G-Nut/Anubis

a tool for Multi-GNSS data quality control

Tutorial 2017

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Outline

- Introduction
- Logic, functionality
- Distribution and installation
- Configuration, IOs
- Running
- QC result description
- Key parameters, monitoring examples
- Future plans
Motivation for GNSS data quality control

**Motto:** Scientific data collection is an irreversible process that needs to be controlled and observed data properly qualified and quantified.

### Goals of quality control
- **Data providers** – early data qualification (optimally on site)
- **Data users** – support for data selection, data and metadata quality
- **Network coordinators** – for optimal control of data dissemination including metadata, modernization monitoring etc.

### Data quality control
- **quantitative** – as possible as algorithm-independent
- **qualitative** – necessarily algorithm-dependent
- **complex** – optimally via data processing

→ **full QC requires complete and reliable ephemeris !!!**
Scientific software for GNSS QC

**TEQC (UNAVCO, 1993)** – translation, editing and quality control

- ‘gold standard’ for handling RINEX2 obs/nav/met files for GPS (and GLONASS)
- **Limitations:** proprietary code, no intention to support of RINEX3 format, multi-GNSS supported only via non-standard RINEX 2.12 format, dual-frequency data handling etc.

**BNC (BKG, 2012)** – BKG Ntrip Client

- open-source Ntrip + PPP client with GUI which has included QC since 2012

**G-Nut/Anubis (GOP, 2013)** – open-source software for multi-GNSS QC

- developing modern (non-redundant) multi-signal/frequency methods of processing
- consistent handling of all global/regional systems multi-frequency/-signal/-file data
- standardization effort – XML QC format designed for European Plate Observing System

**BQC (BACC, 2014)** – multi-GNSS data quality checking toolkit

- not open-source available, strictly following legacy teqc-functionality and approaches
G-Nut/Anubis - Multi-GNSS QC software

- **G-Nut** – core library for GNSS precise point positioning (used for developing applications)
- **G-Nut/Anubis** end-user application for multi-GNSS data quality control (open-source)
- written in C++, object-oriented concept, compatible with Linux, Windows and Mac

Main software functionality:
- Summary statistics over key parameters
- Data availability – data gaps, small pieces
- Observation-specific statistics
- Phase processing (cycle slips, clock jumps)
- Azimuth/elevation information for sky plots
- Pseudo-range multipath and signal noise
- Standard positioning, repeatability, GDOP
- Consolidation of navigation messages
- Format and metadata checking

G-Nut/Anubis - releases


- **2016-10-05** - **Released Anubis 2.0** - teqc-like total summary, expected/have observations at horizon and user elevation mask, new algorithms for estimating expected observations and satellite above the horizon, web mini-documentation, merging and saving navigation messages, initial support for RINEX3.03 and IRNSS, testing release for Win/Mac, etc.

- **2016-01-27** - **Released Anubis 1.4** - SNR support, SP3 format, Windows support, kinematic and high-rate processing

- **2015-01-28** - **Released Anubis 1.3** - complete multi-GNSS capability: all-constellations/-bands/-signal pre-processing & selection, advanced statistics, merged navigation messages

- **2014-08-13** - **Released Anubis 1.2** - navigation messages for all GNSS constellations, GPS, GLONASS, Galileo, BeiDou standard positioning

- **2014-04-29** - **Released Anubis 1.1** - qualitative QC for GPS&GLO, Bancroft positioning, boot-independent version, RINEX3.02 support

- **2013-08-16** - **Released Anubis 1.0** - multi-path detection for all constellations/signals/bands

- **2013-03-10** - **Released Anubis 0.9** - beta version
G-Nut/Anubis distribution

- Under GPL v3 license - [http://www.gnu.org/licenses/gpl-3.0.html](http://www.gnu.org/licenses/gpl-3.0.html)
  - the freedom to use the software for any purpose,
  - the freedom to change the software to suit your needs,
  - the freedom to share the software with your friends and neighbors, and
  - the freedom to share the changes you make.

→ derived applications can be distributed under the GPL v3 license only

- download from GOP - [http://software.pecny.cz/anubis](http://software.pecny.cz/anubis)

- source code
  - TAR + GZIP package
  - includes scripts and README for compilation using `autoconf` tools

- pre-compiled binaries
  - Linux, Windows, Mac OS-X
  - statically compiled for 32-bit and 64-bit architectures (not both for OS-X)

- documentation
  - will be completed in 2017 and made available through the new WEB
Naming conventions are compliant with RINEX3 specification

- **System**: GNSS (3-char/1-char satellite system identification)
  - GPS NAVSTAR (GPS/G), GLONASS (GLO/R), Galileo (GAL/E), BeiDou (BDS/C),
  - QZSS (QZS/J), SBAS (SBS/S), IRNSS (IRN/I)

- **Satellite**: GNSS satellites
  - 3chars: G01..., R02..., E03..., C04...

- **Band**: observation frequency/band number
  - 1char (number): 1, 2, 3, ....

- **Signal**: observation attribute characterizing its tracking mode
  - 1char: A, B, C, ...

- **Observation type**: pseudo range, carrier phase, Doppler, signal strength
  - 1char: C or P, L, D, S

- **Observation code**: combination of observation type + band + attribute
  - 3char: e.g. P1C, or legacy C1, P1

- **Epoch**: obs timestamp (unique for satellites observed synchronously)
Software inputs/outputs

Inputs files:
- Observation RINEX 2x/3x (one or more files)
- Navigation RINEX 2x/3x (one or more files, more sites, more constellations)
- Precise ephemeris in SP3 (one or more files, can be combined with navigation!)
- Anubis 2.1 – gzip (.gz) is automatically recognized/handled (no compress, zip!)

Outputs files:
- XTR – detailed QC extractions
  - Include QC results - epoch-wise, satellite-specific and signal-specific
  - ASCII format - easy to grep for individual file as well as over file for cumulative plotting
  - Organized in sections and supports different levels of verbosity
- XML-QC – summary extractions (new standard QC format for EPOS)
  - Principal QC metadata exchange, e.g. supporting remote RINEX file comparison
Anubis XML configuration - data filtering

$$ Anubis -x MY.cfg

<?xml version="1.0" encoding="UTF-8" standalone="yes" ?>
<!DOCTYPE config>
<config>
  <gen>
    <beg> 2017-05-29 00:00:00 </beg>
    <end> 2017-05-29 23:59:30 </end>
    <int> 30 </int>
    <sys> GPS GLO GAL BDS SBS QZS IRN </sys>
    <rec> BRUX GOPE MATE POTS WTZR </rec>
  </gen>

  <gps>
    <sat> G01 G02 G04 </sat>
    <type> C L D S P </type>
    <band> 1 2 5 </band>
    <attr> A B C D I L M N P Q S W X Y Z </attr>
  </gps>

  <gal>
    <sat> R01 R02 R04 </sat>
    <nav> FNAV INAV_E01 INAV_E07 </nav>
    <type> C L D S P </type>
    <band> 1 2 5 6 7 8 </band>
    <attr> A B C D I L M N P Q S W X Y Z </attr>
  </gal>

  <!-- OTHER SETTINGS ...

</config>
Anubis XML configuration – IO & QC

$$ Anubis -x MY.cfg

<inputs chk_nav="true">  
  <rinexn> DATA/brdm1500.17p.gz </rinexn> <!-- GNSS navigations files -->  
  <rinexn> DATA/brdm1500.17p.gz </rinexn> <!-- GNSS navigations files -->  
  <sp3> DATA/igs119512.sp3.gz </sp3> <!-- GNSS orbit products -->  
  <rinexo> DATA/brdm1500.17o DATA/gope1500.17o DATA/mate1500.17o DATA/mate1500.17o DATA/pots1500.17o </rinexo> <!-- GNSS observation files -->  
</inputs>

<outputs verb="1">  
  <xtr> LOG/EUREF/2017/150/$(rec)171500.xtr </xtr> <!-- native Anubis's report, may use $(rec) variable -->  
  <xml> LOG/EUREF/2017/150/$(rec)171500.xml </xml> <!-- standard QC-XML file, may use $(rec) variable -->  
  <log> LOG/EUREF/2017/150/anub171500.log </log> <!-- Anubis log, linux can support '/dev/stdout' -->  
</outputs>

<qc>  
  sec_sum="2" <!-- [0-9] .. summary statistics -->  
  sec_obs="2" <!-- [0-9] .. observation statistics -->  
  sec_pre="2" <!-- [0-9] .. cycle-slip, clock-jumps -->  
  sec_bnd="2" <!-- [0-9] .. observation bands -->  
  sec_mpx="2" <!-- [0-9] .. multipath calculation -->  
  sec_hdr="2" <!-- [0-9] .. header metadata check -->  
  sec_gap="2" <!-- [0-9] .. data gaps and small pieces -->  
  sec_est="2" <!-- [0-9] .. estimated values (if navigation available) -->  
  sec_ele="2" <!-- [0-9] .. azimuth/elevation (if navigation available) -->  
  sec_snr="2" <!-- [0-9] .. signal-to-noise ratio -->  
  int_stp="900" <!-- int[s] .. reporting interval -->  
  int_gap="600" <!-- int[s] .. interval for gaps -->  
  mpx_nep="20" <!-- int[#] .. epochs for MP -->  
  mpx_lim="3.0" <!-- dbl .. sigma-factor MP cycle-slip/outlier detection -->  
  col_sat="32" <!-- int[#] .. satellites reported -->  
  ele_cut="15" <!-- int[deg] .. user elev cut-off (only for expt/have) -->  
  pos_kin="false" <!-- bool .. kinematic receiver (true = kinematic) -->  
</qc>

/>  
</config>
Anubis command-line configurations

- to run Anubis without preparing XML configuration in advance

Flexible command-line arguments:

- full configuration can be handled as a sequence of command-line arguments:
  
  :element:sub-element  “SUB-ELEMENTS”  e.g.  :outputs:log  MY.LOG
  
  :element:sub-element:attribute=ATTRIBUTE  e.g.  :outputs:verb=2

- principally, Anubis can be started with command-line arguments only, e.g.

```latex
$$\text{Anubis} \ : \ \text{inputs:rinexo} \ \text{GOPE1730.17o} \ : \ \text{inputs:rinexn} \ \text{BRDC1730.17p} \\
\ ; \ \text{outputs:xml} \ \ \text{GOPE1730.xml} \ \ ; \ \text{outputs:xtr} \ \ \text{GOPE1730.xtr} \\
\ ; \ \text{outputs:log} \ \ \text{GOPE1730.log} \ \ ; \ \text{outputs:verb}=1 \\
\ ; \ \text{gen:int} \ 30 \ ; \ \text{gen:sys} \ \ ”\text{GPS GLO}” \\
\ ; \ \text{gen:beg} \ \ ”\text{2017-06-22 00:00:00}” \ ; \ \text{gen:end} \ \ ”\text{2017-06-23 00:00:00}”
$$
```

- command-line arguments can complete/overwrite initial XML configuration:

```latex
$$\text{Anubis} \ -x \ \text{MY.CFG} \ : \ \text{outputs:log} \ \text{MY.LOG} \ ; \ \text{gen:sys} \ \ ”\text{GPS GLO}” \ ; \ \text{outputs:verb}=3
$$
```
Standard operation modes

**Thin operation:**
- EXIT + RETURN CODE after reporting header issues → no QC, no NAV needed

```
$$\text{Anubis} \ : \text{inputs:rinexn} \ \text{MY.RXO} \ : \text{outputs:log} \ \text{MY.LOG} \ : \text{outputs:verb}=2
```

**Light QC:**
- + quantitative control – no navigation messages used

```
$$\text{Anubis} \ -x \ \text{MY_LIGHT.CFG} \ : \text{outputs:log} \ \text{MY.LOG} \ : \text{outputs:verb}=1
```

**Full QC:**
- + qualitative and complex control – requires navigation or precise ephemeris

```
$$\text{Anubis} \ -x \ \text{MY_FULL.CFG} \ : \text{outputs:log} \ \text{MY.LOG} \ : \text{outputs:verb}=1
```

**Navigation Data**
- It is possible to merge x-navigation files to a single one and save RINEX 2 or 3

```
$$\text{Anubis} \ : \text{inputs:rinexn} \ \text{“FILE1 FILE2 FILE3”} \ : \text{outputs:rinexn} \ \text{RINEXN.OUT}
```
Selected advanced functionality

**User elevation settings**

→ ‘User elevation cut-off’ used for elevation-dependent statistics only! (not for data filtering etc.)

```markdown
$$ \text{Anubis –x MY.cfg :qc:ele_cut=10}$$
```

**Satellite healthy status**

→ Satellite filtering for problematic (concerns of potentially problematic navigation messages only)

```markdown
$$ \text{Anubis –x MY.cfg :qc:health=true}$$
```

**Kinematic positioning**

→ Kinematics considered in pre-processing, positioning and elevation/azimuth calculations

```markdown
$$ \text{Anubis –x MY.cfg :qc:pos_kin=true}$$
```

**High-rate data processing**

→ QC statistics normalized to 1s sampling (noted in the report)

```markdown
$$ \text{Anubis –x MY.cfg :gen:int 0.01}$$
```

**Frequency handling – GLONASS & BeiDou**

→ no multipath/positioning for GLONASS without SLOT # → navigation data/RINEX 3.03 requested!
→ B2 handled, B1 from RINEX3.02 corrected to B2
RunQC utility and BRDC archive

```bash
$ git clone git@gitlab.com:gope/RunQC.git (still available on request only)
```

- generate QC metadata for **EPOS GNSS Thematic Core Service (TCS)**
- automated run of Anubis and supported:
  - download navigation message, decompression of input files etc.
  - TCS - communicate with the EPOS DB-API, but can be used individually

**RunQC.pl [options]**

```
--ref_date string .. reference time for data ("YYYY-MM-DD HH:MM:SS")
--fil_mask string .. local mask to files in repository (local path)
--dir_brdc string .. local path to brdc local archive (local dir path)
--db_api string .. EPOS DB-API interface (optional if not used fil_mask)
--inp_json string .. input JSON file (optional if not used fil_mask or db_api)
--out_json string .. store JSON file (optional)
--upd_brdc integer .. update brdc files in local archive (default=1)
--verb integer .. level of verbosity
--debug .. debug mode
--help .. this help message
```
Tools for visualization of Anubis XTR

- **plot_Anubis.pl** - [http://software.pecny.cz/anubis](http://software.pecny.cz/anubis)
  - open-source suite of Perl scripts developed at GOP
  - exploiting Chart-Gnuplot library (need to install libchart-gnuplot-perl)

- **anubisplot.py** - [http://www.westernexplorers.us/GNSSplotters](http://www.westernexplorers.us/GNSSplotters)
  - open-source Python script similar to *teqcplot.py*
  - developed by the same author Stuart Wier

- **web-based browser tool**
  - interactive tool at EUREF BEV data center
  - developed by Philipp Mitterschifthaler (BEV)

For inspiration links to openly available monitoring systems:

Anubis example – BRUX (processing log)

$$ \texttt{Anubis -x BRUX\_EXAMPLE.cfg :outputs:log /dev/stdout :outputs:verb=1} $$

2017-10-23 16:40:38 [main:0] READ: file://TEST/BRDC00IGS_R_20172900000_01D\_MN.rnx.gz 1.729 sec
2017-10-23 16:40:38 [rinexo:0] FILE: short site name: BRUX (4-CH)
2017-10-23 16:40:38 [gobj:0] Warning: object BRUX completed (Name): BRUX
2017-10-23 16:40:38 [gobj:0] Warning: object BRUX completed (Domes): 13101M010
2017-10-23 16:40:38 [gobj:0] Warning: object BRUX completed (NEU Eccentricity): 0.001 0.000 0.469
2017-10-23 16:40:38 [gobj:0] Warning: object BRUX completed (XYZ Eccentricity): 0.295 0.022 0.364
2017-10-23 16:40:41 [main:0] Error: RUN BY not available!
2017-10-23 16:40:41 [main:0] Error: GLO BIASES not available!
2017-10-23 16:40:41 [main:0] Error: GLO BIASES not available!
2017-10-23 16:40:41 [main:0] Error: GLO BIASES not available!
2017-10-23 16:40:41 [main:0] Error: GLO BIASES not available!
2017-10-23 16:40:41 [gxtrqc:0] SITE: BRUX TEST/LOG/BRUX172900.xtr
2017-10-23 16:40:41 [gxtrqc:1] Sync XTR step 2017-10-17 00:00:00 -> 2017-10-17 00:00:00
2017-10-23 16:40:41 [gxtrqc:0] BRUX header [9]: 0.000
2017-10-23 16:40:43 [gxtrqc:0] BRUX satview[9]: 2.000
2017-10-23 16:40:44 [gxtrqc:0] BRUX obsview[9]: 1.000
2017-10-23 16:40:44 [gxtrqc:0] BRUX estima [9]: 0.000
2017-10-23 16:40:44 [gxtrqc:0] BRUX observ [9]: 0.000
2017-10-23 16:40:45 [gxtrqc:0] BRUX nbands [9]: 1.000
2017-10-23 16:40:45 [gxtrqc:0] BRUX pieces [9]: 0.000
2017-10-23 16:40:51 [gxtrqc:0] BRUX prepro [9]: 6.000
2017-10-23 16:40:53 [gxtrqc:0] BRUX skyplt [9]: 2.000
2017-10-23 16:40:56 [gxtrqc:0] BRUX mlpath [9]: 3.000
2017-10-23 16:40:57 [gxtrqc:0] BRUX snoise [9]: 1.000
2017-10-23 16:40:57 [gxtrqc:0] BRUX summar [9]: 0.000
2017-10-23 16:40:57 [main:0] total time: 21.467 sec
XTR output - Total summary (1)

First line – total statistics motivated and modified from TEQC short summary

- counts are applied for selected phase observations over all GNSS constellations
- phase observation type selected per GNSS with a maximum # of observations

<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>======== Summary statistics (v.9)</td>
</tr>
<tr>
<td>#TOTSUM First_Epoch Last_Epoch Hours Sample MinEle # Expt # Have %Ratio o/slps woElev Exp&gt;10 Have&gt;10 %Rt&gt;10</td>
</tr>
<tr>
<td>=TOTSUM 2017-10-17 00:00:00 2017-10-17 23:59:30 24.00 30.00 0.01 99022 90319 91.21 346 3098 75518 74675 98.88</td>
</tr>
</tbody>
</table>

- **Hours** - data length in hours total number of epochs × sampling rate
- **Sample** - data sampling interval (the most frequent sampling from histogram)
- **MinEle** - data minimum elevation angle observed
- **#_Expt** - number of expected observations above the horizon
- **#_Have** - number of existing observations above the horizon
- **%Ratio** - ratio of existing and expected observations above the horizon
- **o/slps** - number of observations per cycle slip
- **woElev** - number of epochs without elevation (i.e. no satellite position available)
- **Expt>10** - number of expected observations above the user mask (10 deg)
- **Have>10** - number of existing observations above the user mask (10 deg)
- **%Rat>10** - ratio of existing and expected observations above the user mask
GNSS-specific summary:
- expected counts of observations require defined data period and sampling intervals

<table>
<thead>
<tr>
<th>GNSSUM 2017-10-17 00:00:00 00:00:00</th>
<th>Epoch_Statistics</th>
<th>Excl_Epochs&amp;Satellites</th>
<th>CycleSlips/Interruptions_And_Other_Discontinuities</th>
<th>Code_Mpth</th>
<th>mp1</th>
<th>mp2</th>
</tr>
</thead>
<tbody>
<tr>
<td>ExpEp_HavEp_UseEp</td>
<td>xCoEp xPhEp xCoSv xPhSv</td>
<td>csAll csEpo csSat csSig nSlp nJmp nGap nPcs</td>
<td>csTot</td>
<td>csEpo</td>
<td>csSat</td>
<td>csSig</td>
</tr>
<tr>
<td>GPSSUM 2017-10-17 00:00:00</td>
<td>2880 2880 2880</td>
<td>0 0 254 265</td>
<td>378 0 138 206 34</td>
<td>0</td>
<td>0</td>
<td>21.0 21.0</td>
</tr>
<tr>
<td>GALSUM 2017-10-17 00:00:00</td>
<td>2880 2880 2880</td>
<td>0 0 249 249</td>
<td>393 0 121 61 211</td>
<td>0</td>
<td>0</td>
<td>15.0</td>
</tr>
<tr>
<td>GLOSUM 2017-10-17 00:00:00</td>
<td>2880 2880 2880</td>
<td>0 0 1866 1890</td>
<td>868 0 110 160 598</td>
<td>0</td>
<td>0</td>
<td>38.3 31.2</td>
</tr>
<tr>
<td>BDSSUM 2017-10-17 00:00:00</td>
<td>2880 2880 1796</td>
<td>1061 1084 2074 2148</td>
<td>109 0 29 80 0</td>
<td>0</td>
<td>0</td>
<td>-41.4</td>
</tr>
</tbody>
</table>

- **ExpEp** - number of expected data epochs
- **HavEp** - number of actual data epochs
- **UseEp** - number of usable epochs (≥ 4 satellites in epoch with dual-frequency data/GNSS)
- **xCoEp** - number of epochs with pseudo-ranges at a single frequency only
- **xPhEp** - number of epochs with carrier-phases at a single frequency only
- **xCoSv** - number of satellites observing pseudo-ranges at a single frequency only
- **xPhSv** - number of satellites observing carrier-phases at a single frequency only
- **csTot** - number of total phase cycle-slips or other interruptions (new ambiguity)
- **csEpo** - number of interruptions due to missing epochs (counted over observed satellite)
- **csSat** - number of interruptions due to missing satellites (whenever satellite expected)
- **csSig** - number of interruptions due to missing signal (whenever others are available)
- **nSlp** - number of identified phase cycle-slips when continuous tracking available
- **nJmp** - number of identified receiver clock jumps (discontinuity of phase & code 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** - mean code multipath moving average RMS [cm] for the 1st..8th band
## XTR output - Total summary (3)

**sec_sum="1"** - provides individual observation types of all available GNSS constellations.
- **nSat** - number of observed satellites
- **ExpObs** - number of expected observations above the horizon
- **HavObs** - number of existing observations above the horizon
- **%Ratio** - ratio of existing and expected observations above the horizon
- **Exp>10** - number of expected observations above the user mask (10 deg)
- **Hav>10** - number of existing observations above the user mask (10 deg)
- **%Rt>10** - ratio of existing and expected observations above the user mask

**sec_sum="2"** - histograms of observations above specific elevation angles:

<table>
<thead>
<tr>
<th>GNSxxx</th>
<th>2017-10-17 00:00:00</th>
<th>nSat</th>
<th>ExpObs</th>
<th>HavObs</th>
<th>%Ratio</th>
<th>Exp&gt;10</th>
<th>Hav&gt;10</th>
<th>%Rt&gt;10</th>
<th>wc/Ele</th>
<th>Ele&gt;0</th>
<th>Ele&gt;5</th>
<th>Ele&gt;10</th>
<th>Ele&gt;15</th>
<th>Ele&gt;20</th>
<th>Ele&gt;30</th>
<th>Ele&gt;50</th>
<th>Ele&gt;70</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPSC1C</td>
<td>2017-10-17 00:00:00</td>
<td>32</td>
<td>35787</td>
<td>32514</td>
<td>90.85</td>
<td>26033</td>
<td>26000</td>
<td>99.87</td>
<td>31639</td>
<td>28921</td>
<td>25223</td>
<td>22309</td>
<td>19613</td>
<td>14691</td>
<td>7062</td>
<td>2599</td>
<td></td>
</tr>
<tr>
<td>GPSC1W</td>
<td>2017-10-17 00:00:00</td>
<td>32</td>
<td>35782</td>
<td>32406</td>
<td>90.57</td>
<td>26029</td>
<td>25996</td>
<td>99.87</td>
<td>31536</td>
<td>28907</td>
<td>25223</td>
<td>22309</td>
<td>19613</td>
<td>14691</td>
<td>7062</td>
<td>2599</td>
<td></td>
</tr>
<tr>
<td>GPSC2L</td>
<td>2017-10-17 00:00:00</td>
<td>19</td>
<td>21582</td>
<td>19254</td>
<td>89.21</td>
<td>15065</td>
<td>15040</td>
<td>99.83</td>
<td>19252</td>
<td>17428</td>
<td>15039</td>
<td>13360</td>
<td>11773</td>
<td>9173</td>
<td>5038</td>
<td>1812</td>
<td></td>
</tr>
<tr>
<td>GPSC2W</td>
<td>2017-10-17 00:00:00</td>
<td>32</td>
<td>35782</td>
<td>32406</td>
<td>90.57</td>
<td>26029</td>
<td>25996</td>
<td>99.87</td>
<td>31536</td>
<td>28907</td>
<td>25223</td>
<td>22309</td>
<td>19613</td>
<td>14691</td>
<td>7062</td>
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<td>3395</td>
<td>1398</td>
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**Note:** The table represents the summary of observations for different GNSS constellations, with columns for observation details, user mask, and various ratios.
Necessary details about satellite availability

for calculating ‘expected number of observations’,

for each individual satellite from all systems

**SKYxxx**  – time of satellite being above the horizon

**MSKxxx**  – time of satellite being above the user elevation cut-off (default 15deg)

**Time [h]**  – length of satellite visibility

**ExptObs**  – number of time epochs when satellite is visible

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<th>Descending_Horizon</th>
<th>Time [h]</th>
<th>ExptObs</th>
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</table>
# XTR output – Header summary

- **Actually** a list for comparison of (might undergo revision in future)
  - RINEX HEADER
  - USER EXPECTATION (or REQUEST via settings)

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<td>=INTHDR 2017-10-17 00:00:00 30.000</td>
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<tr>
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</table>

- Initially, it was foreseen for usage in cross-checking of RINEX header meta data with any meta data validated centrally (e.g. within EPOS GNSS dissemination system)
- Actually, the EPOS system is developing towards cross-validation done within EPOS DB API
- Currently, the Anubis XTR + XML
  - reports HEADER metadata in XML for validation in EPOS DB-API
  - enables easy grepping over sequence of Anubis XTR
  - Actually, does not do any active comparison !
XTR output – Estimated values

- Standard point positioning (SPP) - performed independently for each global constellation:
  - requires navigation data
  - SP3 can support SPP, but no GLONASS (without sat slots!)
- Position estimated using a common sampling rate of 15 minutes.
- GDOP values are calculated in addition

sec_est="1" - mean coordinates (XYZ/BLH) and repeatability (XYZ/NEU)
sec_est="2" - results from epoch-to-epoch positioning + GDOP/PDOP/HDOP/VDOP values

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<td>XYZBDS 2017-10-17 00:00:00</td>
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<tr>
<td>BLHGPS 2017-10-17 00:00:00</td>
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<tr>
<td>BLHBDS 2017-10-17 00:00:00</td>
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<tr>
<td>POSGNS 2017-10-17 00:00:00</td>
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BRUX station - Standard positioning

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<td>GAL: N</td>
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GDOP values are calculated in addition.
XTR output – Observation types

- Report of available observation types
  - from FILE HEADER
  - from FILE DATA

- easy to grep over sequence of Anubis XTR QC files

**sec_obs=1** – summary of satellites per GNSS, observations per system (and from HEADER)

**sec_obs=2** – details of satellite per observation types and GNSS constellation

### Observation types (v.9)

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**GPSC1W 2017-10-17 00:00:00**

**GPSC2L 2017-10-17 00:00:00**

**GPSC2W 2017-10-17 00:00:00**

**GPSC5Q 2017-10-17 00:00:00**

**GALC1C 2017-10-17 00:00:00**

**GALC5Q 2017-10-17 00:00:00**

**GALC7Q 2017-10-17 00:00:00**

**GALC8Q 2017-10-17 00:00:00**
# Preprocessing results (v.9)

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<td>GALL5Q</td>
<td>2017-10-17</td>
<td>00:00:00</td>
<td>105</td>
<td>59</td>
<td>0</td>
<td>32</td>
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<tr>
<td>GALL7Q</td>
<td>2017-10-17</td>
<td>00:00:00</td>
<td>104</td>
<td>59</td>
<td>0</td>
<td>32</td>
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<td>GALL8Q</td>
<td>2017-10-17</td>
<td>00:00:00</td>
<td>88</td>
<td>51</td>
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<tr>
<td>CLKJMP</td>
<td>2017-10-17</td>
<td>00:00:00</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td>GALSLP1</td>
<td>2017-10-17</td>
<td>00:36:00</td>
<td>-</td>
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<tr>
<td>GALSLP2</td>
<td>2017-10-17</td>
<td>02:06:00</td>
<td>-4.0</td>
<td>-</td>
<td>-</td>
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<tr>
<td>GALSLP3</td>
<td>2017-10-17</td>
<td>03:38:00</td>
<td>-</td>
<td>-</td>
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<td>1.0</td>
<td>1.0</td>
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<tr>
<td>GALSLP4</td>
<td>2017-10-17</td>
<td>04:16:00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-2.0</td>
<td>-2.0</td>
</tr>
<tr>
<td>GALSLP5</td>
<td>2017-10-17</td>
<td>04:16:30</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.0</td>
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<tr>
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<td>2017-10-17</td>
<td>05:30:00</td>
<td>-</td>
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<td>80.0</td>
<td>82.0</td>
</tr>
</tbody>
</table>

**XTR output – Phase pre-processing**

Carrier-phase observations at all signals/frequencies and satellite constellations checked for:

- **Clk_Jmp** - number of receiver clock jumps (phase/code inconsistencies)
- **CS_Total** - number of all phase cycle-slips and carrier-phase interruptions
- **CS_Slips** - number of identified real phase cycle-slips during a continuous phase tracking
- **CS_Epoch** - number of phase interruptions due to missing epoch (for available satellites)
- **CS_Satell** - number of phase interruptions due to temporary unavailable satellites
- **CS_Signal** - number of phase interruptions due to temporary unavailable signals
XTR output – Frequency/bands availability

- Performed for a) individual epochs, b) satellites and c) type of observations (code/phase)
- Epochs with 4 satellites for a GNSS considered as usable
- Epochs with single-frequency code/phase counted
- Satellites with SF code/phase counted

sec_bnd="1" - a summary report over % of dual-/multi-band observations
sec_bnd="2" - epoch-wise report over bands of complete dual-/multi-band observations

FewBand – counts of single-frequency observations

GNSCEP/GNSLEP – available bands for code/phase observations at pre-defined epochs

<table>
<thead>
<tr>
<th>Band available (v.9)</th>
<th>FewBand</th>
<th>xSatellite</th>
<th>xEpoch</th>
<th>xPhase</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPSCEP 2017-10-17 00:00:00</td>
<td>254</td>
<td>98</td>
<td>99</td>
<td>98</td>
</tr>
<tr>
<td>GPSLEP 2017-10-17 00:00:00</td>
<td>265</td>
<td>98</td>
<td>99</td>
<td>98</td>
</tr>
<tr>
<td>GALCEP 2017-10-17 00:00:00</td>
<td>249</td>
<td>99</td>
<td>99</td>
<td>99</td>
</tr>
<tr>
<td>GLOCEP 2017-10-17 00:00:00</td>
<td>1866</td>
<td>97</td>
<td>99</td>
<td>100</td>
</tr>
<tr>
<td>BDSCEP 2017-10-17 00:00:00</td>
<td>2074</td>
<td>99</td>
<td>98</td>
<td>99</td>
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<tr>
<td>BDSLEP 2017-10-17 00:00:00</td>
<td>2148</td>
<td>99</td>
<td>98</td>
<td>99</td>
</tr>
</tbody>
</table>

#NxBAND 2017-10-17 00:00:00
nSatellite | xSatellite | xEpoch | xPhase |
GPSCBN 2017-10-17 00:00:00 | 13 | 1 | - | - |
GPSCBN 2017-10-17 00:20:00 | 10 | - | - | - |
GPSCBN 2017-10-17 00:40:00 | 12 | - | - | - |
GPSCBN 2017-10-17 01:00:00 | 12 | - | - | - |
GPSCBN 2017-10-17 01:20:00 | 10 | - | - | - |
GPSCBN 2017-10-17 01:40:00 | 11 | - | - | - |
GPSCBN 2017-10-17 02:00:00 | 11 | - | - | - |
GPSCBN 2017-10-17 02:20:00 | 9 | - | - | - |
GPSCBN 2017-10-17 02:40:00 | 9 | - | - | - |
GPSCBN 2017-10-17 03:00:00 | 10 | - | - | - |
GPSCBN 2017-10-17 03:20:00 | 10 | - | - | - |
XTR outputs – Elevation/Azimuth

- Only if ephemeris available
- Reported in a fixed sampling which can be combined with other QC reports

**sec_ele="1"** – satellite mean values only reported *(verbosity 1)*

**sec_ele="2"** – satellite/epoch-wise values reported *(verbosity 2)*

**int_smp="20"** – requested sampling frequency *(in minutes)*

**num_sat="23"** – number of columns for satellite *(default:32)*

**pos_kin="true"** – kinematic data – applies epoch-specific position for the receiver
Code multipath and noise estimation

Code+phase multipath linear combination

i, j, k .. three frequencies  ( i:code,  j, k: carrier-phase ) 
(for standard dual-frequency approach i = k is used)

\[ LC_{mp} = P_k - L_i - \beta (L_i - L_j) = P_k + \alpha L_i + \beta L_j \]

\[ \alpha = - \frac{f_i^2}{f_k^2} \left( \frac{f_k^2 + f_j^2}{f_i^2 - f_j^2} \right) \]

\[ \beta = \frac{f_j^2}{f_k^2} \left( \frac{f_k^2 + f_i^2}{f_i^2 - f_j^2} \right) \]

Preprocessing

- cycle-slips need to be identify and eliminated (or repaired)
- simple CS identification incorporated within the algorithm
- supports all constellations, all code signals and frequencies when exploiting common dual-frequency phase observations (pre-requisite)

Václavovic P, Douša J (2016)
XTR output – Code multipath and noise

- all code signals/constellations with dual-frequency observations
- mean RMS after removing systematic error from multipath LC

sec_mpX="1" – satellite mean values only reported
sec_mpX="2" – satellite/epoch-wise values reported
mpX_neP="15" – # epochs for multipath RMS calculation (15-25 recommended)
mpX_lIm="3" – sigma multiplication - outliers/cycle-slips detection

<table>
<thead>
<tr>
<th>#====== Code multipath (v.9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#GNSMxx 2017-10-17 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</td>
</tr>
<tr>
<td>GPSM1C 2017-10-17 00:00:00 20.49 19 22 18 19 19 22 20 22 21 21 20 17 22 25 19 22 17 24 21 23 21 15 22</td>
</tr>
<tr>
<td>GPSM1W 2017-10-17 00:00:00 21.42 20 23 18 19 21 22 21 24 22 22 21 18 23 26 20 23 18 25 22 24 22 16 23</td>
</tr>
<tr>
<td>GPSM2L 2017-10-17 00:00:00 25.23 22 - 21 - 26 24 29 24 24 24 - 25 - - 29 - 28 - - - -</td>
</tr>
<tr>
<td>GPSM2W 2017-10-17 00:00:00 16.85 13 19 13 12 19 22 20 16 16 12 19 12 14 15 18 18 18 23 21 23 21 15 22</td>
</tr>
<tr>
<td>GALM1C 2017-10-17 00:00:00 14.51 14 - 12 - - 16 - 15 13 15 -</td>
</tr>
<tr>
<td>GALM5Q 2017-10-17 00:00:00 14.99 16 13 15 14 14 - 15 15 15 - 18</td>
</tr>
<tr>
<td>GALM7Q 2017-10-17 00:00:00 12.48 11 12 12 14 12 - 11 13 13 - 13</td>
</tr>
<tr>
<td>GALM8Q 2017-10-17 00:00:00 14.31 15 13 14 16 14 - 11 15 14 - 15</td>
</tr>
<tr>
<td>GLOM1C 2017-10-17 00:00:00 6.02 7 6 6 6 5 - 6 6 6 - 7</td>
</tr>
<tr>
<td>GLOM2C 2017-10-17 00:00:00 38.26 35 25 37 46 51 45 40 46 32 27 36</td>
</tr>
<tr>
<td>GLOM2P 2017-10-17 00:00:00 36.57 47 27 27 29 64 51 27 30 28 47 29</td>
</tr>
<tr>
<td>GLOM2P 2017-10-17 00:00:00 25.87 30 20 26 26 30 28 26 27 27 30 24</td>
</tr>
<tr>
<td>BDSM2I 2017-10-17 00:00:00 41.41 - - - - 43 45 57 61 37 38 33</td>
</tr>
<tr>
<td>BDSM7I 2017-10-17 00:00:00 21.49 - - - - 22 27 29 27 20 22 16</td>
</tr>
</tbody>
</table>

BRUX station - Code multipath

<table>
<thead>
<tr>
<th>Multipath RMS [cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPSM1C GPSM1W GPSM2L GPSM2W GPSM5Q GLOM2C GLOM2P GALM1C GALM5Q GALM7Q BDSM2I BDSM7I</td>
</tr>
</tbody>
</table>

[Graph showing multipath RMS values for different satellites and times]
XTR output – Signal-to-noise ratio

- Signal-to-noise statistics are represented directly by observations
- SNR depends on elevation, receiver and signal type, environment

sec_snrs="1" – satellite mean values only reported
sec_snrs="2" – satellite/epoch-wise values reported
XML-QC output – designed for EPOS (1)

⇒ split into four sections: 1) metadata about QC, 2) navigation data, 3) header data, and 4) quality control data (details in next slide)
XML-QC output - designed for EPOS (2)

to store minimum original QC metadata, suitable for deriving key-parameter indicators for a long-term monitoring via storage in DB
Example of key-indicators for long-term monitoring

... monitoring performance in long-term & station comparisons

- Data completeness (100% expected, i.e. 24hours)
- Minimum observed elevation angle (≤5° expected)
- Dual-frequency observations (100% expected)
- Existing/expected observation ratio for 0° cut-off (100% expected)
- Existing/expected observation ratio for 15° cut-off (100% expected)
- Data without information about elevation angle (0% expected)
- Standard positioning (≤ 5m expected)
- Mean code multipath (≤ 50cm expected)
- Mean signal-to-noise ratio (≥40dbHz expected)

→ different levels of the network QC monitoring

- 1-site/1-day – for a single Anubis XTR QC output (all details)
- 1-site/X-days – for a single site over sequence of XTR QC outputs (site history)
- X-sites/X-days – long-term comparison of stations in network (site comparisons)
Sky plots – visibility of tracking problems

- Obstacles
- Cut-off mask
- Asymmetry
- Interference
- Multipath
- Signal-to-noise
- Tracking
  lost of frequency, signal/satellite
Code multipath and noise estimation
Signal-to-noise ratio observations
Data quality vs. GNSS tropospheric gradients

GNSS tropospheric horizontal gradients (GRD) are highly sensitive to asymmetry of GNSS observations at low-elevation angles.

GOP Repro2 GRDs are compared to ERA-Interim NWM reanalysis.

Low elevation tracking degradation

Before replacement

After replacement

Daily site QC parameters (4th quarter 2016)
Network monitoring (comparisons over sites)

Data completeness

Dual-frequency data tracking

Code multipath (mean) – MP1

Standard Point Positioning
Plans for future?

Recent development has mainly focused on completing the functionality for QC for the EPOS GNSS Thematic Core Service (TCS)

Next steps:

- software documentation, new WEB & scheme for Anubis RELEASES
  → **stable/unstable version** with separate maintenance and continuous updates
- code optimizing of full QC for high-rate data
- other decompression methods (compress, Hatanaka)
- QC-XML extension for full QC metadata output
- support of historical archive of merged navigation messages
  → merged globally and consolidated for all available systems, RINEX 3/2
  → completing the 3-level quality check of navigation data (by G-Nut/Aset)
    1. correctness of individual messages (internal checks, ranging check)
    2. consistency of sequence of navigation messages (range-checks/satellite)
    3. compare with respect to final products
Thank you for your attention!

with hopes that G-Nut/Anubis could properly serve your needs ...

Questions or feedback:  gnss@pecny.cz

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