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 – necessarilly 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*

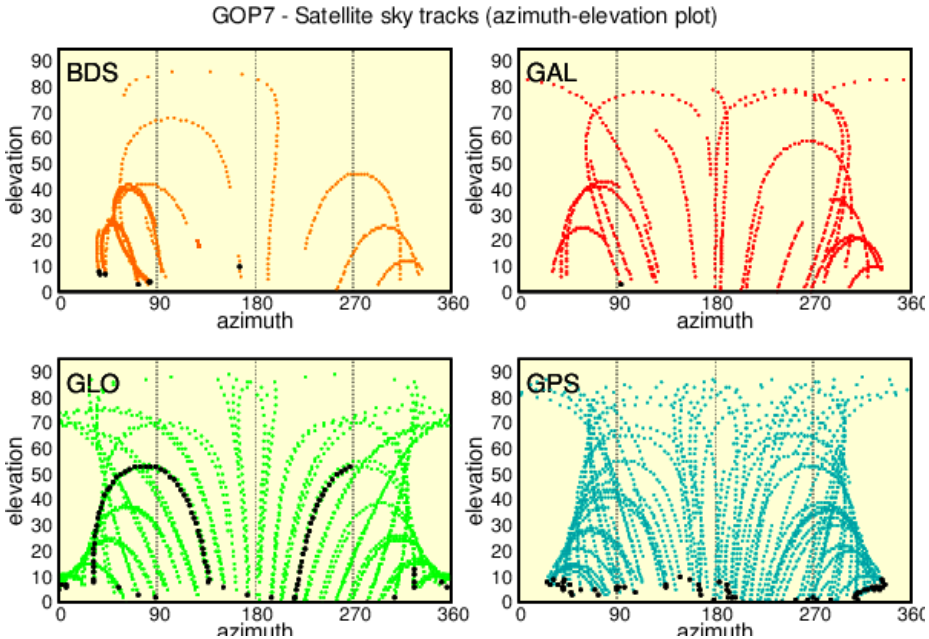
→ *not open-source available, strictly following legacy teqc-functionality and approaches*

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)
- http://software.pecny.cz/anubis (alternatively http://www.pecny.cz → G-Nut library)
- 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



Václavovic P, Douša J (2016), ***G-Nut/Anubis - open-source tool for multi-GNSS data monitoring****, IAG Symposia Series, Springer, Vol. 143*
Václavovic P, Douša J, Gyori G (2013) ***G-Nut software library - state of development and first results****, Acta Geodyn Geomater*

G-Nut/Anubis - releases

- **2017-10-20 - Released Anubis 2.1 (beta)** – ready for the European Plate Observing System: mandatory QC parameters in new QC-XML format, DOP estimates, signal-selection, NAV health status, thin execution with format check, full command-line settings, pre-compiled libraries etc.
- **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, boost-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**
  - *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**
- **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 used by Anubis

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>     <!-- begin time RECOMMENDED  (Default: first observation) -->
            <end>  2017-05-29  23:59:30                 </end>     <!-- end time: RECOMMENDED  (Default: last observation) -->
            <int>  30                                   </int>     <!-- sampling: RECOMMENDED (Default: estimated from file) -->
            <sys>  GPS GLO GAL BDS SBS QZS IRN          </sys>     <!– list of gnss (Default:from file; use '–' to remove GNSS) -->
            <rec>  BRUX GOPE MATE  POTS WTZR            </rec>     <!– list of station names (Default: site names from file)-->
</gen>

<gps>                                                              <!-- GPS|GLO|GAL|BDS|SBS|QZS -->
  <sat> G01 G02 G04 </sat>                                         <!-- list of gps satellites-->
  <type> C L D S P </type                                          <!-- list of gps obs types -->
  <band> 1 2 5 </band>                                             <!-- list of gps obs bands-->
  <attr> A B C D I L M N P Q S W X Y Z </attr>                     <!-- list of gps obs attributes -->
</gps>

<gal>
  <sat> R01 R02 R04 </sat>                                         <!-- list of gal satellites -->
  <nav> FNAV   INAV_E01   INAV_E07 </sat>                          <!-- list of gal satellites -->
  <type> C L D S P </type>                                         <!-- list of gal obs types -->
  <band> 1 2 5 6 7 8 </band>                                       <!-- list of gal obs bands-->
  <attr> A B C D I L M N P Q S W X Y Z </attr>                     <!-- list of gal obs attributes -->
</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/brux1500.17o  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_hdr="2"   <!-- [0-9] .. header metadata check -->
        sec_obs="2"  <!-- [0-9] .. observation statistics --> sec_gap="2"   <!-- [0-9] .. data gaps and small pieces -->
        sec_pre="2"  <!-- [0-9] .. cycle-slip, clock-jumps --> sec_est="2“  <!-- [0-9] .. estimated values (if navigation available) -->
        sec_bnd="2"  <!-- [0-9] .. observation bands -->       sec_ele="2"   <!-- [0-9] .. azimuth/elevation (if navigation available) -->
        sec_mpx="2"  <!-- [0-9] .. multipath calculation -->  sec_snr="2"   <!-- [0-9] .. signal-to-noise ratio -->

        int_stp="900"   <!-- int[s] .. reporting interval -->
        int_gap="600"   <!-- int[s] .. interval for gaps -->      int_pcs="1800“  <!-- int[s] .. interval for small pieces -->
        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) -->
/>
</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=ATRIBUTE e.g. :outputs:verb=2

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

$$ Anubis :inputs:rinexo GOPE1730.17o :inputs:rinexn BRDC173O.17p
:outputs:xml GOPE1730.xml :outputs:xtr GOPE1730.xtr
:outputs:log GOPE1730.log :outputs:verb=1
:gen:int 30 :gen:sys “GPS GLO”
:gen:beg “2017-06-22 00:00:00” :gen:end “2017-06-23 00:00:00”

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

$$ Anubis -x MY.CFG :outputs:log MY.LOG :gen:sys “GPS GLO” :outputs:verb=3

Standard operation modes

Thin operation:

- EXIT + RETURN CODE after reporting header issues → no QC, no NAV needed

$$ Anubis :inputs:rinexn MY.RXO :outputs:log MY.LOG :outputs:verb=2

Light QC:

- + quantitative control – no navigation messages used

$$ Anubis -x MY_LIGHT.CFG :outputs:log MY.LOG :outputs:verb=1

Full QC:

- + qualitative and complex control – requires navigation or precise ephemeris

$$ Anubis -x MY_FULL.CFG :outputs:log MY.LOG :outputs:verb=1

Navigation Data

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

$$ Anubis :inputs:rinexn "FILE1 FILE2 FILE3" :outputs:rinexn RINEXN.OUT

Selected advanced functionality

Satellite healthy status

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

$$ Anubis –x MY.cfg :qc:ele_cut=10 *<qc ele_cut="10" />*

User elevation settings

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

$$ Anubis –x MY.cfg :qc:health=true *<qc health="true" />*

Kinematic positioning

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

$$ Anubis –x MY.cfg :qc:pos_kin=true *<qc pos_kin="true" />*

High-rate data processing

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

$$ Anubis –x MY.cfg :gen:int 0.01 *<int> 0.01 </int>*

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

$$ 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**
  - 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**
  - 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 Phillipp Mitterschifthaler (BEV)

For inspiration links to openly available monitoring systems:

- ROB - EPN CB: http://www.epncb.oma.be/_networkdata/data_quality/index.php
- Swisstopo – AGNES: http://pnac.swisstopo.admin.ch/pages/en/agnes-status.html
- GOP – CzechGeo: http://www.pecny.cz/CzechGeo

Anubis example – BRUX (processing log)

$$ Anubis –x BRUX_EXAMPLE.cfg :outputs:log /dev/stdout :outputs:verb=2

```
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 [main:1] READ: file://TEST/BRUX2900.17O started
2017-10-23 16:40:38 [rinexo:0] FILE: short site name: BRUX (4-CH)
2017-10-23 16:40:38 [gallobj:1] add new obj BRUX
2017-10-23 16:40:38 [rinex:1] Object created, using RINEX header: BRUX 2017-10-17 00:00:00
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 (Antenna): JAVRINGANT_DM   NONE
2017-10-23 16:40:38 [gobj:0] Warning: object BRUX completed (Coordinates):  4027881.848  306998.261  4919498.655
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 16:40:38 [grec:0] Warning: object BRUX completed (Receiver): SEPT POLARX4TR
2017-10-23 16:40:41 [main:0] READ: file://TEST/BRUX2900.17O  3.016 sec
2017-10-23 16:40:41 [main:0] Error: RUN BY not available!
2017-10-23 16:40:41 [main:0] Warning: LEAPSEC not available!
2017-10-23 16:40:41 [main:0] Error: GLO BIASES not available!
2017-10-23 16:40:41 [main:1] Single-thread summary: BRUX started
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] Warning: no receiver settings.
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] Single-thread summary: BRUX  16.602 sec
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

```
# G-Nut/Anubis [2.1.0] compiled: Oct 23 2017 16:08:19 ($Rev: 2020 $)

#====== Summary statistics (v.9)
#TOTSUM First_Epoch________ Last_Epoch_________ Hours_ Sample MinEle #_Expt #_Have %Ratio o/slps woElev Exp>10 Hav>10 %Rt>10
=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
```

- **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

XTR output - Total summary (2)

GNSS-specific summary:

➔ expected counts of observations require defined data period and sampling intervals

	Epoch_Statistics_			Excl_Epochs&Satellites_				CycleSlips/Interruptions_And_Other_Dis						ontinuities	Code_Mpth	
#GNSSUM 2017-10-17 00:00:00	ExpEp	HavEp	UseEp	xCoEp	xPhEp	xCoSv	xPhSv	csAll	csEpo	csSat	csSig	nSlp	nJmp	nGap	nPcs	mp1	mp2
=GPSSUM 2017-10-17 00:00:00	2880	2880	2880	0	0	254	265	378	0	138	206	34	0	0	0	21.0	21.0
=GALSUM 2017-10-17 00:00:00	2880	2880	2880	0	0	249	249	393	0	121	61	211	0	0	0	15.0	-
=GLOSUM 2017-10-17 00:00:00	2880	2880	2880	0	0	1866	1890	868	0	110	160	598	0	0	0	38.3	31.2
=BDSSUM 2017-10-17 00:00:00	2880	2880	1796	1061	1084	2074	2148	109	0	29	80	0	0	0	0	-	41.4

- **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:

>0, >5, >10, >15, >20, >30, >50, >70

#GNSxxx	2017-10-17	00:00:00	nSat	ExpObs	HavObs	%Ratio	Exp>10	Hav>10	%Rt>10	wo/Ele	Ele>0	Ele>5	Ele>10	Ele>15	Ele>20	Ele>30	Ele>50	Ele>70
=GPSC1C	2017-10-17	00:00:00	32	35787	32514	90.85	26033	26000	99.87	875	31639	28921	25223	22309	19613	14691	7062	2599
=GPSC1W	2017-10-17	00:00:00	32	35782	32406	90.57	26029	25996	99.87	870	31536	28907	25223	22309	19613	14691	7062	2599
=GPSC2L	2017-10-17	00:00:00	19	21582	19254	89.21	15065	15040	99.83	2	19252	17428	15039	13360	11773	9173	5038	1812
=GPSC2W	2017-10-17	00:00:00	32	35782	32406	90.57	26029	25996	99.87	870	31536	28907	25223	22309	19613	14691	7062	2599
=GPSC5Q	2017-10-17	00:00:00	12	13815	12167	88.07	9336	9318	99.81	9	12158	10669	9310	8384	7527	5921	3395	1398
=GPSL1C	2017-10-17	00:00:00	32	35787	32505	90.83	26033	26000	99.87	875	31630	28920	25223	22309	19613	14691	7062	2599
=GPSL2L	2017-10-17	00:00:00	19	21582	19254	89.21	15065	15040	99.83	2	19252	17428	15039	13360	11773	9173	5038	1812
=GPSL2W	2017-10-17	00:00:00	32	35781	32391	90.53	26028	25995	99.87	869	31522	28904	25223	22309	19613	14691	7062	2599
=GPSL5Q	2017-10-17	00:00:00	12	13815	12167	88.07	9336	9318	99.81	9	12158	10669	9310	8384	7527	5921	3395	1398
=GPSS1C	2017-10-17	00:00:00	32	35787	32514	90.85	26033	26000	99.87	875	31639	28921	25223	22309	19613	14691	7062	2599
=GPSS1W	2017-10-17	00:00:00	32	35782	32406	90.57	26029	25996	99.87	870	31536	28907	25223	22309	19613	14691	7062	2599
=GPSS2L	2017-10-17	00:00:00	19	21582	19254	89.21	15065	15040	99.83	2	19252	17428	15039	13360	11773	9173	5038	1812
=GPSS2W	2017-10-17	00:00:00	32	35782	32406	90.57	26029	25996	99.87	870	31536	28907	25223	22309	19613	14691	7062	2599
=GPSS5Q	2017-10-17	00:00:00	12	13815	12167	88.07	9336	9318	99.81	9	12158	10669	9310	8384	7527	5921	3395	1398
=GALC1C	2017-10-17	00:00:00	18	21090	18385	87.17	15178	15024	98.99	198	18187	16830	14848	13006	11681	8987	4888	1863
=GALC5Q	2017-10-17	00:00:00	17	20895	18303	87.60	15004	14850	98.97	3	18300	16830	14848	13006	11681	8987	4888	1863
=GALC7Q	2017-10-17	00:00:00	17	20895	18305	87.60	15004	14850	98.97	3	18302	16830	14848	13006	11681	8987	4888	1863
=GALC8Q	2017-10-17	00:00:00	17	20898	18146	86.83	15007	14775	98.45	6	18140	16654	14770	12977	11681	8987	4888	1863
=GALL1C	2017-10-17	00:00:00	18	21090	18385	87.17	15178	15024	98.99	198	18187	16830	14848	13006	11681	8987	4888	1863
=GALL5Q	2017-10-17	00:00:00	17	20895	18303	87.60	15004	14850	98.97	3	18300	16830	14848	13006	11681	8987	4888	1863
=GALL7Q	2017-10-17	00:00:00	17	20895	18305	87.60	15004	14850	98.97	3	18302	16830	14848	13006	11681	8987	4888	1863
=GALL8Q	2017-10-17	00:00:00	17	20898	18146	86.83	15007	14775	98.45	6	18140	16654	14770	12977	11681	8987	4888	1863

XTR output - Total summary (4)

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

```
#SKYxxx Ascending_Horizon__ Descending_Horizon_ Time[h] ExptObs
=SKYC05 2017-10-17 00:00:00 2017-10-18 00:00:00  24.000    2880
=MSKC05 2017-10-17 00:00:00 2017-10-18 00:00:00  24.000    2880
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
=SKYE01 2017-10-17 00:00:00 2017-10-17 05:06:03   5.101     612
=SKYE01 2017-10-17 12:43:04 2017-10-17 15:31:59   2.815     338
=MSKE01 2017-10-17 00:00:00 2017-10-17 04:35:46   4.596     552
=MSKE01 2017-10-17 13:49:11 2017-10-17 14:26:49   0.627      75
=SKYE02 2017-10-17 06:22:37 2017-10-17 11:12:19   4.828     579
=SKYE02 2017-10-17 16:56:59 2017-10-18 00:00:00   7.050     846
=MSKE02 2017-10-17 06:55:55 2017-10-17 10:38:18   3.706     445
=MSKE02 2017-10-17 17:25:33 2017-10-18 00:00:00   6.574     789
=SKYE03 2017-10-17 02:24:28 2017-10-17 04:30:33   2.101     252
=SKYE03 2017-10-17 12:49:00 2017-10-17 21:43:20   8.906    1069
=MSKE03 2017-10-17 13:21:05 2017-10-17 21:13:18   7.870     944
```

XTR output – Header summary

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

```
#====== Header information (v.9)
#RNXHDR 2017-10-17 00:00:00 _RINEX_HEADER_____________ _RINEX_HEADER_____________ _RINEX_HEADER_____________
=RNXVER 2017-10-17 00:00:00 3.03                      M                           2017-10-18 00:02:23
=RNXPGM 2017-10-17 00:00:00 sbf2rin-11.3.2            -
=RNXAGE 2017-10-17 00:00:00 ROB                       ROB

#RNXHDR 2017-10-17 00:00:00 _RINEX_HEADER_____________________________________ _USER_REQUEST_____________________________________
=BEGEND 2017-10-17 00:00:00 2017-10-17 00:00:00     2017-10-17 23:59:30       2017-10-17 00:00:00     2017-10-18 00:00:00
=INTHDR 2017-10-17 00:00:00 30.000                                             30.000
=MARKER 2017-10-17 00:00:00 BRUX 13101M010
=RECEIV 2017-10-17 00:00:00 SEPT POLARX4TR      2.9.6               3001376
=ANTENN 2017-10-17 00:00:00 JAVRINGANT_DM   NONE00464

#RNXHDR 2017-10-17 00:00:00 _RINEX_HEADER_____________________________________ _USER_REQUEST_____________________________________
=XYZAPR 2017-10-17 00:00:00     4027881.8478     306998.2610     4919498.6554          0.0000          0.0000          0.0000
=XYZECC 2017-10-17 00:00:00           0.0000          0.0000          0.0000          0.0000          0.0000          0.0000
=ENUECC 2017-10-17 00:00:00           0.0000          0.0010          0.4689          0.0000          0.0000          0.0000
```

- 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 !**

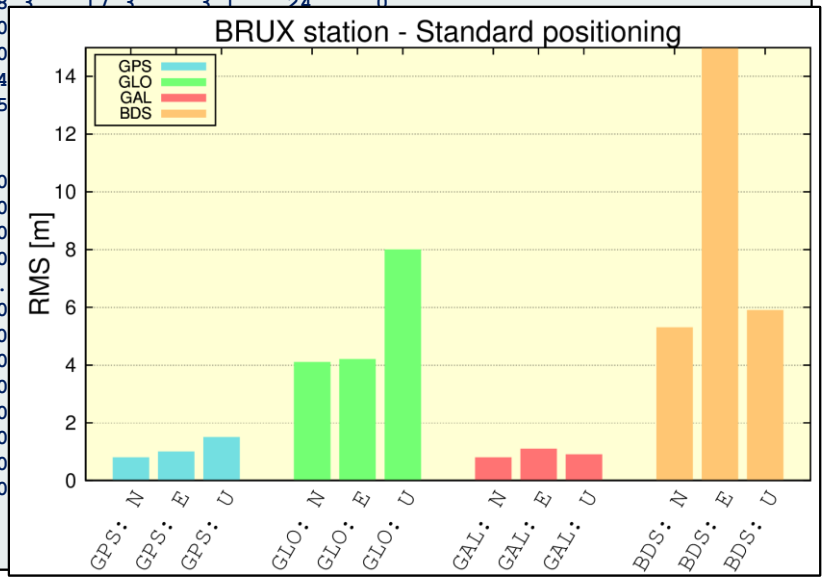
XTR output – Estimated values

- 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

```
#====== Estimated values (v.9)
=PERIOD 2017-10-17 00:00:00 2017-10-17 00:00:00     2017-10-17 23:59:30
=SAMPLE 2017-10-17 00:00:00 30.000
=XYZGPS 2017-10-17 00:00:00     4027882.4905     306998.5610    4919500.2234     1.0     0.6     1.4    95     1
=XYZGAL 2017-10-17 00:00:00     4027881.9460     306998.6773    4919499.7808     0.7     0.6     0.9    86    10
=XYZGLO 2017-10-17 00:00:00     4027883.0126     306998.6388    4919500.5285     5.0     2.7     7.4    92     0
=XYZBDS 2017-10-17 00:00:00     4027883.4427     307010.4951    4919502.7730     8.3    17.3     3.1    24     0
=BLHGPS 2017-10-17 00:00:00     50.798063862     4.358562887        159.7652     0
=BLHGAL 2017-10-17 00:00:00     50.798065850     4.358563983        159.1284     0
=BLHGLO 2017-10-17 00:00:00     50.798061928     4.358563425        160.3344     4
=BLHBDS 2017-10-17 00:00:00     50.798065416     4.358730641        162.9144     5

#POSGNS 2017-10-17 00:00:00          X [m]           Y [m]           Z [m]
 POSGPS 2017-10-17 00:00:00     4027882.7667     306995.9220    4919503.9910    50
 POSGPS 2017-10-17 00:15:00     4027883.3539     306996.6801    4919501.5488    50
 POSGPS 2017-10-17 00:30:00     4027883.2868     306997.9522    4919500.2323    50
 POSGPS 2017-10-17 00:45:00     4027883.1343     306997.9468    4919500.1885    50
 . . . . . .
 POSGAL 2017-10-17 05:00:00     4027885.8327     306995.2343    4919502.2234    50
 POSGAL 2017-10-17 05:15:00     4027884.5166     307002.9106    4919504.2607    50
 POSGAL 2017-10-17 05:30:00     4027882.0961     306998.0823    4919500.7148    50
 POSGAL 2017-10-17 05:45:00     4027881.3244     306997.0231    4919500.6480    50
 POSGAL 2017-10-17 06:00:00     4027880.3769     306995.4235    4919501.8792    50
 POSGAL 2017-10-17 06:15:00     4027883.5153     306997.8101    4919501.3337    50
 POSGAL 2017-10-17 06:30:00     4027882.9539     306997.2001    4919501.1024    50
 POSGAL 2017-10-17 06:45:00     4027886.1815     306993.7040    4919505.1332    50
```



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)
=GNSSYS 2017-10-17 00:00:00       4 GPS GAL GLO BDS

=GPSSAT 2017-10-17 00:00:00      32 G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G12 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23
=GALSAT 2017-10-17 00:00:00      18 E01 E02 E03 E04 E05   - E07 E08 E09   - E11 E12   - E14   -   -   - E18 E19 E20   - E22   -
=GLOSAT 2017-10-17 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
=BDSSAT 2017-10-17 00:00:00      12   -   -   -   - C05 C06 C07 C08 C09 C10 C11 C12 C13 C14   -   -   -   -   -   -   -   -   -

=BDSHDR 2017-10-17 00:00:00       6 C2I L2I S2I C7I L7I S7I
=GALHDR 2017-10-17 00:00:00      12 C1C L1C S1C C5Q L5Q S5Q C7Q L7Q S7Q C8Q L8Q S8Q
=GPSHDR 2017-10-17 00:00:00      14 C1C L1C S1C C1W S1W C2W L2W S2W C2L L2L S2L C5Q L5Q S5Q
=GLOHDR 2017-10-17 00:00:00       9 C1C L1C S1C C2P L2P S2P C2C L2C S2C
=GPSOBS 2017-10-17 00:00:00      14 C1C C1W C2L C2W C5Q L1C L2L L2W L5Q S1C S1W S2L S2W S5Q
=GALOBS 2017-10-17 00:00:00      12 C1C C5Q C7Q C8Q L1C L5Q L7Q L8Q S1C S5Q S7Q S8Q
=GLOOBS 2017-10-17 00:00:00       9 C1C C2C C2P L1C L2C L2P S1C S2C S2P
=BDSOBS 2017-10-17 00:00:00       6 C2I C7I L2I L7I S2I S7I

 GPSC1C 2017-10-17 00:00:00         G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G12 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23
 GPSC1W 2017-10-17 00:00:00         G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G12 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23
 GPSC2L 2017-10-17 00:00:00         G01   - G03   - G05 G06 G07 G08 G09 G10   - G12   -   - G15   - G17   -   -   -   -   -   -
 GPSC2W 2017-10-17 00:00:00         G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G12 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23
 GPSC5Q 2017-10-17 00:00:00         G01   - G03   -   - G06   - G08 G09 G10   -   -   -   -   -   -   -   -   -   -   -   -   -
 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
 GALC1C 2017-10-17 00:00:00         E01 E02 E03 E04 E05   - E07 E08 E09   - E11 E12   - E14   -   -   - E18 E19 E20   - E22   -
 GALC5Q 2017-10-17 00:00:00         E01 E02 E03 E04 E05   - E07 E08 E09   - E11 E12   - E14   -   -   - E18 E19   -   - E22   -
 GALC7Q 2017-10-17 00:00:00         E01 E02 E03 E04 E05   - E07 E08 E09   - E11 E12   - E14   -   -   - E18 E19   -   - E22   -
 GALC8Q 2017-10-17 00:00:00         E01 E02 E03 E04 E05   - E07 E08 E09   - E11 E12   - E14   -   -   - E18 E19   -   - E22   -
 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
```

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

```
#====== Preprocessing results (v.9)
#GNSPRP 2017-10-17 00:00:00      CS_Total       CS_Slip      CS_Epoch     CS_Satell     CS_Signal
=GPSPRP 2017-10-17 00:00:00           378            34             0           138           206
=GALPRP 2017-10-17 00:00:00           393           211             0           121            61
=GLOPRP 2017-10-17 00:00:00           868           598             0           110           160
=BDSPRP 2017-10-17 00:00:00           109             0             0            29            80

#GNSxxx 2017-10-17 00:00:00      CS_Total       CS_Slip      CS_Epoch     CS_Satell     CS_Signal
=GPSL1C 2017-10-17 00:00:00           134            10             0            76            48
=GPSL2L 2017-10-17 00:00:00            82             4             0            17            61
=GPSL2W 2017-10-17 00:00:00           122            15             0            11            96
=GPSL5Q 2017-10-17 00:00:00            40             5             0            34             1
=GALL1C 2017-10-17 00:00:00            96            42             0            27            27
=GALL5Q 2017-10-17 00:00:00           105            59             0            32            14
=GALL7Q 2017-10-17 00:00:00           104            59             0            32            13
=GALL8Q 2017-10-17 00:00:00            88            51             0            30             7

#CLKJMP 2017-10-17 00:00:00  Phase[ms]
 CLKJMP 2017-10-17 00:00:00   -

#GNSSLP 2017-10-17 00:00:00  PRN          L1C          L2L          L2P          L2W          L5Q          L7Q          L8Q
 GPSSLP 2017-10-17 00:03:30  G14          9.0            -            -         -9.0            -            -            -
 GPSSLP 2017-10-17 00:04:00  G14         -5.0            -            -         -1.0            -            -            -
 GPSSLP 2017-10-17 00:05:30  G14            -            -            -         10.0            -            -            -
 GPSSLP 2017-10-17 00:39:30  G15         14.0         11.0            -         11.0            -            -            -
 . . . . . .
 GALSLP 2017-10-17 00:36:00  E19            -            -            -            -        -82.0        -84.0        -82.0
 GALSLP 2017-10-17 02:06:00  E04         -4.0            -            -            -         -3.0         -3.0         -3.0
 GALSLP 2017-10-17 03:38:00  E05            -            -            -            -          1.0          1.0          1.0
 GALSLP 2017-10-17 04:16:00  E03            -            -            -            -         -2.0         -2.0         -2.0
 GALSLP 2017-10-17 04:16:30  E03            -            -            -            -          1.0          1.0          1.0
 GALSLP 2017-10-17 05:30:00  E08            -            -            -            -         80.0         82.0         80.0
```

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

➔ **UseEp** (in Summary)
➔ **xCoEp/xPhEp**
➔ **xCoSv/xPhSv**

sec_bnd="1" - a summary report over % of dual-/multi-band observations

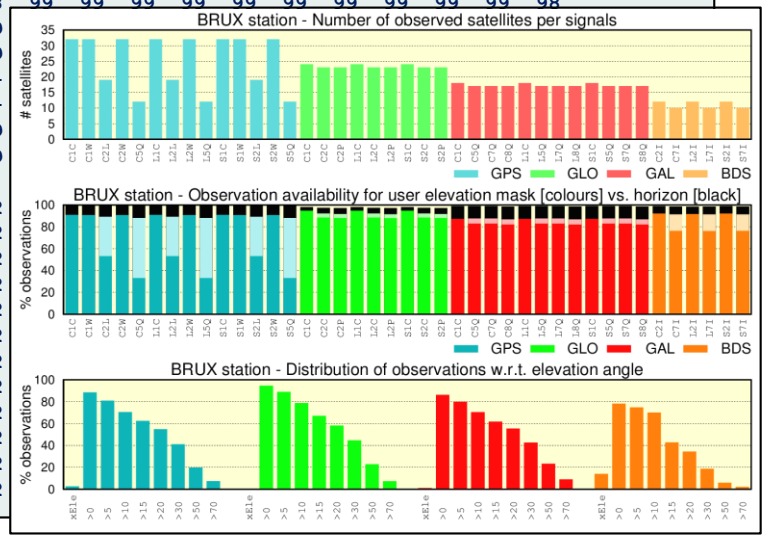
sec_bnd="2" - epoch-wise report over bands of complete dual-/multi-band observations

FewBand – counts of single-frequency observations

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

```
#====== Band available (v.9)
#GNSxEP 2017-10-17 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
=GPSCEP 2017-10-17 00:00:00     254  98  99  98  99  99  98  99  99  97  98  99  99  99  99  99  99  99  99  99  99  99  98
=GPSLEP 2017-10-17 00:00:00     265  98  99  98  99  99  98  99  99  97  98  99  98  99  99  99  99  99  99  99  99  99  98
=GALCEP 2017-10-17 00:00:00     249  99  99  99  99  99   -  100  99  99   -  99  99
=GALLEP 2017-10-17 00:00:00     249  99  99  99  99  99   -  100  99  99   -  99  99
=GLOCEP 2017-10-17 00:00:00    1866  97  99 100  99  90  99  99  99 100  97  99   -
=GLOLEP 2017-10-17 00:00:00    1890  97  99 100  99  90  98  99  99 100  97  99   -
=BDSCEP 2017-10-17 00:00:00    2074   -   -   -   - 100  99  99  98  99  98  99  99
=BDSLEP 2017-10-17 00:00:00    2148   -   -   -   -  98  99  98  98  98  98  99  99

#NxBAND 2017-10-17 00:00:00 nSatell x01 x02 x03 x04 x05 x06 x07 x08 x09 x10 x11 x12
 GPSCBN 2017-10-17 00:00:00      13   1   -   -   -   -   1   -   -   -   3   -   2
 GPSCBN 2017-10-17 00:20:00      10   -   -   -   -   -   3   -   -   -   3   -   2
 GPSCBN 2017-10-17 00:40:00      12   -   2   -   -   -   3   -   -   -   3   -   2
 GPSCBN 2017-10-17 01:00:00      12   -   2   -   -   -   3   -   -   -   -   -   2
 GPSCBN 2017-10-17 01:20:00      10   -   2   -   -   -   3   -   -   -   -   -   2
 GPSCBN 2017-10-17 01:40:00      11   -   2   3   -   -   3   -   -   -   -   -   2
 GPSCBN 2017-10-17 02:00:00      11   -   2   3   -   -   3   -   -   -   -   -   2
 GPSCBN 2017-10-17 02:20:00       9   -   2   -   -   -   3   -   -   -   -   -   2
 GPSCBN 2017-10-17 02:40:00       9   -   2   -   -   -   3   -   -   -   -   -   2
 GPSCBN 2017-10-17 03:00:00      10   -   2   -   -   -   3   -   -   -   -   -   2
 GPSCBN 2017-10-17 03:20:00      10   -   2   -   -   -   3   -   -   -   -   -   2
```

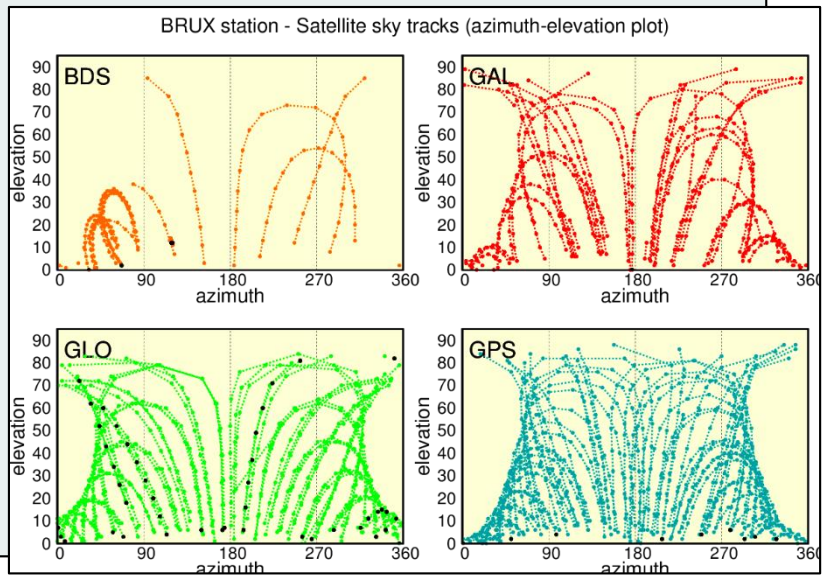


XTR outputs – Elevation/Azimuth

- 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

```
#====== Elevation & Azimuth (v.9)
#GNSELE 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
 GLOELE 2017-10-17 00:00:00      27   -  13  40  25   -   -   -   -   -   -   7  52  53   9   -   -   -   -   -   -  24  40  11
 GLOELE 2017-10-17 00:20:00      30   -   4  33  29   -   -   -   -   -   -   -
 GLOELE 2017-10-17 00:40:00      31   -   -  24  31   7   -   -   -   -   -   -
 GLOELE 2017-10-17 01:00:00      28   -   -  15  29  13   -   -   -   -   -   -
 GLOELE 2017-10-17 01:20:00      32   -   -   6  25  17   -   -   -   -   -   -
 GLOELE 2017-10-17 01:40:00      32   -   -   -  19  20   -   -   -   -   -   -
 GLOELE 2017-10-17 02:00:00      30   -   -   -  12  19   4   -   -   -   -   -
 GLOELE 2017-10-17 02:20:00      30   -   -   -   5  16   8   -   -   -   -   -
 GLOELE 2017-10-17 02:40:00      34   -   -   -   -  12  11   -   -   -   -   -
 GLOELE 2017-10-17 03:00:00      36   -   -   -   -   6  12   1   -   -   -   -
 GLOELE 2017-10-17 03:20:00      40   -   -   -   -   -  11   6   -   -   -   -
 GLOELE 2017-10-17 03:40:00      34   -   -   -   -   -   8   9   -   -   -   -
 GLOELE 2017-10-17 04:00:00      33   -   -   -   -   -   -  11   3   -   -   -
 GLOELE 2017-10-17 04:20:00      35   -   -   -   -   -   -  10   8   -   -   -
 GLOELE 2017-10-17 04:40:00      38   -   -   -   -   -   -   7  12   -   -   -
 GLOELE 2017-10-17 05:00:00      38   9   -   -   -   -   -   -  13   -   -   -
 GLOELE 2017-10-17 05:20:00      32  14   -   -   -   -   -   -  12   5   -   -
 GLOELE 2017-10-17 05:40:00      26  18   5   -   -   -   -   -   9  14   -   -
 GLOELE 2017-10-17 06:00:00      29  19  12   -   -   -   -   -   4  23   -   -
 GLOELE 2017-10-17 06:20:00      35  18  20   -   -   -   -   -   -  31   -   -
 GLOELE 2017-10-17 06:40:00      32  15  26   7   -   -   -   -   -  39   -   -
 GLOELE 2017-10-17 07:00:00      31   9  30  16   -   -   -   -   -  44   5   -
```



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)

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

$$\alpha = -\frac{f_i^2}{f_k^2}\frac{\left(f_k^2 + f_j^2\right)}{\left(f_i^2 - f_j^2\right)} \qquad \beta = \frac{f_j^2}{f_k^2}\frac{\left(f_k^2 + f_i^2\right)}{\left(f_i^2 - f_j^2\right)}$$

Václavovic P, Douša J (2016)

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)

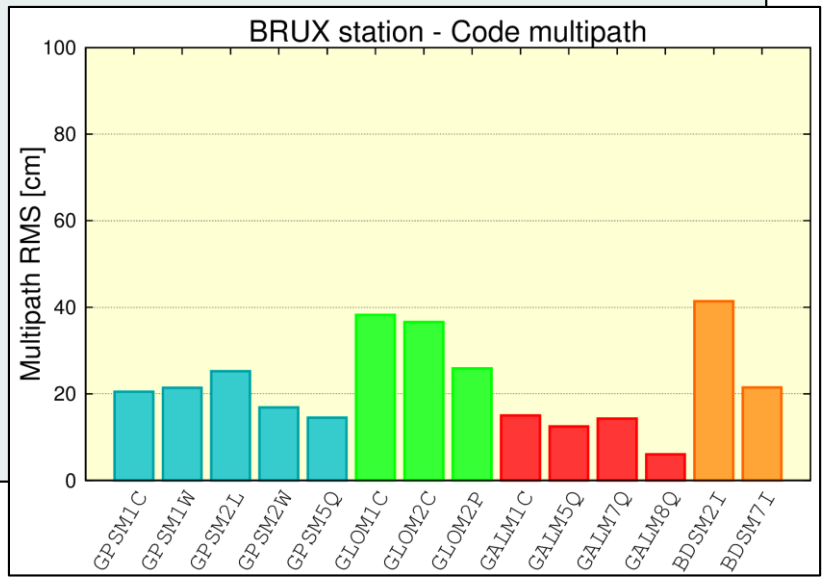
XTR output – Code multipath and noise

- 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

```
#====== Code multipath (v.9)
#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
=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
=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
=GPSM2L 2017-10-17 00:00:00   25.23  22   -  21   -  26  24  29  24  24  24   -  25   -   -  29   -  28   -   -   -   -   -   -
=GPSM2W 2017-10-17 00:00:00   16.85  13  19  13  12  19  20  16  16  12  19  12  14  15  21  18  19  18  23  21  19  16  11  16
=GPSM5Q 2017-10-17 00:00:00   14.51  14   -  12   -   -  16   -  15  13  15   -
=GALM1C 2017-10-17 00:00:00   14.99  16  13  15  14  14   -  15  15  15   -  18
=GALM5Q 2017-10-17 00:00:00   12.48  11  12  12  14  12   -  11  13  13   -  13
=GALM7Q 2017-10-17 00:00:00   14.31  15  13  14  16  14   -  11  15  14   -  15
=GALM8Q 2017-10-17 00:00:00    6.02   7   6   6   6   5   -   6   6   6   -   7
=GLOM1C 2017-10-17 00:00:00   38.26  35  25  37  46  51  45  40  46  32  27  36
=GLOM2C 2017-10-17 00:00:00   36.57  47  27  27  29  64  51  27  30  28  47  29
=GLOM2P 2017-10-17 00:00:00   25.87  30  20  26  26  30  28  26  27  27  30  24
=BDSM2I 2017-10-17 00:00:00   41.41   -   -   -   -  43  45  57  61  37  38  33
=BDSM7I 2017-10-17 00:00:00   21.49   -   -   -   -  22  27  29  27  20  22  16

 GPSM1C 2017-10-17 00:00:00   20.61   -   -   -   -   -  28   -   -   -  34   -
 GPSM1C 2017-10-17 00:20:00   23.53   -  35   -   -   -  24   -   -   -  41   -
 GPSM1C 2017-10-17 00:40:00   23.49   -  32   -   -   -  31   -   -   -  41   -
 GPSM1C 2017-10-17 01:00:00   16.91   -  17   -   -   -  18   -   -   -   -   -
 GPSM1C 2017-10-17 01:20:00   17.69   -  24   -   -   -  18   -   -   -   -   -
 GPSM1C 2017-10-17 01:40:00   19.65   -  13  56   -   -  17   -   -   -   -   -
 GPSM1C 2017-10-17 02:00:00   17.69   -  18  55   -   -  24   -   -   -   -   -
```



XTR output – Signal-to-noise ratio

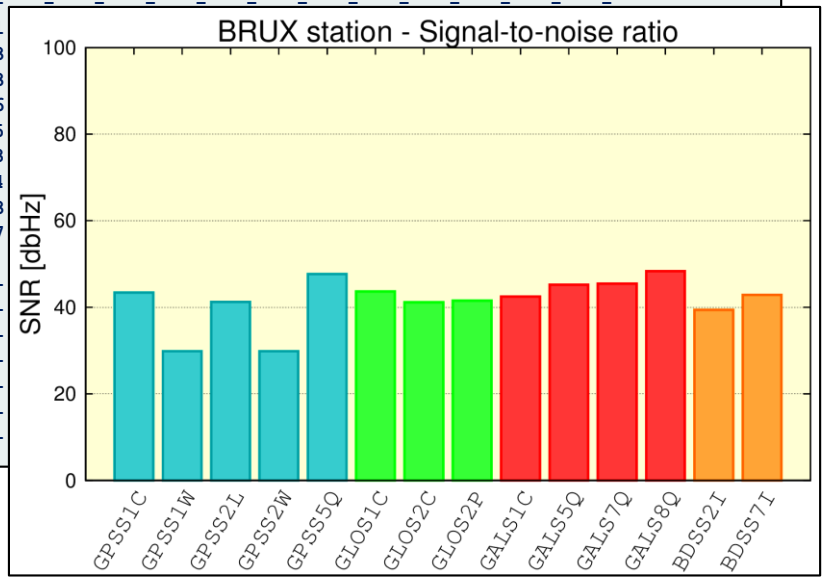
- Signal-to-noise statistics are represented directly by observations
- SNR depends on elevation, receiver and signal type, environment

sec_snr="1" – satellite mean values only reported

sec_snr="2" – satellite/epoch-wise values reported

```
#====== Signal to noise ratio (v.9)
#GNSSxx 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
=GPSS1C 2017-10-17 00:00:00   43.38  45  41  46  43  44  43  45  44  45  43  42  45  43  40  45  41  44  41  42  42  42  45  43
=GPSS1W 2017-10-17 00:00:00   29.86  33  27  35  30  29  30  29  32  34  30  28  31  29  24  30  27  29  25  29  26  29  34  29
=GPSS2L 2017-10-17 00:00:00   41.26  42   -  43   -  40  41  39  42  43  41   -  42   -   -  40   -  39   -   -   -   -   -   -
=GPSS2W 2017-10-17 00:00:00   29.86  33  27  35  30  29  30  29  32  34  30  28  31  29  24  30  27  29  25  29  26  29  34  29
=GPSS5Q 2017-10-17 00:00:00   47.68  48   -  49   -   -  46   -  48  48  47   -   -   -   -   -   -   -   -   -   -   -   -   -
=GALS1C 2017-10-17 00:00:00   42.48  43  44  44  43  44   -  42  43  44   -  41
=GALS5Q 2017-10-17 00:00:00   45.20  46  46  47  45  46   -  46  46  46   -  43
=GALS7Q 2017-10-17 00:00:00   45.46  46  47  47  45  46   -  46  46  46   -  43
=GALS8Q 2017-10-17 00:00:00   48.34  49  50  50  48  49   -  49  48  49   -  46
=GLOS1C 2017-10-17 00:00:00   43.66  44  45  46  45  40  41  45  44  45  45  45
=GLOS2C 2017-10-17 00:00:00   41.15  39  43  44  44  36  39  44  44  44  38  43
=GLOS2P 2017-10-17 00:00:00   41.51  39  44  45  44  36  39  44  44  44  38  44
=BDSS2I 2017-10-17 00:00:00   39.41   -   -   -   -  36  37  36  37  39  38  43
=BDSS7I 2017-10-17 00:00:00   42.86   -   -   -   -  39  40  40  41  42  42  47

 GPSS1C 2017-10-17 00:00:00   41.93   -   -   -   -   -   -   -   -   -  39   -
 GPSS1C 2017-10-17 00:20:00   44.12   -   -   -   -   -  39   -   -   -  36   -
 GPSS1C 2017-10-17 00:40:00   42.54   -  36   -   -   -  39   -   -   -  35   -
 GPSS1C 2017-10-17 01:00:00   42.38   -  39   -   -   -  41   -   -   -   -   -
 GPSS1C 2017-10-17 01:20:00   44.50   -  41   -   -   -  41   -   -   -   -   -
 GPSS1C 2017-10-17 01:40:00   43.86   -  42  32   -   -  42   -   -   -   -   -
 GPSS1C 2017-10-17 02:00:00   43.61   -  44  31   -   -  41   -   -   -   -   -
```



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)

```
▼<QC_GNSS>
  ▼<meta>
      <created>2017-10-23 15:53:55</created>
      <program>G-Nut/Anubis [2.1.0]</program>
      <fmt_ver>1.00</fmt_ver>
      <set_beg>2017-10-17 00:00:00</set_beg>
      <set_end>2017-10-18 00:00:00</set_end>
      <set_smp>30.000</set_smp>
      <set_ele>10.00</set_ele>
      <set_sys>BDS GAL GLO GPS QZS SBS</set_sys>
    </meta>
  ▼<navi>
      <sys type="GPS" flag="1" nsat="31" have="405"/>
      <sys type="GAL" flag="1" nsat="17" have="1620"/>
      <sys type="GLO" flag="1" nsat="24" have="1155"/>
      <sys type="BDS" flag="1" nsat="14" have="336"/>
    </navi>
  ▶<data beg="2017-10-17 00:00:00" end="2017-10-17 23:59:30" smpl="30.00" nepo="2880" ngap="0">...</data>
  ▼<head file="0">
      <file_name>BRUX2900.17O</file_name>
      <file_md5sum>d41d8cd98f00b204e9800998ecf8427e</file_md5sum>
      <site_id>BRUX</site_id>
      <marker_numb>13101M010</marker_numb>
      <receiver_type>SEPT POLARX4TR</receiver_type>
      <receiver_numb>3001376</receiver_numb>
      <antenna_type>JAVRINGANT_DM</antenna_type>
      <antenna_dome>NONE</antenna_dome>
      <antenna_numb>00464</antenna_numb>
      <software>sbf2rin-11.3.2</software>
      <data_format>RINEX 3.03</data_format>
      <data_sampling>30.000</data_sampling>
      <coordinates x="4027881.848" y="306998.261" z="4919498.655"/>
      <eccentricities n="0.001" e="0.000" u="0.469"/>
    ▶<observations>...</observations>
    </head>
</QC_GNSS>
```

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

```
▼<QC_GNSS>
  ▶<meta>...</meta>
  ▶<navi>...</navi>
  ▼<data beg="2017-10-17 00:00:00" end="2017-10-17 23:59:30" smpl="30.00" nepo="2880" ngap="0">
     <tot elev="0.01" expt="99022" have="90319" expt_usr="75518" have_usr="74675" cyc_slps="261" clk_jmps="0"/>
     <exl xbeg="0" xend="0" xsmp="0" xsys="0"/>
    ▼<sys type="GPS" nsat="32" xele="875">
       <epo expt="2880" have="2880" dual="2880"/>
       <amb nepo="0" nsat="138" nsig="206" nslp="34"/>
       <bnd cod_xepo="0" cod_xsat="254" pha_xepo="0" pha_xsat="265"/>
       <obs type="C1C" nsat="32" expt="35787" have="32514" expt_usr="26033" have_usr="26000" mpth="20.5"/>
       <obs type="C1W" nsat="32" expt="35782" have="32406" expt_usr="26029" have_usr="25996" mpth="21.4"/>
       <obs type="C2L" nsat="19" expt="21582" have="19254" expt_usr="15065" have_usr="15040" mpth="25.2"/>
       <obs type="C2W" nsat="32" expt="35782" have="32406" expt_usr="26029" have_usr="25996" mpth="16.9"/>
       <obs type="C5Q" nsat="12" expt="13815" have="12167" expt_usr="9336" have_usr="9318" mpth="14.5"/>
       <obs type="L1C" nsat="32" expt="35787" have="32505" expt_usr="26033" have_usr="26000" slps="10"/>
       <obs type="L2L" nsat="19" expt="21582" have="19254" expt_usr="15065" have_usr="15040" slps="4"/>
       <obs type="L2W" nsat="32" expt="35781" have="32391" expt_usr="26028" have_usr="25995" slps="15"/>
       <obs type="L5Q" nsat="12" expt="13815" have="12167" expt_usr="9336" have_usr="9318" slps="5"/>
       <obs type="S1C" nsat="32" expt="35787" have="32514" expt_usr="26033" have_usr="26000"/>
       <obs type="S1W" nsat="32" expt="35782" have="32406" expt_usr="26029" have_usr="25996"/>
       <obs type="S2L" nsat="19" expt="21582" have="19254" expt_usr="15065" have_usr="15040"/>
       <obs type="S2W" nsat="32" expt="35782" have="32406" expt_usr="26029" have_usr="25996"/>
       <obs type="S5Q" nsat="12" expt="13815" have="12167" expt_usr="9336" have_usr="9318"/>
       <crd x="4027882.490" y="306998.561" z="4919500.223" sx="0.956" sy="0.627" sz="1.362"/>
     </sys>
    ▶<sys type="GAL" nsat="18" xele="198">...</sys>
    ▶<sys type="GLO" nsat="24" xele="33">...</sys>
    ▶<sys type="BDS" nsat="12" xele="1992">...</sys>
   </data>
  ▶<head file="0">...</head>
 </QC_GNSS>
```

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

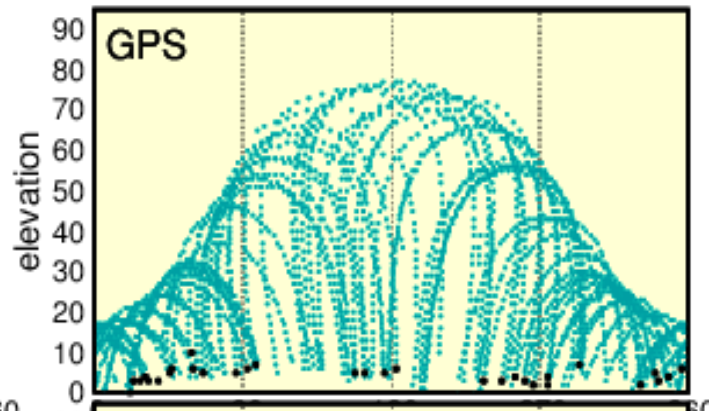
- 1-site/1-day – for a single Anubis XTR QC output **(all details)**
- 1-site/X-days – for a single site over sequence of XTR QC outputs **(site history)**
- X-sites/X-days – long-term comparison of stations in network **(site comparisons)**

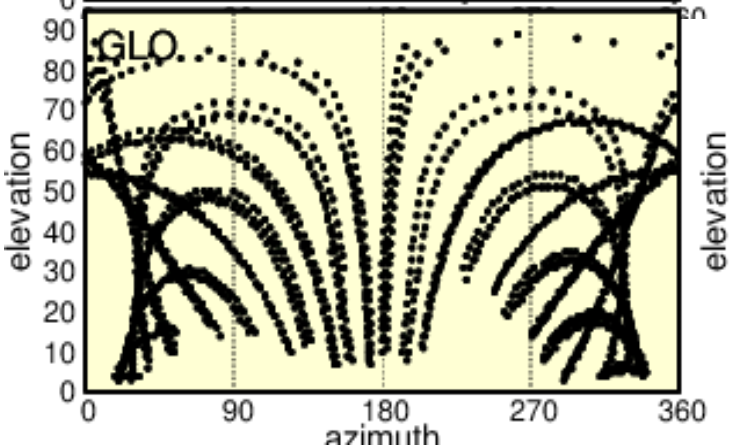
Sky plots – visibility of tracking problems

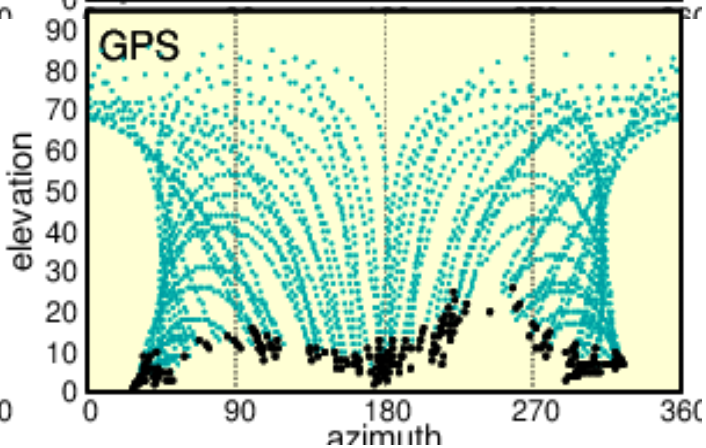
- Obstacles
- Cut-off mask
- Asymmetry
- Interference
- Multipath
- Signal-to-noise
- Tracking

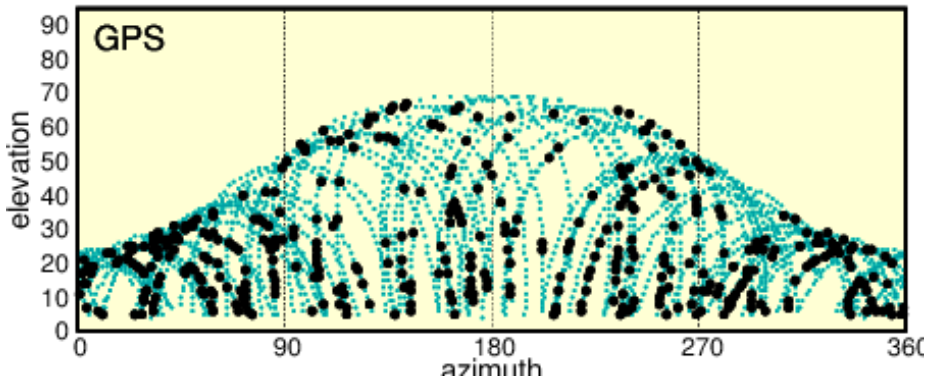
  lost of frequency,

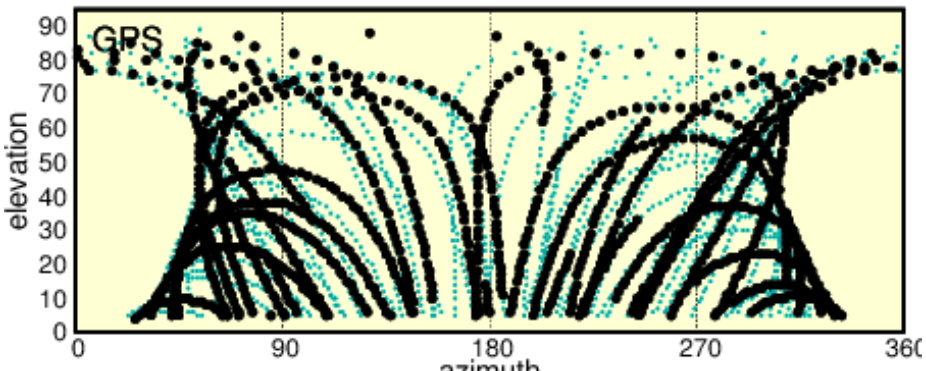
  signal/satellite



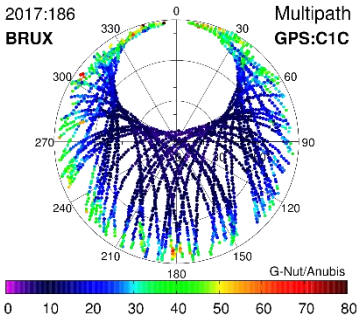


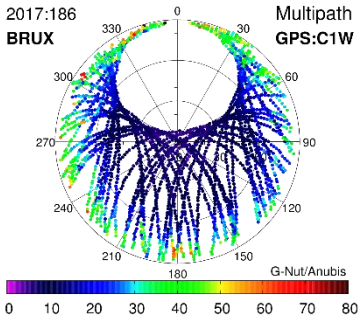


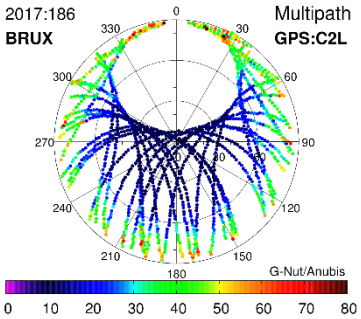


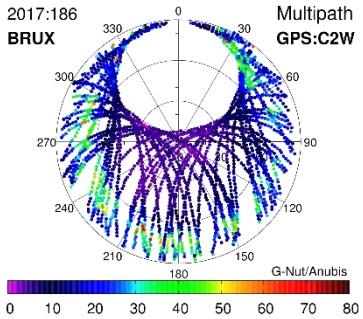


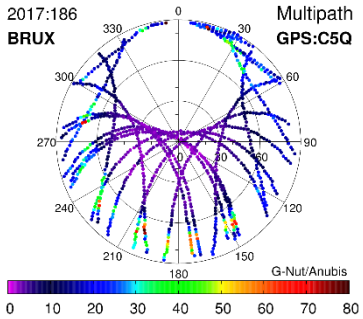
Code multipath and noise estimation

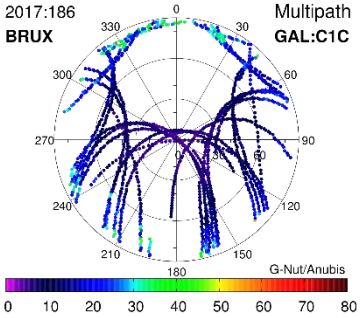


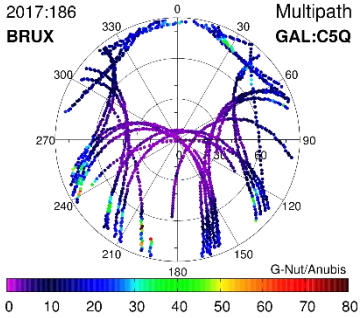


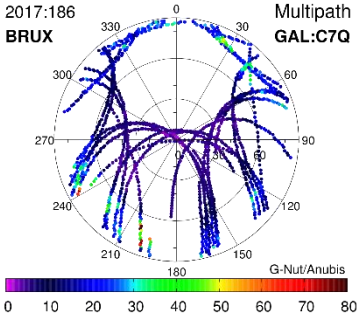


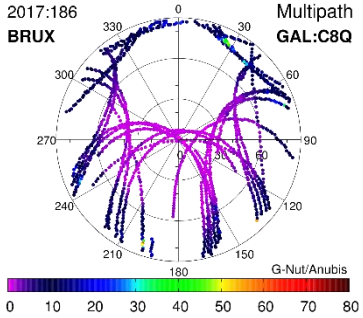


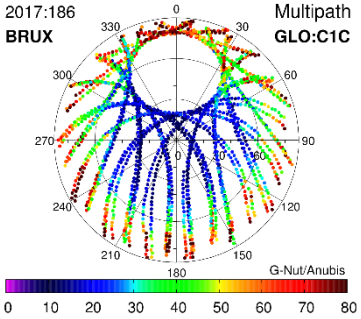


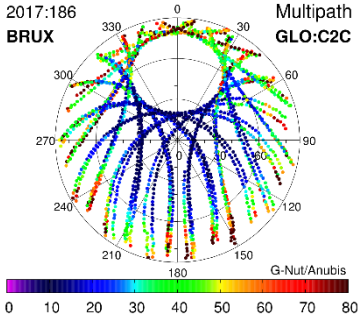


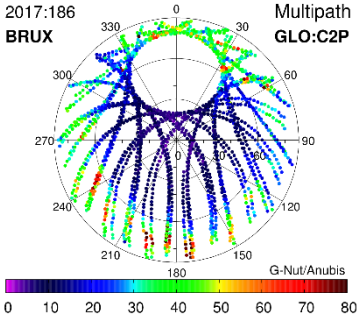




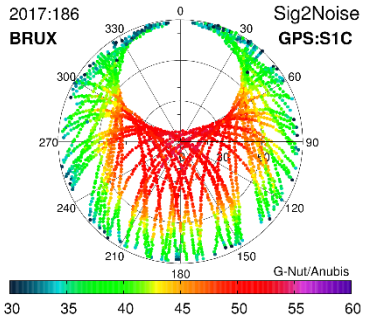


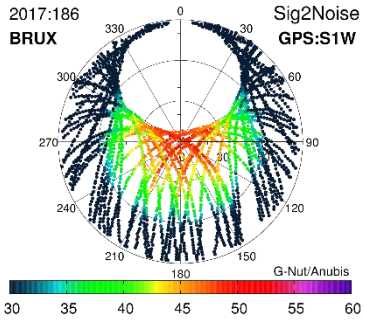


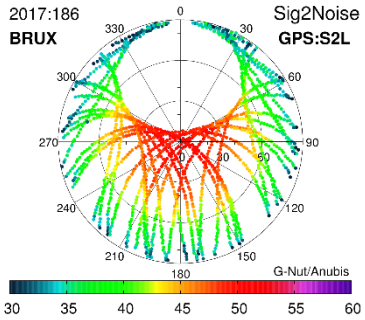


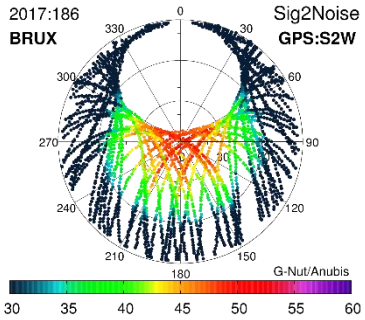


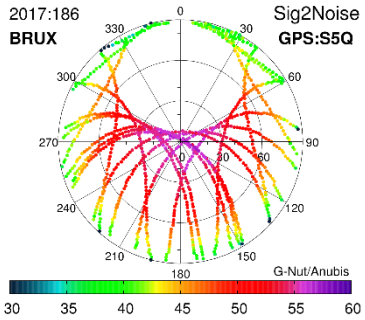
Signal-to-noise ratio observations

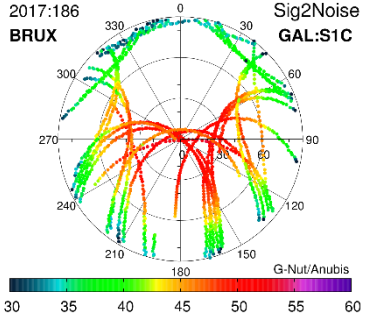


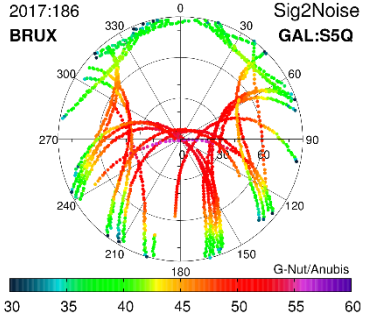


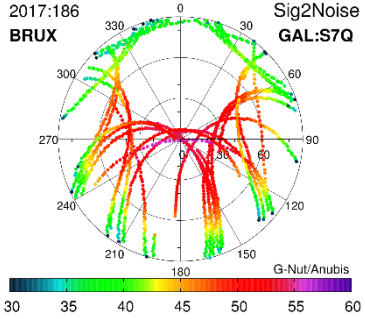


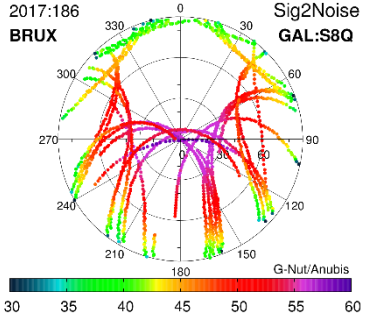


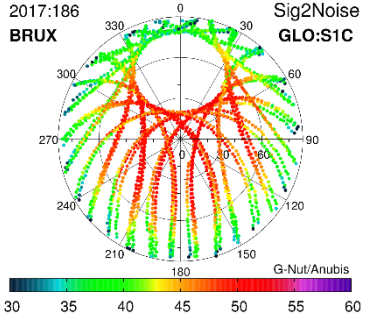


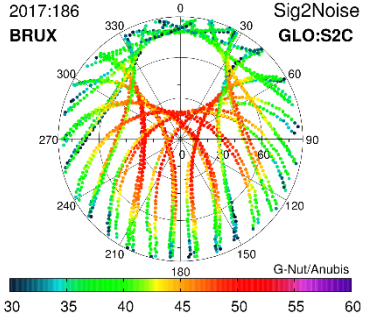


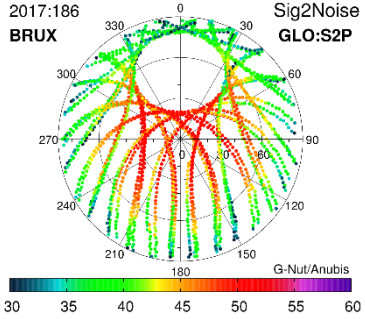






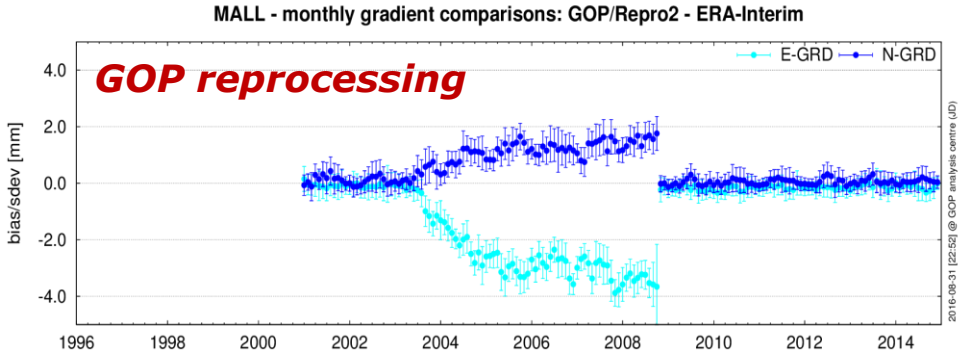




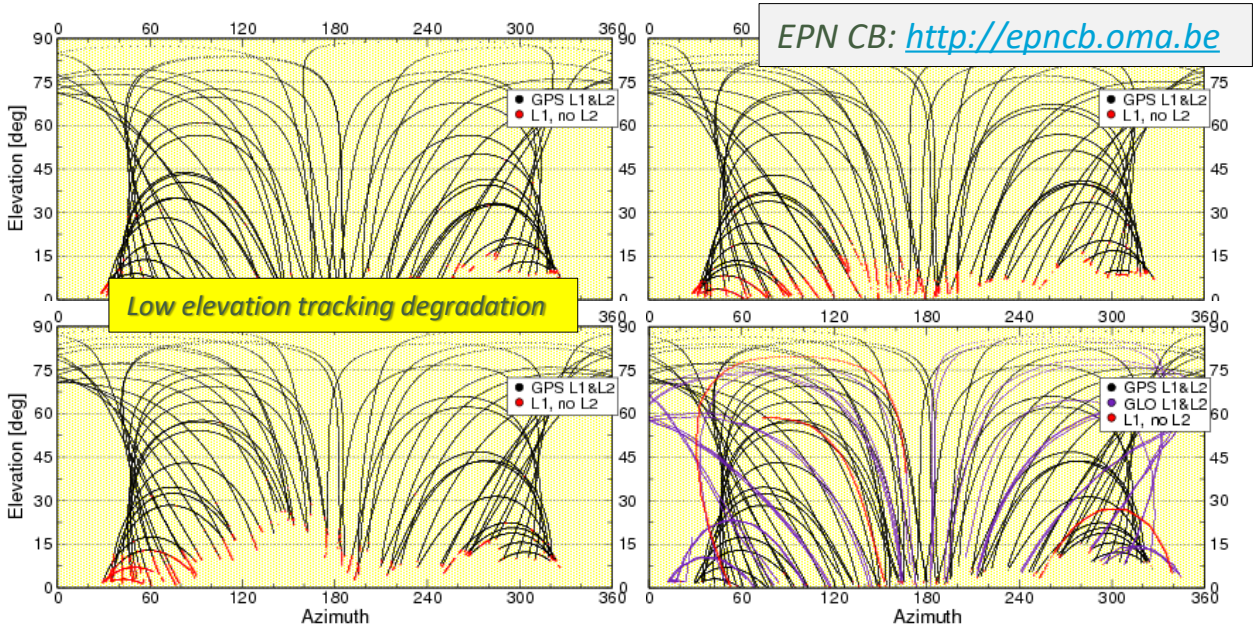


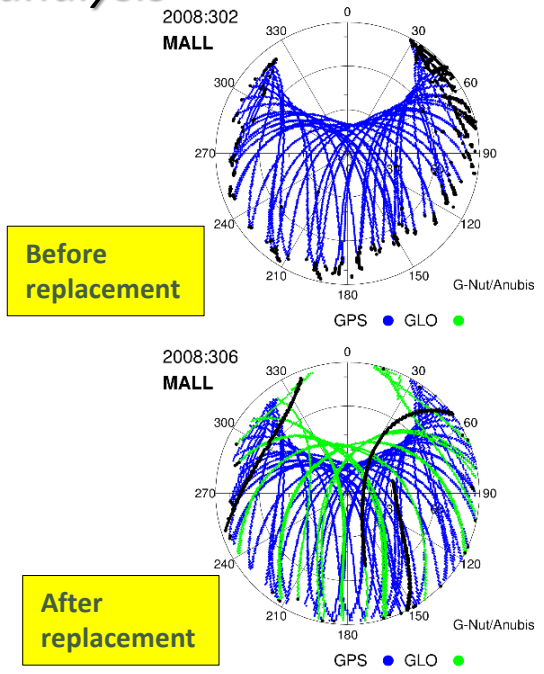
Data quality vs. GNSS tropospheric gradients

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



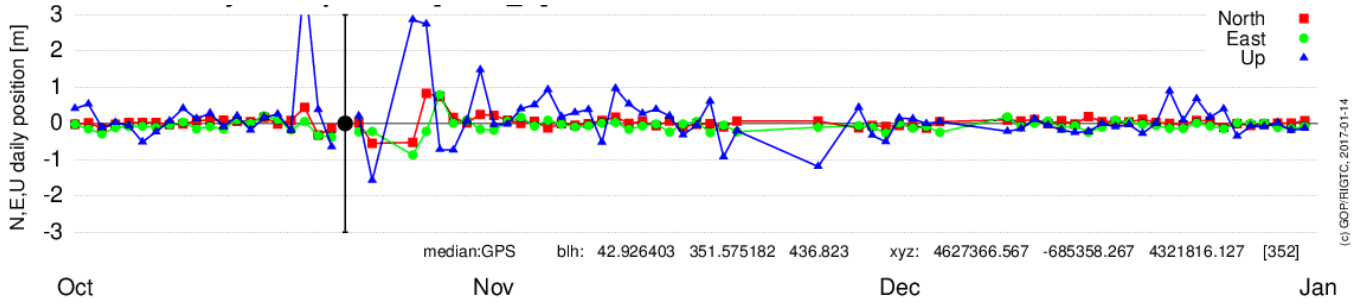
➔ *GOP Repro2 GRDs are compared to ERA-Interim NWM reanalysis*

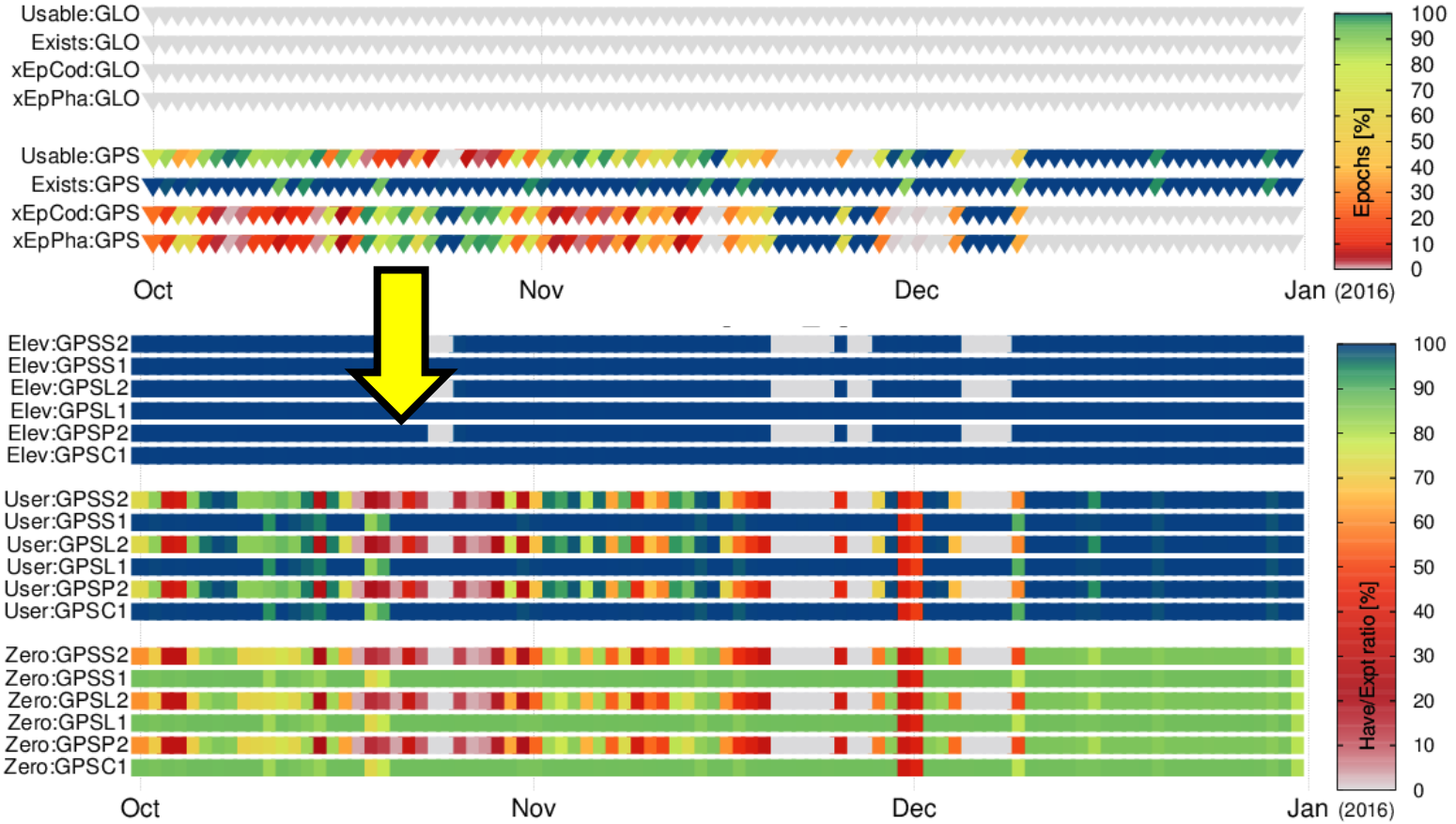




*Douša J, Václavovic P, M. Eliaš (2017)**, Tropospheric products of the second European GNSS reprocessing (1996-2014)**, Atmos. Meas. Tech.*

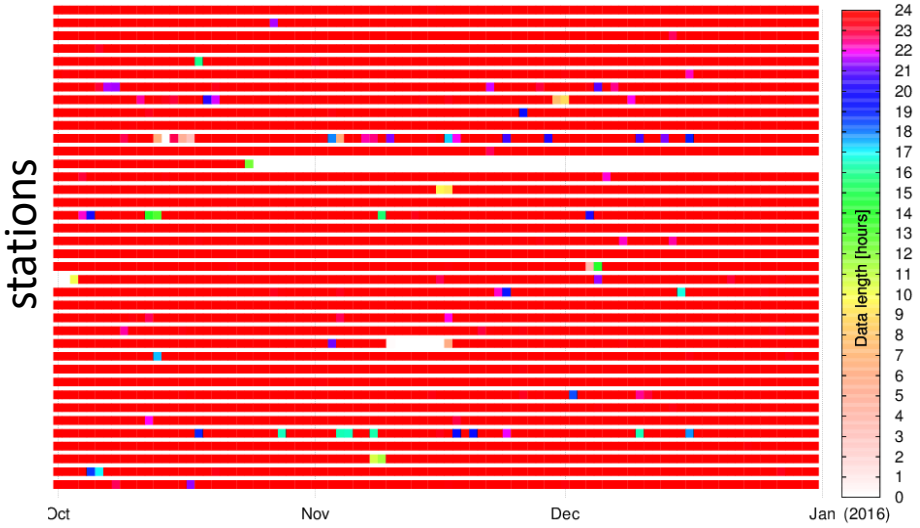
Daily site QC parameters (4th quarter 2016)



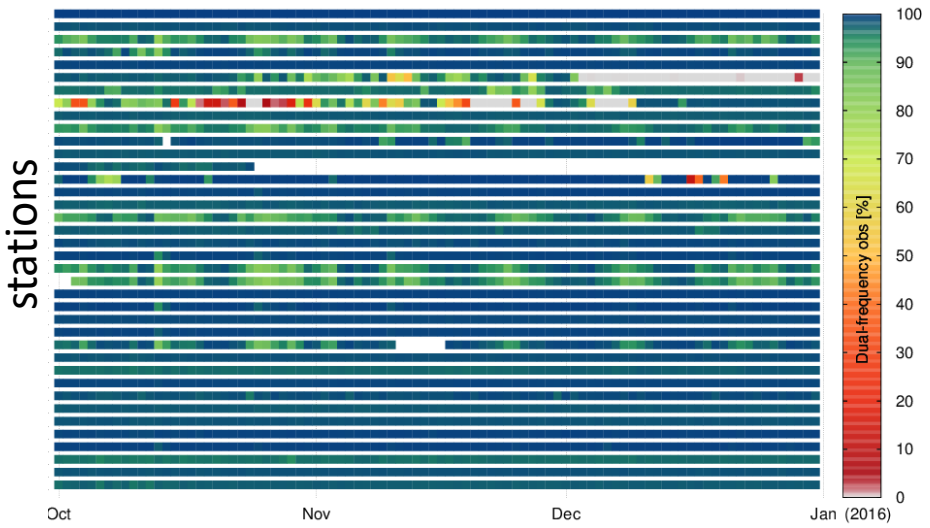


Network monitoring (comparisons over sites)

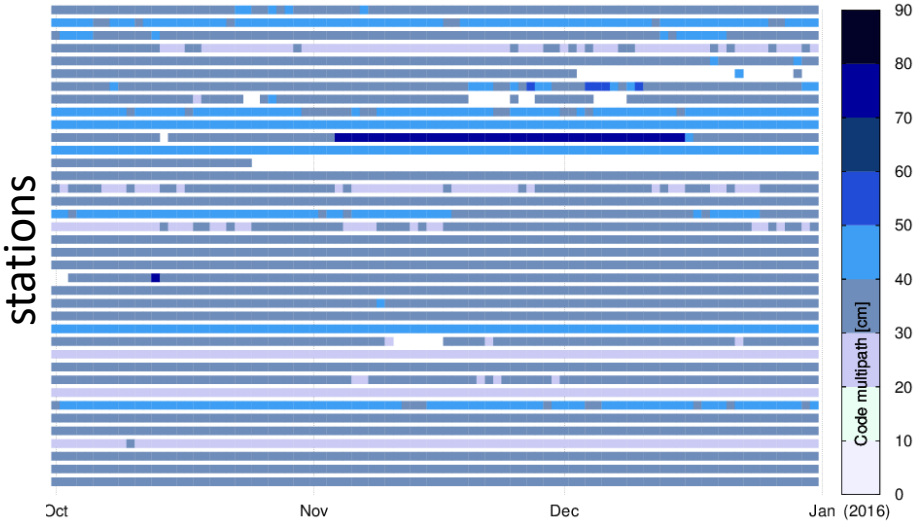
Data completeness



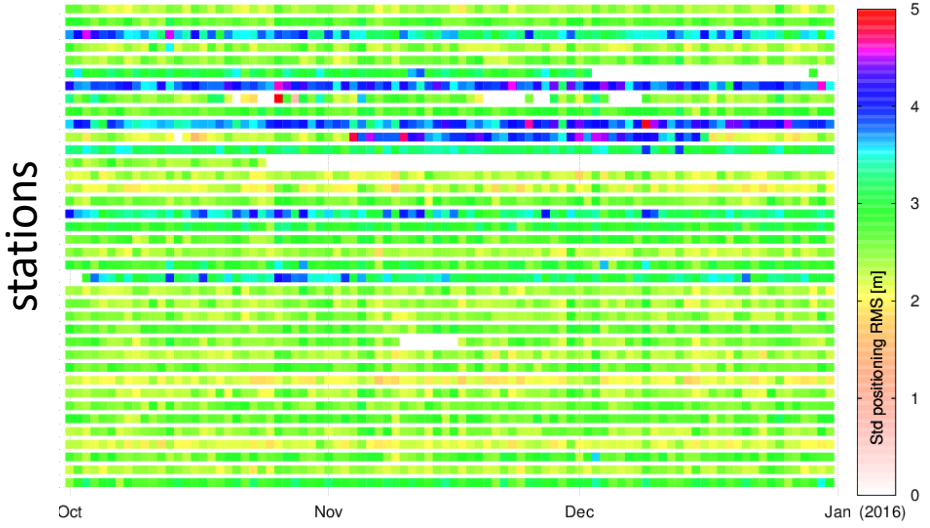
Dual-frequency data tracking



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

Acknowledgements

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