Determination of Pointing Parameters
IRAM Plateau de Bure Interferometer

S. Guilloteau[1]

Document probably older than you think

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(1) Institut de Radio Astronomie Millimétrique
300 Rue de la Piscine
F-38406 Saint Martin d'Hères

This document describes the current tools for determining the pointing of the antennas on Plateau de Bure. Good pointing is essential to the operation of the interferometer. Unfortunately, there are many ways to do bad or poor pointing, and no simple way to do it well. Please read this document carefully . Its contents are important.

This document is a sum up of the steps relevant for pointing. More details on the individual programs and command mentionned in this document are available in:

- IRAM Plateau de Bure Interferometer: Introduction
- IRAM Plateau de Bure Interferometer: OBS Users Guide
- CLASS Users Guide
- CLIC Users Guide
- SIC and GREG Users Guide

Contents

1 Basic pointing parameters

1.1 Parameter List

Let dX and dY be the offsets on the sky parallel to the Azimuth axis and Elevation axis respectively, produced by a pointing error. The standard pointing model for the Plateau de Bure antennas has the following parameters:

```
IAZ      azimuth encoder zero
         dX = IAZ*cos(El)              dY = 0
IEL      elevation encoder zero
         dX = 0                        dY = IEL
COH      telescope azimuth collimation
         dX = cos(El)*asin(COH/cos(El)) dY = -asin(sin(El)/sqrt(1-COH**2))
         for COH << cos(El), equivalent to
         dX = COH                      dY = 0,
COV      telescope vertical collimation
         dX = 0                        dY = COV
MVE      Azimuth axis tilt towards East
         dX =  MVE*cos(Az)*sin(El)     dY = -MVE*sin(Az)
MVN      Azimuth axis tilt towards North
         dX = -MVN*sin(Az)*sin(El)     dY = -MVN*cos(Az)
NPE      Elevation axis tilt (axis non perpendicularity)
         dX = -NPE*sin(El)             dY = 0
         (assuming small NPE and COH in practice.)
REF0     First order refraction coefficient
         dX = 0                        dY = -REF0/tan(El)
REF1     Second order refraction coefficient
         dX = 0                        dY = -REF1/tan(El)**3
ELES     gravity+eccentricity of Elevation encoder
         dX = 0                        dY =  ELES*sin(El)
ELEC     gravity+eccentricity of Elevation encoder
         dX = 0                        dY =  ELEC*cos(El)
AZES     eccentricity of Azimuth encoder
         dX = AZES*sin(Az)*cos(El)     dY = 0
AZEC     eccentricity of Azimuth encoder
         dX = AZEC*cos(Az)*cos(El)     dY = 0
HEL      Homology elevation bending (cos(El))
         dX = 0                        dY = -HEL*cos(El)
```

The total pointing correction is thus, in the small COH approximation

```
    dX = IAZ.cos(El) + COH + sin(El) * (MVE*cos(Az)-MVN*sin(Az)-NPE)
          + cos(El) * (AZES*sin(Az)+AZEC*cos(Az))
    dY = IEL+COV - (MVE*sin(Az)+MVN*cos(Az))
          + (ELES*sin(El)+(ELEC-HEL)*cos(El))
          - REF0/tan(El) - REF1/tan(El)**3 - REF2/tan(El)**5
```

Since each antenna is equipped with an off-axis optical telescope, there are two sets of `(COH,COV)` values, one for the radio axis and one for the optical axis. As only `IEL+COV` is meaningful, the radio `COV` is set to zero, fixing the `IEL` value.

Five terms dominate the pointing model : `IAZ, IEL+COV, COH, MVE` and `MVN`. In principle `COH, IEL,` and `COV` depend only on the antenna, `MVE` and `MVN` depend on the station and antenna (azimuth bearing), and `IAZ` depends on the antenna (encoder), the station (footpad positions) and the positioning of the antenna on the station (repeatability 1 mm).

The refraction coefficients are weather dependant. Accordingly, the parameters are computed in real time, using temperature, pressure and humidity. REF0 and REF1 are thus fixed to zero in the pointing fit.

Among the other terms, all of which depend on the antenna, just two have been found to be of some importance for some antennas: `ELEC` which enters only in combination with `HEL` in radio (small values on all antennas), and possibly `NPE` (Antenna 3). These are marginally different from zero, however, and confirmation will be required. The other parameters can be set to zero.

1.2 Parameter Files

The values for these parameters used in real time are stored in several parameter files, located under directory INTER_BASE:. To follow the logical dependence of the parameters upon antenna and station, several files exist :

- GENERAL.ANk
  where k is an antenna number. These files contain the parameters which only depends on the antenna: radio and optical collimations `COH` and `COV`, `NPE, AZEC, AZES, ELEC, ELES,` and also a default value for `IAZ`. They also contain the homology elevation bending, `HEL`, the subreflector parameters: `HTR0` and `HTR1` for translation, `HVT0` and `HVT1` for tilt, `HFO0` and `HFO1` for focus; and two beam-switch parameters (sign and beam separation).

- Sij.ANk
  where Sij is a station name (for example W00), and k an antenna number. These files contains the Antenna-Station dependent parameters, for pointing `IAZ, MVE,` and `MVN`, and for interferometry, the `Delay`, and the position `X,Y,Z`.

The Sij.ANk should *never* be editted, but should only be changed using the CONFIGURE mode of OBS. The GENERAL.ANk file should be editted if a major change occur.

2 The POINT program

2.1 Description

The POINT program is a pointing parameter fitting program based on the SIC user interface, and GREG for graphic display. It is called by the command:

```
$ POINT
```

A typical session with POINT is:

- `GREG1\DEVICE RETRO`
  Define graphic device for display

- `FILE 16-OCT-1989 RADIO`
  Define the input data file and type. Three data types exist: RADIO, for single-dish radio pointing results, INTER for interferometric pointing results, and OPTICAL for optical pointing data. The file extension is derived from the data type using the following defaults :

.RAD, .INT and .OPT respectively. .RAD files are produced by the CLASS `ANALYSE\PRINT POINTING` command, .INT files are produced by the CLIC `CLIC\SOLVE POINTING` command, and .OPT files are produced by the DCL SAV command on the real-time microVAX BURE01. The data type also defines the default variable parameters.

- `READ 2`
  Read the data for Antenna 2 from the input file.

- `SOLVE`
  Solve for the pointing parameters using the currently read data.

- `PLOT SUMMARY`
  Display on the graphic device a summary of residual pointing errors; residual in Elevation versus residual in Azimuth.

- `PLOT COVERAGE`
  Display the Azimuth and Elevation coverage to see whether correlated parameters, such as `IAZ` and `COH` for example, are well determined or not.

- `PRINT/OUTPUT 16-OCT-1989.RADIO/HEADER`
  If both the summary and coverage look good, write the fit results to a file for the archive. The `/HEADER` option is used to write out the values of the fixed parameter also.

If some points appear discrepant in the fit or if the fit residuals are large, there are several possibilities for rejecting bad data points.

- `REJECT 8.0`
  Reject all data points with pointing residuals higher than 8.0" after the last `SOLVE` command.

- `SET RMS 2.0`
  Select only those data points for which the formal error on the pointing observation is less than 2.0". For INTER and RADIO data types, the formal error is computed by the CLIC and CLASS gauss fit commands, and the error is set to zero for OPTICAL data.

- `SET ELEVATION 10.0 80.0`
  Select only data points in the elevation range 10 to 80 degrees. The default elevation range is 5 to 90 degrees.

- `IGNORE/SCAN s1 s2 s3 TO s4 BY s5/SOURCE JUPITER`
  Ignore some scans in the data (the scan numbers are displayed by the `PLOT SUMMARY` command), or some sources. Previously ignored scans and sources can be reconsidered agin using the `INCLUDE` command (same syntax as `IGNORE`).

If the coverage is bad, it is interesting to fix some parameter to reduce the errors on correlated parameters. This is especially true for the radio COH, because the collimation is essentially a constant that depends only on the antenna. For example

- `PARAMETER COH 42.0`
  Will fix `COH` to 42".

- `PARAMETER MVE/FREE`
  Will free the (previously fixed) parameter `MVE`.

2.2 Optical versus Radio

The types of data files treated by POINT differ slightly. For Optical data, the pointing error is relative to a perfect antenna. Hence the `POINT\PRINT` output directly indicates the new pointing parameter values. For Radio (or Interferometer) data, however, the pointing error is relative to the previous model, *except for the collimations*. Hence `POINT\PRINT` yields directly `COH` and `COV`, but for all other parameters the POINT results should be added to the previous values.

In particular, the Radio results can be used in the OBS `SET\POINTING` command in an incremental way:

```
SET\POINTING IAZ IAZ+dIaz IEL IEL+dIel/ANTENNA 2
```

where `dIaz, dIel` are the results given by command `POINT\PRINT` for the parameters `IAZ, IEL`.

3 Optical Pointing

3.1 Getting data

Optical pointing is done using the MNU program, and the DCL commands CRE (CREate the data file), SAV (SAVe telescope coordinates in the data file), CAT (select a star from the star CATalog), and PLA (select a PLAnet), or using the automatic searching mode of MNU. Please refer to the document “Foreign Commands” by A. Perrigouard for a complete description of these commands.

Two different approaches can be used for the optical pointing, depending whether you have an idea of the pointing parameters or not.

- First, make a crude optical pointing with a few stars, 5-8 at low and 3-6 at high elevations, with good azimuth coverage. The accuracy need not be very good (5”). Then, use the newly determined pointing constants to make a more accurate pointing session with 40 to 60 stars. All stars should be rather well centered already , and now the centering accuracy can be made better (1”). Uniform coverage is not required: most important is to have low and high elevation sources.

- Or use only a single pass with 60 stars centered within 1”. This can take somewhat longer because the stars may be far off center.

3.2 Optical Pointing using MNU

MNU includes a mode for optical pointing, accessible through the `REFLECTOR` page:

GOLD /DEF	HELP /TOP	POINT /STOP	REMOTE MICRO
C.SYS /HORI	SPI.	Tracking GUID.	OFFS.
FOCUS	Second. TRANS	Mirror V TILT	H TILT
SAVE	NEXT /DIST	SLEW	MNU
INIT /SUB	ANT. REF.	REF. RAD /OPTIC	ANTEN.

In this mode, activated by the `POINT` key (`PF3` on the `REFLECTOR` page), it tries to find the best candidates to map the sky uniformly in azimuth and elevation. The density of stars is given by specifying the minimal distance angle between stars, using the `GOLD/DISTANCE (PF1/KP2)` key. To hasten a pointing session, the program will try to find candidates above 10 degrees in elevation and at the minimum distance (in time) from the current telescope position.

MNU uses a catalog of bright stars named J2000R.CAT in the [CONTROL.COMMAND] directory, on disk COMP$DISK:, and writes the pointing data in the most recently created *Date*.OPT file on directory [OBSERVER.POINTING], on disk RLTDATA (*Date* being a date in format DD-MMM-YYYY as usual). The file POINTING.OPT, also in [OBSERVER.POINTING], contains the name of the last pointing data file created along with its creation time. MNU assumes that the pointing concerns the default antenna. To find out or modify this default use the DCL command DEF [Ant], or use the `GOLD/DEF (PF1/PF1)` key to change it.

To start an optical pointing session, press the `POINT` key. The program opens the data file *Date*.OPT, reads and processes the records concerning the default antenna, and then closes the file. It opens the catalog file J2000R.CAT and processes the star coordinates in order to prepare and to speed up the calculations next to be performed. Next, the file is closed.

Specify a minimum distance between stars using the `GOLD/DISTANCE` key, for instance 10.0 for 10 degrees. MNU will look for the best candidate, given the present telescope position, the data already saved in *Date*.OPT, and the possible stars in the catalog file. To move to the next star, press the `NEXT (KP2)` key.

When the telescope stops slewing and tracks the star, use MNU to move the telescope slightly so the TV cross-hair is on the star. Meanwhile, as soon as the command to send the telescope to the requested position has been spawned, the catalog is searched for the next star candidate. Once the TV cross-hair is on the star, press the `SAVE (KP1)` key to append the star position, the current telescope position, the sidereal time and the refraction correction to the data file. If an error occurs while opening the file, the operation can be executed again.

Then go on using the `NEXT` key... Every time you press the `NEXT` key, a message saying "`No more candidate`" may appear. You should then either suspend your pointing sessions using the `GOLD/STOP (PF1/PF3)` key, or decrease the minimal distance between stars using the `GOLD/DISTANCE (PF1/KP2)` key.

3.3 Reducing data

To reduce optical pointing data, work on BURE02, in the [OBS.POINTING] directory, and use POINT, specifying the RLTDATA:[OBSERVER.POINTING]*Date*.OPT file as input:

```
$ SET DEF [OBS.POINTING]
$ POINT
POINT> FILE Date OPTICAL
POINT> READ Antenna_Number
POINT> SOLVE
POINT> [ Other commands ]
```

The file is fetch by default from directory RLTDATA:[OBSERVER.POINTING]. A fit will be made with the free parameters `IAZ IEL+COV COH MVE MVN`, and all other parameters fixed at zero. A fit with more free parameters (e.g. ELEC and NPE) can be made using the commands :

```
POINT> PARAMETER NPE/FREE
POINT> PARAMETER ELEC/FREE
```

Optical pointing gives only the sum `IEL+COV`. The zero of the elevation encoder is an antenna constant. After a fit by POINT all parameters should be replaced in the antenna-station parameter file.

4 Radio Pointing

4.1 Full sky, single-dish radio pointing

If the radio pointing has to be determined for the first time (new antenna, new receiver, new subreflector alignment, or other major changes), a full sky radio pointing is necessary. Using the OBS `OBS\POINT` command, observe 30 to 40 positions, preferably clustered at high and low elevations, but well spaced in azimuth.

Use CLASS on BURE02 to reduce the pointing measurements, working on the [OBS.SINGLE] directory. A procedure named PR:INIT_POINT can be used in CLASS to get started. Open the .BUR input file, get a list of the pointing scan, using commands FIND and LIST. Then the procedure PR:POINT can be used to process the data scan by scan. For each pointing scan, it averages separately the two azimuth and two elevation subscans, fit gaussians, with two coupled components in case of beam switching, to the averages, and at each PAUSE, the user can write the result in an output data file, named *Date*.BUR-POINT. This can be done while data acquisition is still going on. Once all data have been reduced, open the reduced data file in input, select all data using the `LAS\FIND` command, and then use `ANALYSE\PRINT POINT/OUTPUT [-.POINTING]`*`Date`*`.RAD` to write out the fit results.

Stop CLASS and move to [OBS.POINTING] directory to use POINT to fit the pointing parameters. The default adjustable parameters are `IAZ, IEL+COV, MVE,` and `MVN`, while `COH` is set to its antenna dependent value, found from file INTER_BASE:GENERAL.ANk.

In RADIO mode, POINT gives *variations from the previous parameter values, except for* `COH` *where it gives the absolute value* (note `COV = dIEL`, the variation of `IEL`). Refraction parameters should always be fixed to zero, since the radio refraction is computed in real time.

4.2 Interferometer pointing

Pointing sources can be observed with the OBS command

```
OBS\POINT /ANTENNA Iant /LENGTH 60
```

in INTERferometry mode if only antenna `Iant` is to be pointed, or

```
OBS\POINT /LENGTH 40
```

if all antennas must be pointed.

Data reduction can then be done with the `CLIC\SOLVE POINTING` command in CLIC, working on the [OBS.POINTING] directory. Select a set of pointing scans with the `CLIC\FIND` command (use `SET PROCEDURE POINT`) and process these scans with `CLIC\SOLVE POINTING [/PLOT] /OUTPUT `*`Date`*`.INT`. By default data is appended to that file, add argument `NEW` after the *`Date`*`.INT` file name to create a new one.

For continuum sources, you should use `SET SUB C01 TO C10` and `SET AVERAGE METHOD VECTOR`. You might want to do an RF_PASSBAND calibration to be able to average both sidebands (`SET RF ON, SET BAND AVERAGE`); this is absolutely necessary at high frequencies to improve signal to noise ratio. If observing SiO masers at the standard frequency (86.051 USB LOW), use `SET SUB C02` and `SET BAND UPPER` to process the data in CLIC.

Then, use POINT the same way as for the RADIO (single-dish) data.

4.3 Limited radio pointing determination

Once the optical pointing parameters have been determined and entered in the Antenna-Station file, only one radio pointing on a strong source is needed to get the radio `COV` and the radio `IAZ`. The radio `COH` should be set to its (antenna-only dependent) value.

If the optical `COV` was already well known, you should find the radio `COV = 0`. Radio `IAZ` is determined as follows: measure the azimuth pointing error, divide it by `cos(Elevation)`, and **subtract** the result from `IAZ` (Oui, **soustraire**). You should then be ready for a radio observing !

5 Inclinometers

All antennas are equipped with one inclinometer, that should allow determination of the inclinations without astronomical pointing. Regular monitoring of the inclinometer outputs *must be made*. It is especially important to get the inclinometer results before and after each pointing session. To use the inclinometers:

- Send an antenna North at some elevation, chosen to avoid the sun at any azimuth, for example using antenna `Iant`
  `$ COO ANTE Iant HO 180D 85D NULL`, under DCL, or
  `OBS\SOURCE INCLINO, OBS\LOAD`, within OBS
- Once the antenna stops, run the inclinometer program
  `$ INC Iant /PLOT`

The antenna will do a full turn at the current elevation, and a sine curve will be fit to the inclinations measured every 5 degrees. From this fit, the parameters MVE and MVN are derived from the azimuth axis tilt measured by the inclinometers using three additional corrections:

- a change of sign due to conventions on the orientation of the vertical.
- a local vertical correction to refer the inclinations to the vertical of the array center
- a global gravity corrections of MVE = +10", MVN = +7", to correct for large scale deviations of the gravity field due to the Alps.

The resulting `MVE` and `MVN` are displayed and written in the file `INTER_BASE:INCLINO.ANi`, where `i = Iant`. The fit is displayed by GreG if you specified the `/PLOT` option for the INC command. A hardcopy possibility is offered.

6 Cookbook, Tricks, and Traps

It is difficult to produce a cookbook recipe for getting the pointing parameters. The following **Traps** should be avoided, however:

- Azimuth Elevation coverage
  It MUST be reasonable. Never believe the formal errors on `MVE` or `MVN` if the Azimuth coverage is less than 270 degrees. Never believe the formal error on `COH` if the elevation coverage is less than 60 degrees. From the pointing error equations, it can be seen that the best coverage consists in sources equally spaced in Azimuth, but clustered at high and low elevations.

- Radio Collimation `COH`
  This is essentially an antenna constant. It is better to fix `COH` to the previous value, rather than trying to fit it (see the `INTER_BASE:GENERAL.ANi` file to get this number). Accordingly, this is done by default. Do not believe `COH` has changed unless you have 1) many data points (> 40) 2) a good sky coverage, and 3) a formal error on `COH` less than 0.5".

- Gauss fit formal error
  For radio pointing, if the formal error on the position from gauss fit is higher than 2.0", the data may be useless.

- Avoid long pointing sessions and systematic Az-El coverage
  At least in OPTICAL pointing. Time dependent effects, such as thermal behaviour of the optical telescope mount, may then become inextricably mixed with Az or El dependent terms.

Accordingly, the following **Tricks** should be used:

- Use SiO Masers in Pseudo Continuum
  They will help you get a good Az-El coverage. They are usually stronger than continuum sources.

- Use the beam switch
  Always for continuum sources, but also for SiO masers if the weather is poor.

- Fix the beam width for CLASS gauss fits
  This helps to reduce the formal error on the position, specially for weak sources. This can be done using the CLASS command `ANALYZE\METHOD CONTINUUM Width`, where Width is in arc seconds. The beam width is 55" at 86 GHz. The PR:INIT_POINT.CLASS procedure executes such a command if the observing frequency is specified.

- Use the inclinometers
  At least just before and just after the pointing session, but also later from time to time to check any time dependence of `MVE` or `MVN`.

- Use the specially designed procedure `POINT_INTER` and `POINT_MULTI`
  These procedures have been written to produce a reasonable coverage, considering the functional form of the pointing model equations. Pointing sources have been selected to avoid excessive noise.

7 POINT Language Internal Help

7.1 FILE

```
[POINT\]FILE Name Type
```

Specify the input file name and type of data (OPTICAL, RADIO or INTERFEROMETRY). The file extension is derived according to Type using the following defaults : .OPT, .RAD and .INT respectively. The file header are read, but not the data.

7.2 IGNORE

```
[POINT\]IGNORE [/SCAN List of scans] [/SOURCE List of sources]
[/TIME TimeMin TimeMax]
```

Ignore part of the input data for the next SOLVE command. The data must have been read before. The Scan list, Source list and time ranges are emptied each time a new READ or FILE command is typed.

7.3 INCLUDE

```
[POINT\]INCLUDE [/SCAN List of scans] [/SOURCE List of source]
[/TIME Tmin Tmax]
```

Include part of the input data (presumably previously ignored) for the next minimization. The data must have been read before. The Scan list or Source list can be replaced by the "wildcard" * to include any scan or source.

7.4 LIST

```
[POINT\]LIST [Scan] [/OUTPUT Filename]
```

List the current data or the specified scan. The bad data is flagged with an exclamation point. Option /OUTPUT can be used to redirect the LIST command output (default Terminal).

7.5 PARAMETER

```
[POINT\]PARAMETER NAME [Value] [/FREE]
```

Fix a fit parameter at the specified value, or free the specified parameter if option /FREE is present. Value is in arcsecond. Available parameters are

```
IAZ     Zero azimuth
IEL+COV Zero elevation
```

```
     COH     Azimuth collimation
     MVE     East Inclination
     MVN     North Inclination
     NPE     Non perpendicularity
     REF1    1st order refraction
     REF2    2nd order refraction
     ELES    grav.+exc. coder ele. (sin)
     ELEC    grav.+exc. coder ele. (cos)
     AZES    excen. coder az. (sin)
     AZEC    excen. coder az. (cos)
```

REF1 and REF2 are preset to 0 and 0 by default, because on Plateau de Bure the refraction is computed in real from meteo parameters. They should not be freed, except for very specific purposes.

7.6 PLOT

```
        PLOT [Argument] [/BAD]
```

Plot some aspect of the data and fit results. Argument may be

SUMMARY (Default).
Residuals in El versus residuals in Az.

COVERAGE
Elevation versus Azimuth of data points.

ERRORS AZIMUTH or ERRORS ELEVATION
Original pointing errors in Az or El, as a function of Az and El.

RESIDUALS AZIMUTH or RESIDUALS ELEVATION
Residual pointing errors in Az or El, as a function of Az and El.

TIME
Residual pointing errors as a function of time.

CIRCLE
General summary of pointing behaviour : arrows indicating the pointing error magnitude and direction on a (Az,El) circular diagram.

By default, only good data points (those considered for the fit) are plotted. If option /BAD is present, rejected data points (as implicitely specified by commands IGNORE, REJECT, SET ELEVATION and SET RMS) are also plotted, using the virtual pen number 2.

7.7 PRINT

```
[POINT\]PRINT [/OUTPUT Filename|PRINTER] [/HEADER]
```

List the last fit results computed by command SOLVE. Option /HEADER can be used to list all fit parameters; by default only variable parameters are listed. Option /OUTPUT can be used to redirect the PRINT command output (default Terminal); if PRINTER is specified as argument to /OUPUT option, the fit results are printed.

7.8 READ

```
[POINT\]READ AntennaOmber [StationOme]
```

Read the data of antenna AntennaOmber (on station StationOme if specified). A file must have been opened using command FILE before.

7.9 REJECT

```
[POINT\]REJECT MaxError
```

Reject all data points with pointing residuals greater than MaxError for the next fits. A READ command will reset the rejection threshold to infinity.

7.10 SET

```
[POINT\]SET Item Value1 [Value2]
```

Set some selection criterium. Possible items are

    ELEVATION Elmin Elmax :
    specify valid elevation range (default 5 90, in degrees)

    RMS rmsmax :
    specify maximum standard deviation (from gauss fit) for the
    measured pointing errors.

Optical pointing data has measured pointing errors with standard deviation set to 0, so that SET RMS although meaningfull only for RADIO or INTER data, can also be used transparently.

As for comands IGNORE, INCLUDE and REJECT, selection criteria specified by the SET command will be considered for the next PLOT and FIT commands. However, contrary to commands IGNORE, INCLUDE and REJECT, the criteria will not be reset by any READ or FILE command.

7.11 SHOW

```
[POINT\]SHOW Item

 shows the specified items :
 RMS        The maximum standard deviation of original measurements
 IGNORED    Data points ignored based on Scans or Source name
 ELEVATION  The elevation range
 REJECTED   The rejected data scans, based on previous fit model
```

7.12 SOLVE

```
[POINT\]SOLVE

     Compute fit results, considering only the valid data points implied
by commands IGNORE, REJECT, SET RMS or SET ELEVATION.
```

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