

G-NUT/ANUBIS

Version 3

User manual

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1. Introduction

1.1 Purpose

G-Nut/Anubis [1] is a software designed for file header checking and quantitative, qualitative and complex control (QC) of data collected by one or more receivers of Global Navigation Satellite Systems (GNSS) and their regional augmentations.

The software provides the following data characteristics:

- Statistics of observations, signals, frequency bands, tracking types, satellites, etc..
- Standard point positioning of standalone GPS, GLONASS, Galileo and BeiDou systems.
- Pre-processing – detecting receiver clock jumps and cycle slips and other interruptions.
- Satellite visibility above the horizon and a user elevation angle mask cut-off.
- Satellite elevations and azimuths, tracking bands etc..
- Satellite navigation data availability and satellite health status.
- Expected counts of observations, elevation-dependent statistics.
- Presence of data gaps and small pieces.
- Code pseudorange multipath and signal noise.
- Phase signal-to-noise density.
- Receiver clock corrections.
- Dilution of precision (DOPs).
- Horizontal and vertical positioning indicators.
- Header metadata and format validation.
- Metadata editing and data filtering.

The software supports these input formats (including CRX, gz and Z compression):

- Data files: RINEX 2/3 and BNC OBS (observation data), RINEX 2/3 (navigation data), SP3 (precise ephemeris), SINEX (metadata).
- Data streams: RTCM 3 (observation and navigation data), BNC OBS (observation data).

The software supports these output formats (including CRX, gz and Z compression):

- Data files: RINEX 2/3 and BNC OBS (observation data), RINEX 2/3 (navigation data), SP3 (precise ephemeris), SINEX (metadata).
- Data streams: RTCM 3 (observation and navigation data), BNC OBS (observation data).
- QC outputs: native Anubis' QC data format (XTR), satellite- and epoch-specific data (JSON), and XML (QC summary).

The software can be executed from the console user interface (CUI). It can be configured using an XML file, from a command-line arguments, or both. It has no graphic user interface (GUI).

The software is currently available for Linux, Windows and MacOS operating systems.

1.2 Versions

The G-Nut/Anubis is being released in three different software versions:

Anubis Free

is an open-source version with a fundamental functionality:

- Observation statistics (signals, bands, satellites, etc.).
- Data availability (data gaps and small pieces).
- Pre-processing of carrier phases (cycle slips, clock jumps).
- Satellite information (azimuth/elevations).
- Single point positioning (repeatability, GDOP).
- Code multipath and phase signal-to-noise ratio.
- Navigation data, information on satellite health status.
- Header and format validation.

Anubis Pro

is a commercial version with advanced functionality. Compared to the Free version, it brings additional benefits:

- Direct access to archive files (Hatanaka + gzip/compress).
- Basic metadata and data editing, filtering and concatenating.
- Navigation and observation data file encoding (RINEX 3/2).
- XML/SINEX input for modifying/validating site metadata.
- JSON output for plotting and support for visualisation service.
- Enhanced configuration/help, predefined processing modes.
- Satellite health status applied in positioning and observation statistics.
- Parallel processing configuration (CPU, RAM, files).

Anubis RT

is a commercial version with advanced and real-time functionality. Compared to the Pro version, it brings additional benefits:

- QC monitoring of real-time data (format, content and latency).
- Stream format convertor (stream formats RTCM/BNCOBS, RTCM-SSR/IGS-SSR).
- Stream-to-data convertor (file formats RINEX/BNCOBS).
- RTCM and BNC format decoder/encoder.
- TCP/NTRIP client.

*Important note: individual functionalities are not always explicitly distinguished within this manual. Use of term **Anubis** in examples refers to any version relevant for the operation.*

1.3 Licences

The Anubis Free version is an open-source software which can be redistributed and/or modified under the terms of the GNU General Public License Version 3 (<http://www.gnu.org/licenses>) as published by the Free Software Foundation.

The Anubis Pro and Anubis RT are provided under a commercial licence.

1.4 Installation

The software is distributed from <http://www.gnutsoftware.com>. It can be downloaded as a pre-compiled binary (static/dynamic, 32b/64b) and it does not need any specific installation or compilation procedure. The source code is eventually distributed for the Anubis Free which may be compiled for any standard Linux platform.

1.5 Development

The software has been developed using the G-Nut core library [2] initially designed at the Geodetic Observatory Pecný of the Research Institute of Geodesy, Topography and Cartography. Since 2018, both the library and user applications has been maintained as well as further developed by the G-Nut Software s.r.o..

In case of bug reporting, feedback or wish-list, and other questions, contact us via the email: support@gnutsoftware.com. Note: a support is currently on the best-effort basis only. In case you need any specific support, contact us for negotiation.

1.6 Acknowledgements

We acknowledge the availability of third-party libraries used within the G-Nut:

- Newmat - C++ Matrix library (http://www.robertnz.net/nm_intro.htm).
- Pugixml - a light-weight, simple and fast XML parser for C++ (<http://pugixml.org/>).
- RNXCMP - a Hatanaka's RINEX compression (<https://terras.gsi.go.jp/ja/crx2rnrx/>) [3].
- md5 - a reference implementation of RFC 1321 converted to C++ by Frank Thilo for bzflag (<http://www.bzflag.org>).
- rapidjson - a fast JSON parser/generator for C++ with both SAX/DOM style API (<https://rapidjson.org/>).
- zlib - a free lossless data-compression C library (<https://www.zlib.net>).
- gzstream - a small C++ wrapper providing the functionality of the zlib C-library (<https://www.cs.unc.edu/Research/compgeom/gzstream/>).

2. Operating modes

The software can operate in several user modes. These are introduced together with additional aspects useful for understanding the software background operation, e.g. data decoding, data filtering, QC performing and results storing, see Figure 2.1.

These operating modes can be triggered by using one of the command-line arguments:

```
Anubis --help | --thin | --edit | --summ | --full | --lite | --kpis
```

- **Help mode** for configuration options and default settings.
- **Thin mode** for metadata control and header check.
- **Edit mode** for metadata editing and data filtering.
- **Lite mode** for quantitative control with optional navigation data.
- **Full mode** for qualitative and complex control with mandatory navigation data.
- **Summ mode** is a full mode with a minimum output, but still supporting the XML output (some processes performed on background in this mode).
- **KPIs** represents a specific mode extending the Anubis output towards horizontal and vertical positioning and DOP key-parameter indicators (KPIs).

Figure 2.1 shows relations of internal operations with user inputs, decoding procedures, observation and navigation data representation, QC operations and outputs. Obviously, the navigation data are mandatory for QC full. Thin mode operates on data decoding only. Data decoding includes filtering according to user settings (e.g. selecting systems, satellites, observation types, frequency bands, tracking attributes, navigation data types). The edit and QC modes then use pre-filtered data from internal containers.

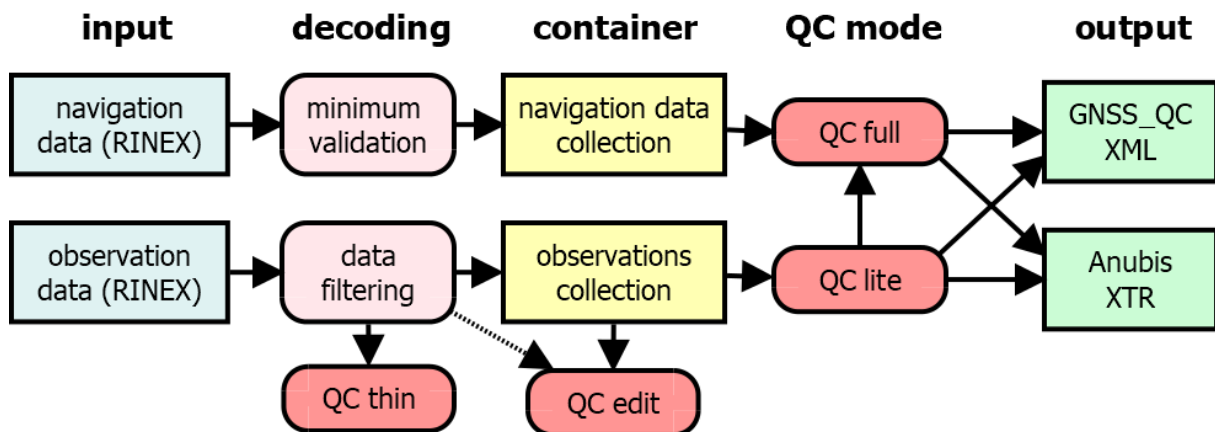


Figure 2.1: Anubis operating modes and relation to inputs, outputs and internal procedures

2.1 User help

A basic help (*-help*) shows principal command-line arguments.

```
G-Nut/Anubis Pro [3.1] compiled: Jan 11 2021 18:41:07 (Rev: 3113)
```

Usage:

```
-h|--help      .. this help
-V            .. software version
-x file       .. configuration input file
-X           .. configuration stdout (default)
-Z           .. log-file without time stamps
-z file       .. configuration output file
xml-settings  .. XML settings via a command line (see below)
```

XML settings via command line:

```
:elem:subelem val .. set xml element value (e.g. :inputs:rinexo <rinexo file>)
:elem:attribute=val .. set xml attribute value (e.g. :outputs:verb=1)
:elem[ID]:subelem val .. set xml element value (e.g. :sys[GPS]:sat "G01_G02_G03")
:elem[ID]:attribute=val .. set xml attribute value (e.g. :site[GOPE]:rec="RECEIVER")
```

An extended help (`-X`) then gives a detailed list of applicable configuration options including a brief description and default values.

```
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<!DOCTYPE config>
<config>
  <!--general settings:
max_cores=integer      .. max cores to be used (0=any)
max_files=integer      .. max files in a batch (0=all)

beg      %Y-%m-%d %H:%M:%S .. beg time % (empty=auto)
end      %Y-%m-%d %H:%M:%S .. end time % (empty=auto)
int      integer          .. beg time (empty=all)
rec      list of strings  .. receiver(s) (empty=all)
sys      list of strings  .. GNSS system(s) (empty=all)
-->
<gen max_cores="1" max_files="1"><beg /><end /><int /><rec /><sys /></gen>

<!--quality check settings:
sec_sum=int           .. summary statistics
sec_hdr=int           .. header metadata check
sec_obs=int           .. observation statistics
sec_est=int           .. estimated values
sec_gap=int           .. gap & pieces
sec_bnd=int           .. observation bands
sec_pre=int           .. cycle-slip, clock-jumps
sec_ele=int           .. azimuth/elevation (if navigation)
sec_mpx=int           .. multipath calculation
sec_snr=int           .. signal-to-noise ratio
sec_sat=int           .. satellite information
sec_kpi=int           .. key-parameter indicators

int_stp=int           .. [s] interval for time-spacing
int_gap=int           .. [s] interval for gap identification
int_pcs=int           .. [s] interval for small pieces identification
mpx_nep=int           .. number of epochs for multipath calculation
mpx_all=bool          .. high-resolution multipath: estimate all or interpolate
mpx_lim=double        .. sigma-multiplier for MP cycle-slip & outlier detection
pos_kin=bool          .. kinematic receiver (true = kinematic)
pos_int=int           .. positioning interval
pos_cut=double        .. positioning elevation angle cut-off (degrees)
ele_cut=double        .. user elevation cut-off (only for expt/have, degrees)
ele_new=bool          .. new strategy for cut-off + horizon estimates
ele_app=bool          .. approximated elevations (true = less precise)
col_sat=int           .. number of columns for sat-specific reporting
sat_rec=bool          .. expected observations from satellites (true:any | false:signal)
use_health=enum       .. use of satellite health (position|statistics|all)
max_vpe=double        .. maximum vertical position error
max_hpe=double        .. maximum horizontal position error
max_dop=double        .. maximum PDOP
-->
.....
</config>
```


2.2 Thin mode – metadata control

The *thin* mode is ultra fast because it exits just after reading RINEX file header, i.e. prior any data decoding. It can be effectively applied for single/multiple files providing errors or warning messages on standard error output (*/dev/stderr*). Every present error increases a return code from the software.

Each file header is confronted with a user metadata introduced either from the XML configuration file (the `<site>` element), see Section 3, or from a SINEX input file (or both).

For a set of RINEX files, the bellow command generates errors and warning messages and, optionally, a non-zero return CODE if a serious problem (error) occurs. A silent output, and a zero return CODE, characterises a fully compliant RINEX header format and metadata corresponding with user requests.

```
Anubis --thin :inp:rinxo '\$(ls *crx.gz)' -x My-Site-Meta-Data.xml
```

Examples of RINEX header metadata inconsistency:

```
*** Warning: AZGROOPRT - object inconsistent DOMES: 31902M004 !! AZGR
*** Warning: MPTBOOM0Z - object inconsistent DOMES: 39308M001 !! Unknown
*** Error: ABFCOONGA - object inconsistent ECC: 0.0000 0.0000 0.1800 !! 0.0000 0.0000 0.1710
*** Error: PAGU00PRT - object inconsistent ANT: TRM55971.00 NONE !! TRM57971.00 NONE
```

Examples of RINEX header format incompatibility:

```
*** Warning: BDS band changed: B1->B2 (RNX 3.02) .. SUBI00PRT_R_20203000000_01D_30S_M0.crx.gz
*** Warning: INTERVAL not available! .. ABFCOONGA_R_20203000000_01D_30S_M0.crx.gz
*** Error: GLO BIASES not available! .. FTNA00WLF_R_20203000000_01D_30S_M0.crx.gz
*** Error: GLO SLOT/FREQ not available! .. PAGU00PRT_R_20203000000_01D_30S_M0.crx.gz
```

2.3 Edit mode – data filtering, metadata modifying

The *edit* mode can be fast if header metadata are modified only. The file body remains untouched, though the file still needs to be uncompressed/compressed for header reading/writing (in case of gz/Z input or output file).

Actual data filtering, e.g. down-sampling, system elimination, satellite selection, signal filtering, window editing, already requires decoding of all data, applying user filters, storing data into internal container, and finally encoding. The data can be thus re-organised in output file (satellite and observation orders, etc.).

Output file compression (Z/gz) can be applied independently from input file, and arbitrarily with/without use of Hatanaka GNSS data compression. Any operation, uncompressing + editing or editing + compressing, is thus supported. Standard compression of the output file is handled automatically according to the requested output file name extension (similarly as in case of input files):

- .gz** for GZ file compression,
- .Z** for LZH file compression.

The format of output file, including Hatanaka compression, is requested explicitly by user in specification of output format (*Note: input file is recognised and handled automatically*):

:out:rinexo2 for RINEX 2 output file,
:out:rinexo3 for RINEX 3 output file,
:out:crinexo2 for RINEX 2 Hatanaka output file,
:out:crinexo3 for RINEX 3 Hatanaka output file,
:out:bncobs for BKG Client [4] observation output file.

Some limitations still exists within the *edit mode* of the Anubis 3.0 (exists on TODO list):

1. format conversion is not supported (from RINEX 3 to RINEX 2 and vice versa).
2. editing can be performed on data from a single station only, although multiple input files can be concatenated into a single one.

User metadata can be provided through either XML configuration file `<site>` element or from a SINEX input file. Both can be even combined too, see 3. Data filtering can be requested only via the XML setting (or command-line arguments).

Example of header metadata modification using XML `<site>` configuration, and SINEX:

```
Anubis  --edit -x My-Site-Meta-Data.xml           \
         :inp:rinexo GOPE3660.20D.Z             \
         :out:rinexo2 gope3660.20o.gz          \
         :out:crinexo2 gope3660.20d.gz

or

Anubis  --edit :inp:rinexo GOPE3660.20D.Z      \
         :inp:sinex My-Site-Meta-Data.snx.gz   \
         :out:rinexo2 gope3660.20o.Z         \
         :out:crinexo2 gope3660.20d.Z
```

Example of metadata modification (receiver type change) from a command-line arguments:

```
Anubis  --edit :inp:rinexo GOPE3660.20D.Z :out:crinexo2 gope3660.20d.gz \
         :site[GOPE]:rec=TRIMBLE
```

Example of data filtering (down-sampling, window of 1h, GNSS with selected observations):

```
Anubis  --edit :inp:rinexo GOPE00CZE_R_20203660000_01D_30S_MO.crx.gz \
         :out:rinexo3 GOPE00CZE_R_20203660100_01H_60S_MO.rnx \
         :out:crinexo3 GOPE00CZE_R_20203660100_01H_60S_MO.crx.gz \
         :gen:sys 'GPS GAL GLO BDS' \
         :gen:beg '2020-12-31 00:00:00' \
         :gen:end '2020-12-31 01:00:00' \
         :gen:int 60 \
         :sys[GPS]:gobs 'C1 P2 L1 L2'
```

2.4 QC mode – quantitative and qualitative control

The quality control (QC *lite*, *full*, *summ* and *kpis*) modes can be used on single or multiple files and stations. The mode can also be specified in XML settings (*use_qcmode*).

Various modes differ in QC section pre-setting (modify default settings, see Table 2.1), however, these may be still changed with individual section settings.

Table 2.1: Anubis pre-settings for different operating modes

Operating mode	Thin	Edit	Lite	Full	Summ	KPIs
XML-settings			(quality control)			
<i>:qc:sec_sum=</i>	0	0	1	2	2	3
<i>:qc:sec_hdr=</i>	0	0	1	1	1	1
<i>:qc:sec_obs=</i>	0	0	1	1	1	1
<i>:qc:sec_gap=</i>	0	0	1	1	-1	1
<i>:qc:sec_bnd=</i>	0	0	1	1	-1	1
<i>:qc:sec_pre=</i>	0	0	1	1	-1	0
<i>:qc:sec_est=</i>	0	0	0	1	0	0
<i>:qc:sec_ele=</i>	0	0	0	1	0	0
<i>:qc:sec_mpx=</i>	0	0	0	1	-1	-1
<i>:qc:sec_snr=</i>	0	0	0	1	0	0
<i>:qc:sec_sat=</i>	0	0	0	1	0	0
<i>:qc:sec_kpi=</i>	0	0	0	0	0	9

Anubis supports three complementary QC output formats, which contents are described in sections 4, 5, and 6.

XTR QC output – a native ASCII format organised by QC sections with an adaptable output verbosity; easy used for multi-file grepping; for details see Section 4.

XML output – a QC summary using extensible markup language (XML) format and containing data optimal for populating a database system; efficient for visualising time series of QC key parameters, suitable for monitoring an evolution of site quality in time; for details see Section 5.

JSON output – a JSON high-resolution format designed primarily for an efficient archive of satellite-/epoch-wise data; convenient for visualisation of positioning and skyplots from a single data file with QC results; for details see Section 6.

Example of QC lite operation without navigation data file, requesting multipath and signal-to-noise outputs, and eliminating a majority of other quantitative sections:

```
Anubis  --lite :inp:rinexo GOPE3660.20D.Z \
          :out:xtr  GOPE3660.xtr.gz \
          :out:log  anubis.log \
          :qc:sec_mpx=2 :qc:sec_snr=2 \
          :qc:sec_hdr=0 :qc:sec_obs=0 :qc:sec_bnd=0 :qc:sec_gap=0 :qc:sec_pre=0
```

Example of QC full operation supported with a global navigation file and all QC outputs:

```
Anubis  --full :inp:rinexn BRDC00GOP_R_20203660000_01D_MN.rnx.gz \
          :inp:rinexo GOPE3660.20D.Z \
          :out:xtr  GOPE3660.xtr.gz \
          :out:xml  GOPE3660.xml.gz \
          :out:json GOPE3660.json.gz \
          :out:log  /dev/stdout \
          :out:verb=2
```

Example of QC summary targeting a full XML output for populating QC database:

```
Anubis --summ :inp:rinxn BRDC00GOP_R_20203660000_01D_MN.rnx.gz \
      :inp:rinxo GOPE3660.20D.Z \
      :out:xml GOPE3660.xml
```

2.5 KPI mode - position performance

This mode remains experimental. It has been developed for a purpose of monitoring individual GNSS constellations through site(s) horizontal and vertical positioning performance, and DOP values. The mode obviously depends on complete and correct navigation data. It is able to measure Signal-in-Space (SiS) errors based on processing data from one or more station(s) and reflecting the quality of navigation data together with actually exploited signals. However, the results might be affected by site environment and instrumentation.

The mode is enabled by exploiting a reference station position, given either from a SINEX file or from XML <site> configuration, for estimating horizontal and vertical position differences in epoch-by-epoch single point positioning.

Figure 2.2 shows example of improved performance of E1+E5a positioning supported by Galileo FNAV navigation data after four new Galileo satellites became active on February 11, 2019, first enabling a stable $GDOP < 6$ every day all over the globe. Prior the date, the positioning solution was regularly unavailable at some areas due to few observed satellites only. With data filtering, such positioning can be performed for any individual constellations, combination of tracking signal and navigation data types. The output is described in details in the KPI section 4.12.

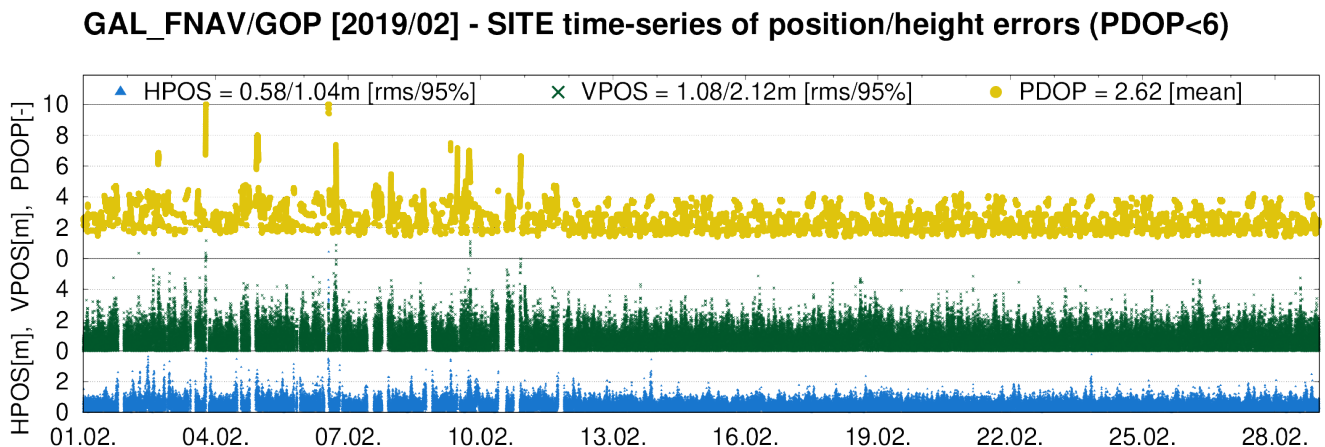


Figure 2.2: Monthly positioning performance with Galileo E1+E1a signals and FNAV data

Example of KPI estimates exploiting globally merged (GOP BRDC) navigation data file:

```
Anubis --kpis :inp:rinxn BRDC00GOP_R_20203660000_01D_MN.rnx.gz \
      :inp:sinex MetaData+ReferenceCRD.snx \
      :inp:rinxo GOPE3660.20D.Z \
      :out:xtr GOPE3660.xtr \
      :out:json GOPE3660.json
```

2.6 Multiple files

Anubis was initially designed for a single RINEX input file operation, which can still be optimal particularly for a single file metadata control and header compliance (return code) or for a single-file data filtering or metadata editing:

```
Anubis --thin -x Metadata.xml :inp:rinxo GOPE3660.20D.Z :out:xtr GOPE3660.xtr
Anubis --edit -x Editing.xml :inp:rinxo GOPE3660.20D.Z :out:crinexo2 GOPE3660.20D.gz
```

QC can be performed also on massive file databases such as data centres, large network operator's or data analyst's repositories. Huge numbers of input files can still be handled efficiently. Following example is for actual contents of multiple files listed via a shell command-line argument expansion:

```
Anubis --thin :inp:rinxn '\$(ls brdc/BRDC00GDP_R_2000366*rnx.gz) \
:inp:rinxo '\$(ls dir1/2020/366/*crx.gz dir2/2020/366/*crx.gz) \
:out:xtr '\$(rec)_%Y-%m-%d.xtr.gz' \
:out:xml '\$(rec)_%Y-%m-%d.xml.gz' \
:out:log 'anubis.log'
```

The user then need to specify a generic file mask for each input (output) format. Any site name identified within the processed data then replaces a generic variable \$(rec). Several time-dependent variables (listed bellow) are eventually substituted for reference epoch(s) of the processed data:

- '%Y' – 4-char year,
- '%y' – 2-char year,
- '%j' – doy of year (DoY),
- '%m' – month of year,
- '%d' – day of month,
- '%w' – day of GPS week,
- '%W' – GPS week,
- '%H' – hours of day,
- '%M' – minutes of day,
- '%S' – seconds of day.

If site-/time-dependent variable is identified within the input (output) format, it is considered as a file mask instead of a single file name. Such mask is then expanded into a site-/time-specific list of input (output) candidate files that will be processed. Finally, only those relevant (existing for input, applicable for output), are eventually read (written), others are ignored.

There is also specific settings to control efficient operation on a multiple files, which can be processed 1) in parallel, or in a sequence, 2) possibly restricting a number of used cores (understand processing threads), or a maximum of files processed within a single batch. The following configuration enables to configure these operations:

- *max_cores* defines a maximum number of cores to be used (0=auto),
- *max_files* defines a maximum number of files to be used in a single batch (0=auto).

3. Configuration

The software can be configured from an XML configuration file, using command-line arguments, or mixing both inputs. In principal, the XML configuration represents the Anubis' internal settings structure, while command-line arguments enable user to a) fully configure Anubis, or b) modify default settings (or the XML configuration) for a particular Anubis execution. This section describes only the XML configuration since any command-line argument only expresses the native settings by applying the following principles:

```
:elem:subelem val .. set xml element value (e.g. :inputs:rinexo <rinexo file>)
:elem:attribute=val .. set xml attribute value (e.g. :outputs:verb=1)
:elem[ID]:subelem val .. set xml element value (e.g. :sys[GPS]:sat "G01_G02_G03")
:elem[ID]:attribute=val .. set xml attribute value (e.g. :site[GOPE]:rec="RECEIVER")
```

Contrary to the XML settings, there are conditions that need to be considered:

- a duplicitous argument (e.g. :elem:attribute="value") overwrites an existing one or default.
- multi-elements (:sys[id], :site[id]) require an element identifier (e.g. [GPS], [GOPE]).

It is important to note that for avoiding duplicitous command-line arguments, user has to enclose multiple values in quotation marks, if any. Obviously, any input previously set from either the XML or command-line settings is finally replaced with the last command-line argument.

A basic help (*-help*) as well as a full help (*-X*) has already been introduced in Section 2.1.

The examples below show the software execution using the XML settings (only)

```
Anubis -x my_config.xml
```

and with command-line settings (only)

```
Anubis :inp:rinexo GOPE1730.17o \
:inp:rinexn BRDC1730.17p \
:out:xtr GOPE1730.xtr \
:out:xml GOPE1730.xml \
:out:log GOPE1730.log \
:out:verb=1 \
:gen:beg "2017-06-22_00:00:00" \
:gen:end "2017-06-23_00:00:00" \
:gen:sys "GPS_GLO" \
:gen:int 30
```

Mixing both configurations can be useful particularly for specifying user-default (static) parameters in the XML file (e.g. generic configuration, output file masks, site metadata) and adding/adapting selected (dynamic) parameters from the command-line (e.g. input files):

```
Anubis -x metadata.xml :inp:rinexo "$(ls_data/????????_R????????_01D_30S_M0.crx.gz)" \
:inp:rinexn "$(ls_brdc/BRDC????_R????????_01D_M0.rnx.gz)"
```

*Hint: in this particular case, it is recommended to store actual configuration (*-z final.cfg*) along with archiving QC output files.*

3.1 XML settings structure

A structure of the Anubis XML configuration file consists of elements and attributes of the Extensible Markup Language (XML). The configuration is placed within a root element `<config>` and following XML tree of child elements:

- `< gen >` for general settings,
- `< sys >` for GNSS-specific settings,
- `< nav >` for navigation data settings,
- `< inp >` for input settings,
- `< out >` for output settings,
- `< qc >` for QC settings,
- `< site >` for site metadata settings.

Selected elements can be omitted (default software values are considered then), however, input and output elements are mandatory. Individual elements are described in following sections.

3.2 General configuration

The element `<gen>` includes general settings for the software operation such as a start and end time of a processing period, requested GNSS constellations, list of GNSS sites (receivers), and a sampling interval of the processing. *Remark: the general settings is applied at the decoding level, thus data/products are filtered by the settings prior any data analysis, see Section 2.*

The settings is defined using the XML sub-elements.

```

<gen
  max_cores="0"                # maximum number of cores to be used (0=all)
  max_files="0"               # maximum number of files in a batch (0=all)
>
  <beg> "2014-03-01_00:00:00" </beg>
  <end> "2014-03-01_23:59:59" </end>
  <sys> GPS GLO GAL BDS QZS </sys>
  <rec> GOPE POTS WTZR </rec>
  <int> 300 </int>
</gen>

```

The attributes `max_cores` and `max_files` configure sequential/parallel processing, which were described in Section 2.6.

The two elements (`<sys>`, `<rec>`) support multiple values (strings), and these should be separated by one or more blank characters.

The elements `<beg>` and `<end>` define the start and the end of the processing interval, both in the format `'%Y-%m-%d %D:%M:%S'` (or in a single string `'%Y-%m-%dT%D:%M:%S'`).

The `<sys>` element specifies global and regional systems considered in the processing. These 3-char GNSS abbreviations are allowed: **GPS**, **GLO**, **GAL**, **BDS**, **QZS**, **SBS**, and **IRN** for GPS, GLONASS, Galileo, BeiDou, QZSS, SBAS, and IRNSS, respectively. By default (or empty element), all these above supported GNSS and regional systems are considered.

Remark: while empty element represents all the systems, the '-' pre-fix (minus) enables rejecting any particular system.

The `<rec>` element enables a list of receiver (site) identifiers to be processed. The list may be left empty (default), considering any site identified within input data can be processed. It may contain string(s) corresponding to the name(s) found in the **MARKER** field of the RINEX observation header(s), or NTRIP [5] **mountpoints** in case of real-time input data stream(s).

Remark: the MARKER of the RINEX file may not be filled properly, or it may be inconsistent with the site name from the file name (e.g. 4-char vs. 9-char long file name), the Anubis guesses a correct name when confronting MARKER, file name, and the <rec> user settings. The guess name is reported in the log file, and it is used for the user variable $\$(rec)$, see Section 2.6.

The `<int>` element represents the processing sampling rate expressed in seconds. The sampling rate defines an interval for decoding (and filtering, see Section 2)) input data, thus affecting majority of output QC characteristics.

Remark: in normal cases, the element should contain integer number, however, for processing high-rate data ($> 1\text{Hz}$), the sampling rate may be float with a number of extra decimal digits ('0') to define a time resolution of the input data.

3.3 GNSS configuration

Constellation-specific configuration is enabled in the `<sys>` element, which needs to be identified with a mandatory **id** attribute in order to distinguish individual GNSS constellations, see Section 3.2. Hence, multiple elements are supported.

Each system may contain the following sub-elements:

- `<nav>` for navigation type selection,
- `<sat>` for satellite selection,
- `<type>` for observation type selection,
- `<band>` for observation frequency band selection,
- `<attr>` for observation tracking attribute selection,
- `<gobs>` for observation signal-specific selection (add-on/pure signal settings).

These can be used for defining a set of conditions applied for input data filtering during decoding process. By default, all the settings are empty, thus no filtering is applied. By introducing any single value into any single element then activates the filter and, consequently, all enabled values should be explicitly specified.

Remark: A combination of <gobs> settings together with observation type, frequency band, or attribute results represents the add-on signal-specific settings with respect to the other elements. Codes representing observation types, frequency bands, tracking attributes or specific signals correspond to the RINEX standards.

An example of settings for Galileo (not very meaningful):

```

<sys id='GAL'>
  <sat> E01 E05 E06 E08 E09 E12 E14 </sat> # disable unspecified Galileo satellites
  <nav> FNAV INAV_E07 </nav> # disable INAV_E01
  <type> C L </type> # disable Doppler and signal-to-noise ratio
  <band> 1 2 5 7 8 </band> # disable E6 frequency band observations
  <attr> C L X P W </attr> # disable unspecified observation attributes
  <gobs> C1C C2P L1C L2P S1C S2P L2P </attr> # add-on specifically mentioned signals
</sys>
```


The `<sat>` element specifies a list of 'enabled' satellites (PRNs). If the element is not specified in the configuration file, or is empty, all available (supported) satellites for given constellations contribute as default.

Remark: similarly as for the `<sys>`, the '-' pre-fix (minus) enables a negative selection, i.e. rejecting only particular satellite.

The `<nav>` element specifies the navigation data types when supporting:

- **FNAV** for Galileo FNAV from the E5a signal,
- **INAV** for Galileo INAV from any signal,
- **INAV_E01** for Galileo INAV from the E1 signal,
- **INAV_E07** for Galileo INAV from the E5b signal,
- **CNAV** for GPS CNAV navigation type (not implemented yet in RINEX 3),
- **NAV** for any navigation type.

3.4 Navigation data configuration

Handling navigation data is optional settings for two specific purposes:

1. filtering, checking, and handling navigation data within G-Nut applications, and
2. generating merged and quality control navigation data, i.e. BRDC file, [6]).

Selected parameters can be used in any G-Nut application:

- **chk_record** (boolean) – use simple range checking for individual navigation records
- **chk_health** (boolean) – filter out satellites with unhealthy status
- **chk_duplic** (boolean) – filter out duplicitous navigation records
- **chk_tot** (boolean) – check navigation data validity with respect to the ToT epoch
- **key_tot** (boolean) – store/search navigation records according to the ToT epoch
- **ext_nav** (double) – multiplier to extended navigation data validity interval

Remaining parameters are used for the comprehensive navigation data consolidation (merging and checking). These are specific and should be applied only with a sufficient number of input navigation files and enabling duplicitous records for possible data selecting:

- **chk_header** (boolean) – NAV data statistical analysis for BRDC header
- **chk_params** (boolean) – NAV data time-series analysis for key parameters
- **chk_others** (boolean) – NAV data statistical analysis for other parameters
- **sig_bounds** (double) – a sigma multiplier for outliers in NAV time-series analysis

Default values for navigation data settings should be convenient for a majority of Anubis QC data utilisation, and these are provided below:

```

<nav chk_record="true"   chk_health="true"   chk_duplic="true"
      chk_tot="true"     key_tot="true"     ext_nav="1.0"
      chk_header="false" chk_params="false" chk_others="false"  sig_bounds="3.0"
/>
```

3.5 Input configuration

Supported input formats were introduced in Section 1.1. The `<inp>` element includes sub-elements for individual inputs for observation data, navigation data, and metadata. Each sub-element represents a specific format which may contain a space-separated list of more input paths, e.g.:

```
<inp>
  <!-- input settings: path may include prefix file:// [..tcp,ntrip]
  <rinexn>    path1 [path2 ..] </rinexn>    # for RINEXN format (file)
  <rinexo>    path1 [path2 ..] </rinexo>    # for RINEXO format (file)
  <sinex>    path1 [path2 ..] </sinex>    # for SINEX format (file)
  <sp3>      path1 [path2 ..] </sp3>      # for SP3 format (file)
  <rtcm>     path1 [path2 ..] </rtcm>     # for RTCM format (file or stream)
  <bncobs>   path1 [path2 ..] </bncobs>   # for BNCOBS format (file or stream)
  -->
</inp>
```

The path represents a generic input such as data files, data streams, and file masks.

Remark: the file mask is not a valid path, but contains user- or time-specific variables, see Section 2.6 that are replaced with valid strings prior a file searching.

The path may include one of the following structures (the **file://** prefix is optional):

- **file://basename.ext** – file accessible within a local/network file system,
- **tcp://host:port** – TCP data stream from host+port (Anubis-RT only),
- **ntrip://mnt/user:pwd@host:port** – NTRIP data stream from mountpoint (mnt), accessible with username (user) with password (pwd) from a host+port (Anubis-RT only).

*Remark: the file name doesn't play any role in the format definition. The RINEX format version is automatically recognised in the software as well as the **Hatanaka** compression if used as an input (Hatanaka format is not supported with Anubis Free). Files are also automatically compressed/decompressed by the software when using the **.gz/.Z** extension in the file name (only **.gz** is supported with Anubis Free).*

An example below shows a mixed input for GNSS observation and navigation files using relative and absolute paths and RINEX 2 and 3 input formats:

```
<inp>
  <rinexn> file:///../data/brdc/brdm0220.15p.gz </rinexn>
  <rinexo> file:///../data/obs/onsa0220.15o.gz
             /home/jan/data/obs/GOPE00CZE_R_201522000000_01D_30S_M0.crx.gz
</rinexo>
</inp>
```

Remark: Windows users should specify the file path as supported by the platform.

3.6 Output configuration

Supported output formats were introduced in Section 1.1. The `<out>` element includes sub-elements for individual outputs for QC results, log files and, optionally, observation and navigation data.

As described for inputs in the previous section 3.5, each sub-element represents a specific format and contain a space-separated list of one or more output paths (the path again represents a generic output, i.e. data file, data stream, file mask):

```
<out
  verb="[integer]"                # log verbosity (default: 0)
  append="[boolean]"              # log appending (default: false)
>
  <!-- output settings: path may include prefix file:// [..tcp,ntrip]
<log>      path1 [path2 ..]      </log>      # for LOG format      (file)
<xml>      path1 [path2 ..]      </xml>      # for XML format      (file)
<xtr>      path1 [path2 ..]      </xtr>     # for XTR format      (file)
<json>     path1 [path2 ..]      </json>    # for JSON format     (file)
<crinexo2> path1 [path2 ..]      </crinexo2> # for CRINEXO2 format (file)
<crinexo3> path1 [path2 ..]      </crinexo3> # for CRINEXO3 format (file)
<rinexn2>  path1 [path2 ..]      </rinexn2>  # for RINEXN2 format  (file)
<rinexn3>  path1 [path2 ..]      </rinexn3>  # for RINEXN3 format  (file)
<rinexo2>  path1 [path2 ..]      </rinexo2>  # for RINEXO2 format  (file)
<rinexo3>  path1 [path2 ..]      </rinexo3>  # for RINEXO3 format  (file)
<bncobs>   path1 [path2 ..]      </bncobs>   # for BNC OBS format  (file or stream)
<rtcm>     path1 [path2 ..]      </rtcm>     # for RTCM format     (file or stream)
-->
</out>
```

The `<out>` element contains also two attributes related to the log file:

- **verb** (integer) defines a verbosity level with values 0-9 representing details of printed information.
- **append** (boolean) may enforce a continuation of writing into the existing file (the file is created if does not exist). The default is 'false' for creating (new) or overwriting (existing) file.

Remark: if the path contains a non-existing directory, it will be automatically created.

The example below shows the output settings for the Anubis QC operation:

```
<out verb=2 append="false">
  <log>      OUT/anubis-2015-220.log.gz      </log>
  <xtr>      OUT/$(rec)-2015-220.xtr.gz      </xtr>
  <xml>      OUT/$(rec)-2015-220.xml.gz      </xml>
  <json>     OUT/$(rec)-2015-220.json.gz     </json>
</out>
```

Supported QC data output formats are described in Sections 4, 5, and 6.

Remark: any output file, a log in particular, may be also redirected to the standard output (/dev/stdout) or the error output (/dev/stderr), on a Linux platform. Note also the variable \$(rec) enabling a single mask for a common output setting for all simultaneously processed files/stations.

Using the edit mode, the output format for RINEX observations and navigation files needs to be set explicitly, using a specific encoder keyword, see Section 2.3, e.g.:

```
<out verb=2 append="false">
  <log>      /dev/stdout                </log>
  <rinexn3>  OUT/BRDC2200.15p.gz        </rinexn3>
  <rinexo2>  OUT/GOPE2200.15o.Z        </rinexo2>
  <crinexo2> OUT/GOPE2200.15d.Z        </crinexo2>
</out>
```

The Anubis log file reports individual lines started with an event epoch (system time), followed with an object identifier (the one throwing the message) and its verbosity, and the message itself. An example of a log file with **verb=2** is given below:

```

2017-08-10 06:25:19 [main:1] READ: file:///data/brdc/yel22370.16p started
2017-08-10 06:25:19 [rinexn:1] skipped sat G04 warning: unhealthy satellite G04 2016-08-23 22:00:00
2017-08-10 06:25:19 [rinexn:1] skipped sat G04 warning: unhealthy satellite G04 2016-08-23 21:59:28
2017-08-10 06:25:19 [main:0] READ: file:///data/brdc/yel22370.16p 0.171 sec
2017-08-10 06:25:19 [main:1] READ: file:///data/obs/yel22370.16o started
2017-08-10 06:25:19 [rinexo2:0] MARKER NAME: YEL2 (4-CH)
2017-08-10 06:25:19 [gallobj:i] add new obj YEL2
2017-08-10 06:25:19 [rinex:1] Object created, using RINEX header: YEL2 2016-08-24 00:00:00
2017-08-10 06:25:19 [gobj:0] Warning: object YEL2 completed (Name): YEL2
2017-08-10 06:25:19 [gobj:0] Warning: object YEL2 completed (Domes): 40127M006
2017-08-10 06:25:19 [gobj:0] Warning: object YEL2 completed (Antenna): LEIAR25.R4 NONE
2017-08-10 06:25:19 [gobj:0] Warning: object YEL2 completed (Coordinates): -1224441.973 -2689174.628 5633660.332
2017-08-10 06:25:19 [gobj:0] Warning: object YEL2 completed (NEU Eccentricity): 0.000 0.000 0.050
2017-08-10 06:25:19 [gobj:0] Warning: object YEL2 completed (XYZ Eccentricity): -0.010 -0.021 0.044
2017-08-10 06:25:19 [grec:0] Warning: object YEL2 completed (Receiver): SEPT POLARX4TR
2017-08-10 06:25:21 [main:0] READ: file:///data/obs/yel22370.16o 1.974 sec
2017-08-10 06:25:21 [main:0] Error: RUN BY not available!
2017-08-10 06:25:21 [main:0] Warning: LEAPSEC not available!
2017-08-10 06:25:21 [main:1] Single-thread summary: YEL2 started
2017-08-10 06:25:21 [gxtrqc:0] SITE: YEL2 YEL2.xtr
2017-08-10 06:25:21 [gxtrqc:1] Sync XTR step 2016-08-24 00:00:00 -> 2016-08-24 00:00:00
2017-08-10 06:25:21 [gxtrqc:0] Warning: no receiver settings.
2017-08-10 06:25:21 [gxtrqc:0] YEL2 header [i]: 0.000
2017-08-10 06:25:21 [gxtrqc:0] YEL2 obsstt [0]: 0.000
2017-08-10 06:25:21 [gxtrqc:0] YEL2 estima [i]: 0.000
2017-08-10 06:25:21 [gxtrqc:0] YEL2 observ [i]: 0.000
2017-08-10 06:25:22 [gxtrqc:0] YEL2 nbands [i]: 1.000
2017-08-10 06:25:22 [gxtrqc:0] YEL2 pieces [i]: 0.000
2017-08-10 06:25:24 [gxtrqc:0] YEL2 prepro [i]: 2.000
2017-08-10 06:25:24 [gxtrqc:0] YEL2 skyplt [i]: 0.000
2017-08-10 06:25:25 [gxtrqc:0] YEL2 mlpath [i]: 1.000
2017-08-10 06:25:25 [gxtrqc:0] YEL2 snoise [0]: 0.000
2017-08-10 06:25:25 [gxtrqc:0] YEL2 summar [0]: 0.000
2017-08-10 06:25:25 [main:0] Single-thread summary: YEL2 4.370 sec
2017-08-10 06:25:26 [main:0] total time: 6.545 sec

```

3.7 Quality check configuration

The QC settings is managed using attributes of the `<qc>` element:

```

<qc
  <!--quality check settings:
  use_health="[enumerate]" # use of satellite health (position/statistics/all)
  use_qcmode="[enumerate]" # section pre-settings (thin/edit/summ/lite/full/kpis)
  sec_sum="[integer]" # section for summary
  sec_hdr="[integer]" # section for metadata information
  sec_est="[integer]" # section for estimated values
  sec_obs="[integer]" # section for observation statistics
  sec_gap="[integer]" # section for data gap and small pieces
  sec_bnd="[integer]" # section for availability frequency bands
  sec_pre="[integer]" # section for detecting cycle slips and clock jumps
  sec_ele="[integer]" # section for azimuths and elevations of visible satellites
  sec_mpx="[integer]" # section for code multipath and signal noise estimates
  sec_snr="[integer]" # section for signal-to-noise ratio observations
  sec_sat="[integer]" # section for satellite health status and navigation records
  sec_kpi="[integer]" # section for positioning performance indicators
  ele_cut="[double]" # [deg] user elevation cut-off for expt/have ratio estimates
  pos_cut="[double]" # [deg] elevation angle cut-off mask for positioning estimates
  pos_int="[integer]" # [s] interval for single point positioning estimates
  pos_kin="[boolean]" # enables processing of data from a receiver in kinematic mode
  sat_rec="[boolean]" # satellite observations expected (true:any, false:signal)
  mpx_lim="[double]" # [-] sigma multiplier for phase pre-processing in multipath
  mpx_nep="[integer]" # [#] number of epochs used for code multipath estimates
  col_sat="[integer]" # [#] number of columns for satellite-specific columns
  int_stp="[integer]" # [s] interval for QC parameters sampling
  int_gap="[integer]" # [s] interval for reporting data gaps
  int_pcs="[integer]" # [s] interval for reporting small data pieces
  max_vpe="[double]" # [m] maximum vertical position error
  max_hpe="[double]" # [m] maximum horizontal position error
  max_dop="[double]" # [m] maximum PDOP value in positioning performance
  -->
/>

```

The attributes for individual sections (`sec...`) correspond with the structure of the Anubis' native XTR output, see Section 4, where the value defines a verbosity level for each individual part of the XTR format. The higher value, the more detailed information are reported in the

log file. The zero verbosity deactivates any corresponding section for the reporting as well as the data processing. A negative value then deactivates only the reporting, and is used for triggering any mandatory process on the background (done by the software for some closely related operations).

The *use_qcmode* attribute represents individual sections' verbosity pre-settings, and it has been described in Section 2.

The *use_health* attribute, together with the *chk_record* from the <nav> element, controls the usage of unhealthy satellites in QC functioning within different QC sections, see Table 3.1.

Table 3.1: Satellites used in different sections when considering the health status

Settings attribute	Value	Value	Value	Value
<i>:nav:chk_health=</i>	"false"	"true"	"true"	"true"
<i>:qc:use_health=</i>	n/a	"position"	"statistics"	"all"
QC functioning in section	Satellites	Satellites	Satellites	Satellites
Positioning	all used	healthy	healthy	healthy
Position KPIs	all used	healthy	healthy	healthy
Observations	all used	all used	healthy	healthy
Summary statistics	all used	all used	healthy	healthy
Azimuth/elevation	all used	all used	all used	healthy
Frequency bands	all used	all used	all used	healthy
Pre-processing	all used	all used	all used	all used
Code multipath	all used	all used	all used	all used
Signal-to-noise	all used	all used	all used	all used
Satellite information	all used	all used	all used	all used

The *int_stp* attribute defines a synchronous sampling of QC parameters reported within the most sections (*sec_ele* , *sec_bnd* , *sec_mpx* , *sec_snr*), e.g. necessary for sky-plots QC visualisations. The *pos_int* attribute then defines a specific sampling for a position estimates and positioning indicators (*sec_est* , *sec_kpi*).

Similarly, while the *ele_cut* attribute specifies a user elevation angle for ratio of expected and existing observations, the *pos_cut* affects the elevation cut-off mask in a single point positioning.

The *mpx_lim* attribute is used for a threshold definition for a cycle-slip detection within the code multipath calculation. Average code multipath is estimated exploiting a specific linear combination of a code and dual-frequency phase observations, see Section 4.9 requiring a sequence of n-epochs (*mpx_nep*) without phase cycle slips. The algorithm exploits the threshold *mpx_lim*sigma* for identifying a potential cycle slip, while the sigma has been estimated from the noise of a consecutive (and continuous) multipath observations.

The *max_vpe* , *max_hpe* , and *max_dop* attributes specify maximum values for the positioning performance indicators – vertical error, horizontal error, and PDOP value, respectively.

When processing data from a kinematic receiver (*pos_kin="true"*), the position is estimated every epoch on the basis of code observations using the ionosphere-free linear combination.

The processing time increases when analysing kinematic data, thus for a permanent station, the default value ("false") should be optimally used for estimating coordinates just once.

3.8 Site metadata configuration

A site metadata can be obtained either from the SINEX [7] or defined in the XML settings, see Section 2.2. The latter enables specification of the following metadata types:

- **id** (string) – unique site identifier (internal software identifier)
- **name** (string) – site name (4-char/9-char station name)
- **domes** (string) – site DOMES number
- **desc** (string) – site description
- **rec** (string) – site receiver name
- **ant** (string) – site antenna+radome name
- **X | Y | Z** (double) – site cartesian coordinates [m]
- **DN | DE | DU** (double) – site North, East, and Up eccentricities [m]
- **SX | SY | SZ** (double) – site coordinates sigmas [m]

Selected metadata types (**rec**, **ant**, **X/Y/Z**, **DN/DE/DU**, **SX/SY/SZ**) might be attributed with a time validity if defined using a time-dependent sub-element.

Common (or static) metadata are set simply in the `<site>` parent element, i.e. without a time-dependent sub-element:

```
<site id="GOPE" name="GOPE00CZE" domes="11502M002" desc="Geodetic_Observatory_Pecny"
      X="3979316.1" Y="1050312.6" Z="4857067.4" DN="0.0" DE="0.0" DU="0.1114"
      REC="TPS_NETG3"
      ANT="TPSCR.G3_00000000_TPSH"
/>
```

*Remark: the **id** should be unique site identifier, possibly linked with the rec IDs specified within the `<gen><site>` element.*

As long as any individual site metadata are valid for a particular time interval, it should be set up using one or more time-dependent elements (`<set>`) with possibility to specify explicitly the **beg** and the **end** timestamp attributes, e.g.:

```
<site id="GOPE00CZE" name="GOPE00CZE" domes="11502M002" desc="Pecny, Ondrejov/Czech_Republic" X="3979316.1" Y="1050312.5" Z="4857067.1" >
  <set beg="2019-04-10T00:00:00" end="2019-04-10T00:00:00" rec="TRIMBLE_ALLOY" ant="TPSCR.G3_00000000_TPSH" DU="0.1114" DN="0.0000" DE="0.0000" />
  <set beg="2018-08-08T00:00:00" end="2019-04-10T00:00:00" rec="TRIMBLE_SPS855" ant="TPSCR.G3_00000000_TPSH" DU="0.1114" DN="0.0000" DE="0.0000" />
  <set beg="2009-12-14T00:00:00" end="2018-08-08T00:00:00" rec="TPS_NETG3" ant="TPSCR.G3_00000000_TPSH" DU="0.1114" DN="0.0000" DE="0.0000" />
  <set beg="2006-07-14T00:00:00" end="2009-12-14T00:00:00" rec="ASHTECH_Z18" ant="TPSCR3_GGD_00000000_CONE" DU="0.1114" DN="0.0000" DE="0.0000" />
  <set beg="2006-01-24T00:00:00" end="2006-07-14T00:00:00" rec="ASHTECH_Z18" ant="ASH701946.3_00000000_SNOW" DU="0.0467" DN="0.0000" DE="0.0000" />
  <set beg="2000-10-04T00:00:00" end="2006-01-24T00:00:00" rec="ASHTECH_Z18" ant="ASH701946.3_00000000_SNOW" DU="0.0464" DN="0.0000" DE="0.0000" />
  <set beg="2000-07-24T00:00:00" end="2000-10-04T00:00:00" rec="TRIMBLE_4000SSE" ant="TRM14532.00_00000000_NONE" DU="0.0464" DN="0.0000" DE="0.0000" />
  <set beg="1999-11-04T00:00:00" end="2000-07-24T00:00:00" rec="ASHTECH_Z18" ant="ASH701073.3_00000000_SNOW" DU="0.0464" DN="0.0000" DE="0.0000" />
  <set beg="1997-06-20T00:00:00" end="1999-11-04T00:00:00" rec="TRIMBLE_4000SSE" ant="TRM14532.00_00000000_NONE" DU="0.0464" DN="0.0000" DE="0.0000" />
  <set beg="1997-06-11T00:00:00" end="1997-06-20T00:00:00" rec="SPP_GEOTRACER100" ant="TRM14532.00_00000000_NONE" DU="0.0464" DN="0.0000" DE="0.0000" />
  <set beg="1995-05-13T00:00:00" end="1997-06-11T00:00:00" rec="TRIMBLE_4000SSE" ant="TRM14532.00_00000000_NONE" DU="0.0464" DN="0.0000" DE="0.0000" />
</site>
```

The time evolution metadata settings should facilitate validating or editing station metadata in the RINEX header. The IGS site-log files can be extracted into the G-Nut XML settings, and introduced as a common input for the QC operation or file editing, e.g. by combining 'static' XML settings (e.g. metadata) and 'dynamic' input/output configurations from the software command-line arguments.

4. XTR QC output

The XTR file is organised in sections consisting of related QC results corresponding to QC settings. Each section is introduced with an initialisation string (‘#=====’), the section name and its verbosity level. Each data lines starts with a unique 6-char keyword helpful for an easier QC results searching, handling, and filtering. It can be effectively used for convenient single-/multi-file QC data processing or plotting within a script.

Within each individual section, a level of output details can be controlled via its verbosity level (see Section 2.4). The verbosity level 1 (e.g. *sec_est=1*) provides usually a summary statistics only, while the verbosity 2 (e.g. *sec_est=2*) gives more concrete details including time-dependent QC results. The zero verbosity (e.g. *sec_est=0*) then corresponds to a switching off both processing and output related to the section (and could speed up the solution). The Anubis may however still trigger some operations on the background (e.g. *sec_est=-1*) if these are mandatory for other QC output. Next sections describe a content of the XTR file when using the highest verbosity.

4.1 Summary statistics

The summary section contains a collection of the most interesting statistics obtained during the QC processing. Constellation-/satellite-/signal-specific outputs are included together with an overall observation statistics. Basic characteristics over all GNSS global constellations are represented with a single summary line (with individual columns described below):

```
#===== Summary statistics
#TOTSUM First_Epoch----- Last_Epoch----- Hours_ Sample MinEle #_Expt #_Have %Ratio o/slps woElev Exp>10 Hav>10 %Rt>10
=TOTSUM 2020-12-31 00:00:00 2020-12-31 23:59:30 24.00 30.00 0.02 148580 120525 81.12 161 6201 114833 104528 91.03
```

- Hours** – data window length in hours (estimated from a total number of epochs and sampling rate)
- Sample** – data sampling interval (estimated from existing observations)
- MinEle** – data minimum elevation angle (estimated from observation elevation angles, if possible)
- #_Expt** – number of expected observations above the horizon (carrier-phase signal with a maximum count for each GNSS)
- #_Have** – number of existing observations above the horizon (carrier-phase signal with a maximum count for each GNSS)
- %Ratio** – ratio of existing/expected observations above the horizon (calculated from values given above)
- o/slps** – number of carrier-phase observations per one cycle slip
- woElev** – number of carrier-phase observations without available elevation angle (missing valid satellite ephemeris)
- Exp>10** – number of expected observations above user mask (carrier-phase signal with a maximum count for each GNSS)
- Hav>10** – number of existing observations above user mask (carrier-phase signal with a maximum count for each GNSS)
- %Rt>10** – ratio of existing/expected observations above user elevation-cut of mask (calculated from values given above)

The line is identified with the keyword (‘=TOTSUM’), which is followed with the first and the last observation epoch of available GNSS observations. Epoch strings are reported in the form – ‘%Y-%m-%d %D:%M:%S’ , see Section 2.6.

A data window length (‘Hours’) is represented in hours when estimated from a total number of data epochs multiplied by an estimated sampling interval (‘Sample’).

The ‘MinEle’ is estimated as a minimum elevation angle over all collected observations (and constellations) provided the valid complete navigation data are available.

Total counts of carrier-phase observations are calculated as sums of representative signals for each individual GNSS (the one with a maximum number of carrier-phase observations). *Note:*

a traditional signal at the first frequency is often selected as it usually has a good signal-to-noise density and is transmitted by all satellites.

The ‘*#_Expt*’, ‘*#_Have*’ and ‘*%Ratio*’ values express expected number of observations, existing numbers of observations, and their ratio, respectively. All these values characterise the availability of observations above the horizon.

The ‘*Exp>10*’, ‘*Hav>10*’, and ‘*%Rt>10*’ parameters represent similar counts as described above, however, reflecting a user elevation angle settings (10 degrees in the example).

The ‘*o/slps*’ reflects a number of carrier-phase observations per single cycle slip when considering the same carrier-phase signals selected for individual constellations.

The ‘*woElev*’ represents a number of satellite carrier-phase observations (count over a signal per GNSS) without valid ephemeris and, consequently, without calculated satellite positions and elevation/azimuth angles. A large value (> 200) indicates a problem with available navigation data (for one or more constellations).

Additional lines report a summary statistics on data quality and availability for each individual constellation (specified in the keyword prefix, e.g. ‘*=GPSSUM*’):

#GNSSUM	2020-12-31	00:00:00	Epoch_Statistics_				Excl_Epochs&Satellites_				CycleSlips/Interruptions_And_Other_Discontinuities						Code_Multipath_Mean_...				
#GNSSUM	2020-12-31	00:00:00	ExpEp	HavEp	UseEp	xCoEp	xPhEp	xCoSv	xPhSv	csAll	csEpo	csSat	csSig	nSlp	nJmp	nGap	nPcs	mp1	mp2	mp3	...
=GPSSUM	2020-12-31	00:00:00	2880	2880	2880	0	0	360	400	471	0	171	271	29	0	0	0	26.0	24.3	-	...
=GALSUM	2020-12-31	00:00:00	2880	2880	2880	0	0	15	15	228	0	200	22	6	0	0	0	19.7	-	-	...
=GLOSUM	2020-12-31	00:00:00	2880	2880	2880	0	0	2997	3016	639	0	254	118	267	0	0	0	30.1	34.7	-	...
=BDSSUM	2020-12-31	00:00:00	2880	2880	2880	0	0	2435	2488	3471	0	790	491	2190	0	0	0	-	46.8	-	...

ExpEp – number of expected epochs (user pre-defined data window and sampling, otherwise estimated from data)

HavEp – number of available epochs (counting actual data epochs)

UseEp – number of usable epochs (criterion is 4 satellites in the epoch with dual-frequency data for each GNSS constellation)

xCoEp – number of epochs with less than 4 satellites providing dual-frequency pseudorange observations

xPhEp – number of epochs with less than 4 satellites providing dual-frequency carrier-phase observations

xCoSv – number of single-frequency pseudorange data only

xPhSv – number of single-frequency carrier-phase data only

csTot – number of total phase cycle slips or interruptions (corresponds to setting a new initial phase ambiguity)

csEpo – number of interruptions due to a missing epoch (counting all previously observed satellites)

csSat – number of interruptions due to a missing satellite at a specific epoch (when it is expected)

csSig – number of interruptions due to a missing signal from a single satellite (and others are available)

nSlp – number of identified phase cycle slips during a continuous tracking (counting for satellite and signal)

nJmp – number of identified receiver clock jumps (or an incoherence of code and phase observations)

nGap – number of data total gaps (according to the setting *int_gap* = 600 in seconds)

nPcs – number of small data pieces (according to the setting *int_pcs* = 1800 in seconds)

mpX – code multipath moving average RMS [cm] (mean value over all all signals at a given frequency band)

All ‘*expected*’ values are estimated according to the window specified in the <beg>, <end> elements of the <gen> settings. If the window is not set up (by default), the interval is defined from the first and the last observation epochs. *Note: the window definition by user is highly recommended, else any missing epoch at the beginning/end of a data file will distort ‘expected’ parameters, and thus all the quantitative QC indicators.*

A minimum number of four satellites is requested in the single point position, hence a number of ‘*usable*’ epochs (‘*UseEp*’) represents those epochs providing dual-frequency observations from 4 satellites at least. Numbers of ‘*unusable*’ epochs with few insufficient code and carrier-phase observations are reported in ‘*xCoEp*’ and ‘*xPhEp*’ parameters, and numbers of single-frequency code and carrier-phase measurements for individual satellites are reported in ‘*xCoSv*’ and ‘*xPhSv*’ parameters, respectively.

Pre-processing results are characterised by the number of receiver clock jumps ‘*nJmp*’ and numbers of carrier-phase interruptions such as cycle slips ‘*nSlp*’, discontinuities of observations for individual satellite ‘*csSat*’, epochs ‘*csEpo*’ and signals ‘*csSig*’. Epoch-/signal-specific information details on data pre-processing can be found in Section 4.7.

Data gap may cause a significant problem in the processing as the carrier-phase observation continuity is lost, and all ambiguities need to be re-initialised, and the solution converges again. Overcoming data gaps or connecting short data pieces is possible only with advanced processing techniques. Numbers of data gaps ‘*nGap*’ and short data pieces ‘*nPcs*’ are reported according to user settings 3. Details are provided in Section 4.6.

Mean code multipath and noise characterise a quality of an observed signal and the site environment. Mean values per frequency band and constellation are reported here. A detailed description of such values (epoch-/satellite-/signal-specific) is given in the section 4.9.

A verbose summary gives characteristics for individual observations and each constellation:

#GNSSxx	2020-12-31	00:00:00	<i>nSat</i>	<i>ExpObs</i>	<i>HavObs</i>	<i>%Ratio</i>	<i>Exp>10</i>	<i>Hav>10</i>	<i>%Rt>10</i>	<i>wo/Elev</i>	<i>Ele>0</i>	<i>Ele>5</i>	<i>Ele>10</i>	<i>Ele>15</i>	...
=GPSC1C	2020-12-31	00:00:00	31	33515	29709	88.64	25388	25365	99.91	0	29709	28452	25365	22200	...
=GPSC2W	2020-12-31	00:00:00	31	33515	29048	86.67	25388	25364	99.91	0	29048	28144	25364	22200	...
=GPSC2X	2020-12-31	00:00:00	23	33515	21706	64.77	25388	18553	73.08	0	21706	20852	18553	16178	...
=GPSC5X	2020-12-31	00:00:00	16	33515	14952	44.61	25388	12728	50.13	0	14952	14304	12728	11135	...
=GPSL1C	2020-12-31	00:00:00	31	33515	29542	88.15	25388	25364	99.91	0	29542	28370	25364	22200	...
=GPSL2W	2020-12-31	00:00:00	31	33515	28971	86.44	25388	25363	99.90	0	28971	28102	25363	22200	...
=GPSL2X	2020-12-31	00:00:00	23	33515	21706	64.77	25388	18553	73.08	0	21706	20852	18553	16178	...
=GPSL5X	2020-12-31	00:00:00	16	33515	14952	44.61	25388	12728	50.13	0	14952	14304	12728	11135	...
=GALC1X	2020-12-31	00:00:00	24	26275	22111	84.15	19650	19363	98.54	0	22111	21352	19363	17005	...
=GALC5X	2020-12-31	00:00:00	24	26275	22067	83.98	19650	19363	98.54	0	22067	21341	19363	17005	...
=GALC6X	2020-12-31	00:00:00	24	26275	22074	84.01	19650	19362	98.53	0	22074	21345	19362	17004	...
=GALC7X	2020-12-31	00:00:00	24	26275	21950	83.54	19650	19363	98.54	0	21950	21313	19363	17005	...
=GALC8X	2020-12-31	00:00:00	24	26275	22094	84.09	19650	19363	98.54	0	22094	21346	19363	17005	...
=GALL1X	2020-12-31	00:00:00	24	26275	22101	84.11	19650	19363	98.54	0	22101	21351	19363	17005	...
=GALL5X	2020-12-31	00:00:00	24	26275	22067	83.98	19650	19363	98.54	0	22067	21341	19363	17005	...
=GALL6X	2020-12-31	00:00:00	24	26275	22065	83.98	19650	19362	98.53	0	22065	21344	19362	17004	...
=GALL7X	2020-12-31	00:00:00	24	26275	21950	83.54	19650	19363	98.54	0	21950	21313	19363	17005	...
=GALL8X	2020-12-31	00:00:00	24	26275	22094	84.09	19650	19363	98.54	0	22094	21346	19363	17005	...
=GLOC1C	2020-12-31	00:00:00	24	27183	24345	89.56	21630	21329	98.61	942	23403	22571	20492	17659	...
=GLOC1P	2020-12-31	00:00:00	24	27173	24293	89.40	21621	21312	98.57	932	23361	22543	20484	17659	...
=GLOC2C	2020-12-31	00:00:00	21	27170	20927	77.02	21618	18641	86.23	929	19998	19406	17816	15481	...
=GLOC2P	2020-12-31	00:00:00	21	27173	21336	78.52	21621	18925	87.53	932	20404	19768	18097	15694	...
=GLOL1C	2020-12-31	00:00:00	24	27183	24345	89.56	21630	21329	98.61	942	23403	22571	20492	17659	...
=GLOL1P	2020-12-31	00:00:00	24	27173	24287	89.38	21621	21311	98.57	932	23355	22540	20483	17658	...
=GLOL2C	2020-12-31	00:00:00	21	27170	20924	77.01	21618	18639	86.22	929	19995	19404	17814	15480	...
=GLOL2P	2020-12-31	00:00:00	21	27173	21313	78.43	21621	18917	87.49	932	20381	19752	18089	15693	...
=BDSC2I	2020-12-31	00:00:00	42	61618	44565	72.32	48175	38495	79.91	5270	39295	37792	33811	29719	...
=BDSC6I	2020-12-31	00:00:00	40	59396	42117	70.91	46200	36307	78.59	3048	39069	37573	33598	29506	...
=BDSC7I	2020-12-31	00:00:00	11	56348	12797	22.71	43491	11129	25.59	0	12797	12405	11129	9954	...
=BDSSL2I	2020-12-31	00:00:00	42	61607	44537	72.29	48165	38472	79.88	5259	39278	37777	33798	29706	...
=BDSSL6I	2020-12-31	00:00:00	40	59371	42046	70.82	46178	36246	78.49	3023	39023	37532	33559	29467	...
=BDSSL7I	2020-12-31	00:00:00	11	56348	12770	22.66	43491	11103	25.53	0	12770	12378	11103	9928	...

nSat – number of satellites transmitting the signal

ExpObs – number of expected observations above the horizon (user-defined window, data sampling, visible satellites)

HavObs – number of available observations above the horizon (counting actual observations for tracked satellites)

%Ratio – ratio of existing/expected observations above the horizon (calculated from above values)

wo/Elev – number of observations without knowing an elevation angle (missing or invalid satellite ephemeris)

Exp>10 – number of expected observations above user mask (e.g. above 10-deg elevation angle cut-off)

Hav>10 – number of existing observations above user mask (e.g. above 10-deg elevation angle cut-off)

%Rt>10 – ratio of existing/expected observations above the user elevation angle cut-off (using values above)

Ele> X – number of existing observations above the X-deg elevation angle

Each line is introduced with a keyword generated from GNSS system and RINEX observation code, and provides similar statistics as described in the ‘*TOTSUM*’ line. The ‘*nSat*’ expresses counts of satellites tracking a particular signal, e.g. the third GPS frequency signals (C5/L5) are obviously transmitted by modern satellites only (16). The ‘*wo/Elev*’ represents numbers

of observations without calculated elevation angle (e.g. BeiDou), and higher numbers may indicate an increased uncertainty for ‘*expected*’ counts.

Finally, the summary reports times of satellite ascending/descending for horizon (‘*SKYxxx*’) and a user elevation angle mask (‘*MSKxxx*’):

# <i>SKYxxx</i>	<i>Ascending_Horizon_</i>	<i>Descending_Horizon_</i>	<i>Time[h]</i>	<i>ExptObs</i>
=SKYC02	2020-12-31 00:00:00	2020-12-31 23:59:30	23.992	2879
=SKYC05	2020-12-31 00:00:00	2020-12-31 23:59:30	23.992	2879
=MSKC05	2020-12-31 00:00:00	2020-12-31 23:59:30	23.992	2879
=SKYC06	2020-12-31 00:00:00	2020-12-31 07:01:21	7.023	843
=SKYC06	2020-12-31 22:47:54	2020-12-31 23:59:30	1.193	143
=MSKC06	2020-12-31 00:00:00	2020-12-31 05:43:24	5.723	687
=MSKC06	2020-12-31 23:38:18	2020-12-31 23:59:30	0.353	42
=SKYC07	2020-12-31 06:36:53	2020-12-31 14:52:36	8.262	991
=MSKC07	2020-12-31 07:30:26	2020-12-31 13:30:11	5.996	720
=SKYC08	2020-12-31 14:38:50	2020-12-31 23:05:10	8.439	1013
=MSKC08	2020-12-31 15:22:32	2020-12-31 21:52:50	6.505	781
=SKYC09	2020-12-31 00:00:00	2020-12-31 11:20:08	11.336	1360
=SKYC09	2020-12-31 23:23:48	2020-12-31 23:59:30	0.595	71
=MSKC09	2020-12-31 00:12:23	2020-12-31 09:31:59	9.327	1119
.....				

A satellite visibility interval (‘*Time[h]*’) and counts of expected observations (‘*ExptObs*’) complete each record. The C02 and C05 are BeiDou geostationary satellites visible above the horizon whole day, but C05 above the user mask as the station is located in Europe.

4.2 Header information

Selected station metadata are stored in the header of the RINEX observation file, and their correctness is very critical for precise GNSS application. Data analysts usually perform an independent cross-validation of the RINEX metadata against external metadata source. The International GNSS Service (IGS, <https://www.igs.org>) has developed a station log file for the purpose of a long-term maintenance of all changes at GNSS site instrumentation, environment and other information.

Currently, Anubis is able to check the RINEX header metadata against external information provided either in Anubis configuration or from the SINEX input file. Anubis is not capable of handling the IGS site-log format, but a support of its future replacement – GeodesyML (<http://geodesyml.org/>) is on Anubis’ TODO list. A user metadata can be utilised for a cross-validation of RINEX header files. Both RINEX header and user metadata are reported in the XTR file within the **QC mode** and this can be archived or exploited in a post-processing. However, header metadata inconsistencies can directly be reported as warnings and errors on the standard error output when using the **thin mode** , see 2.2.

The RINEX header metadata reported in XTR output are introduced with:

##### Header information			
#RNXHDR	2020-12-31 00:00:00	_RINEX_HEADER_-----	_RINEX_HEADER_-----
=RNXVER	2020-12-31 00:00:00	3.03	M
=RNXPGM	2020-12-31 00:00:00	ALLOY 5.45&OBSRINEX	RIGTC, GO PECNY
=RNXAGE	2020-12-31 00:00:00	GOP OC STAFF	RIGTC, GO PECNY

‘=RNXVER’ – RINEX file version, observation data type, and the date of file creation.

‘=RNXPGM’ – program name and the operator who created the RINEX.

‘=RNXAGE’ – observer name and the agency name.

The second part contains RINEX header (RINEX_HEADER) and user metadata (USER_REQUEST) provided in parallel for easy grepping through an archive of XTR files:

```
#RNXHDR 2020-12-31 00:00:00 _RINEX_HEADER----- _USER_REQUEST-----
=BEGEND 2020-12-31 00:00:00 2020-12-31 00:00:00      xxxx-xx-xx  xx:xx:xx      2020-12-31 00:00:00      2020-12-31 23:59:30
=INTHDR 2020-12-31 00:00:00 30.000
=MARKER 2020-12-31 00:00:00 GOPE 11502M002
=RECEIV 2020-12-31 00:00:00 TRIMBLE ALLOY      5.45      40016      TRIMBLE ALLOY
=ANTENN 2020-12-31 00:00:00 TPSCR.G3      TPSH30161      TPSCR.G3      TPSH
```

- '=BEGEND' – start and end epoch of the file.
- '=INTHDR' – sampling interval.
- '=MARKER' – marker name (site name).
- '=RECEIV' – receiver type, version and the firmware.
- '=ANTENN' – antenna type, radome and serial number.

The last part consists of coordinate and eccentricity metadata:

```
#RNXHDR 2020-12-31 00:00:00 _RINEX_HEADER----- _USER_REQUEST-----
=XYZAPR 2020-12-31 00:00:00      3979316.4389      1050312.2534      4857066.9036      3979316.4389      1050312.2534      4857066.9036
=XYZECC 2020-12-31 00:00:00      0.0694      0.0183      0.0852      0.0694      0.0183      0.0852
=ENUECC 2020-12-31 00:00:00      0.0000      0.0000      0.1114      0.0000      0.0000      0.1114
```

- '=XYZAPR' – approximate site coordinates.
- '=XYZECC' – XYZ eccentricities (from marker to antenna reference point).
- '=ENUECC' – ENU eccentricities (from marker to antenna reference point).

4.3 Estimated values

The complex overview on quality of GNSS observations and navigation messages can be obtained with data analysis. Epoch-wise single point positioning exploiting code pseudorange observations only is used to estimate site coordinates and receiver clock offsets.

The section for estimated values contains summary information:

```
##### Estimated values
=PERIOD 2020-12-31 00:00:00 2020-12-31 00:00:00      2020-12-31 23:59:30
=SAMPLE 2020-12-31 00:00:00 30.000
=XYZGPS 2020-12-31 00:00:00      3979316.8216      1050312.7641      4857068.3343      1.4      0.9      1.5      96      0
=XYZGAL 2020-12-31 00:00:00      3979315.9539      1050312.7662      4857067.3737      0.7      0.4      0.7      96      0
=XYZGLO 2020-12-31 00:00:00      3979315.6761      1050311.1717      4857067.1897      3.5      3.3      7.5      96      0
=XYZBDS 2020-12-31 00:00:00      3979322.6273      1050310.6425      4857071.7062      6.1      3.6      13.2      96      0
=BLHGPS 2020-12-31 00:00:00      49.913706685      14.785623749      594.0187      1.0      1.2      1.9      96      0
=BLHGAL 2020-12-31 00:00:00      49.913706891      14.785626860      592.7439      0.6      0.6      0.8      96      0
=BLHGLO 2020-12-31 00:00:00      49.913710472      14.785606383      592.1682      4.0      4.6      7.5      96      0
=BLHBDS 2020-12-31 00:00:00      49.913691320      14.785574563      599.8646      4.5      4.7      13.9      96      0
```

- '=PERIOD' – first and last observations of available data.
- '=SAMPLE' – estimated sampling rate (using a statistical approach).
- '=XYZGPS' – mean XYZ coordinates estimated using GPS system, uncertainties, numbers of used and excluded epochs.
- '=BLHGPS' – mean BLH coordinates estimated using GPS system, uncertainties, numbers of used and excluded epochs.

Earth-centred, Earth-fixed (XYZ) and ellipsoidal (BLH) site coordinates are estimated from individual GNSS constellations. Mean values are reported together with uncertainties and numbers of samples/outliers (96 position epochs in a 15-min sampling defined in settings 3.7).

A higher verbosity gives epoch-wise coordinate estimates for user settings:

```
#POSGNS 2020-12-31 00:00:00      X [m]      Y [m]      Z [m]      B [deg]      L [deg]      H [m]      GDOP ... REC_CLK[m] #Sat #Excl
POSGPS 2020-12-31 00:00:00      3979317.8132      1050313.7215      4857069.2804      49.913703888      14.785633113      595.5173      1.7 ... 130455.0 11 0
POSGPS 2020-12-31 00:15:00      3979317.7813      1050312.8226      4857071.1510      49.913718613      14.785621126      597.0594      1.6 ... 130455.8 11 0
POSGPS 2020-12-31 00:30:00      3979318.2924      1050313.8926      4857070.2627      49.913706087      14.785633713      596.5954      1.7 ... 130455.6 12 2
POSGPS 2020-12-31 00:45:00      3979320.1232      1050314.1277      4857071.6890      49.913701756      14.785630374      598.8651      1.7 ... 130457.6 11 1
POSGPS 2020-12-31 01:00:00      3979319.2242      1050314.4574      4857070.1991      49.913698531      14.785638005      597.2196      1.4 ... 130456.7 11 0
POSGPS 2020-12-31 01:15:00      3979319.0981      1050314.7318      4857068.3179      49.913687998      14.785642147      595.7469      1.9 ... 130455.2 11 2
POSGPS 2020-12-31 01:30:00      3979317.4467      1050314.0329      4857068.7116      49.913702485      14.785638607      594.9051      1.5 ... 130454.5 11 0
...
POSGAL 2020-12-31 00:00:00      3979316.4862      1050312.7723      4857067.8515      49.913706107      14.785625050      593.4419      1.8 ... 130456.8 9 0
POSGAL 2020-12-31 00:15:00      3979315.2428      1050312.9022      4857066.8290      49.913708228      14.785631216      591.9068      1.8 ... 130456.0 10 1
POSGAL 2020-12-31 00:30:00      3979316.2332      1050312.7339      4857068.0952      49.913709267      14.785625432      593.4645      1.8 ... 130457.1 9 0
POSGAL 2020-12-31 00:45:00      3979315.2297      1050312.3404      4857068.0463      49.913716348      14.785623700      592.7376      1.8 ... 130456.6 9 0
POSGAL 2020-12-31 01:00:00      3979314.6228      1050312.1410      4857067.4003      49.913716994      14.785623173      591.8328      2.5 ... 130456.0 9 1
POSGAL 2020-12-31 01:15:00      3979315.8496      1050312.7399      4857068.1353      49.913712040      14.785626876      593.2574      3.0 ... 130457.0 7 0
POSGAL 2020-12-31 01:30:00      3979315.9424      1050312.7756      4857068.3518      49.913712613      14.785627026      593.4866      2.8 ... 130457.3 7 0
...
```

- ‘X’, ‘Y’, ‘Z’ – cartesian coordinates estimated for the given GNSS constellation and time epoch.
- ‘B’, ‘L’, ‘H’ – ellipsoidal coordinates estimated for the given GNSS constellation and time epoch.
- ‘GDOP’, ‘PDOP’, ‘HDOP’, ‘VDOP’ – geometric, position, horizontal and vertical dilution of precision (DOP).
- ‘REC_CLK[m]’ – receiver clock offsets given in length unit (meters).
- ‘#Sat’, ‘#Excl’ – numbers of all and excluded satellites.

4.4 Observation types

A quantitative statistics of actually observed data is provided within this section. *Note: actual data are product of filtering applied during data decoding.* The below example shows results stemming from the verbosity `sec_obs=1` :

```
#===== Observation types
#GNSSYS 2020-12-31 00:00:00      4 GPS GAL GLO BDS

#GPSSAT 2020-12-31 00:00:00    31 G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 - G12 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 ...
#GALSAT 2020-12-31 00:00:00    24 E01 E02 E03 E04 E05 - E07 E08 E09 - E11 E12 E13 E14 E15 - - E18 E19 - E21 - - E24 E25 E26 E27 - ...
#GLOSAT 2020-12-31 00:00:00    24 R01 R02 R03 R04 R05 R06 R07 R08 R09 R10 R11 R12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22 R23 R24 - - - - ...
#BDSSAT 2020-12-31 00:00:00    42 - - - - C05 C06 C07 C08 C09 C10 C11 C12 C13 C14 - C16 - - C19 C20 C21 C22 C23 C24 C25 C26 C27 C28 ...

#BDSHDR 2020-12-31 00:00:00    12 C5X L5X S5X C2I L2I S2I C7I L7I S7I C6I L6I S6I
#GALHDR 2020-12-31 00:00:00    15 C1X L1X S1X C5X L5X S5X C7X L7X S7X C8X L8X S8X C6X L6X S6X
#GPSHDR 2020-12-31 00:00:00    12 C1C L1C S1C C2W L2W S2W C2X L2X S2X C5X L5X S5X
#IRNHDR 2020-12-31 00:00:00     3 C5A L5A S5A
#QZSHDR 2020-12-31 00:00:00    15 C1C L1C S1C C1X L1X S1X C1Z L1Z S1Z C2X L2X S2X C5X L5X S5X
#GLOHDR 2020-12-31 00:00:00    12 C1C L1C S1C C1P L1P S1P C2C L2C S2C C2P L2P S2P
#SBSHDR 2020-12-31 00:00:00     3 C1C L1C S1C
#GPSOBS 2020-12-31 00:00:00    12 C1C C2W C2X C5X L1C L2W L2X L5X S1C S2W S2X S5X
#GALOBS 2020-12-31 00:00:00    15 C1X C5X C6X C7X C8X L1X L5X L6X L7X L8X S1X S5X S6X S7X S8X
#GLOOBS 2020-12-31 00:00:00    12 C1C C1P C2C C2P L1C L1P L2C L2P S1C S1P S2C S2P
#BDSOBS 2020-12-31 00:00:00     9 C2I C6I C7I L2I L6I L7I S2I S6I S7I
```

- ‘#GNSSYS’ – count and list of observed systems.
- ‘#GPSSAT’ – count and list of observed satellites for the GPS system.
- ‘#GPSHDR’ – count and list of observation types for the GPS system (from a file header).
- ‘#GPSOBS’ – count and list of observation types for the GPS system (from actual data).

It may happen that the measurements reported in a file header are actually not present in RINEX data. It can be seen from a comparison of the ‘#GPSHDR’ and ‘#GPSOBS’ lines.

Nowadays, series of satellite block types carrying different equipment are common to GNSS constellation. All signals don’t have to be transmitted by all satellites, e.g. the L5 frequency is transmitted by modern GPS satellites only at the moment. A signal selection thus becomes important for any data analysis, in particular for a method utilising difference data. By increasing the section verbosity, more information is provided about available satellites and signals from data of each GNSS constellation.

```
GPSC1C 2020-12-31 00:00:00      G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 - G12 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 ...
GPSC2W 2020-12-31 00:00:00      G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 - G12 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 ...
GPSC2X 2020-12-31 00:00:00      G01 - G03 G04 G05 G06 G07 G08 G09 G10 - G12 - G14 G15 - G17 G18 - - - G23 G24 G25 G26 G27 - ...
GPS5X 2020-12-31 00:00:00      G01 - G03 G04 - G06 - G08 G09 G10 - - - G14 - - - G18 - - - G23 G24 G25 G26 G27 - ...
.....
GALL1X 2020-12-31 00:00:00      E01 E02 E03 E04 E05 - E07 E08 E09 - E11 E12 E13 E14 E15 - - E18 E19 - E21 - - E24 E25 E26 E27 - ...
GALL5X 2020-12-31 00:00:00      E01 E02 E03 E04 E05 - E07 E08 E09 - E11 E12 E13 E14 E15 - - E18 E19 - E21 - - E24 E25 E26 E27 - ...
GALL6X 2020-12-31 00:00:00      E01 E02 E03 E04 E05 - E07 E08 E09 - E11 E12 E13 E14 E15 - - E18 E19 - E21 - - E24 E25 E26 E27 - ...
GALL7X 2020-12-31 00:00:00      E01 E02 E03 E04 E05 - E07 E08 E09 - E11 E12 E13 E14 E15 - - E18 E19 - E21 - - E24 E25 E26 E27 - ...
GALL8X 2020-12-31 00:00:00      E01 E02 E03 E04 E05 - E07 E08 E09 - E11 E12 E13 E14 E15 - - E18 E19 - E21 - - E24 E25 E26 E27 - ...
.....
GLOS1C 2020-12-31 00:00:00      R01 R02 R03 R04 R05 R06 R07 R08 R09 R10 R11 R12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22 R23 R24 - - - - ...
GLOS1P 2020-12-31 00:00:00      R01 R02 R03 R04 R05 R06 R07 R08 R09 R10 R11 R12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22 R23 R24 - - - - ...
GLOS2C 2020-12-31 00:00:00      R01 R02 R03 R04 R05 - R07 R08 R09 - R11 R12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22 - R24 - - - - ...
GLOS2P 2020-12-31 00:00:00      R01 R02 R03 R04 R05 - R07 R08 R09 - R11 R12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22 - R24 - - - - ...
.....
BDS2I 2020-12-31 00:00:00      - - - - C05 C06 C07 C08 C09 C10 C11 C12 C13 C14 - C16 - - C19 C20 C21 C22 C23 C24 C25 C26 C27 C28 ...
BDS6I 2020-12-31 00:00:00      - - - - C05 C06 C07 C08 C09 C10 C11 C12 C13 C14 - C16 - - C19 C20 C21 C22 C23 C24 C25 C26 C27 C28 ...
BDS7I 2020-12-31 00:00:00      - - - - C05 C06 C07 C08 C09 C10 C11 C12 C13 C14 - C16 - - - - - - - - - - - - - - - ...
.....
```

- ‘GPSC1C’ – list of GPS satellites for code observations (C1C etc.).
- ‘GALL1X’ – list of Galileo satellites for phase observations (L1X etc.).
- ‘GLOS1C’ – list of GLONASS satellites for signal-to-noise density observations (C1C etc.).
- ‘BDS2I’ – list of BeiDou satellites for Doppler observations (D2I etc.).

```

G01OBS 2020-12-31 00:00:00 12 C1C C2W C2X C5X L1C L2W L2X L5X S1C S2W S2X S5X
G02OBS 2020-12-31 00:00:00 6 C1C C2W L1C L2W S1C S2W
.....
G05OBS 2020-12-31 00:00:00 9 C1C C2W C2X L1C L2W L2X S1C S2W S2X
G06OBS 2020-12-31 00:00:00 12 C1C C2W C2X C5X L1C L2W L2X L5X S1C S2W S2X S5X
.....
E01OBS 2020-12-31 00:00:00 15 C1X C5X C6X C7X C8X L1X L5X L6X L7X L8X S1X S5X S6X S7X S8X
E02OBS 2020-12-31 00:00:00 15 C1X C5X C6X C7X C8X L1X L5X L6X L7X L8X S1X S5X S6X S7X S8X
.....
R01OBS 2020-12-31 00:00:00 12 C1C C1P C2C C2P L1C L1P L2C L2P S1C S1P S2C S2P
R02OBS 2020-12-31 00:00:00 12 C1C C1P C2C C2P L1C L1P L2C L2P S1C S1P S2C S2P
R03OBS 2020-12-31 00:00:00 12 C1C C1P C2C C2P L1C L1P L2C L2P S1C S1P S2C S2P
R04OBS 2020-12-31 00:00:00 12 C1C C1P C2C C2P L1C L1P L2C L2P S1C S1P S2C S2P
R05OBS 2020-12-31 00:00:00 12 C1C C1P C2C C2P L1C L1P L2C L2P S1C S1P S2C S2P
R06OBS 2020-12-31 00:00:00 6 C1C C1P L1C L1P S1C S1P
.....
C05OBS 2020-12-31 00:00:00 9 C2I C6I C7I L2I L6I L7I S2I S6I S7I
C06OBS 2020-12-31 00:00:00 9 C2I C6I C7I L2I L6I L7I S2I S6I S7I
.....
C19OBS 2020-12-31 00:00:00 6 C2I C6I L2I L6I S2I S6I
C20OBS 2020-12-31 00:00:00 6 C2I C6I L2I L6I S2I S6I
.....

```

- '=G01OBS' – list of observations collected from the GPS satellite (G01 etc.).
- '=E01OBS' – list of observations collected from the Galileo satellite (E01 etc.).
- '=R01OBS' – list of observations collected from the GLONASS satellite (R01 etc.).
- '=C01OBS' – list of observations collected from the BeiDou satellite (C01 etc.).

4.5 Bands available

A traditional strategy for GNSS data processing is based on analyzing dual-frequency observations for largely eliminating ionospheric delay. Anubis thus considers valid satellite observations whenever at least two frequency carrier-phase and code observations are available. This section reports availability of frequencies and focuses on a lack of dual-frequency data. The section report consists of:

```

#==== Band available
#GNSSeP 2020-12-31 00:00:00 FewBand x01 x02 x03 x04 x05 x06 x07 x08 x09 x10 x11 x12 x13 x14 x15 x16 x17 x18 x19 x20 x21 x22 x23 x24 x25 x26 x27 x28 ...
=GPSCEP 2020-12-31 00:00:00 360 99 98 100 99 99 100 99 100 100 100 - 100 89 99 98 95 99 100 98 96 95 98 99 100 100 100 99 93 ...
=GPSLEP 2020-12-31 00:00:00 400 99 97 100 99 99 100 98 100 100 99 - 100 89 99 97 95 99 99 98 96 95 98 99 100 99 100 99 93 ...
=GALCEP 2020-12-31 00:00:00 15 100 100 100 100 100 - 100 100 99 - 100 100 100 99 100 - - 100 100 - 100 - - 100 100 100 - ...
=GALLEP 2020-12-31 00:00:00 15 100 100 100 100 100 - 100 100 99 - 100 100 100 99 100 - - 100 100 - 100 - - 100 100 100 - ...
=GLOCEP 2020-12-31 00:00:00 2997 99 99 99 99 99 0 99 99 99 0 99 99 100 99 99 99 99 99 100 100 99 88 0 99 - - - - ...
=GLOLEP 2020-12-31 00:00:00 3016 99 99 99 99 99 0 99 99 99 0 99 99 100 99 99 99 99 99 99 100 99 87 0 99 - - - - ...
=BDSCEP 2020-12-31 00:00:00 2435 - - - - 92 100 100 100 100 100 100 99 100 100 - 100 - - 100 100 99 99 99 99 100 99 100 100 ...
=BDSLCEP 2020-12-31 00:00:00 2488 - - - - 91 100 100 100 100 100 100 99 100 100 - 100 - - 100 100 99 99 99 99 100 99 100 100 ...

```

- '=GPSCEP' – percentage of dual-frequency code observations available for individual GPS satellites.
- '=GPSLEP' – percentage of dual-frequency carrier-phase observations available for individual GPS satellites.
- 'FewBand' – count of satellites with single-frequency code and phase observations (see also 'xCoSv' and 'xPhSv'), 4.1.

A higher verbosity reports actual frequency bands available at given sampling epochs:

```

#nxBAND 2020-12-31 00:00:00 nSatell x01 x02 x03 x04 x05 x06 x07 x08 x09 x10 x11 x12 x13 x14 x15 x16 x17 x18 x19 x20 x21 x22 x23 x24 x25 x26 x27 x28 ...
GPSCBN 2020-12-31 00:00:00 11 - - - - - - 2 3 - 3 - - - - 2 2 - 3 - 2 2 - 3 - - 3 3 - ...
GPSCBN 2020-12-31 00:15:00 11 - - - - - - 2 3 - 3 - - - - 2 2 - 3 - 2 2 - 3 - - 3 3 - ...
GPSCBN 2020-12-31 00:30:00 12 - - - - - - 2 3 - 3 - - - - 2 2 - 3 - 2 2 - 3 - - 3 3 - ...
GPSCBN 2020-12-31 00:45:00 11 - - - - - - 3 - 3 - - - - 2 2 - 3 - 2 2 - 3 - - 3 3 - ...
.....
GALLBN 2020-12-31 00:00:00 9 5 - - - - - 5 5 - - - - 5 5 - - - - - - - 5 - 5 - - ...
GALLBN 2020-12-31 00:15:00 10 5 - - - - - 5 5 - - - - 5 5 - - - - - - - 5 - 5 - - ...
GALLBN 2020-12-31 00:30:00 9 5 - - - - - 5 5 - - - - 5 5 - - - - - - - 5 - 5 - - ...
GALLBN 2020-12-31 00:45:00 9 5 - - - - - 5 5 - - - - 5 5 - - - - - - - 5 - 5 - - ...
.....
GLOCBN 2020-12-31 00:00:00 9 2 2 - - - - - 2 - - - - 2 2 2 2 - - - - 1 2 - - - ...
GLOCBN 2020-12-31 00:15:00 10 2 2 - - - - - 2 - - - - 2 2 2 2 - - - - 1 2 - - - ...
GLOCBN 2020-12-31 00:30:00 10 2 2 - - - - - 2 - - - - 2 2 2 2 - - - - 1 2 - - - ...
GLOCBN 2020-12-31 00:45:00 10 2 2 - - - - - 2 - - - - 2 2 2 2 - - - - 1 2 - - - ...
.....
BDSLBN 2020-12-31 00:00:00 18 - - - - 3 3 - - 3 - 3 3 3 - - 3 - - 2 - 2 2 2 2 - - - ...
BDSLBN 2020-12-31 00:15:00 19 - - - - 3 3 - - 3 - 3 3 3 - - 3 - - 2 - 2 2 2 2 2 - - - ...
BDSLBN 2020-12-31 00:30:00 19 - - - - 3 3 - - 3 - 3 3 3 - - 3 - - 2 - 2 2 2 2 2 - - - ...
BDSLBN 2020-12-31 00:45:00 19 - - - - 3 3 - - 3 - 3 3 3 - - 3 - - 2 - 2 2 2 2 2 - - - ...

```

- '=GPSCBN' – count of frequency bands for code observations available at a given epoch for individual GPS satellites.
- '=GPSLBN' – count of frequency bands for carrier-phase observations available at a given epoch for individual GPS satellites.
- 'nSatell' – count of satellites providing dual-frequency observations at a given epoch.

Epochs with a single-frequency data or number of satellites less than 4 are eventually reported:

```
#GNSSBND 2020-12-31 00:00:00 C<2 L<2 nSv SvList
GPSXBN 2020-12-31 00:30:00 1 1 12 G32
GPSXBN 2020-12-31 00:31:00 0 1 12 G32
GPSXBN 2020-12-31 00:35:00 0 1 12 G07
GPSXBN 2020-12-31 00:36:30 0 1 12 G07
GPSXBN 2020-12-31 01:05:00 1 2 12 G15 G22
GALXBN 2020-12-31 10:54:30 1 1 8 E14
GALXBN 2020-12-31 11:44:30 1 1 8 E14
GALXBN 2020-12-31 11:45:00 1 1 8 E14
GALXBN 2020-12-31 14:17:00 1 1 8 E31
GALXBN 2020-12-31 22:32:30 1 1 8 E36
GALXBN 2020-12-31 23:35:30 1 1 8 E09
GALXBN 2020-12-31 23:36:00 1 1 8 E09
GLOXBN 2020-12-31 00:00:00 1 1 9 R23
.....
```

‘ $C < 2$ ’, ‘ $L < 2$ ’ – count of satellites at a given epoch providing only single-frequency code and phase observations.

‘ nSv ’ – count of satellites available in a given epoch.

‘ $SvList$ ’ – list of satellites not providing dual-/multi-frequency observations.

4.6 Gaps & Pieces

GNSS observations with many data gaps are more difficult to process because some parameters, e.g. ambiguities, need to be reinitialised. Also within a short data block, parameters cannot be estimated precisely due to their long convergence (e.g. in Precise Point Positioning). This section reports large data gaps and short data pieces:

```
#===== Gaps & Pieces
#GAPLST 2020-12-31 begTime endTime >600s
GAPLST 2020-12-31 00:22:00 00:39:00 1020
GAPLST 2020-12-31 01:05:00 01:22:00 1020
GAPLST 2020-12-31 02:02:30 02:24:00 1290

#PCSLST 2020-12-31 begTime endTime <1800s
PCSLST 2020-12-31 00:00:00 00:22:00 1320
PCSLST 2020-12-31 00:39:00 01:05:00 1560

#SMPLST 2020-12-31 00:00:00 sampling count
SMPLST 2020-12-31 00:00:00 30 2744
SMPLST 2020-12-31 00:00:00 90 2
SMPLST 2020-12-31 00:00:00 120 1
SMPLST 2020-12-31 00:00:00 420 1
SMPLST 2020-12-31 00:00:00 1020 2
SMPLST 2020-12-31 00:00:00 1290 1
```

‘ $GAPLST$ ’ – list of large data gaps (defined by user).

‘ $PCSLST$ ’ – list of small data pieces (defined by user).

‘ $SMPLST$ ’ – list of frequencies of intervals between consecutive observations.

The first time (‘ $begTime$ ’) and the last time (‘ $endTime$ ’) of a data gap or small data piece are reported followed by the length in seconds. The length criteria is defined by the user and written in the header line. The last block summarises frequencies of intervals between consecutive epochs collected from observation data. The sampling rate is then estimated as the most frequent interval between observations.

4.7 Pre-processing results

The observation pre-processing is an essential part of precise GNSS analysis. It consists of detecting receiver clock jumps and detecting and possibly repairing carrier-phase cycle slips.

Along with real cycle slips (‘*CS_Slip*’), i.e. jumps in carrier-phase observations, additional three kinds of discontinuities are defined and counted: due to missing epochs (‘*CS_Epoch*’), due to missing satellites ‘*CS_Satell*’ , and due to missing signal (‘*CS_Signal*’) when considering two consecutive epochs, see Figure 4.1.

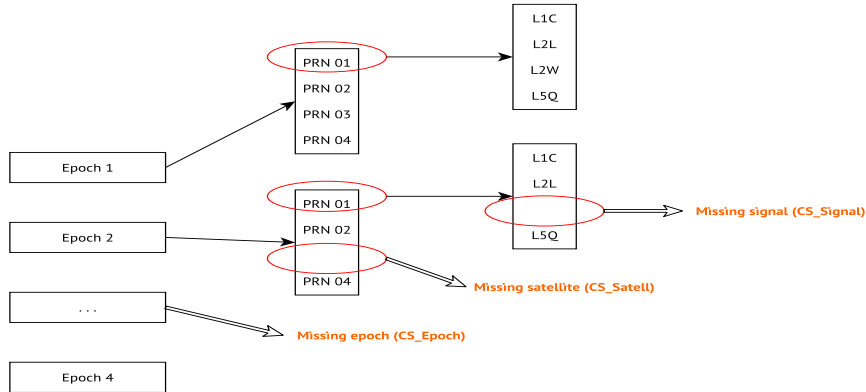


Figure 4.1: Signal discontinuities (epoch, satellite, and observation).

A minimum output (*sec_pre=1*) reports a summary over all constellations and signals:

```
#===== Preprocessing results
#GNsprp 2020-12-31 00:00:00      CS_Total      CS_Slip      CS_Epoch      CS_Satell      CS_Signal
=GPSRP 2020-12-31 00:00:00          471           29            0             171            271
=GALRP 2020-12-31 00:00:00          228            6            0             200            22
=GLOPRP 2020-12-31 00:00:00         639          267            0             254           118
=BDSRP 2020-12-31 00:00:00        3471         2190            0             790           491

#GNsxxx 2020-12-31 00:00:00      CS_Total      CS_Slip      CS_Epoch      CS_Satell      CS_Signal
=GPSL1C 2020-12-31 00:00:00          208           12            0              70            126
=GPSL2W 2020-12-31 00:00:00          152           12            0              27            113
=GPSL2X 2020-12-31 00:00:00           62            3            0              30            29
=GPSL5X 2020-12-31 00:00:00           49            2            0              44             3
=GALL1X 2020-12-31 00:00:00           49            1            0              46             2
=GALL5X 2020-12-31 00:00:00           46            2            0              42             2
=GALL6X 2020-12-31 00:00:00           44            0            0              34             10
=GALL7X 2020-12-31 00:00:00           43            1            0              37             5
=GALL8X 2020-12-31 00:00:00           46            2            0              41             3
=GLOL1C 2020-12-31 00:00:00          167           66            0             101            0
=GLOL1P 2020-12-31 00:00:00          158           69            0              67            22
=GLOL2C 2020-12-31 00:00:00          123           56            0              32            35
=GLOL2P 2020-12-31 00:00:00           191           76            0              54            61
=BDSL2I 2020-12-31 00:00:00         1069          669            0             376            24
=BDSL6I 2020-12-31 00:00:00         1290          775            0             235           280
=BDSL7I 2020-12-31 00:00:00         1112          746            0             179           187
```

‘*GPSRP*’ – count of carrier-phase interruptions counted over all signals for GPS.

‘*GPSL1C*’ – count of carrier-phase interruptions counted for GPS signals (L1C etc.).

‘*CLKJMP*’ – count of receiver clock jumps (no clock jump in the above example).

The principles of cycle-slip detection algorithm implemented in Anubis are referred to [8]. The algorithm has been improved for supporting all available multi-GNSS frequencies and signals, and cycle slips are reported for individual constellations.

For receivers equipped with a low-quality oscillators, the clocks may diverge fast compared to a stable satellite atomic clocks. If the difference becomes too large, the receiver corrects the clocks by a particular number of milliseconds. This correction causes a jump in receiver clocks and, consequently, also in carrier-phase observations. A cycle slip common to all satellites can be then observed. Anubis analyses GNSS observations and provides estimated number of milliseconds at all epochs where a receiver generates such a clock jump. Actual clock jumps are reported with *sec_pre=2* as in example below:

```
#CLKJMP 2010-04-15 00:00:00 Phase[ms]
CLKJMP 2010-12-26 00:07:30 1
CLKJMP 2010-12-26 00:19:30 2
CLKJMP 2010-12-26 00:31:00 3
CLKJMP 2010-12-26 00:42:30 4
CLKJMP 2010-12-26 00:54:30 5
CLKJMP 2010-12-26 01:06:00 6
CLKJMP 2010-12-26 01:17:30 7
CLKJMP 2010-12-26 01:29:30 8
CLKJMP 2010-12-26 01:41:00 9
..
```

The most comprehensive report of cycle slips provides lists of all identified cycle slips for individual satellites and constellations:

```
#GNSSLP 2016-08-24 00:00:00 PRN L1C L2C L2I L2L L2P L2W L3Q L5Q ...
GPSSLP 2016-08-24 00:39:00 G08 -12.0 - - - - -9.0 - -9.0 ...
GPSSLP 2016-08-24 00:39:30 G08 16.0 - - - - -12.0 - 12.0 ...
GPSSLP 2016-08-24 00:40:00 G30 4.0 - - - - -3.0 - 3.0 ...
.....
GALSLP 2020-12-31 08:22:30 E18 - - - 12 - - - - ...
GALSLP 2020-12-31 11:56:30 E15 - - - - - - - - ...
.....
GLOSLP 2020-12-31 00:30:00 R14 -9 -9 - -7 - -7 - - ...
GLOSLP 2020-12-31 00:32:30 R18 -9 -9 - -7 - -7 - - ...
GLOSLP 2020-12-31 00:42:00 R16 -9 -9 - -7 - -7 - - ...
.....
BDSSLP 2020-12-31 00:00:30 C05 - - - - -6 - - - - ...
BDSSLP 2020-12-31 00:01:00 C05 - - - - -1 - - - - ...
BDSSLP 2020-12-31 00:03:00 C05 - - - - - - - - - - ...
```

‘GPSSLP’ – cycle slips [unit of cycle] for individual GPS observations, given epoch and satellite.

4.8 Elevation & azimuth

Satellite ephemeris (navigation data or precise orbits in SP3) are needed for qualitative and complex control, however, it can be useful also for plotting satellite skyplots and when calculating the ratio of existing/expected observations, see 4.1, within the quantitative control.

Satellite elevations and azimuths are calculated in user-defined sampling interval:

```
##### Elevation & Azimuth
#GNSELE 2020-12-31 00:00:00 Mean x01 x02 x03 x04 x05 x06 x07 x08 x09 x10 x11 x12 x13 x14 x15 x16 x17 x18 x19 x20 x21 x22 x23 x24 x25 x26 x27 x28 ...
GPSELE 2020-12-31 00:00:00 37 - - - - - - 9 32 - 57 - - - - 15 49 - 31 - 55 11 - 56 - - 22 72 - ...
GPSELE 2020-12-31 00:15:00 37 - - - - - - 7 38 - 62 - - - - 14 42 - 25 - 51 16 - 53 - - 16 79 - ...
GPSELE 2020-12-31 00:30:00 33 - - - - - - 4 44 - 66 - - - - 12 36 - 19 - 46 22 - 48 - - 10 85 - ...
GPSELE 2020-12-31 00:45:00 34 - - - - - - - 51 - 67 - - - - 10 29 - 13 - 40 28 - 43 - - 4 83 - ...
GPSELE 2020-12-31 01:00:00 33 8 - - - - - - 58 - 66 - - - - 7 22 - 8 - 34 33 - 37 - - 76 - ...
GPSELE 2020-12-31 01:15:00 32 13 - - - - - - 64 - 62 - - - - - 16 - 3 - 28 39 4 31 - - 69 - ...
GPSELE 2020-12-31 01:30:00 32 19 - - - - - - 69 - 56 - - - - 9 - 9 - - 22 45 10 25 - - 61 - ...
.....
BDSELE 2020-12-31 00:00:00 27 - - - - 21 13 - - 7 - 11 61 16 - - 13 - - 33 - 12 42 - 15 22 - - - ...
BDSELE 2020-12-31 00:15:00 27 - - - - 21 15 - - 10 - 16 67 14 - - 16 - - 30 - 18 47 8 10 20 - - ...
BDSELE 2020-12-31 00:30:00 28 - - - - 21 18 - - 13 - 21 73 12 - - 19 - - 27 - 24 51 10 5 17 - - ...
BDSELE 2020-12-31 00:45:00 29 - - - - 21 20 - - 17 - 26 79 11 - - 21 - - 23 - 30 53 11 0 14 - - ...
BDSELE 2020-12-31 01:00:00 30 - - - - 21 22 - - 20 - 32 84 9 - - 23 - - 18 - 37 54 11 - 10 - - ...
BDSELE 2020-12-31 01:15:00 30 - - - - 21 23 - - 23 - 37 86 8 - - 25 - - 13 - 43 54 10 - 6 - - ...
BDSELE 2020-12-31 01:30:00 31 - - - - 21 25 - - 26 - 43 81 6 - - 27 - - 8 - 50 51 9 - 2 - - ...
.....
#GNSAZI 2020-12-31 00:00:00 Mean x01 x02 x03 x04 x05 x06 x07 x08 x09 x10 x11 x12 x13 x14 x15 x16 x17 x18 x19 x20 x21 x22 x23 x24 x25 x26 x27 x28 ...
GPSAZI 2020-12-31 00:00:00 180 - - - - - - 307 299 - 147 - - - - 51 207 - 66 - 78 254 - 83 - - 185 300 - ...
GPSAZI 2020-12-31 00:15:00 176 - - - - - - 302 300 - 137 - - - - 45 203 - 69 - 69 258 - 72 - - 184 295 - ...
GPSAZI 2020-12-31 00:30:00 167 - - - - - - 296 300 - 123 - - - - 39 200 - 72 - 62 262 - 64 - - 183 264 - ...
GPSAZI 2020-12-31 00:45:00 145 - - - - - - - 300 - 105 - - - - 34 197 - 75 - 58 266 - 58 - - 181 177 - ...
GPSAZI 2020-12-31 01:00:00 148 264 - - - - - 297 - 87 - - - - 29 195 - 79 - 56 270 - 54 - - 160 - ...
GPSAZI 2020-12-31 01:15:00 163 268 - - - - - 291 - 73 - - - - - 194 - 82 - 55 274 220 52 - - 157 - ...
GPSAZI 2020-12-31 01:30:00 184 272 - - - - - 280 - 65 - - - 329 - 192 - - 54 278 222 51 - - 157 - ...
.....
BDSAZI 2020-12-31 00:00:00 149 - - - - 127 70 - - 97 - 284 296 60 - - 73 - - 57 - 175 128 - 233 290 - - ...
BDSAZI 2020-12-31 00:15:00 162 - - - - 127 68 - - 96 - 287 301 63 - - 72 - - 52 - 174 121 331 230 284 - - ...
BDSAZI 2020-12-31 00:30:00 162 - - - - 127 67 - - 95 - 290 308 66 - - 70 - - 47 - 173 112 326 227 278 - - ...
BDSAZI 2020-12-31 00:45:00 162 - - - - 127 65 - - 94 - 293 317 69 - - 68 - - 43 - 172 102 321 223 273 - - ...
BDSAZI 2020-12-31 01:00:00 167 - - - - 127 63 - - 93 - 296 340 72 - - 66 - - 40 - 171 91 316 - 268 - - ...
BDSAZI 2020-12-31 01:15:00 150 - - - - 127 61 - - 91 - 298 75 75 - - 64 - - 38 - 170 81 310 - 264 - - ...
BDSAZI 2020-12-31 01:30:00 156 - - - - 127 59 - - 90 - 300 114 78 - - 62 - - 37 - 168 71 305 - 260 - - ...
.....
```

‘GPSELE’ – elevation angles of individual GPS satellites.

‘GPSAZI’ – azimuth angles of individual GPS satellites.

4.9 Code multipath

GNSS tracking is affected by the so-called multipath effect due to the site environment and surrounding objects. In such a case, an original signal is not the only one received by the antenna, but also various reflected signals characteristics with extended paths. The multipath effect can be reduced by choke-ring or ecosorb material placed under the antenna. The multipath affects both code and carrier-phase observations, however, for code observations the effect is significantly higher.

Anubis calculates code multipath and the signal noise on the basis of the so-called multipath linear (MP) combinations for MP_1 and MP_2 , [9]

$$MP_1 = P_1 - L_1 - \frac{2f_2^2}{(f_1^2 - f_2^2)}(L_1 - L_2) \quad (4.1)$$

$$MP_2 = P_2 - L_2 - \frac{2f_1^2}{(f_2^2 - f_1^2)}(L_2 - L_1) \quad (4.2)$$

where indices 1 and 2 represent the first and the second original (GPS) frequencies.

In principal, the MP linear combination is a difference of code and phase observations for removing a geometric term and, additionally, an ionospheric path delay eliminated by using carrier-phase observations from two frequencies. The L_1 and L_2 terms however still contain unknown ambiguities. The MP observation needs to be thus accumulated over several consecutive epochs (15-30; configurable with the attribute `mpx_nep`, see 3) for estimating a mean value that can be subtracted as unknown ambiguity. Anyway, a strategy for detecting cycle slips should be applied because any change in the ambiguity during the interval would disable its subtracting from the MP values. If phase observations are continuous (free of cycle slips), a root-mean-square error can be estimated to characterise a combined signal noise and code multipath effect (both cannot be further separated).

Anubis handles any multipath for any code observations if dual-frequency carrier phases are available for eliminating the ionospheric effect. Any code signal can be combined with a selected (unique) dual-frequency carrier phases using the generalised formula of the MP linear combination:

$$MP_k = P_k - L_i - \beta(L_i - L_j) = P_k + \alpha L_i + \beta L_j, \quad (4.3)$$

with

$$\alpha = -\frac{(f_j^2 + f_k^2) f_i^2}{(f_i^2 - f_j^2) f_k^2} \quad \beta = \frac{(f_i^2 + f_k^2) f_j^2}{(f_i^2 - f_j^2) f_k^2}, \quad (4.4)$$

where k , i and j are indices for any GNSS frequency band.

Mean multipath values for all satellites of all constellations are reported:

##### Code multipath		mean	x01	x02	x03	x04	x05	x06	x07	x08	x09	x10	x11	x12	x13	x14	x15	x16	x17	x18	x19	x20	x21	x22	x23	x24	x25	x26	x27	x28	...	
#GNSS	2020-12-31 00:00:00																															
=GPSM1C	2020-12-31 00:00:00	25.96	23	25	23	24	31	29	26	29	20	28	-	24	22	27	27	27	26	25	27	32	22	23	27	23	23	28	26	31	...	
=GPSM2W	2020-12-31 00:00:00	22.76	16	26	16	21	35	27	21	23	18	24	-	17	17	23	24	27	25	23	28	30	15	20	24	15	15	22	19	31	...	
=GPSM2X	2020-12-31 00:00:00	25.87	23	-	17	35	32	29	27	28	21	25	-	21	-	25	30	-	28	24	-	-	-	-	25	26	20	27	29	-	...	
=GPSM5X	2020-12-31 00:00:00	16.31	13	-	11	31	-	20	-	15	11	20	-	-	-	14	-	-	-	14	-	-	-	-	15	18	9	17	22	-	...	
=GALM1X	2020-12-31 00:00:00	19.67	27	15	15	15	18	-	26	21	20	-	19	21	23	35	18	-	21	17	-	30	-	-	20	19	19	20	-	-	...	
=GALM5X	2020-12-31 00:00:00	15.33	20	9	13	11	13	-	22	15	15	-	15	15	17	59	13	-	17	13	-	24	-	-	15	13	16	13	-	-	...	
=GALM6X	2020-12-31 00:00:00	21.73	30	15	19	17	20	-	30	24	19	-	21	20	24	70	19	-	24	19	-	34	-	-	20	19	29	21	-	-	...	
=GALM7X	2020-12-31 00:00:00	22.22	32	12	18	17	20	-	35	23	22	-	24	26	25	22	20	-	26	19	-	40	-	-	21	19	27	22	-	-	...	
=GALM8X	2020-12-31 00:00:00	6.26	7	3	4	3	5	-	9	5	6	-	5	6	5	50	4	-	7	4	-	12	-	-	5	4	5	7	-	-	...	
=GLOM1C	2020-12-31 00:00:00	34.97	36	30	34	32	31	-	33	36	32	-	-	32	46	31	28	40	31	34	46	46	30	51	-	31	-	-	-	-	...	
=GLOM1P	2020-12-31 00:00:00	25.20	20	19	24	25	24	-	28	35	20	-	-	24	30	22	19	22	23	22	39	34	25	37	-	23	-	-	-	-	...	
=GLOM2C	2020-12-31 00:00:00	51.04	61	48	49	47	52	-	49	54	46	-	-	44	61	46	43	68	41	52	58	47	45	78	-	46	-	-	-	-	...	
=GLOM2P	2020-12-31 00:00:00	18.42	17	19	17	17	15	-	20	21	17	-	-	18	15	15	16	20	14	17	19	15	15	47	-	18	-	-	-	-	...	
=BDSM2I	2020-12-31 00:00:00	46.80	-	-	-	-	276	36	42	33	35	34	29	28	35	22	-	38	-	-	33	24	26	28	28	30	29	30	29	26	...	
=BDSM6I	2020-12-31 00:00:00	41.79	-	-	-	-	355	31	35	28	23	25	19	11	22	9	-	37	-	-	18	13	14	19	14	20	17	20	15	14	...	
=BDSM7I	2020-12-31 00:00:00	91.64	-	-	-	-	378	48	46	37	34	34	26	22	35	17	-	51	-	-	-	-	-	-	-	-	-	-	-	-	...	

'=GPSM1C' – average value of code multipath [m] for all GPS satellites and signal on L1 frequency (C1C etc.).
 '=GALM5X' – average value of code multipath [m] for all Galileo satellites and signal on E5a frequency (C4X etc.).

Epoch-wise code multipath values are reported with *sec.mpx=2* :

GPSM1C	2020-12-31	00:00:00	26.26	-	-	-	-	-	-	38	30	-	20	-	-	-	-	-	37	16	-	22	-	18	32	-	20	-	-	39	17	-	...	
GPSM1C	2020-12-31	00:15:00	25.67	-	-	-	-	-	-	39	23	-	13	-	-	-	-	-	34	24	-	27	-	18	30	-	18	-	-	38	18	-	...	
GPSM1C	2020-12-31	00:30:00	26.66	-	-	-	-	-	-	21	15	-	-	-	-	-	-	39	37	-	22	-	21	21	-	24	-	-	44	13	-	...		
GPSM1C	2020-12-31	00:45:00	26.37	35	-	-	-	-	-	16	16	-	-	-	-	-	-	43	21	-	37	-	19	27	-	19	-	-	35	15	-	...		
GPSM1C	2020-12-31	01:00:00	31.02	54	-	-	-	-	-	14	16	-	-	-	-	-	-	31	-	45	-	28	20	65	25	-	-	-	13	-	...			
GPSM1C	2020-12-31	01:15:00	25.89	28	-	-	-	-	-	14	17	-	-	-	-	-	-	44	-	-	-	26	22	33	32	-	-	-	19	-	...			
GPSM1C	2020-12-31	01:30:00	25.62	23	-	-	-	-	-	13	15	-	-	-	-	-	-	35	-	36	-	45	17	27	34	-	-	-	12	-	...			
.....																																		
GPSM2W	2020-12-31	00:00:00	18.89	-	-	-	-	-	-	27	15	-	7	-	-	-	-	33	10	-	42	-	11	34	-	9	-	-	14	7	-	...		
GPSM2W	2020-12-31	00:15:00	19.00	-	-	-	-	-	-	23	7	-	4	-	-	-	-	56	9	-	42	-	6	19	-	11	-	-	23	8	-	...		
GPSM2W	2020-12-31	00:30:00	20.80	-	-	-	-	-	-	8	3	-	-	-	-	-	-	44	23	-	36	-	12	26	-	11	-	-	31	6	-	...		
GPSM2W	2020-12-31	00:45:00	24.94	44	-	-	-	-	-	7	5	-	-	-	-	-	-	41	23	-	38	-	14	17	-	16	-	-	58	6	-	...		
GPSM2W	2020-12-31	01:00:00	26.80	22	-	-	-	-	-	6	5	-	-	-	-	-	-	32	-	43	-	22	18	87	25	-	-	-	6	-	...			
GPSM2W	2020-12-31	01:15:00	23.22	30	-	-	-	-	-	5	8	-	-	-	-	-	-	27	-	-	-	29	13	57	24	-	-	-	12	-	...			
GPSM2W	2020-12-31	01:30:00	21.47	29	-	-	-	-	-	7	7	-	-	-	-	-	-	23	-	29	-	39	8	25	41	-	-	-	6	-	...			
.....																																		
GALM1X	2020-12-31	00:00:00	21.18	15	-	-	-	-	-	23	45	-	-	-	20	51	15	-	-	-	-	-	-	-	-	-	15	-	7	-	-	...		
GALM1X	2020-12-31	00:15:00	19.21	25	-	-	-	-	-	20	43	-	-	-	21	11	-	-	-	-	-	-	-	-	-	-	19	-	10	-	-	...		
GALM1X	2020-12-31	00:30:00	15.92	19	-	-	-	-	-	19	32	-	-	-	22	6	-	-	-	-	-	-	-	-	-	-	15	-	10	-	-	...		
GALM1X	2020-12-31	00:45:00	20.10	49	-	-	-	-	-	26	29	-	-	-	16	11	-	-	-	-	-	-	-	-	-	-	21	-	11	-	-	...		
GALM1X	2020-12-31	01:00:00	17.83	41	-	-	-	-	-	17	-	-	-	-	15	15	-	-	-	-	-	-	-	-	-	-	17	-	11	-	-	...		
GALM1X	2020-12-31	01:15:00	13.26	-	-	-	-	-	-	12	-	-	-	-	16	12	-	-	-	-	-	-	-	-	-	-	13	-	15	-	-	...		
GALM1X	2020-12-31	01:30:00	18.33	-	-	-	-	-	-	17	-	-	-	-	16	25	-	-	-	-	-	-	-	-	-	-	14	-	23	-	-	...		
.....																																		

'GPSM1C' – values of code multipath [m] for all GPS satellites and signal on L1 frequency (C1C etc.).
 'GALM5X' – values of code multipath [m] for all Galileo satellites and signal on E5a frequency (C4X etc.).

4.10 Signal to noise ratio

The signal strength is reported as a summary for each satellite and signal over the data period, and, optionally (*sec.snr=2*), using original values with user-defined sampling interval:

#===== Signal to noise ratio																																		
#GNSS	time	mean	x01	x02	x03	x04	x05	x06	x07	x08	x09	x10	x11	x12	x13	x14	x15	x16	x17	x18	x19	x20	x21	x22	x23	x24	x25	x26	x27	x28	...			
GPSS1C	2020-12-31	00:00:00	43.54	45	43	45	43	43	42	43	42	46	44	-	46	44	42	43	42	43	42	42	41	44	46	42	45	45	42	43	42	...		
GPSS2W	2020-12-31	00:00:00	36.96	44	29	45	33	38	38	39	39	46	38	-	46	34	29	39	27	39	30	29	27	34	35	29	45	44	38	40	27	...		
GPSS2X	2020-12-31	00:00:00	43.65	46	-	46	45	41	42	41	43	46	43	-	45	-	44	41	-	41	44	-	-	-	-	43	47	45	43	45	-	...		
GPSS5X	2020-12-31	00:00:00	46.50	49	-	48	47	-	45	-	46	48	45	-	-	45	-	-	46	-	-	-	-	45	48	48	45	47	-	-	...			
GALS1X	2020-12-31	00:00:00	44.73	43	47	46	47	46	-	42	43	46	-	43	43	41	43	45	-	-	46	43	-	42	-	46	46	45	45	-	-	...		
GALS5X	2020-12-31	00:00:00	43.86	42	48	45	47	45	-	41	42	45	-	41	42	40	45	45	-	-	44	42	-	41	-	45	45	44	44	-	-	...		
GALS6X	2020-12-31	00:00:00	40.61	39	44	41	45	42	-	38	38	42	-	38	39	36	41	41	-	-	41	39	-	37	-	42	42	41	40	-	-	...		
GALS7X	2020-12-31	00:00:00	42.77	41	46	44	46	44	-	40	40	44	-	40	42	39	45	43	-	-	43	41	-	40	-	43	44	43	43	-	-	...		
GALS8X	2020-12-31	00:00:00	46.84	45	50	48	50	48	-	44	45	48	-	43	45	43	47	48	-	-	47	45	-	44	-	48	48	47	47	-	-	...		
GLOS1C	2020-12-31	00:00:00	45.78	45	48	48	48	49	43	47	46	47	46	48	49	39	48	49	43	49	46	38	38	48	42	47	49	-	-	-	-	...		
GLOS1P	2020-12-31	00:00:00	44.42	44	47	46	46	47	42	46	44	46	45	47	47	37	47	47	41	47	45	37	36	47	42	46	47	-	-	-	-	...		
GLOS2C	2020-12-31	00:00:00	41.40	39	42	42	41	43	-	42	42	44	-	43	43	38	43	43	38	44	42	40	43	42	34	-	43	-	-	-	-	...		
GLOS2P	2020-12-31	00:00:00	40.58	37	42	41	40	42	-	41	41	43	-	42	43	40	42	42	37	43	41	39	43	42	30	-	42	-	-	-	-	...		
BDSS2I	2020-12-31	00:00:00	42.17	-	-	-	-	35	36	36	37	38	38	42	42	40	44	-	38	-	-	42	45	45	43	44	43	44	43	44	44	...		
BDSS6I	2020-12-31	00:00:00	39.66	-	-	-	-	34	34	34	35	36	35	41	43	36	44	-	32	-	-	39	41	43	41	42	41	42	40	40	40	...		
BDSS7I	2020-12-31	00:00:00	38.56	-	-	-	-	37	35	36	37	38	37	42	44	37	45	-	35	-	-	-	-	-	-	-	-	-	-	-	-	...		
.....																																		
GPSS1C	2020-12-31	00:00:00	44.14	-	-	-	-	-	39	43	-	52	-	-	-	-	40	47	-	43	-	48	35	-	48	-	-	40	50	-	-	...		
GPSS1C	2020-12-31	00:15:00	43.51	-	-	-	-	-	34	46	-	52	-	-	-	-	38	46	-	39	-	47	40	-	48	-	-	38	51	-	-	...		
GPSS1C	2020-12-31	00:30:00	41.80	-	-	-	-	-	30	46	-	54	-	-	-	-	37	46	-	38	-	47	39	-	48	-	-	34	51	-	-	...		
GPSS1C	2020-12-31	00:45:00	43.32	-	-	-	-	-	49	-	52	-	-	-	-	-	38	43	-	38	-	46	43	-	47	-	-	33	52	-	-	...		
GPSS1C	2020-12-31	01:00:00	43.18	36	-	-	-	-	50	-	53	-	-	-	-	-	34	41	-	36	-	44	45	-	45	-	-	52	-	-	...			
GPSS1C	2020-12-31	01:15:00	42.45	38	-	-	-	-	52	-	52	-	-	-	-	-	39	-	32	-	42	45	34	42	-	-	52	-	-	...				
GPSS1C	2020-12-31	01:30:00	43.12	41	-	-	-	-	50	-	52	-	-	-	-	-	36	-	38	-	-	38	47	38	41	-	-	51	-	-	...			
.....																																		

4.11 Satellite information

Satellite information consists of navigation data availability and satellite health.

#===== Satellite information																																
#GNSS	time	x01	x02	x03	x04	x05	x06	x07	x08	x09	x10	x11	x12	x13	x14	x15	x16	x17	x18	x19	x20	x21	x22	x23	x24	x25	x26	x27	x28	...		
GPSHLT	2020-12-31	00:00:00	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	...
GPSHLT	2020-12-31	01:59:44	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	...
GPSHLT	2020-12-31	02:00:00	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	...
GPSHLT	2020-12-31	03:59:28	1	1	1																											

GALHLT 2020-12-31 00:00:00	1	1	1	1	1	-	1	1	1	-	1	1	1	1	1	-	-	1	1	-	1	-	-	1	1	1	1	-	...	
GALHLT 2020-12-31 00:10:00	1	1	1	1	1	-	1	1	1	-	1	1	1	1	1	-	-	1	1	-	1	-	-	1	1	1	1	-	...	
GALHLT 2020-12-31 00:20:00	1	1	1	1	1	-	1	1	1	-	1	1	1	1	1	-	-	1	1	-	1	-	-	1	1	1	1	-	...	
GALHLT 2020-12-31 00:30:00	1	1	1	1	1	-	1	1	1	-	1	1	1	1	1	-	-	1	1	-	1	-	-	1	1	1	1	-	...	
GALHLT 2020-12-31 00:40:00	1	1	1	1	1	-	1	1	1	-	1	1	1	1	1	-	-	1	1	-	1	-	-	1	1	1	1	-	...	
.....																														
GLOHLT 2020-12-31 00:15:00	1	1	1	1	1	1	1	1	1	1	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-	...
GLOHLT 2020-12-31 00:45:00	1	1	1	1	1	1	1	1	1	1	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-	...
GLOHLT 2020-12-31 01:15:00	1	1	1	1	1	1	1	1	1	1	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-	...
GLOHLT 2020-12-31 01:45:00	1	1	1	1	1	1	1	1	1	1	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-	...
GLOHLT 2020-12-31 02:15:00	1	1	1	1	1	1	1	1	1	1	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-	...
.....																														
BDSHLT 2020-12-31 00:00:00	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	...
BDSHLT 2020-12-31 01:00:00	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	...
BDSHLT 2020-12-31 02:00:00	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	...
BDSHLT 2020-12-31 03:00:00	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	...
BDSHLT 2020-12-31 04:00:00	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	...
.....																														
GPSRED 2020-12-31 00:00:00	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	...
GPSRED 2020-12-31 01:59:44	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	...
GPSRED 2020-12-31 02:00:00	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	...
GPSRED 2020-12-31 03:59:28	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	...
GPSRED 2020-12-31 03:59:44	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	...
GPSRED 2020-12-31 04:00:00	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	...
.....																														
GALRED 2020-12-31 00:00:00	2	2	2	2	2	0	2	2	2	0	2	2	2	2	2	2	0	0	2	2	0	2	0	0	2	2	2	2	0	...
GALRED 2020-12-31 00:10:00	2	2	2	2	2	0	2	2	2	0	2	2	2	2	2	2	0	0	2	2	0	2	0	0	2	2	2	2	0	...
GALRED 2020-12-31 00:20:00	2	2	2	2	2	0	2	2	2	0	2	2	2	2	2	2	0	0	2	2	0	2	0	0	2	2	2	2	0	...
GALRED 2020-12-31 00:30:00	2	2	2	2	2	0	2	2	2	0	2	2	2	2	2	2	0	0	2	2	0	2	0	0	2	2	2	2	0	...
GALRED 2020-12-31 00:40:00	2	2	2	2	2	0	2	2	2	0	2	2	2	2	2	2	0	0	2	2	0	2	0	0	2	2	2	2	0	...
GALRED 2020-12-31 00:50:00	2	2	2	2	2	0	2	2	2	0	2	2	2	2	2	2	0	0	2	2	0	2	0	0	2	2	2	2	0	...
.....																														

‘GPSHLT’ – list of navigation records with corresponding signal health status for each satellite.
 ‘GPSRED’ – list of navigation records with number of duplicity records for each satellite.

The ‘-’ characterises unavailable navigation data for the given satellite. The satellite health status is represented as binary code (*unhealth* = 0, *health* = 1). Duplicity records are counted with the same IOD number. In case of Galileo satellites in the example, it is represented with FNAV and INAV records of navigation types.

4.12 Key-parameter indicators

Along with a single point positioning, a key-parameter indicators (KPIs) can be estimated from horizontal and vertical positioning errors when the reference coordinates are provided by a user (via settings or an input SINEX file). Alternatively, the errors might represent residuals if reference is given by mean position, see Section 4.3. Criteria for horizontal (*max_hpe*), vertical (*max_vpe*), and PDOP (*max_dop*) values can be specified by user too, see 3.

An example of 30-sec data analysis using Galileo FNAV navigation data and E1+E5a signals:

#===== Key-parameter indicators							
#GNSSKPI	2020-11-16 00:00:00	CountOK	CountXX	%_Expect	%_Exist	%_Posit	%_DopOK
GAL_EP	2020-11-16 00:00:00	2874	6	99.792	99.792	-	-
GAL_DH	2020-11-16 00:00:00	2858	0	99.236	99.236	99.443	100.000
GAL_DV	2020-11-16 00:00:00	2858	0	99.236	99.236	99.443	100.000
GAL_PD	2020-11-16 00:00:00	2858	16	99.236	99.236	99.443	100.000
GAL_DF	2020-11-16 00:00:00	2880	0	100.000	100.000	-	-

‘GAL_EP’ – number of epochs usable for KPI calculation, i.e. supported with valid navigation data.
 ‘GAL_DH’ – number of epochs with horizontal positioning error smaller than criterion (e.g. 10 m).
 ‘GAL_DV’ – number of epochs with vertical positioning error smaller than criterion (e.g. 10 m).
 ‘GAL_PD’ – number of epochs with PDOP satisfying user-defined criterion (e.g. *PDOP* < 6).
 ‘GAL_DF’ – number of epochs with available dual-frequency data.

Numbers of ‘fine’ epochs (*CountOK*) and ‘outlier’ epochs (*CountXX*) in different lines reflect various bases: 1) ‘GAL_EP’ – epochs usable for KPI calculation equals to a count of positioning results ‘POSGAL’ in Section 4.3, 2) ‘GAL_DH’, ‘GAL_DV’, and ‘GAL_DP’ – epochs of horizontal, vertical, PDOP results satisfying the criteria, and 3) ‘GAL_DF’ – epochs with dual-frequency observations. From the above example, the total number of expected

epochs is 2880 (all providing dual-frequency data), 2854/26 epochs are with/without valid navigation data (usable for positioning) and, 2838/16 epochs are with/without positioning results satisfying the criteria (16 epochs doesn't satisfy $PDOP < 6$).

The percentages are represented with respect to different bases (counts of epochs): expected ('*%_Expect*'), existing ('*%_Exists*'), positioning ('*%_Posit*'), and those with satisfying PDOP criteria ('*%_DopOK*'). The last value ('*GAL_DH*' , '*GAL_DV*' lines only) is 1-sigma error of horizontal and vertical positioning, respectively.

=XYZREF	2020-11-16	11:59:45	3979319.0580	1050312.4160	4857064.7259	0.0057	0.0047	0.0058
=ECCREF	2020-11-16	11:59:45	0.0107	0.0407	0.0500			
#GALKPI	2020-11-16	00:00:00	<i>dN[m]</i>	<i>dE[m]</i>	<i>dU[m]</i>	<i>PDOP</i>	<i>FLAGS</i>	
GALKPI	2020-11-16	04:03:30	0.198	0.347	0.021	3.63	---	
GALKPI	2020-11-16	04:04:00	0.074	0.068	1.551	3.62	---	
GALKPI	2020-11-16	04:04:30	-0.153	-0.002	1.947	18.87	D_	
GALKPI	2020-11-16	04:05:00	0.450	0.097	0.388	19.26	D_	
GALKPI	2020-11-16	04:05:30	-0.578	0.037	1.304	3.59	---	
GALKPI	2020-11-16	04:06:00	-0.285	0.303	0.639	3.58	---	
GALKPI	2020-11-16	04:06:30	-0.546	0.110	-0.341	19.84	D_	
GALKPI	2020-11-16	04:07:00	-0.114	0.036	0.135	19.79	D_	
GALKPI	2020-11-16	04:07:30	-0.648	0.327	0.387	19.62	D_	
GALKPI	2020-11-16	04:08:00	-0.275	0.165	-0.378	19.33	D_	
GALKPI	2020-11-16	04:08:30	-0.158	0.241	-2.322	18.95	D_	
GALKPI	2020-11-16	04:09:00	0.221	0.479	-5.694	18.49	D_	
GALKPI	2020-11-16	04:09:30	0.669	0.234	-6.403	17.97	D_	
GALKPI	2020-11-16	04:10:00	-0.439	0.177	-4.531	17.40	D_	
GALKPI	2020-11-16	04:10:30	-0.094	0.477	-3.984	16.81	D_	
GALKPI	2020-11-16	04:11:00	0.118	0.256	-1.159	16.21	D_	
GALKPI	2020-11-16	04:11:30	0.219	-0.156	1.066	15.61	D_	
GALKPI	2020-11-16	04:12:00	0.501	0.268	-3.015	15.02	D_	
GALKPI	2020-11-16	04:12:30	0.046	-0.021	1.378	14.44	D_	
GALKPI	2020-11-16	04:13:00	0.330	-0.331	-1.940	13.89	D_	
GALKPI	2020-11-16	04:13:30	-0.031	-0.178	3.138	4.22	---	
GALKPI	2020-11-16	04:14:00	-1.064	-0.016	-1.299	4.24	---	
.....								

'XYZREF' – reference cartesian coordinates of the site.

'ECCREF' – reference eccentricities of the site.

'GALKPI' – epoch-by-epoch North, East and Up differences to reference coordinates and PDOP value.

The North (*dN*), East (*dE*) and Up (*dU*) differences from a given epoch with respect to reference coordinates are confronted with user-defined criteria and the flag is setup for any exceeding values (D=DOP, H=Horizontal, V=Vertical).

5. XML QC output

The eXtensible Markup Language (XML) is a human-readable and machine-readable format.

The Anubis' XML output has been developed within the European Plate Observing System (EPOS) implementing phase. It has been designed for a standard summary of the most important QC parameters stemming from a single file, and for archiving or filling database in support of a continuous long-term monitoring of GNSS site metadata, data, instrumentation and environment.

A minimum of original and non-redundant QC quantitative and qualitative parameters is stored in the XML output for each RINEX file, i.e. system- and signal-specific data, while no epoch-/satellite-specific data. The XML content enables a flexible time-series visualisation of selected parameters (or user-defined QC indicators derived from the original parameters) for easy detection of any significant change of the site evolution.

Figure 5.1 shows a graph of the XML structure which contains four main elements:

- META – metadata on the XML output file generation.
- NAVI – navigation data availability (indicators of qualitative control).
- DATA – system dependent/independent quantitative/qualitative QC parameters.
- HEAD – metadata from RINEX file header.

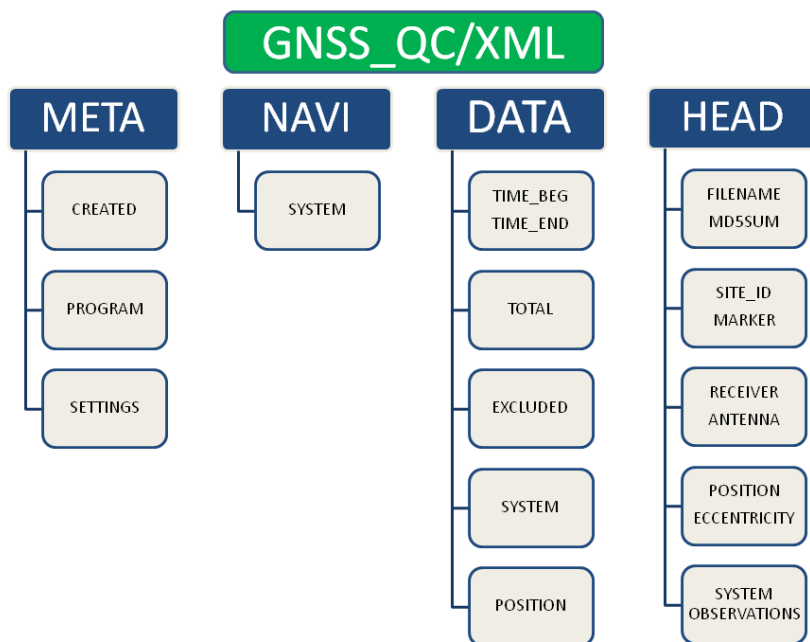


Figure 5.1: GNSS_QC XML output

The XML starts with the file pre-ambule:

```

<?xml version="1.0"?>
<QC_GNSS gml:id="GOPE00CZE_20201231T000000_20201231T235930" # XML file identifier
  xmlns="https://software.pecny.cz/anubis" # XML namespace declared
  xmlns:gml="http://www.opengis.net/gml/3.2" # GML namespace introduced
  xmlns:xsi="https://www.w3.org/2001/XMLSchema/instance" # XSI namespace introduced
  schemaVersion="1.1"
...
</QC_GNSS>
  
```

The XML META element includes the software, its settings and the file creation time:

```
<meta>
  <created>2021-01-18T10:37:54</created>
  <program>G-Nut/Anubis Pro [3.1]</program>
  <settings>
    <time_beg>2020-12-31T00:00:00</time_beg>
    <time_end>2020-12-31T23:59:30</time_end>
    <data_int>30.000</data_int>
    <elev_min>10.00</elev_min>
    <system type="GPS" />
    <system type="GAL" />
    <system type="GLO" />
    <system type="BDS" />
  </settings>
</meta>
...
</QC_GNSS>
```

The XML NAVI element reports counts of satellites (*'nsat'*) and records (*'have'*) available in navigation data for individual GNSS (*'type'*) which are critical for reliable qualitative control:

```
<navi>
  <system type="GPS" nsat="32">
    <have>449</have>
  </system>
  <system type="GAL" nsat="24">
    <have>5006</have>
  </system>
  ...
</navi>
```

system-specific element
count of available navigation records

The XML DATA element starts with estimated generic parameters (constellation-independent):

```
<data>
  <time_beg>2020-12-31T00:00:00</time_beg>
  <time_end>2020-12-31T23:59:30</time_end>
  <data_int>30.00</data_int>
  <data_lag>12.62488</data_lag>
  <numb_epo>2880</numb_epo>
  <numb_gap>0</numb_gap>
  <total>
    <expt>148580</expt>
    <have>120525</have>
    <expt_usr>114833</expt_usr>
    <have_usr>104528</have_usr>
    <elev_min>0.02</elev_min>
    <cyc_slps>748</cyc_slps>
    <clk_jmps>0</clk_jmps>
  </total>
  <excluded>
    <xbeg>0</xbeg>
    <xend>0</xend>
    <xint>0</xint>
    <xsys>0</xsys>
  </excluded>
```

data first epoch
data last epoch
data sampling interval
data file latency
number of epochs
number of data gaps
sum of expected observations (selected signal and all GNSS)
sum of existing observations (selected signal and all GNSS)
sum of existing observations above user mask
sum of existing observations above user mask
a minimum observed elevation angle
sum of cycle slips
sum of clock jumps
counts of epochs filtered out (prior user-defined observation interval)
counts of epochs filtered out (after user-defined observation interval)
counts of epochs filtered out (higher user-defined observation sampling)
counts of epochs filtered out (outside user-defined GNSS constellations)

The XML DATA element contains quantitative and qualitative QC parameters:

```
<data>
  ...
  <system type="GPS" nsat="31" xele="0">
    <epo>
      <expt>2880</expt>
      <have>2880</have>
      <dual>2880</dual>
    </epo>
    <amb>
      <nepo>0</nepo>
      <nsat>171</nsat>
      <nsig>271</nsig>
      <nslp>29</nslp>
    </amb>
    <bnd type="code">
      <xepo>0</xepo>
      <xsat>360</xsat>
    </bnd>
    <bnd type="phase">
      <xepo>0</xepo>
      <xsat>400</xsat>
    </bnd>
    <obs type="C1C">
      <nsat>31</nsat>
      <expt>33515</expt>
      <have>29709</have>
      <expt_usr>25388</expt_usr>
      <have_usr>25365</have_usr>
```

system-specific element
count of expected data epochs
count of existing data epochs
count of dual-frequency data epochs
carrier-phase interruptions
count of interruptions due to gap in epoch
count of interruptions due to gap in satellite
count of interruptions due to gap in signal
count of interruptions due to cycle slips
bands for code observation type
code: count of epochs with single-frequency data
code: count of satellites with single-frequency data
bands for phase observation type
phase: count of epochs with single-frequency data
phase: count of satellites with single-frequency data
code observation element
C1C: count of observed satellites
C1C: count of expected observations
C1C: count of existing observations
C1C: count of expected observations above user mask
C1C: count of existing observations above user mask

```

    <mpth>26.0</mpth> # C1C: code multipath
  </obs>
  ...
  <obs type="L2W"> # phase observation element
    <nsat>31</nsat> # L2W: count of observed satellites
    <expt>33515</expt> # L2W: count of expected observations
    <have>28971</have> # L2W: count of existing observations
    <expt_usr>25388</expt_usr> # L2W: count of expected observations above user mask
    <have_usr>25363</have_usr> # L2W: count of existing observations above user mask
    <slps>12</slps> # L2W: count of detected cycle slips
  </obs>
  ...
  <obs type="S5X"> # signal strength observation element
    <nsat>16</nsat> # S5X: count of observed satellites
    <expt>33515</expt> # S5X: count of expected observation
    <have>14952</have> # S5X: count of existing observation
    <expt_usr>25388</expt_usr> # S5X: count of expected observation above user mask
    <have_usr>12728</have_usr> # S5X: count of existing observation above user mask
  </obs>
</system>
...
</data>

```

'system type="GPS"' – GPS-specific output section.

'system nsat="31"' – number of observed satellites for the SYSTEM.

'system xele="0"' – number of observations without available observation azimuth/elevation information.

The XML DATA element contains positioning results:

```

<data>
  ...
  <position type="GPS" source="analysis"> # GPS single point positioning
    <coordinate>
      <gml:Point gml:id="GPS_analysis">
        <gml:pos>3979316.822 1050312.764 4857068.334</gml:pos> # X,Y,Z cartesian coordinates [m]
      </gml:Point>
    </coordinate>
    <deviation>
      <axis name="X">1.427</axis> # X,Y,Z standard deviations [m]
      <axis name="Y">0.876</axis>
      <axis name="Z">1.501</axis>
    </deviation>
  </position>
  <position type="GAL" source="analysis"> ... </position> # GAL single point positioning
  <position type="GLO" source="analysis"> ... </position> # GLO single point positioning
  <position type="BDS" source="analysis"> ... </position> # BDS single point positioning
</data>

```

The XML HEAD element contains metadata of a single input file (*file_num=1*):

```

<head file_num="1">
  <file_name>GOPE00CZE_R_20203660000_01D_30S_M0.crx.gz</file_name> # original file name
  <file_md5sum>40622a882a555ce2e6ccd1403632c985</file_md5sum> # original file md5sum (uncompressed Z/gz)
  <file_format>RINEX3.03</file_format> # original file format
  <site_id>GOPE00CZE</site_id> # site name (identified by Anubis)
  <marker_name>GOPE</marker_name> # site marker (RINEX header field)
  <marker_num>11502M002</marker_num> # site marker number (RINEX field)
  <receiver_type>TRIMBLE_ALLOY</receiver_type> # receiver type
  <receiver_num>40016</receiver_num> # receiver number
  <receiver_vers>5.45</receiver_vers> # receiver firmware
  <antenna_type>TPSCR.G3</antenna_type> # antenna type
  <antenna_dome>TPSH</antenna_dome> # antenna radome
  <antenna_num>30161</antenna_num> # antenna number
  <software>ALLOY 5.45&OBSRINEX</software> # software used in RINEX creation
  <data_int>30.000</data_int> # data sampling (RINEX header)
  <position type="GNS" source="rinex_header">
    <coordinate>
      <gml:Point gml:id="rinex_header">
        <gml:pos>3979316.439 1050312.253 4857066.904</gml:pos> # X,Y,Z cartesian coordinates (RINEX header)
      </gml:Point>
    </coordinate>
    <eccentricity>
      <axis name="N">0.0000</axis> # N,E,U marker eccentricity
      <axis name="E">0.0000</axis>
      <axis name="U">0.1114</axis>
    </eccentricity>
  </position>
  <system type="BDS"> # BeiDou observation types (RINEX header)
    <obs type="C5X" />
    <obs type="L5X" />
    <obs type="S5X" />
    <obs type="C2I" />
    <obs type="L2I" />
  </system>
  <system type="GAL"> ... </system> # Galileo observation types (RINEX header)
  <system type="GLO"> ... </system> # GLONASS observation types (RINEX header)
  <system type="GPS"> ... </system> # GPS observation types (RINEX header)
  <system type="IRN"> ... </system> # IRNSS observation types (RINEX header)
  <system type="SBS"> ... </system> # SBAS observation types (RINEX header)
  <system type="QZS"> ... </system> # QZSS observation types (RINEX header)
</head>

```

6. JSON QC output

JSON (JavaScript Object Notation, <https://www.json.org>) is a lightweight data-interchange format. The Anubis' JSON output format has been developed for optimal high-resolution visualisation of a single QC data file output such as skyplots, positioning charts or parameter high-resolution time series. The JSON structure contains two main elements:

- META – metadata about the XML file (XML creation, software usage and settings).
- DATA – parts containing time-, system-, satellite-, and signal-dependent output data.

Metadata part of the Anubis' JSON 1.0 contains:

```
{ "META":
  { "version": "1.0",                # JSON version
    "created": "2021-01-18T10:38:12", # JSON created
    "rxnver": "3.03",                # RINEX version
    "marker": "GOPE",                # site marker
    "number": "11502M002",           # site number
    "anttype": "TPSCR.G3",           # antenna type
    "antdome": "TPSH",               # antenna radome
    "antnumb": "30161",              # antenna number
    "rectype": "TRIMBLE_ALLOY",      # receiver type
    "recnumb": "40016",              # receiver number
    "recvers": "5.45"                # receiver firmware
  },
  "DATA": { "POS": { ... },
            "SAT": { ... }
  }
}
```

For an easy use in various frameworks, the Anubis' JSON data part can be converted into two individual hash structures (system *sys*, epoch *epo*, and satellite number *sat*):

- DATA ["POS"] [*sys*] [*epo*] + [keys: "XYZ"|"SAT"|"DOP"|"NEU"]
- DATA ["SAT"] [*sys*] [*epo*] [*sat*] + [keys: "AZI"|"ELE"|"CBN"|"LBN"|"Sxx"|"Mxx"]

Data part with positioning results contains:

```
{ "DATA" :
  { "POS":
    { "GPS":
      { "2020-12-31T00:00:00":
        { "XYZ": [3979317.8132,1050313.7215,4857069.2804,130455.0137],
          "SAT": [11,0],
          "DOP": [1.7,1.5,0.7,1.2],
          "NEU": [-0.3112,0.6726,1.4986]
        },
      },
      "2020-12-31T00:15:00":
      { "XYZ": [3979317.7813,1050312.8226,4857071.515,130455.8477],
        "SAT": [11,0],
        "DOP": [1.6,1.4,0.6,1.1],
        "NEU": [1.3268,-0.1884,3.0406]
      },
      },
      "2020-12-31T00:30:00":
      { "XYZ": [3979318.2924,1050313.8926,4857070.2627,130455.6004],
        "SAT": [12,2],
        "DOP": [1.7,1.5,0.7,1.2],
        "NEU": [-0.0665,0.7158,2.5767]
      } ...
    } ...
  } ...
  "SAT": { ... }
}
```


- “XYZ” – array(4) of cartesian coordinates X,Y,Z [m] and receiver clocks [m].
- “SAT” – array(1) of number of available and excluded satellites in solution.
- “DOP” – array(4) of dilution of precision values (GDOP, PDOP, HDOP, VDOP).
- “NEU” – array(3) of N,E,U residuals [m] with respect to reference coordinates.

Part with satellite-/observation-specific data contains:

```

{ "DATA" :
  { "POS": { ... },
    "SAT":
      { "GPS":
          { "2020-12-31T00:00:00":
              { "07":
                  { "AZI":307.988,
                    "ELE":9.29,
                    "CBN":2,
                    "LBN":2,
                    "S1C":38.6,
                    "S2W":17.8,
                    "S2X":33.2,
                    "M1C":37.84,
                    "M2W":26.72,
                    "M2X":30.18
                  },
                "08":
                  { "AZI":299.019,
                    "ELE":32.085,
                    "CBN":3,
                    "LBN":3,
                    "S1C":42.9,
                    "S2W":41.8,
                    "S2X":43.5,
                    "S5X":47.1,
                    "M1C":29.81,
                    "M2W":15.12,
                    "M2X":21.21,
                    "M5X":7.09
                  } ...
                } ...
              } ...
            } ...
          }
        }
      }
    }
  }

```

- “AZI”, “ELE” – satellite azimuth, elevation angle [deg].
- “CBN”, “LBN” – number of code and phase frequency bands.
- “Mxx”, “Sxx” – code multipath and noise [m] and signal-to-noise density [DbHz] where “xx” represents individual signals.

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