Navigation message and time scale issues for GPS Glonass Galileo Beidou QZSS and SBAS

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Outlook

- MGEX (http://igs.org/mgex/):
  - GNSS interoperability (GPS, Glonass, Galileo, BeiDou, QZSS, SBAS)
  - Intersystem biases
  - Performance comparison among various receivers/antennas
  - Development of sw handling multiGNSS data and nav messages
- This study:
  - BRDC vs SP3 position and clocks of the GNSS satellites
  - Relative time offset between pairs of constellations (TIME SYSTEM CORR in the RINEX header of the NAV file), and its possible receiver dependency.
  - Possible activities within the TWG:
    - Monitoring receiver biases of EPN-MGEX sites, GNSS specific time scales, in analogy to IGS and related LACs
    - Use the navigation messages to compute skyplots, sPP of EPN-MGEX sites, station performance and support Anubis

Selection of multiGNSS sites

- various receivers
- all possible GNSS

- Note: EPN web site is based on logsheet, not on rinex obs files
- Some discrepancy exists between log and rinex
- A number of European GNSS sites track multiGNSS and deliver data to MGEX, but are not EPN

HOME

EUREF Permanent Network

ROB
GNSS Research Group
EUREF

ORGANISATION — Creation, Management, Structure, Relation to IGS, Projects

NETWORK & DATA — Station list, Maps, Tracking status, Data access, Proposed stations, Station log submission, Station picture submission

PRODUCTS & SERVICES — Data analysis, Weekly EPN solutions, Coordinates, Position time series, Tropospheric delays, ETRS89/ITRS transformation, Satellite Orbit & Clock Correction Streams

DOCUMENTATION — Formats, Guidelines, Equipment & calibration, Papers, FAQ

NEWS, EVENTS & LINKS — News, Mails, Calendar, Workshops, FTP server, Site map, Web history, Links

NETWORK & DATA > **STATION LIST**

As of 10 March 2014, 247 permanent GNSS tracking stations (including 1 inactive) are part of the EUREF Permanent Network.

For a better understanding of the table, see the legend.

Station Identification
- [x] Marker Name
- [ ] Marker Number
- [ ] Station log
- [ ] Station name

Station Location
- [x] City
- [x] Country
- [ ] Tectonic plate
- [x] Lat, long, h
- [ ] X, Y, Z

Data
- [x] Quality
- [x] Availability
- [x] Latency

Receiver Information
- [ ] Type
- [x] Satellite system
- [ ] Serial number
- [ ] Firmware version
- [ ] Frequency Standard

Antenna Information
- [ ] Type/Radome
- [ ] Serial number
- [ ] Height
- [ ] Reference point
- [ ] Calibration

Meteorological Instr.
- [ ] Meteo data
- [ ] Humidity sensor
- [ ] Pressure sensor
- [ ] Temperature sensor
- [ ] Water vapor radiometer

Additional Information
- [ ] Primary data centre
- [ ] Secondary data centre
- [x] RINEX 3 data available
- [ ] Networks
- [x] Remarks

Station Status
- [x] Active
- [x] Inactive
- [ ] Former

Submit

Marker Name	City	Country	Lat.	Long.	H.	DQ (%) 0°	DQ (%) 15°	Availability (%) Daily BKG	Availability (%) Daily OLG	Availability (%) Hourly BKG	Availability (%) Hourly OLG	Availability (%) RT	Latency Hourly(%) BKG	Latency Hourly(%) OLG	Latency RT (s)	Receiver Sat. System G	R	E	C	J	S	RINEX 3 data available	Remarks
ACOR	A Coruna	Spain	43.36	-8.40	67.0	84	98	100	100	100	100	99	94	96	1.0	✔	_	_	_	_	_	_	
AJAC	Ajaccio	France	41.93	8.76	99.0	92	99	100	100	100	100	98	96	97	0.9	✔	✔	✔	_	_	✔	3.01	
ALAC	Alicante	Spain	38.34	-0.48	60.0	95	99	100	100	90	90	99	67	66	0.8	✔	✔	✔	_	_	✔	3.01	
ALBA	Albacete	Spain	38.98	-1.86	751.8	96	100	100	100	100	100	99	93	92	0.6	✔	✔	✔	_	_	✔	3.01	
ALCI	Alchevsk/Mikhailovka	Ukraine	48.46	38.91	152.1	90	97	100	100	87	86	_	74	0	_	✔	_	_	_	_	_	_	
ALME	Almeria	Spain	36.85	-2.46	127.0	87	100	100	100	97	100	99	90	95	2.0	✔	_	_	_	_	_	_	
ANKR	Ankara	Turkey	39.89	32.76	974.8	91	100	100	100	99	100	_	98	0	_	✔	✔	_	_	_	_	_	
AQUI	L'Aquila	Italy	42.37	13.35	713.0	83	97	100	100	100	100	_	99	99	_	✔	_	_	_	_	_	_	
ARGI	Argir, Tórshavn	Faroe Islands	62.00	-6.78	110.2	87	96	100	100	100	100	_	100	100	_	✔	✔	_	_	_	_	_	
AUT1	Thessaloniki	Greece	40.57	23.00	150.0	85	97	100	100	100	100	_	99	99	0.9	✔	_	_	_	_	_	_	
AUTN	Autun	France	46.95	4.29	353.0	93	100	100	100	100	100	_	98	96	_	✔	✔	✔	_	_	✔	3.01	
AXPV	Aix En Provence	France	43.49	5.33	229.4	89	98	100	100	100	100	_	99	96	_	✔	✔	✔	_	_	✔	3.02	
BACA	Bacau	Romania	46.56	26.91	219.2	83	96	93	93	92	92	_	92	92	_	✔	_	_	_	_	_	_	
BADH	Bad Homburg	Germany	50.23	8.61	261.6	89	96	100	100	100	100	_	100	0	_	✔	✔	_	_	_	_	_	

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	Receiver	Antenna	Calibration	GNSS Capability
BRUX	Sept. PolarX4TR	JAVRINGANT_DM	Individual	GREC
TLSE	Trimble NETR9	TRM59800	Type	GRESI
WTZZ	Leica GRX1200	LEIAR25.R3	Type	GRESCI
PADO	Leica GR10	LEIAR25	Type	GRES
ALAC	Leica GR10	LEIAR25.R3	Type	GRE
ALBA	Leica GR10	LEIAR25.R3	Type	GRE
CANT	Leica GR10	LEIAR25.R4	Type	GRE
AXPV	Trimble NETR9	TRM57971	Individual	GRESC
KIRU	Sept. PolarX4	SEPCHOKE_MC	Type	GRESCJ

G = GPS;
R = Glonass;
E = Galileo;
C = BeiDou;
S = SBAS;
J = QZSS;
I = GAGAN GSAT;

File	GNSS	Source
BRDM<doy>.13p	GRECJ	DLR/TUM ftp://cddis.gsfc.nasa.gov/gnss/data/campaign/mgex/daily/RINEX3/2013/brdm
IGS<gpsweek>2.sp3	G	IGS ftp://cddis.gsfc.nasa.gov/pub/gps/products/<gpsweek>/
IGL<gpsweek>2.sp3	R	IGS ftp://cddis.gsfc.nasa.gov/pub/glonass/products/<gpsweek>/
IAC<gpsweek>2.sp3	R	IAC ftp://cddis.gsfc.nasa.gov/pub/glonass/products/<gpsweek>/
TUM<gpsweek>2.sp3	EJ	TUM ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex/<gpsweek>/
QZF<gpsweek>2.sp3	J	JAXA ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex/<gpsweek>/

Constants

(to be considered in the broadcast orbit model)

	μ [m³/s²]	$\omega_\oplus$ [rad/s]	Source
GPS	$3.986005 \cdot 10^{14}$	$7.2921151467 \cdot 10^{-5}$	ICD-GPS-200 Rev.c http://www.navcen.uscg.gov/pubs/gps/icd200/icd200cw1234.pdf
Glonass	$3.986004418 \cdot 10^{14}$	$7.292115 \cdot 10^{-5}$	Glonass ICD v.5.1 facility.unavco.org/data/docs/**ICD_GLONASS**_5.1_(2008)_en.pdf
Galileo	$3.986004418 \cdot 10^{14}$	$7.2921151467 \cdot 10^{-5}$	Galileo OS SIS ICD 1.1 http://ec.europa.eu/enterprise/policies/satnav/galileo/open-service/
BeiDou	$3.986004418 \cdot 10^{14}$	$7.2921150 \cdot 10^{-5}$	http://en.beidou.gov.cn/
QZSS	$3.986005 \cdot 10^{14}$	$7.2921151467 \cdot 10^{-5}$	Interface Specifications for QZSS http://qz-vision.jaxa.jp/USE/is-qzss/DOCS/IS-QZSS_15_E.pdf
IERS standard	$3.986004418 \cdot 10^{14}$	$7.2921150 \cdot 10^{-5}$	IERS Technical Note No.36 http://tai.bipm.org/iers/conv2010/conv2010.html

Note: PZ90.02 and WGS84 Datums are related by the 3 parameters transformation:
Source: http://www.navipedia.net/index.php/Reference_Frames_in_GNSS

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{ITRF2000} = \begin{bmatrix} x \\ y \\ z \end{bmatrix}_{PZ-90.02} + \begin{bmatrix} -0.36\,m \\ 0.08\,m \\ 0.18\,m \end{bmatrix}$$

The two broadcast models

	Model	Update rate	Validity
GPS	Keplerian with secular and periodic perturbations; GPS time (no leap seconds; fixed offset to UTC)	2 hr	2 hr
Galileo		(10 min – 3 hr)(*)	
BeiDou		1 hr	
QZSS		15 min	
Glonass	Runge Kutta (4.order) numerical integration of 9D state vector; Potential up to J_2; Glonass: UTC(SU) time scale (leap seconds required for interoperability) SBAS: probably UTC	30 min	15 min
SBAS		(2 min –30 min)	

(*) different clock offsets (40 ns in this case) and offset rate (10^-14 s/s) depending on frequency and service (Free vs. Integrity)

Two clock models are available in the navigation messages of GALILEO:

- F/NAV (free accessible navigation)
- I/NAV (integrity navigation)

The SV clock parameters depend on the origin of the message (F-NAV vs. I-NAV) and define the satellite clock for the dual-frequency iono-free combination:

- F/NAV: E5a-E1 (1176.45 - 1575.42 MHz)
- I/NAV: E5b-E1 (1207.40 – 1575.42 MHz)

Decoding the 2. word, 6.line (Rinex 3.x + ICD):

HS=3 *'signal component currently in test'*

DVS=0 '*Navigation Data Valid (tbc)*'

```
E11 2013 03 30 02 50 00 4.727053456008e-04 8.196820999729e-11-5.204170427930e-18
     1.130000000000e+02 1.143750000000e+01 3.869089734546e-09-2.259200878362e+00
     4.637986421585e-07 2.963528968394e-04 3.503635525703e-06 5.440594156265e+03
     5.286000000000e+05-2.048909664154e-08-1.161089147383e+00 5.587935447693e-09
     9.570887936756e-01 2.623125000000e+02-1.080462976088e+00-5.986677940595e-09
     1.310768884500e-10 5.130000000000e+02 1.733000000000e+03
    -1.000000000000e+00 3.900000000000e+02-5.355104804039e-09-6.519258022308e-09
     5.292850000000e+05
E11 2013 03 30 02 50 00 4.727416671813e-04 8.198242085200e-11-5.204170427930e-18
     1.130000000000e+02 1.143750000000e+01 3.869089734546e-09-2.259200878362e+00
     4.637986421585e-07 2.963528968394e-04 3.503635525703e-06 5.440594156265e+03
     5.286000000000e+05-2.048909664154e-08-1.161089147383e+00 5.587935447693e-09
     9.570887936756e-01 2.623125000000e+02-1.080462976088e+00-5.986677940595e-09
     1.310768884500e-10 2.580000000000e+02 1.733000000000e+03
    -1.000000000000e+00 4.800000000000e+01-5.355104804039e-09 0.000000000000e+00
     5.293300000000e+05
```

Bit0=1 →I-NAV E1-B

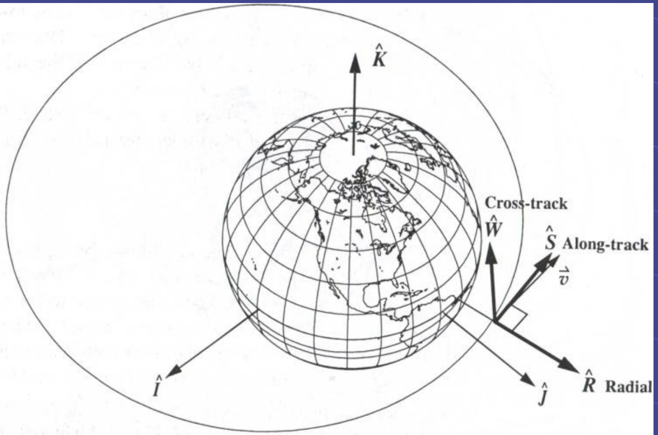
Bit1=1 →F-NAV E5a-I

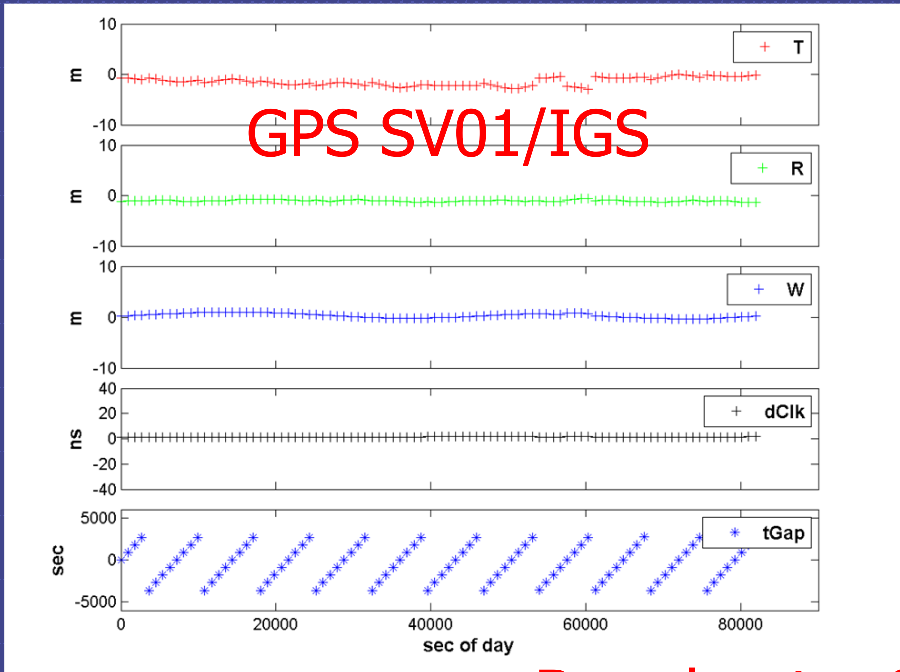
Software implementation

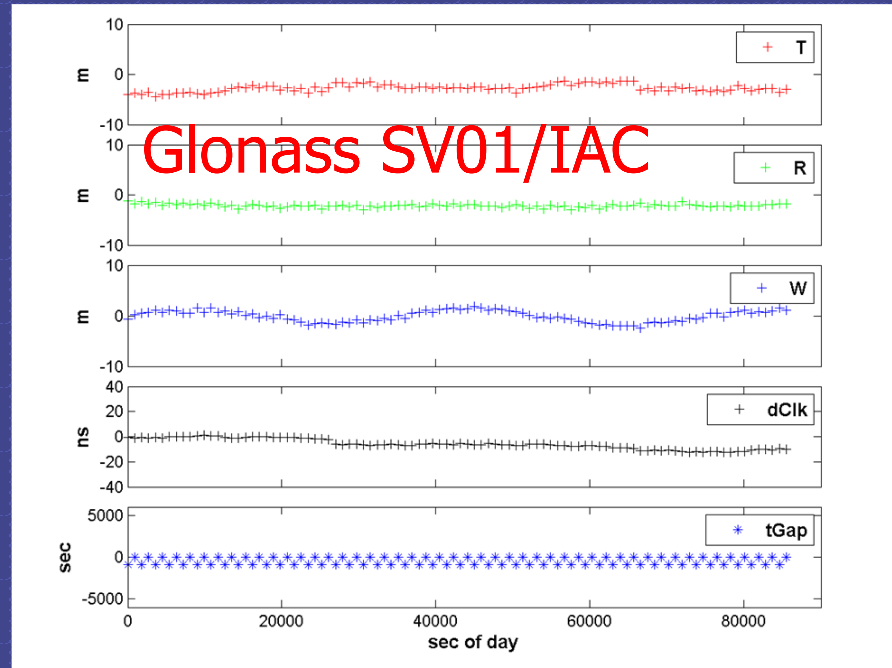
- C program for unpacking Rinex Obs and Nav files (3.x)
- Matlab routines
  - I/O
  - Broadcast orbit model
    - Analytic for GPS Galileo BeiDou QZSS, with adaptation for BeiDou low inclination orbits (C05), according to ICD
    - Runge Kutta 4. order (Earth potential truncated to J_2) for Glonass, SBAS (EGNOS, GAGAN-GSAT)
  - Measurement model : 3 coordinates, 1 rcvr+GNSS clock bias, 1 TZD solved for every epoch
  - All GNSS data are processed in one block simultaneously at each epoch (interoperability!)
  - Partials, AZ El angles, TZD, clock bias and post fit residuals saved to file for possible reprocessing/smoothing

Strategy for SP3/BRDC comparison of computed positions of the SV's

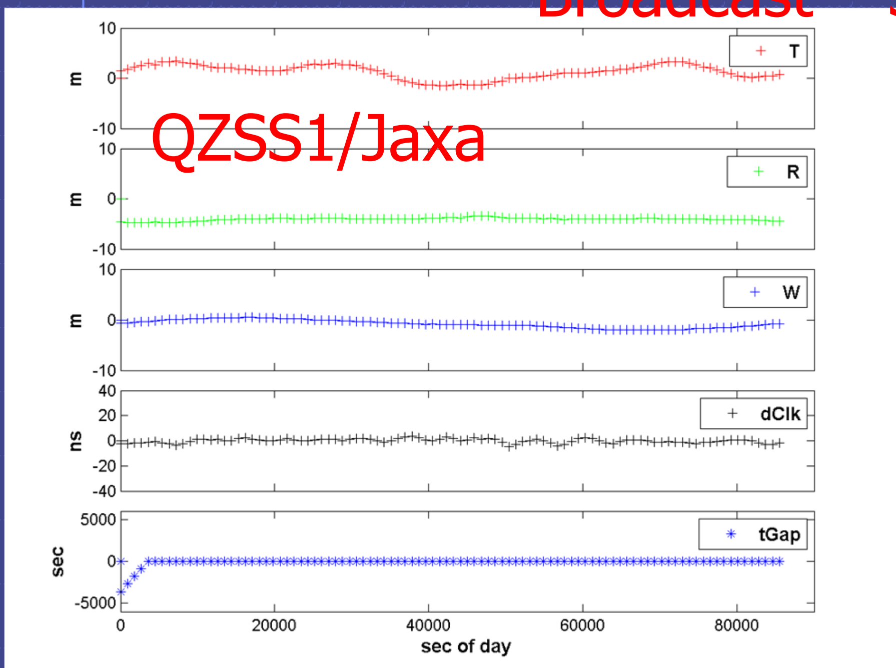
- Form differences BRDC-SP3 for XYZ ECEF
- Rotate to inertial frame at 0h GPStime
- Compute Tangential, Radial, Cross Track (T R W) versors in inertial frame
- Project differences BRDC-SP3 onto TRW triad
- Monitor that updated broadcast message is used

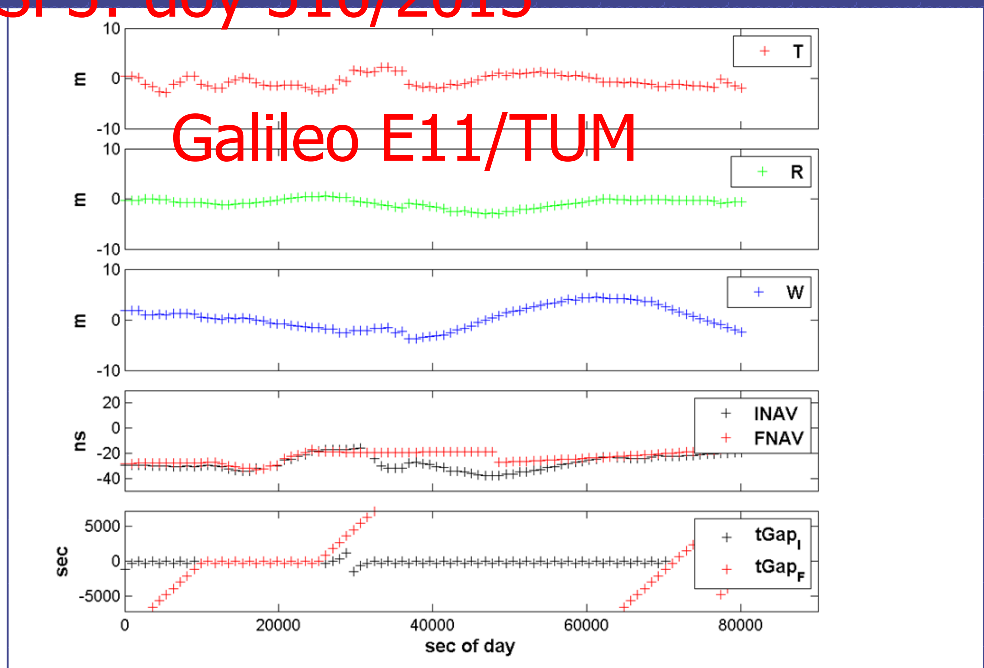






Broadcast – SP3: doy 316/2013





Intersystem time bias (1/3)

Theoretically:

- once the satellite clock error has been included into the pseudorange model, all the GNSS's should be synchronized among each other within few ns

- Consequently, one has to solve for coordinates and receiver clock error (4 unknowns)

In practice it turns out that:

- each GNSS, after the polynomial correction of satellite clock drift, has its own bias

- One has to solve for the sum of receiver clock error **and a GNSS specific clock bias**

$$x=[H^T H]^{-1}H^T y$$

$$x=\begin{bmatrix} \Delta x \\ \Delta y \\ \Delta z \\ rcvrbias+TimeSystemCorr\_GPS \\ rcvrbias+TimeSystemCorr\_GLO \\ rcvrbias+TimeSystemCorr\_GAL \\ rcvrbias+TimeSystemCorr\_BeiDou \\ rcvrbias+TimeSystemCorr\_QZSS \\ TZD \end{bmatrix}$$

$$H=\begin{bmatrix}
-\frac{x_{1G}-x_0}{\rho_{1G}} & -\frac{y_{1G}-y_0}{\rho_{1G}} & -\frac{z_{1G}-z_0}{\rho_{1G}} & 1 & 0 & 0 & 0 & 0 & \frac{1}{\sin El_{1G}} \\
-\frac{x_{2G}-x_0}{\rho_{2G}} & -\frac{y_{2G}-y_0}{\rho_{2G}} & -\frac{z_{2G}-z_0}{\rho_{2G}} & 1 & 0 & 0 & 0 & 0 & \frac{1}{\sin El_{2G}} \\
\dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \\
-\frac{x_{nG}-x_0}{\rho_{nG}} & -\frac{y_{nG}-y_0}{\rho_{nG}} & -\frac{z_{nG}-z_0}{\rho_{nG}} & 1 & 0 & 0 & 0 & 0 & \frac{1}{\sin El_{nG}} \\
-\frac{x_{1R}-x_0}{\rho_{1R}} & -\frac{y_{1R}-y_0}{\rho_{1R}} & -\frac{z_{1R}-z_0}{\rho_{1R}} & 0 & 1 & 0 & 0 & 0 & \frac{1}{\sin El_{1R}} \\
\dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \\
-\frac{x_{nR}-x_0}{\rho_{nR}} & -\frac{y_{nR}-y_0}{\rho_{nR}} & -\frac{z_{nR}-z_0}{\rho_{nR}} & 0 & 1 & 0 & 0 & 0 & \frac{1}{\sin El_{nR}} \\
-\frac{x_{1E}-x_0}{\rho_{1E}} & -\frac{y_{1E}-y_0}{\rho_{1E}} & -\frac{z_{1E}-z_0}{\rho_{1E}} & 0 & 0 & 1 & 0 & 0 & \frac{1}{\sin El_{1E}} \\
\dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \\
-\frac{x_{nR}-x_0}{\rho_{nR}} & -\frac{y_{nR}-y_0}{\rho_{nR}} & -\frac{z_{nE}-z_0}{\rho_{nE}} & 0 & 0 & 1 & 0 & 0 & \frac{1}{\sin El_{nE}} \\
-\frac{x_{1C}-x_0}{\rho_{1C}} & -\frac{y_{1C}-y_0}{\rho_{1C}} & -\frac{z_{1C}-z_0}{\rho_{1C}} & 0 & 0 & 0 & 1 & 0 & \frac{1}{\sin El_{1C}} \\
\dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \\
-\frac{x_{nC}-x_0}{\rho_{nC}} & -\frac{y_{nC}-y_0}{\rho_{nC}} & -\frac{z_{nC}-z_0}{\rho_{nC}} & 0 & 0 & 0 & 1 & 0 & \frac{1}{\sin El_{nC}} \\
-\frac{x_{1J}-x_0}{\rho_{1J}} & -\frac{y_{1J}-y_0}{\rho_{1J}} & -\frac{z_{1J}-z_0}{\rho_{1J}} & 0 & 0 & 0 & 0 & 1 & \frac{1}{\sin El_{1J}} \\
\dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \\
-\frac{x_{nJ}-x_0}{\rho_{nJ}} & -\frac{y_{nJ}-y_0}{\rho_{nJ}} & -\frac{z_{nJ}-z_0}{\rho_{nJ}} & 0 & 0 & 0 & 0 & 1 & \frac{1}{\sin El_{nJ}}
\end{bmatrix}$$

GPS GLONASS GALILEO BeiDou QZSS

Intersystem time bias (2/3)

Define TIME SYSTEM CORR relative to GPS

No need to solve for coordinates: assume ITRF2008 values

Strategy: 1. iteration: coordinates constrained, solve for tropo and clock

2. iteration: back substitute clock and tropo with constraints, adjust coords

$$x=[H^T H + C]^{-1} H^T y$$

$$C=\begin{bmatrix} \sigma & 0 & 0 & 0 & \dots & 0 \\ 0 & \sigma & 0 & 0 & \dots & 0 \\ 0 & 0 & \sigma & 0 & \dots & 0 \\ 0 & 0 & 0 & 0 & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & 0 & 0 & \dots & 0 \end{bmatrix}$$

$$x=\begin{bmatrix} \boxed{\begin{matrix}\Delta x \\ \Delta y \\ \Delta z\end{matrix}} \\ rcvrbias + TimeSystemCorr\_GPS \\ rcvrbias + TimeSystemCorr\_GLO \\ rcvrbias + TimeSystemCorr\_GAL \\ rcvrbias + TimeSystemCorr\_BeiDou \\ rcvrbias + TimeSystemCorr\_QZSS \\ TZD \end{bmatrix}$$

Constrained to near zero

Solved for parameters

$$GLGP = \cancel{rcvrbias} + TimeSystemCorr\_GLO - \left(\cancel{rcvrbias} + TimeSystemCorr\_GPS\right)$$

$$GPGA = \cancel{rcvrbias} + TimeSystemCorr\_GPS - \left(\cancel{rcvrbias} + TimeSystemCorr\_GAL\right)$$

.....

```
GAUT  1.8626451492e-09-8.881784197e-16  82800 1757 1757   0 TIME SYSTEM CORR
GLGP -3.7252902985e-07 0.000000000e+00  86400 1757 1757   0 TIME SYSTEM CORR
GLUT -1.8673017621e-07 0.000000000e+00  86400 1757 1757   0 TIME SYSTEM CORR
GPGA  8.7020453066e-09 1.776356839e-15 172800 1757 1757   0 TIME SYSTEM CORR
GPUT -9.3132257462e-10-7.993605777e-15 319488 1757 1757   0 TIME SYSTEM CORR
QZUT -1.0710209608e-08-3.019806627e-14 403200 1757 1757   0 TIME SYSTEM CORR
```

Verify information in the header of the RINEX 3.x NAV header

Intersystem time bias (3/3)
Doy 253/2013

LEICA

Trimble

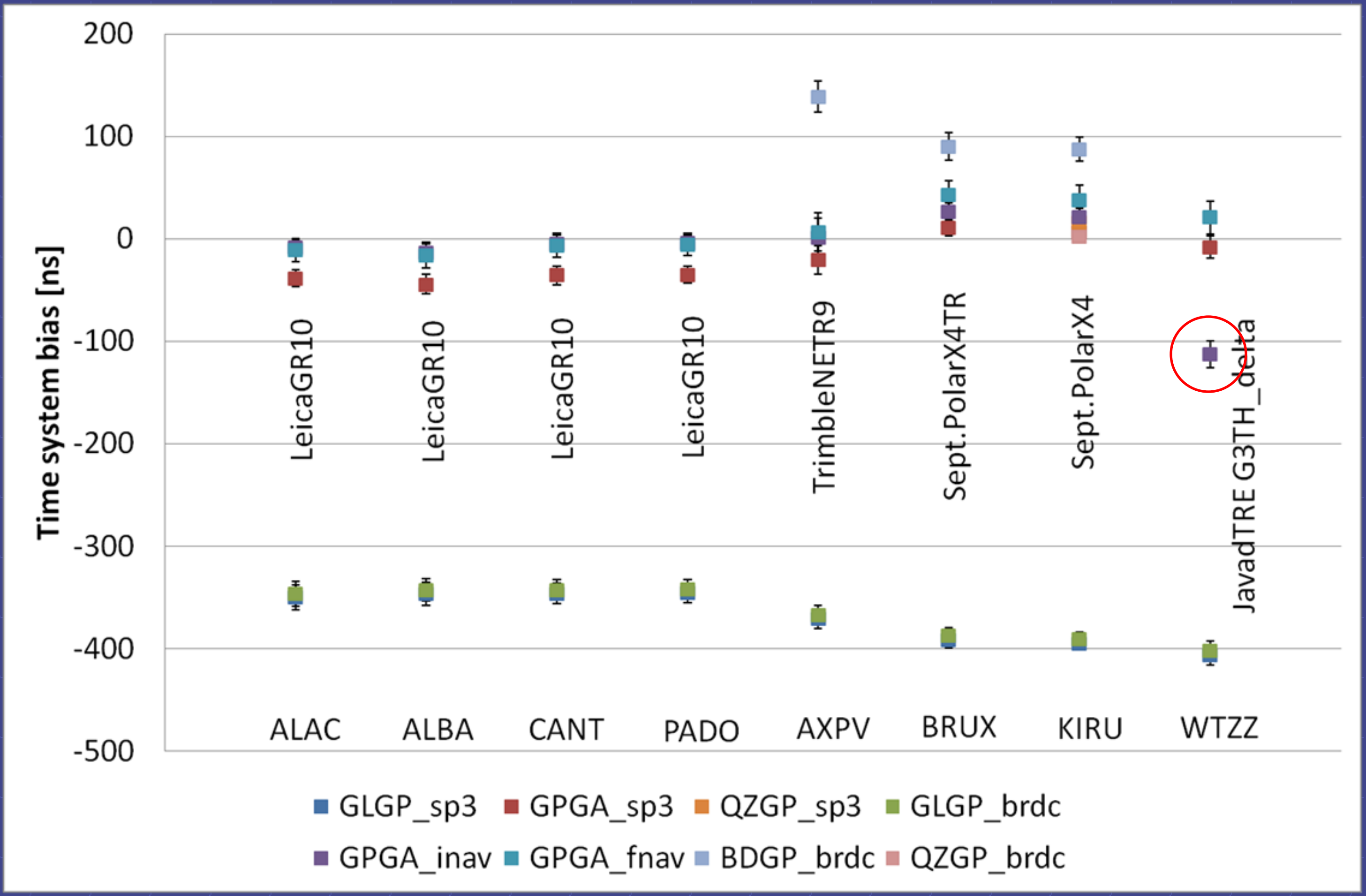
Septentrio

Javad

DOY 253/2013	SP3 (ns)				Broadcast (ns)				
	GLGP (IAC)	GLGP (IGL)	GPGA (TUM)	QZGP (TUM)	GLGP	GPGA (I/NAV)	GPGA (F/NAV)	BDGP	QZGP
ALAC	-338.8±13.3	-155.4±13.4	-35.9±1.2		-334.5±13.4	*33.7 ± 11.2 (E1-E5a)*	-0.8± 12.1		
ALBA	-335.1± 12.0	-151.7±12.1	-37.4±10.1		-330.7±12.1	*32.5 ± 10.1 (E1-E5a)*	-2.1± 15.0		
CANT	-337.1± 13.8	-153.7±13.6	-30.6±10.2		-332.0±11.3	*38.8 ± 10.9 (E1-E5a)*	5.3 ± 14.5		
PADO	-334.4± 10.8	-150.9±10.5	-32.1±11.4		-330.2±10.7	*36.9 ± 13.1 (E1-E5a)*	2.8 ± 13.3		
AXPV	-360.6±10.4	-177.1±10.4	-12.3± 8.9		-356.5±10.5	51.1 ± 10.0	25.3± 12.6	146.0±18.0	
BRUX	-380.6 ± 9.2	-197.1 ± 9.0	15.1 ± 8.6		-375.8 ± 9.0	66.5 ± 10.8	50.1± 16.5	100.4±15.5	
KIRU	-385.6 ± 6.4	-201.8 ± 6.9	12.6 ± 6.8	8.9±9.6	-381.1 ± 6.5	63.4 ± 8.0	46.8± 12.2	93.1± 10.5	1.6±7.0
WTZZ	-392.2 ± 8.6	-208.9 ± 8.7	-3.5 ± 8.8		-388.0 ± 8.7	-68.6±11.1	30.7± 13.5	255.1±13.7	
RINEX					-372.53	8.70	8.70		-9.78

- Time System Correction depends on Receiver type
- Rinex GLGP resembles Septentrio
- SP3 files are not unique as to the clock of non GPS GNSS's
- WTZZ/Javad E5b problem
- LEICA does not track E5b → inconsistent I-NAV clock model

Receiver dependent Time System Correction



SBAS (from brdm089.13p)

```
S20 2013 03 30 00 14 20 0.000000000000e+00 0.000000000000e+00 5.192460000000e+05
     4.063672000000e+04 0.000000000000e+00 0.000000000000e+00 0.000000000000e+00
    -1.124591600000e+04 0.000000000000e+00 0.000000000000e+00 0.000000000000e+00
     0.000000000000e+00 0.000000000000e+00 0.000000000000e+00 5.600000000000e+01
S20 2013 03 30 00 16 44 0.000000000000e+00 0.000000000000e+00 5.193980000000e+05
     4.063672000000e+04 0.000000000000e+00 0.000000000000e+00 0.000000000000e+00
    -1.124591600000e+04 0.000000000000e+00 0.000000000000e+00 0.000000000000e+00
     0.000000000000e+00 0.000000000000e+00 0.000000000000e+00 5.700000000000e+01
S20 2013 03 30 00 19 18 0.000000000000e+00 0.000000000000e+00 5.195550000000e+05
     4.063672000000e+04 0.000000000000e+00 0.000000000000e+00 0.000000000000e+00
    -1.124591600000e+04 0.000000000000e+00 0.000000000000e+00 0.00000
     0.000000000000e+00 0.000000000000e+00 0.000000000000e+00 5.80000
S20 2013 03 30 00 22 08 0.000000000000e+00 0.000000000000e+00 5.19712
     4.063672000000e+04 0.000000000000e+00 0.000000000000e+00 0.00000
    -1.124591600000e+04 0.000000000000e+00 0.000000000000e+00 0.00000
     0.000000000000e+00 0.000000000000e+00 0.000000000000e+00 5.90000
S20 2013 03 30 00 24 46 0.000000000000e+00 0.000000000000e+00 5.19871
     4.063672000000e+04 0.000000000000e+00 0.000000000000e+00 0.00000
    -1.124591600000e+04 0.000000000000e+00 0.000000000000e+00 0.00000
     0.000000000000e+00 0.000000000000e+00 0.000000000000e+00 6.00000
```

Health: 0=OK (!?)

Satellite 20 set to OK but :
- clock polynomial has zero coefficients
- orbit information seems incomplete (XY constant, Z=0, zero velocity and acceleration)
- update rate (2-3 min) compatible with broadcast model
- Other Sxx do have complete ephemeris message, but no tracking data are available from EPN stations

http://ec.europa.eu/enterprise/policies/satnav/files/egnos/egnos_os_sdd_v2.0_en.pdf

5. EGNOS Receivers

EGNOS

Since the SBAS standards have been initially derived to meet the stringent navigation performance requirements applicable to civil aviation approach operations, the reference SBAS receiver standards have been also developed by the civil aviation community. These standards are called SBAS Minimum Operational Performance Standards (MOPS) and are published by the Radio Technical Commission for Aeronautics (RTCA) under the reference DO-229 [RD-2]. This receiver standard has been designed by and for the aviation community and therefore supports both horizontal and vertical navigation and implements a large number of features aimed at ensuring the integrity of the derived position.

A number of these specific message processing techniques are not required for non–Safety of Life applications and may even result in degraded performance over what could be reached if implementing a tailored processing of EGNOS signals for OS. However, at this stage, no unique standard exists describing the use of EGNOS messages for OS users and therefore, different types of implementation have been selected by receiver manufacturers.

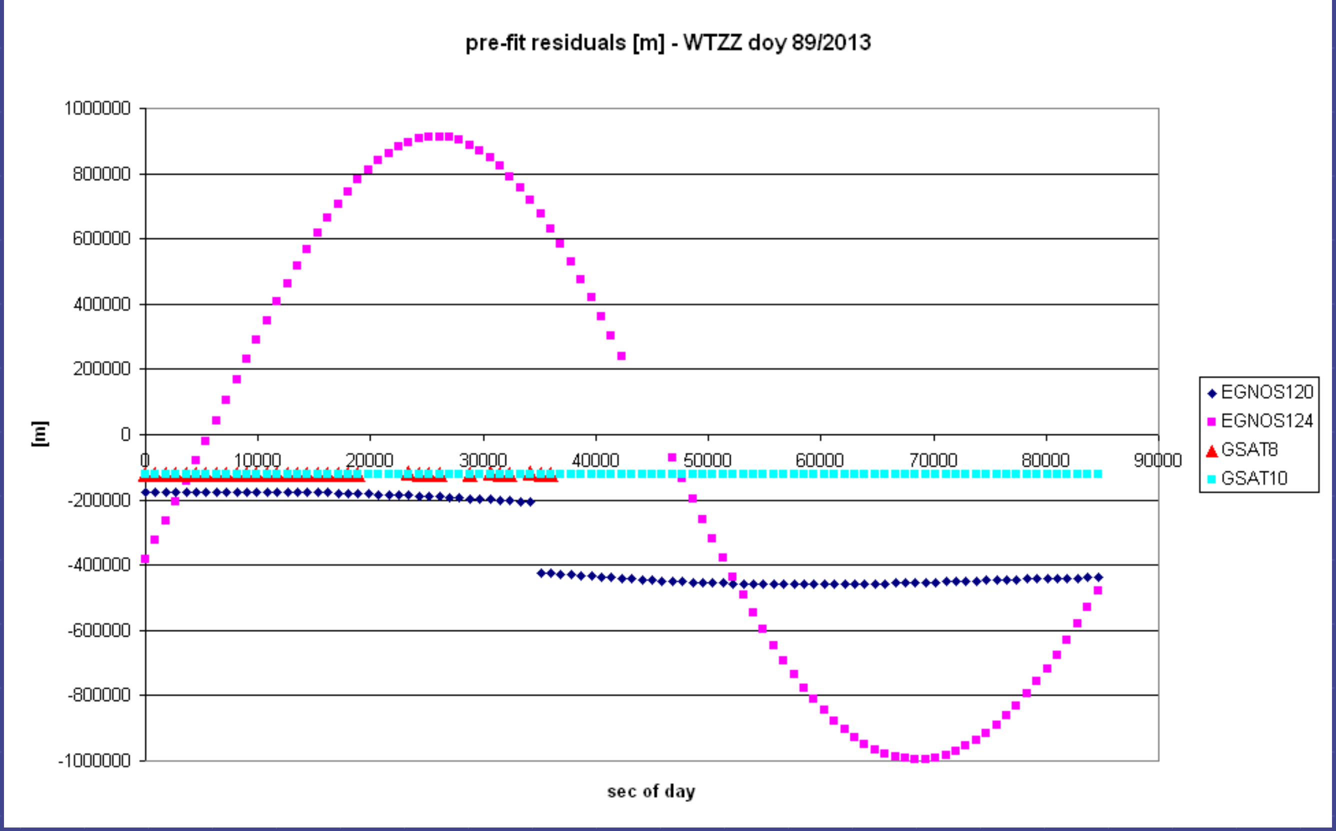
Typically, SBAS receiver designed to support the OS is expected to:

- Use the Geostationary satellite ranging function if available (broadcast through message types 9 and 17). This function is not currently supported by EGNOS.
- Decode and apply satellite clock corrections (broadcast through message types 2–5 and corresponding to satellites selected by message type 1).
- Decode and apply satellite ephemeris corrections (broadcast though message types 24–25).
- Decode and apply ionospheric corrections (broadcast through message type 26 for ionospheric grid points selected by message type 18)
- Take into account major warnings sent through the SBAS messages (broadcast through message types 2–5 and 6).

SBAS: EGNOS + GAGAN

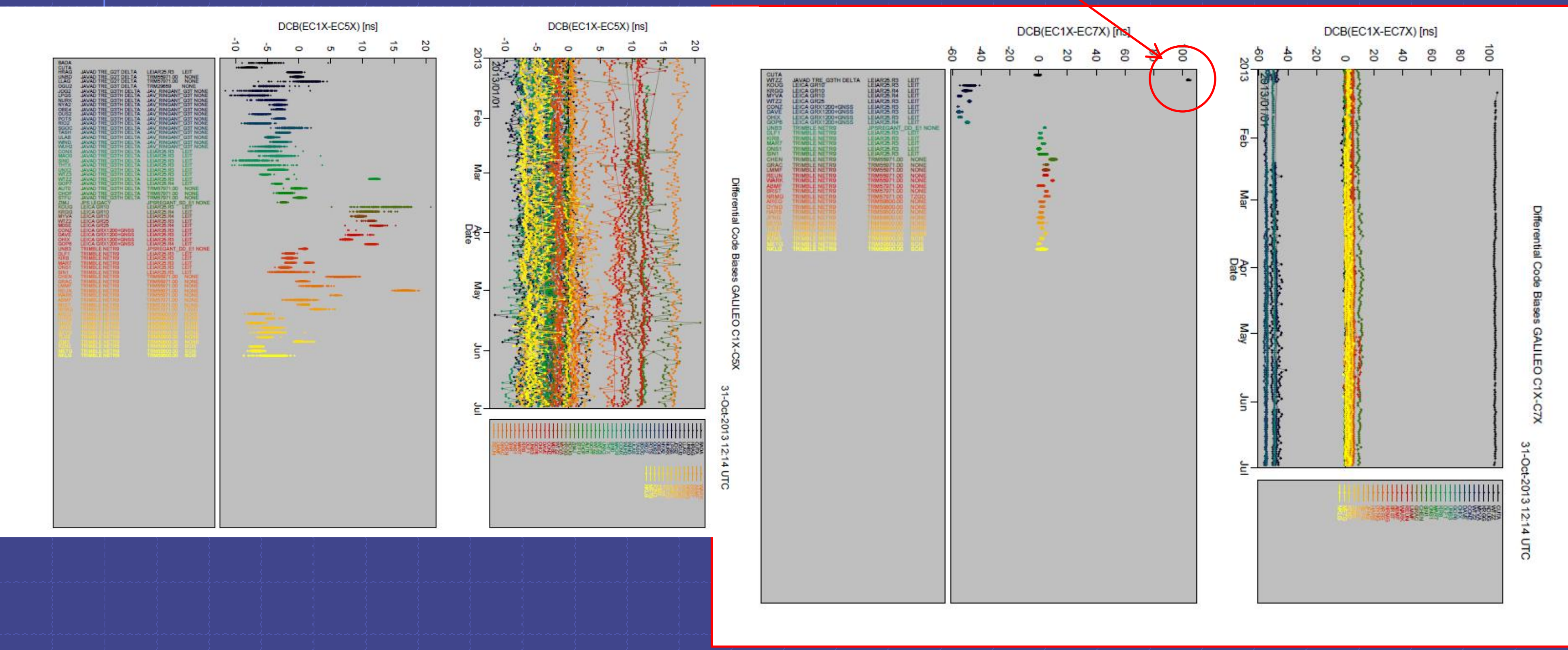
No clock data for EGNOS 20 and 24

GAGAN could be usable



Work at TUM/DLR (O.Montenbruck) Galileo only, worldwide, no Septentrio

Receiver dependent DCB; WTZZ problem



Measurement model

$$p(t) = cdt(t') +$$

Sync SV's of the same GNSS among each other

$$\sqrt{\left[X(t') + \omega_e Y(t - t') - x\right]^2 + \left[Y(t') - \omega_e X(t - t') - y\right]^2 + \left[Z(t') - z\right]^2} +$$

Geometric term

$$c\left[b_0 + b_1(t' - T_0)\right] + cdT +$$

Sync GNSS to GPS time + RCVR clock

$$\frac{TZD}{\sin(El)}$$

TZD model

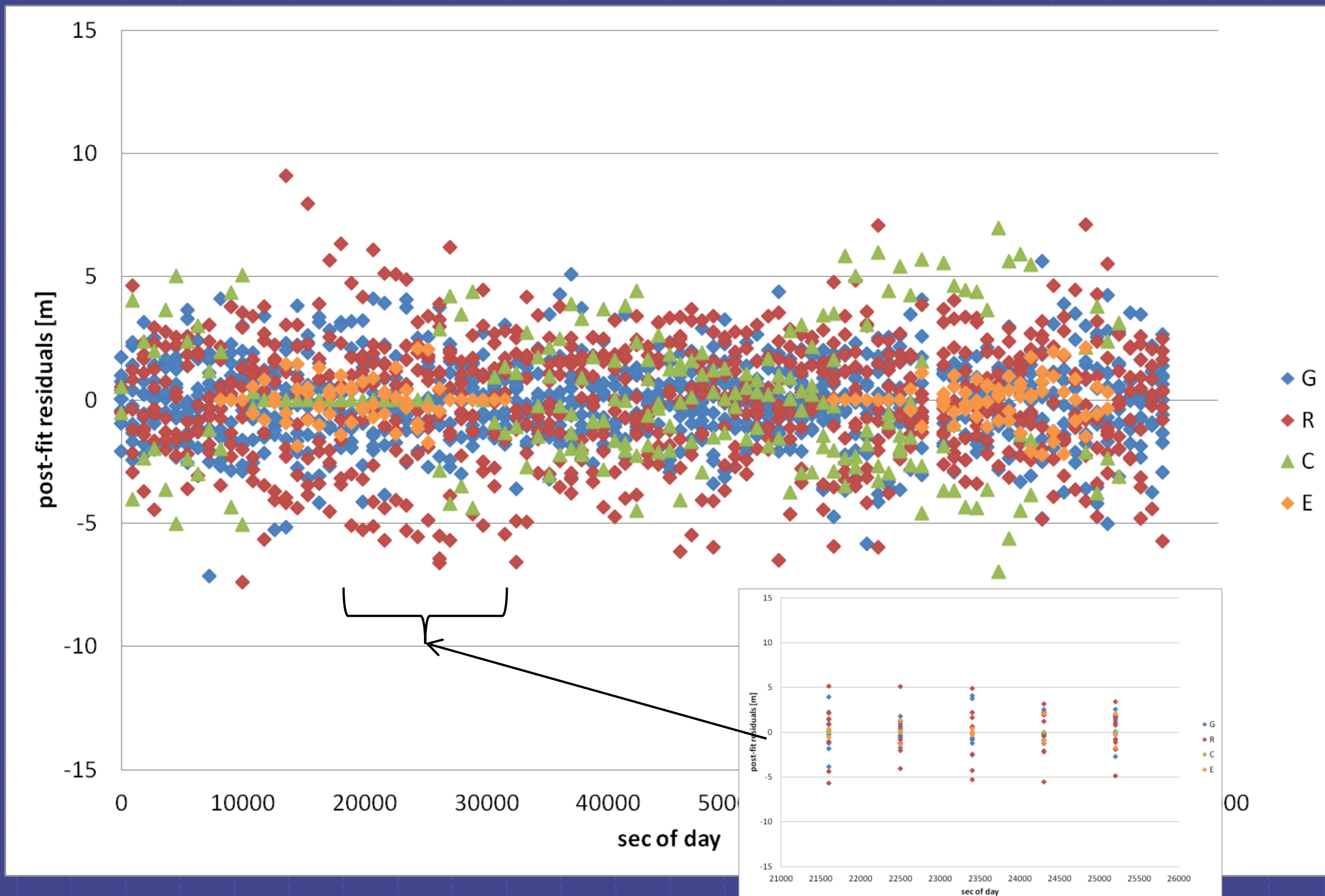
with

$$t' \approx t + \Delta t - \frac{\sqrt{(X - x)^2 + (Y - y)^2 + (Z - z)^2}}{c} \qquad \Delta t = \begin{cases} \text{14 sec for BeiDou} \\ \text{leap seconds (16 to date) for GLONASS} \end{cases}$$

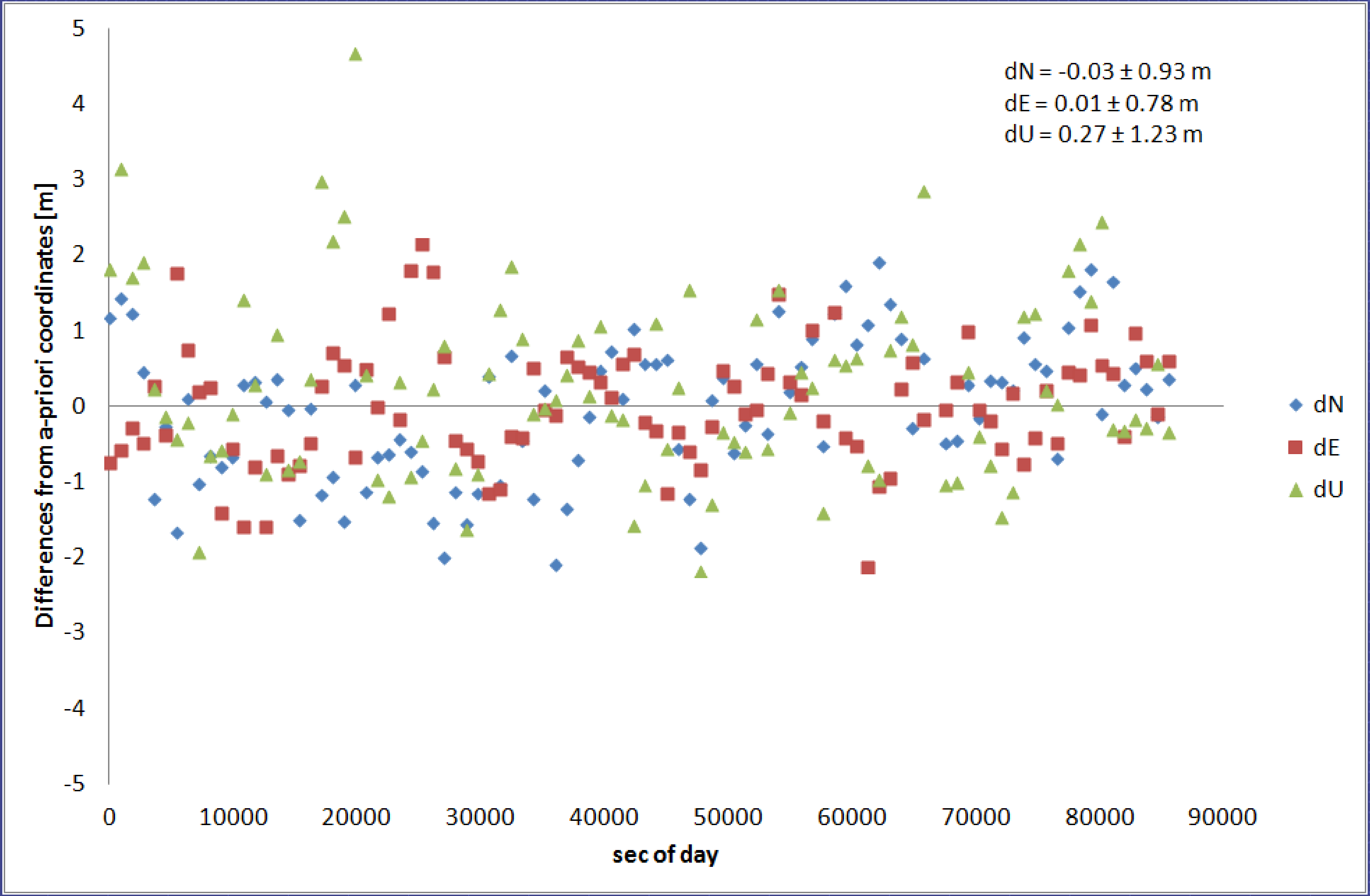
$$dt(t) = a_0 + a_1(t - T_{oc}) + a_2(t - T_{oc})^2 - \frac{2\sqrt{\mu a}}{c^2} e \sin E(t)$$

MultiGNSS postfit residuals

(KIRU doy 253 sPP with broadcast ephemeris @ 15 min)

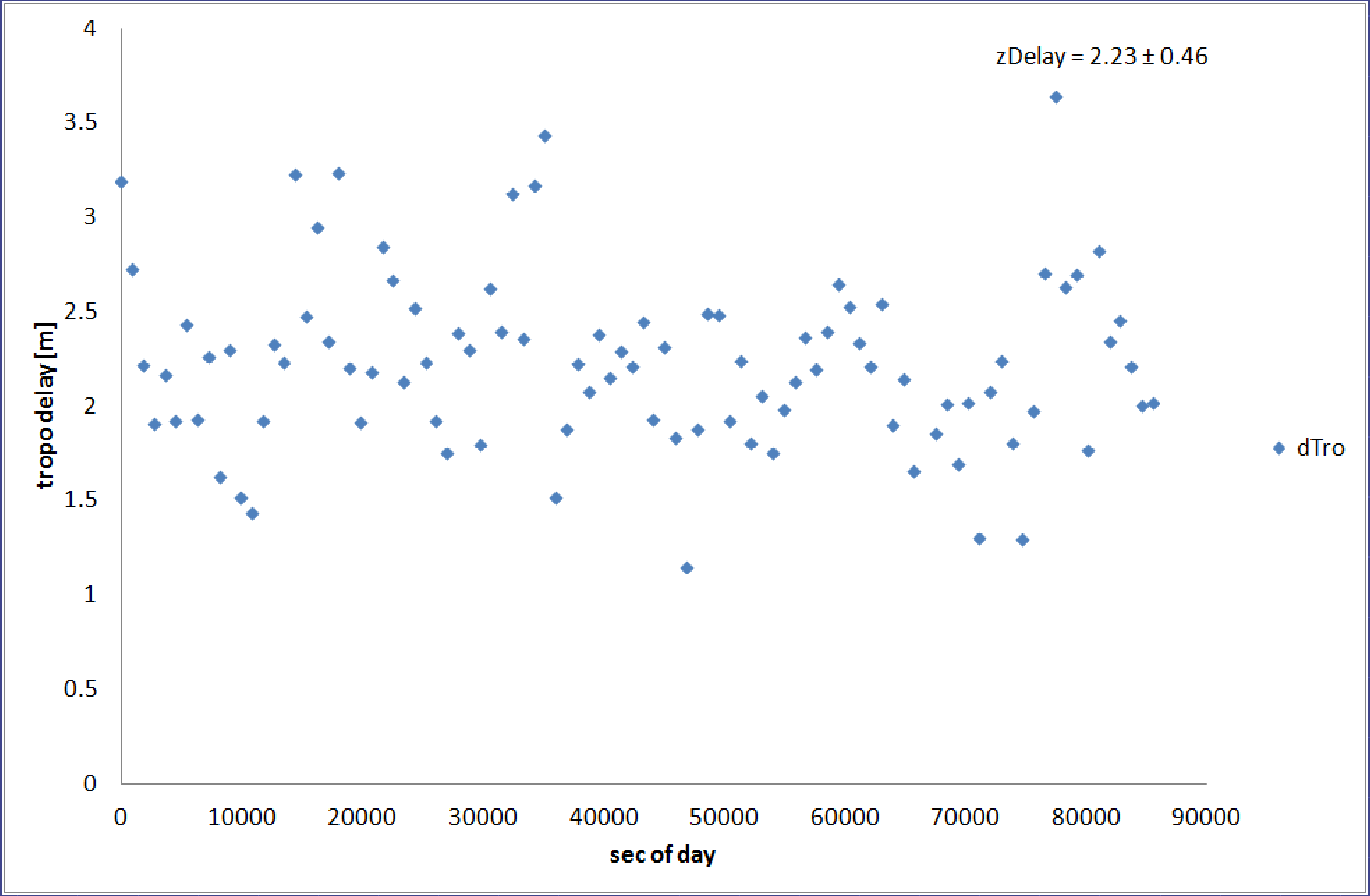


MultiGNSS time series of coords of KIRU (doy 253) relative to EPN values as a priori

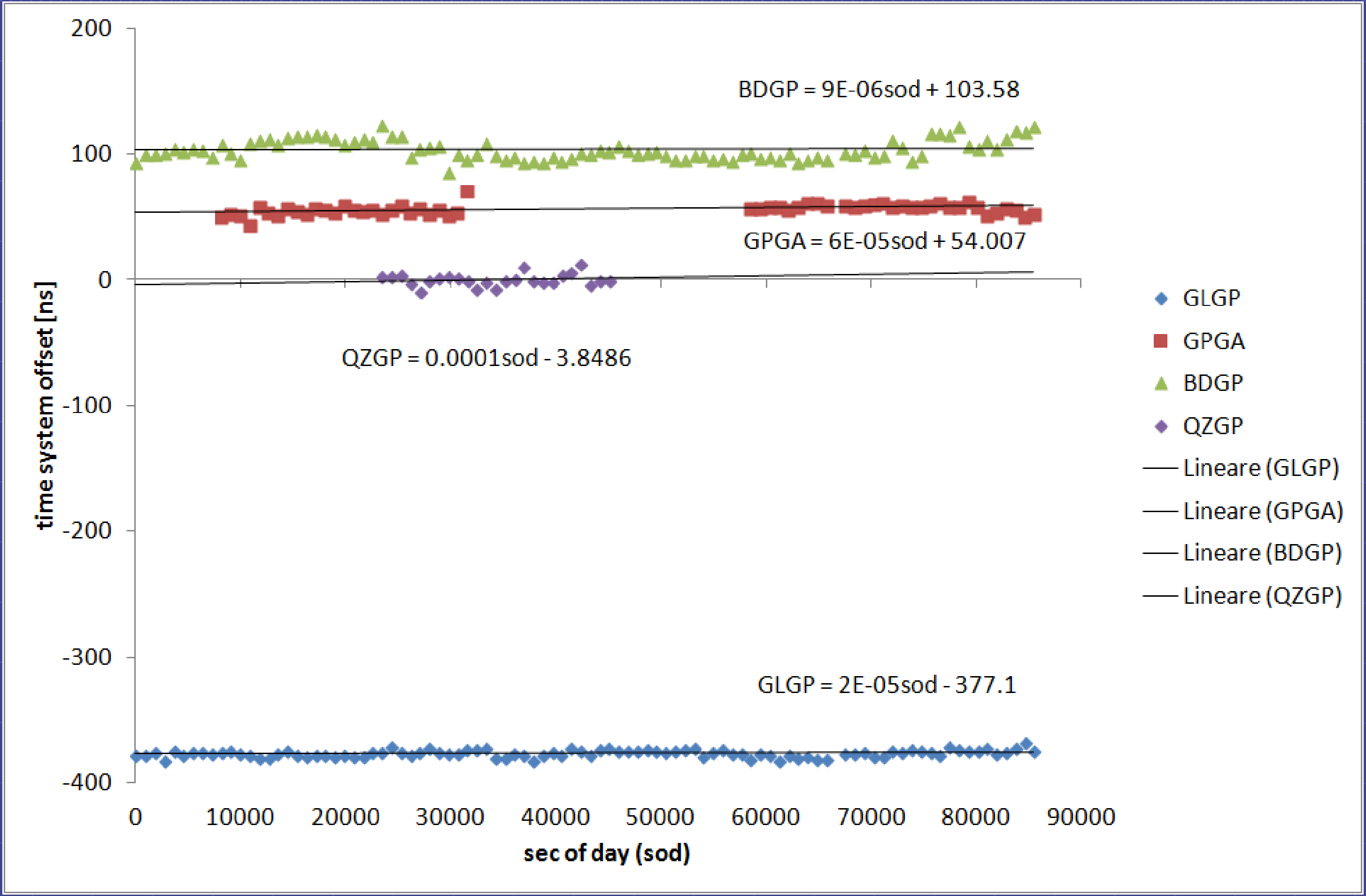


sPP with ionofree code data, broadcast ephemeris

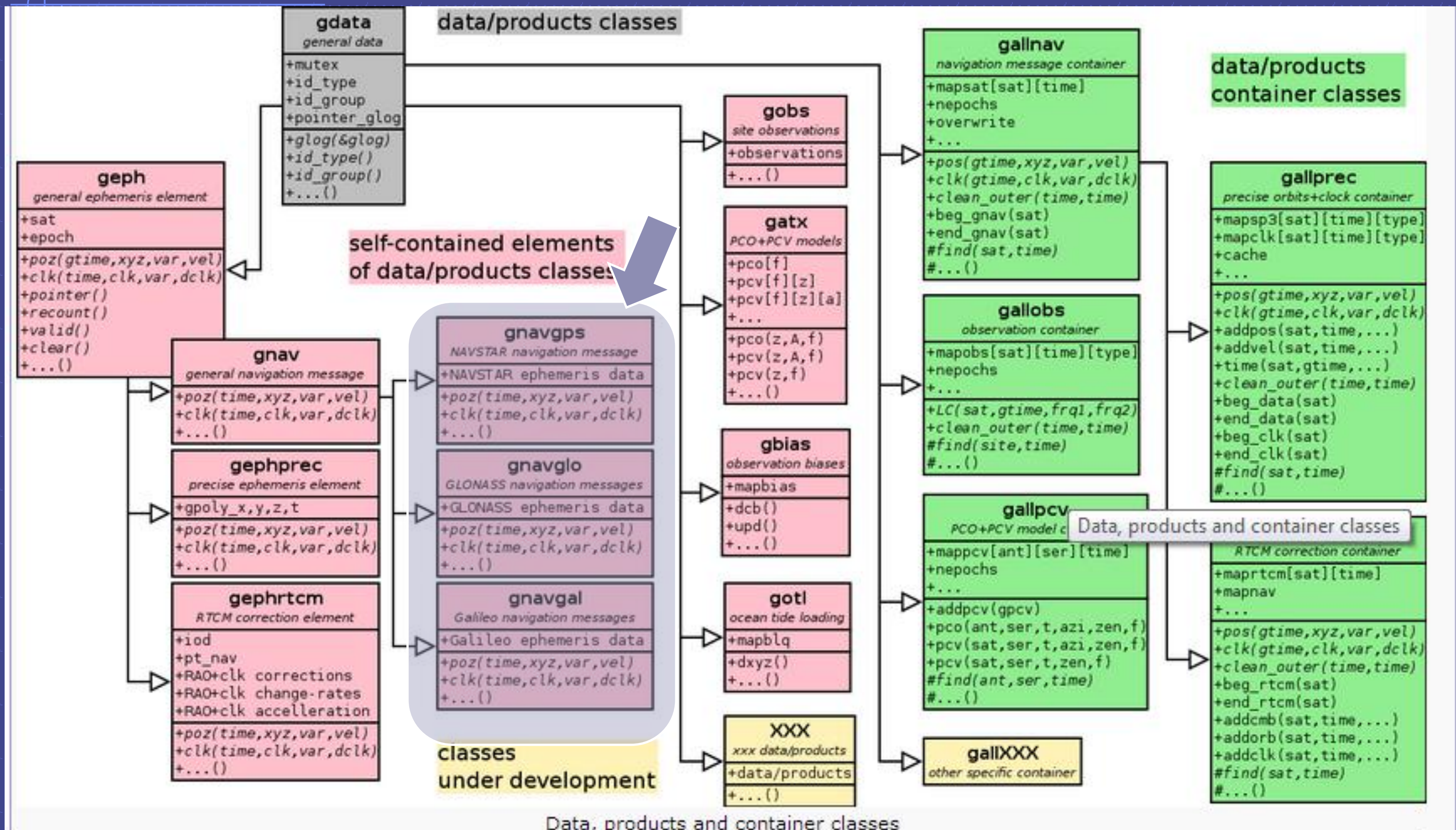
KIRU doy 253 – TZD epochwise



TIME SYSTEM CORR KIRU → Septentrio



Anubis block model



Summary

- Tested 4 days across 2013; 9 EPN MGEX sites; 4 types of receivers; 7 GNSS's
- Broadcast vs. SP3 orbit and clocks:
  - GALILEO: discrepancy of several 10's to 100's of ns between the broadcast and SP3 satellite clock; disagreement between the F-NAV and I-NAV broadcast clock model of several 10's of ns
  - Others: agreement to better than 10 ns
  - All: broadcast orbit within 10 m from SP3 orbit
- Intersystem Time Bias
  - Receiver dependent systematic error
  - GNSS dependent systematic error (misalignment of GNSS time scales)
  - Need: receiver intercalibration (manufacturer), compute and broadcast polynomial to syncrhronize GNSS's to GPS

- Other GNSS's:
  - **SBAS (EGNOS, GAGAN): no SP3, broadcast orbit and clocks very suspicious and probably too inaccurate to be useful**
- **Propose:**
  - **Pilot project: Monitoring activity of EPN- MGEX stations (TEQC like): need orbits (broadcast is enough) for Az-el computation, expected # of obs above an elev mask, detection of large cycle slips/clock jumps, Receiver dependent DCB's, sPP.**
  - **Support all the GNSS tracked by EPN MGEX sites (GRECJS)**
  - **Integrate into Anubis GNSS orbit computation from broadcast ephemeris message**
- **Routines are available for all GNSS's, interface to RINEX 3.01**