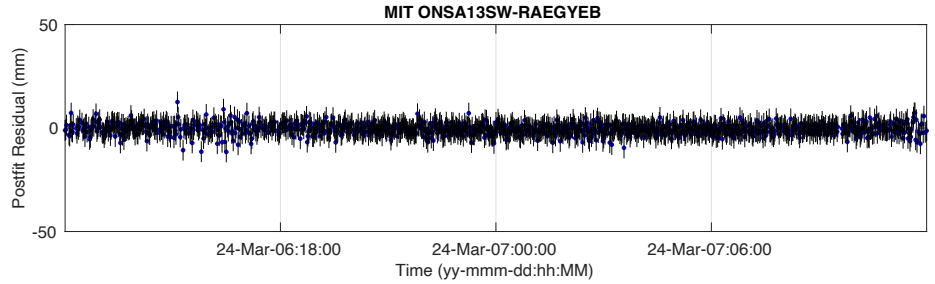
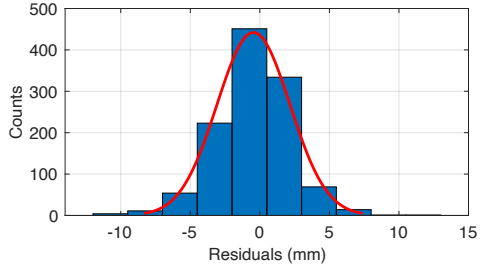
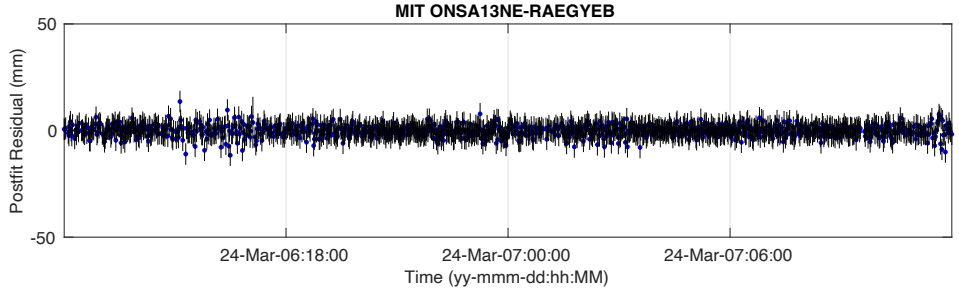
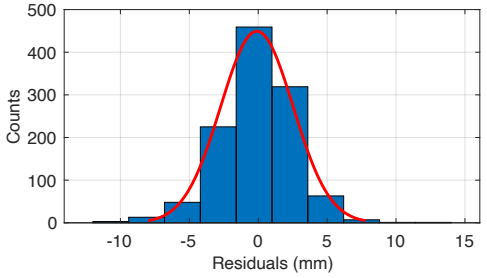
Plotting the results





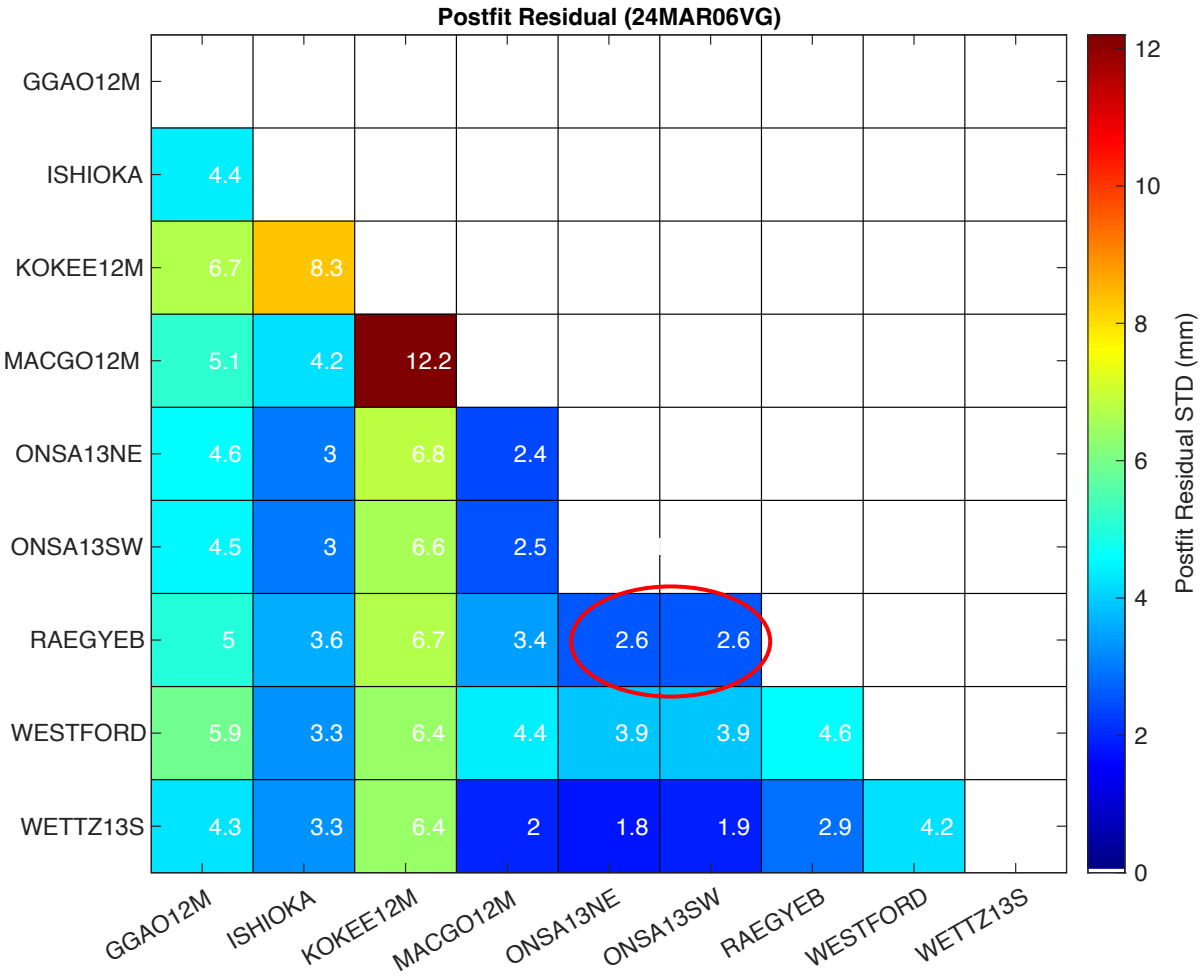
residual μ = -0.458 mm
residual σ = 2.6 mm
observations used = 1162
outliers = 0





residual μ = -0.096 mm
residual σ = 2.6 mm
observations used = 1139
outliers = 0

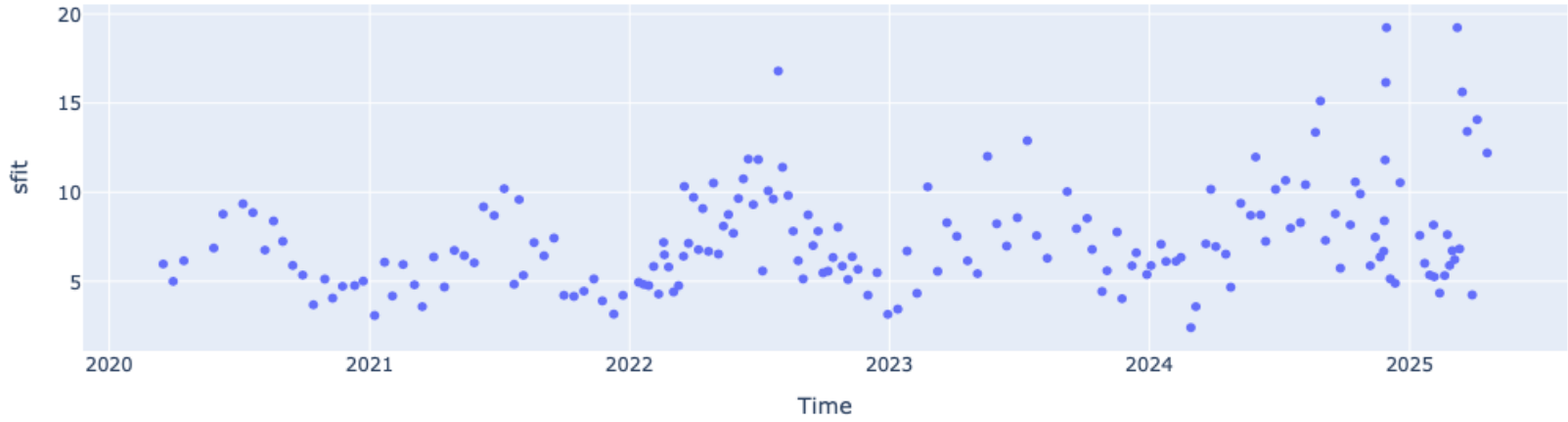
dUT1 = 4.7±1.1 mu s



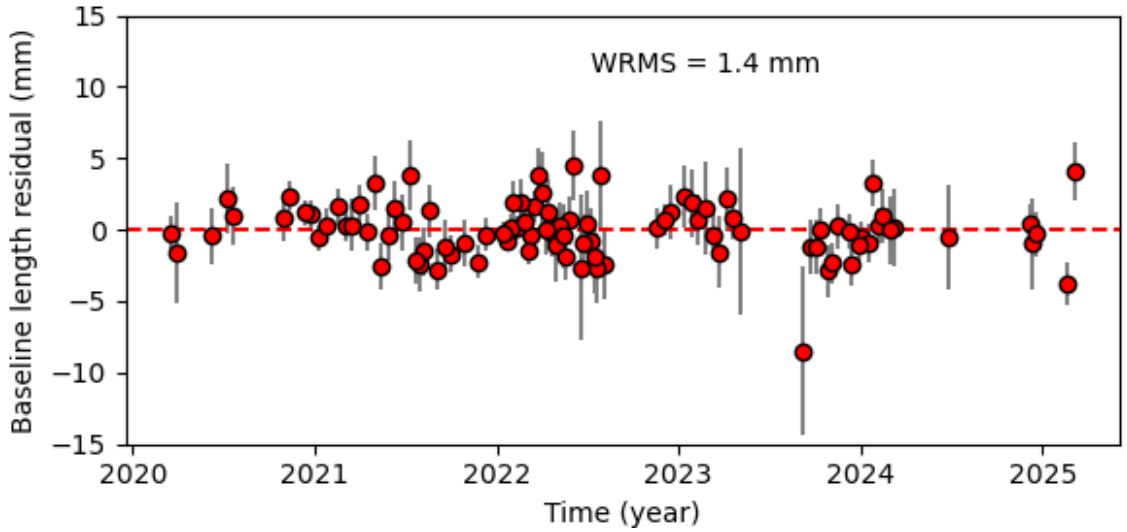
X coordinate estimate (1.16 +- 0.09 cm) of GGAO12M (in NNR/NNT) is significant on 5 sigma level
Y coordinate estimate (-1.84 +- 0.15 cm) of GGAO12M (in NNR/NNT) is significant on 5 sigma level
Y coordinate estimate (2.16 +- 0.16 cm) of ISHIOKA (in NNR/NNT) is significant on 5 sigma level
X coordinate estimate (-2.62 +- 0.30 cm) of KOKEE12M (in NNR/NNT) is significant on 5 sigma level
Y coordinate estimate (-0.94 +- 0.15 cm) of KOKEE12M (in NNR/NNT) is significant on 5 sigma level
Z coordinate estimate (-0.74 +- 0.12 cm) of KOKEE12M (in NNR/NNT) is significant on 5 sigma level
Z coordinate estimate (-1.69 +- 0.26 cm) of MACGO12M (not in NNR/NNT) is significant on 5 sigma level
Y coordinate estimate (0.35 +- 0.04 cm) of ONSA13NE (in NNR/NNT) is significant on 5 sigma level
Y coordinate estimate (0.35 +- 0.04 cm) of ONSA13SW (in NNR/NNT) is significant on 5 sigma level
X coordinate estimate (0.83 +- 0.13 cm) of RAEGYEB (in NNR/NNT) is significant on 5 sigma level
Y coordinate estimate (0.40 +- 0.06 cm) of RAEGYEB (in NNR/NNT) is significant on 5 sigma level
Z coordinate estimate (0.71 +- 0.11 cm) of RAEGYEB (in NNR/NNT) is significant on 5 sigma level
X coordinate estimate (0.68 +- 0.09 cm) of WESTFORD (in NNR/NNT) is significant on 5 sigma level

Comparing the results

Session fit (mm)



Gg-Wf baseline



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