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HAS Preliminary Assessement

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Outline

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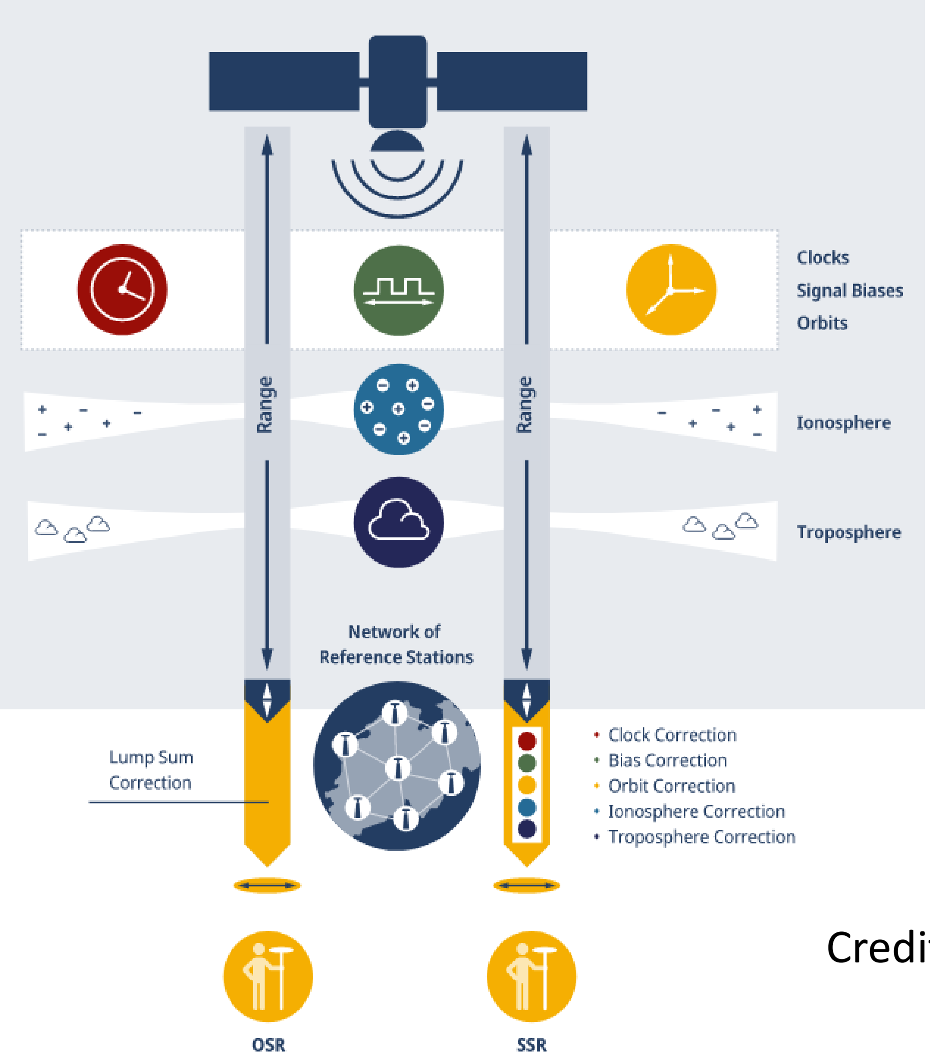
SSR vs OSR

- OSR = Observation Space Representation (e.g. RTK): all GNSS errors are lumped into a range correction

- SSR = Space State Representation: the GNSS errors are broadcast in separate messages:
  - Satellite Clocks
  - Satellite Orbits
  - Satellite Signal Biases
  - Ionospheric Delay/Advance
  - Tropospheric Delay



Credit: Geo++

SSR Overview (after M. Schmitz, 2023)

- RTCM3 MSM (“classical RTCM”) : 1019, 1020, 1042, 1045/6 for GPS, Glonass, Beidou, and 1021 for the Helmert parameters
- RTCM3 SSR standardized (limited to GPS, GLO, code biases)
- RTCM3 SSR proposed (adds other GNSS, phase biases, VTEC)
- IGS SSR (refactoring of standardized and proposed RTCM3 SSR)
- Galileo HAS (E6B HAS data: GPS + Galileo orbit, clock, code & phase biases, URA)
- NovAtel GALHAS messages (decoding Galileo HAS, orbit, clock, code & phase biases, URA)
- Geo++ SSRZ (full set of GNSS corrections)
- Geoflex “1272” message (local atmospheric corrections)

HAS General

- Galileo provides a High Accuracy Service (HAS) based on the transmission of PPP (Precise Point Positioning) corrections in a SSR sense.
- The Galileo High Accuracy Service is transmitted through the Signal-In-Space in the C/NAV pages of the E6-B signal component of the E6 signal, at a carrier frequency of 1278.75 MHz
- MT1 (Message Type 1) body: it provides data for
  - Orbit: along track, cross track and radial corrections in meters
  - Clock: bias in meters
  - Phase bias: fractional part of the phase ambiguity at the message reference time, including indicator for cycle slips
  - Code bias: to be used when signal combination other than E1C-E5bQ for I/NAV (Galileo) and L1 C/A-L2P for LNAV (GPS) is used
  - URA: it tells if a satellite can/cannot be used

Method of assessement: rationale

Station independent

System performance assessement

1. The Navigation messages of Galileo

- Review of the messages: latency, content

2. The HAS corrections to the nav message

- Review of the –orb, -clk files of HAS: how do they improve on the standard NAV message
  - Plot of the HAS corrections onto the differences $(XYZ)_{SP3.CNES}$ - $(XYZ)_{broadcast}$ (TRW frame) for I-NAV
  - For clock corrections: plot the differences $(T)_{SP3.CNES}$ - $(T)_{broadcast.I\text{-}NAV}$ and the HAS corrections;
    - *SP3 IGS clocks refer to F-NAV, by 'silent' convention (O. Montenbruck, private comm. of Apr. 28, 2021)*
- Preliminary conclusion: assessement of the accuracy of the BRDM+HAS orbit and clocks relative to a precise product (SP3.CNES)

Station dependent

Service performance assessement

3. The HAS corrections to the ionofree pseudoranges and phases

- Start from a RINEX 3.0x obs file
- For I-NAV data, no code bias necessary, only phase biases need to be added to the carrier phases (G+E)
- Process multiGNSS data for one station in PPP mode using CNES SP3-- > reference
- Process multiGNSS data for one station in PPP mode using I-NAV (HAS_orb=Yes, HAS_clk=Yes, HAS_phasebias =Yes) -- > test

The starting orbit and clock model

3 reference frames: ECEF, RTN and Body Fixed; 2 origins: CoM and ionofree APC

- For Broadcast Ephemeris: Antenna Phase Center of the iono-free combination.
- For SP3 orbits: satellite Center of Mass to APC vector is given in the IGS .atx file. Largest in the x (Sun Pointing) and z (Earth pointing) directions, depending on satellite block
- Convert offset vector from Body Fixed frame to TRW frame using the attitude model (Yaw Steering mode: Solar Panels always orthogonal to the line of sight to Sun)

Clock :

- offset to System Time (GST or GPSTime) is modeled by a 2. order polynomial
- The polynomial coefficients are different for F_NAV and I_NAV

Orbit:

- Keplerian ellipse + secular perturbations in Inclination and Node + sinusoidal perturbations (6 hr period) altk (mean anomaly), xtrck (inclination) and radial. Same model for GPS and Galileo
- Same numerical values for F_NAV and I_NAV orbital parameters

Message:

- Update: 10 minutes typical, gaps of 1 – 2 hrs exist; for GPS the Nav message is updated every 2 hours, typically.
- IODE in the broadcast message is used for match with the gnssIOD in the HAS orb and clck file

Reference Frame:

- normally the GTRF is aligned to IGb14 to within few cm or mas, with some exceptions (e.g. E19: Tz)

Montenbruck et al., 2015)

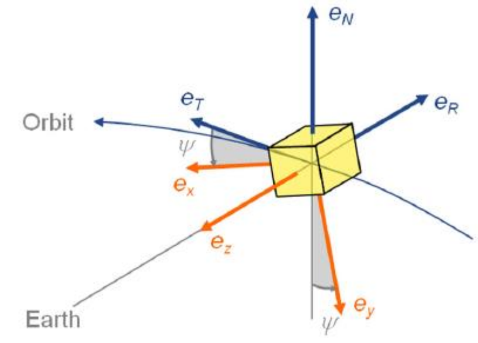


Fig. 1. Definition of the yaw-angle ψ for an Earth pointing spacecraft.

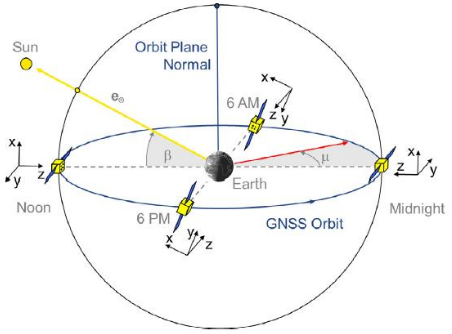
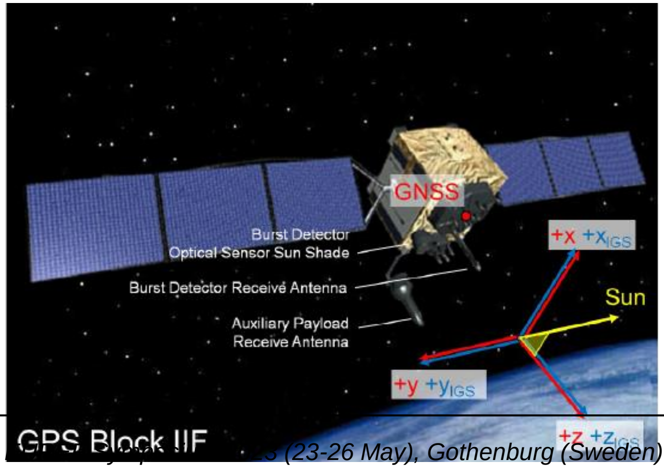


Fig. 2. GNSS satellite orientation in nominal yaw-steering mode. The x-, y- and z-vectors indicate the axes of the body-fixed reference frame $\mathcal{R}_{BF,IGS}$ (following the IGS axis convention), which is here aligned with the $\mathcal{R}_{YS}$ frame.



Part 1 of 3: Review of HAS data

Examples of HAS data using JRC and Novatel decoders

- ASCII log GAL_202203220300 from a Novatel receiver

#GALHASORBITSA,ICOM1,0,50.0,SATTIME,2202,184450.000,02100000,fd4a,16650;1,15,300,GALILEO,22,1,49,-0.242500007,0.119999997,-0.200000003,2,49,-0.067500003,0.175999999,0.263999999,3,49,-0.187500000,0.024000000,-0.039999999,4,

Epoch is different by 2 sec

184452.0,2202,850,15,49,300,2,1, -0.2425, 0.12, -0.2

- ASCII file SEPT0810.22_has_orb generated by the JRC decoder from a Septentrio receiver

#GALHASCLOCKSA,ICOM1,0,49.0,SATTIME,2202,184447.000,02108000,d050,16650;1,15,60,GALILEO,22,1,-0.115000002,2,0.227500007,3... etc

184448.0,2202,847,15,49,60,2,1,1.0,-0.115,0
184448.0,2202,847,15,49,60,2,2,1.0,0.2275,0

Epoch is different by 1 sec

- ASCII file SEPT0810.22_has_clck generated by the JRC decoder from a Septentrio receiver

Part 2 of 3: review of HAS data/orb

0= GPS
2= Galileo

Seconds from previous epoch

ToW	WN	ToH	IOD	gnssIOD	validity	gnssID	PRN	delta_radial	delta_in_track	delta_cross_track		sec_of_day	
129202.00	2202	3200	3	85	300	2	4	-0.11	0.016	0.256		42802	
129204.00	2202	3200	3	85	300	2	4	-0.11	0.016	0.256		42804	2
129206.00	2202	3200	3	85	300	2	4	-0.11	0.016	0.256		42806	2
129211.00	2202	3200	3	85	300	2	4	-0.11	0.016	0.256		42811	5
129252.00	2202	3250	3	85	300	2	4	-0.11	0.008	0.256		42852	41
129254.00	2202	3250	3	85	300	2	4	-0.11	0.008	0.256		42854	2
129256.00	2202	3250	3	85	300	2	4	-0.11	0.008	0.256		42856	2
129261.00	2202	3250	3	85	300	2	4	-0.11	0.008	0.256		42861	5
129302.00	2202	3300	4	86	300	2	4	-0.1025	-0.016	0.192		42902	41
129304.00	2202	3300	4	86	300	2	4	-0.1025	-0.016	0.192		42904	2
129306.00	2202	3300	4	86	300	2	4	-0.1025	-0.016	0.192		42906	2
129311.00	2202	3300	4	86	300	2	4	-0.1025	-0.016	0.192		42911	5
129352.00	2202	3350	4	86	300	2	4	-0.1025	-0.024	0.192		42952	41
129354.00	2202	3350	4	86	300	2	4	-0.1025	-0.024	0.192		42954	2
129356.00	2202	3350	4	86	300	2	4	-0.1025	-0.024	0.192		42956	2
129361.00	2202	3350	4	86	300	2	4	-0.1025	-0.024	0.192		42961	5
129402.00	2202	3400	4	86	300	2	4	-0.1025	-0.024	0.192		43002	41
129404.00	2202	3400	4	86	300	2	4	-0.1025	-0.024	0.192		43004	2
129406.00	2202	3400	4	86	300	2	4	-0.1025	-0.024	0.192		43006	2

- No indication on the accuracy of the HAS data
- No indication as to the algorithm to compute these corrections

Novatel: clock corrections @10 sec; orbit corrections @ 50 sec

Septentrio

HAS corrections are provided at intervals of 2,2,5 and 41 seconds
This is true also for clocks and code biases (which are very nearly constant)
Occasionally other intervals occur

The rate of update is irregular, typically one or more minutes
Relative to SSR, HAS does not foresee the use of linear interpolation of the orbit corrections

Part 3 of 3: review of HAS data/phase bias

ToW	WN	ToH	IOD	gnssIOD	validity	gnssID	PRN	signal	phasebias	av_flag	phase_discontinuity_ind
345604	2223	0	15	62	120	2	1	1	-0.45	1	3
345604	2223	0	15	62	120	2	1	4	-0.42	1	1
345604	2223	0	15	62	120	2	1	7	0.83	1	0
345604	2223	0	15	62	120	2	1	13	-0.88	1	3
345611	2223	0	15	62	120	2	1	1	-0.45	1	3
345611	2223	0	15	62	120	2	1	4	-0.42	1	1
345611	2223	0	15	62	120	2	1	7	0.83	1	0
345611	2223	0	15	62	120	2	1	13	-0.88	1	3
345615	2223	0	15	62	120	2	1	1	-0.45	1	3
345615	2223	0	15	62	120	2	1	4	-0.42	1	1
345615	2223	0	15	62	120	2	1	7	0.83	1	0
345615	2223	0	15	62	120	2	1	13	-0.88	1	3
345622	2223	0	15	62	120	2	1	1	-0.45	1	3
345622	2223	0	15	62	120	2	1	4	-0.42	1	1

………

Signal Index	Galileo	GPS
0	E1-B I/NAV OS	L1 C/A
1	E1-C	Reserved
2	E1-B + E1-C	Reserved
3	E5a-I F/NAV OS	L1C(D)
4	E5a-Q	L1C(P)
5	E5a-I+E5a-Q	L1C(D+P)
6	E5b-I I/NAV OS	L2 CM
7	E5b-Q	L2 CL
8	E5b-I+E5b-Q	L2 CM+CL
9	E5-I	L2 P
10	E5-Q	Reserved
11	E5-I + E5-Q	L5 I
12	E6-B C/NAV HAS	L5 Q
13	E6-C	L5 I + L5 Q
14	E6-B + E6-C	Reserved
15	Reserved	Reserved

Table 20. Signal Index Table

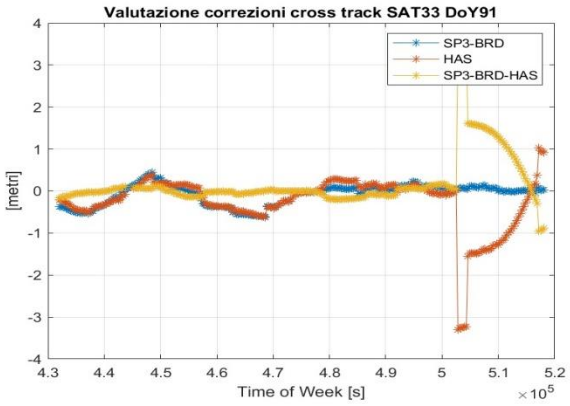
Galileo HAS SIS ICD, Issue 1.0, May 2022

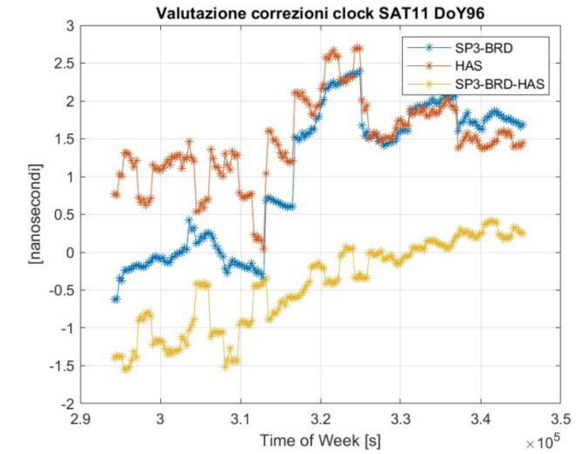
Likewise for GPS

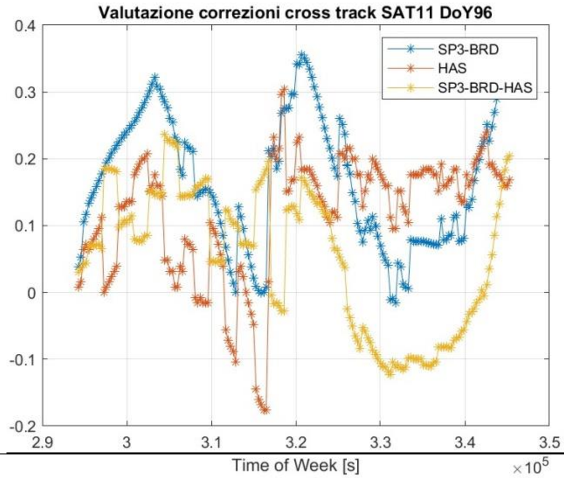
Note: the phase discontinuity does not account for user specific cycle slips

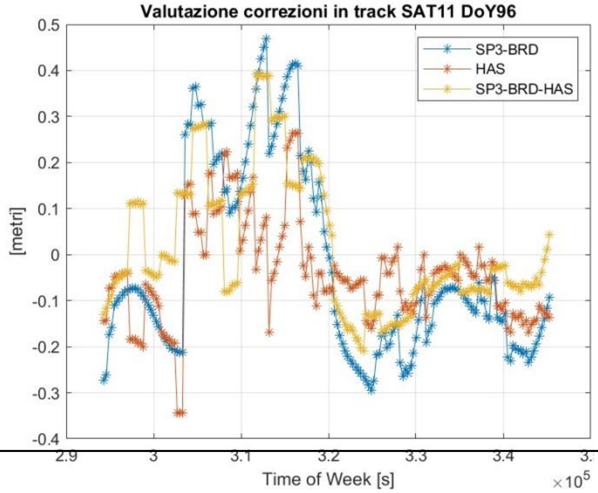
Review of HAS data: Notable (bad) facts in the March/April (doys 80:119) 2022 HAS data

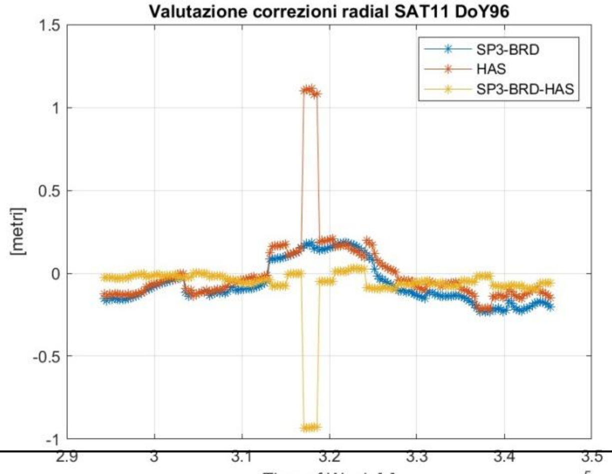
- DOYs 80, 81, 82, 84, 89, 96: HAS data available for only parts of the day
- HAS data at the start of the day may have a GNSSiod pointing to at a iodNAV in the rinex file of the previous day, and in some cases this iodNAV is not available.
- DOYs 91 92 93 and 96: jumps, NaNs and bad clock
- DOY 86 for E13, DOY 116 for E08 and DoY 81 for E26: no match of GNSSiod in RINEX eph file.
- DOY 96: radial HAS anomalies for all SVs (below example for SV11; BRDC data seem also bad)



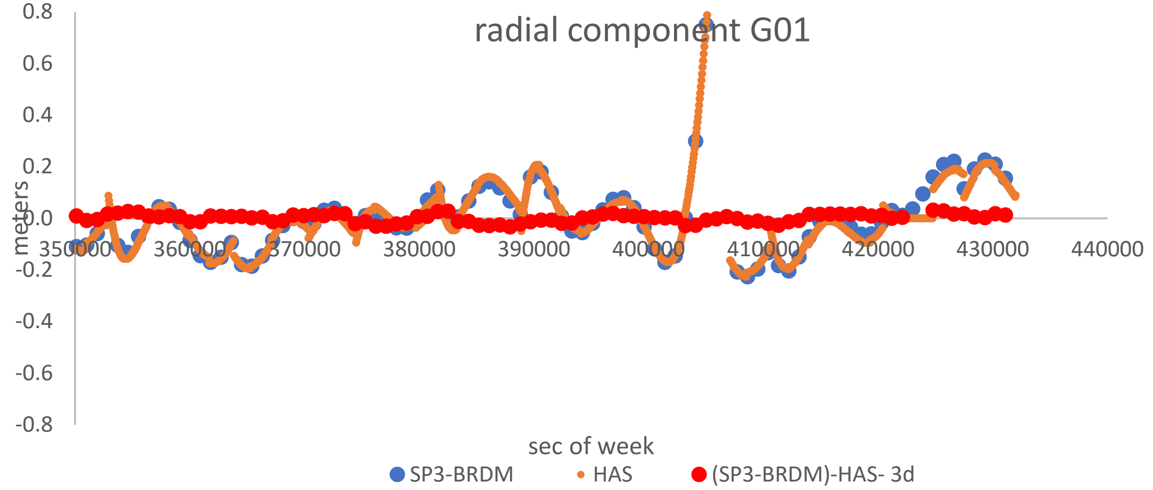


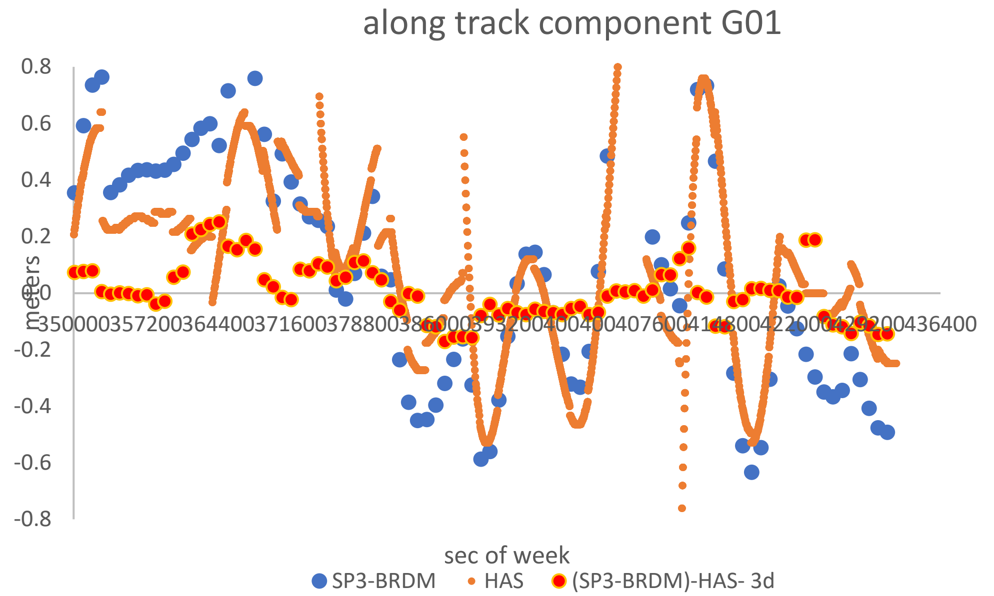


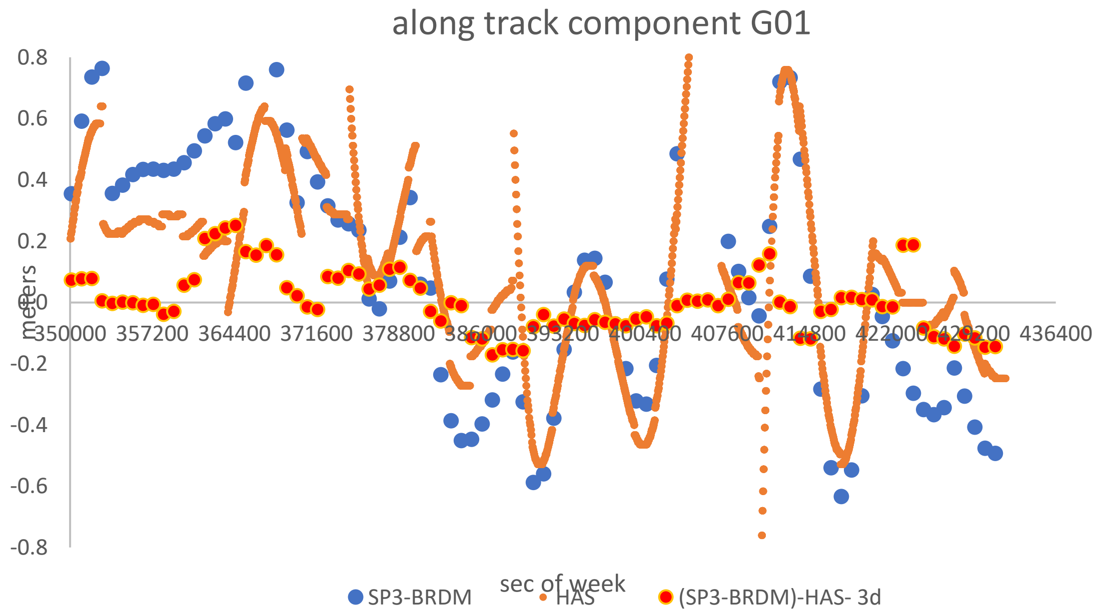


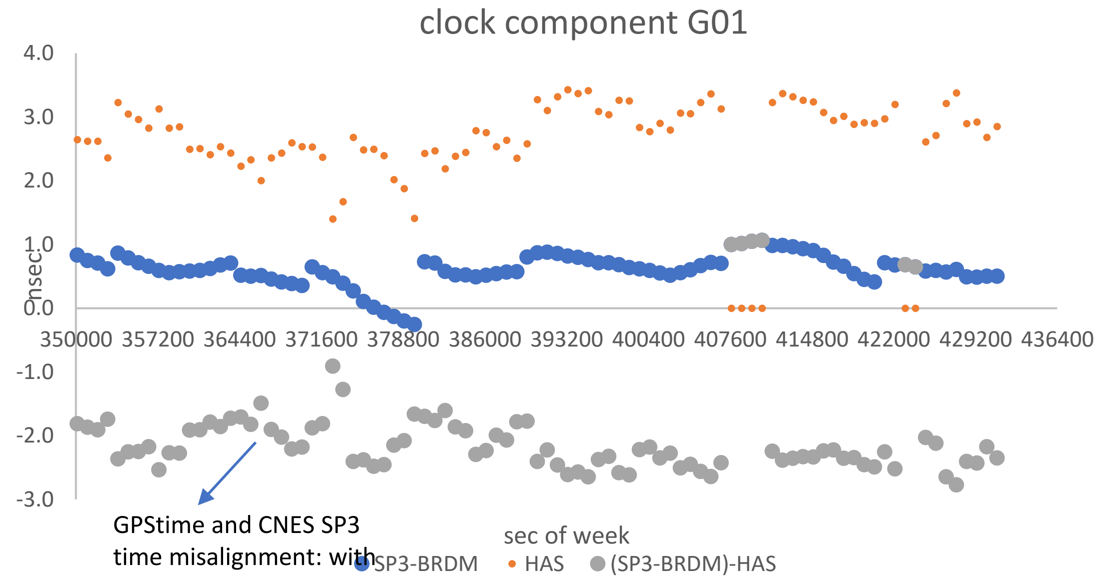


… and now the good news!



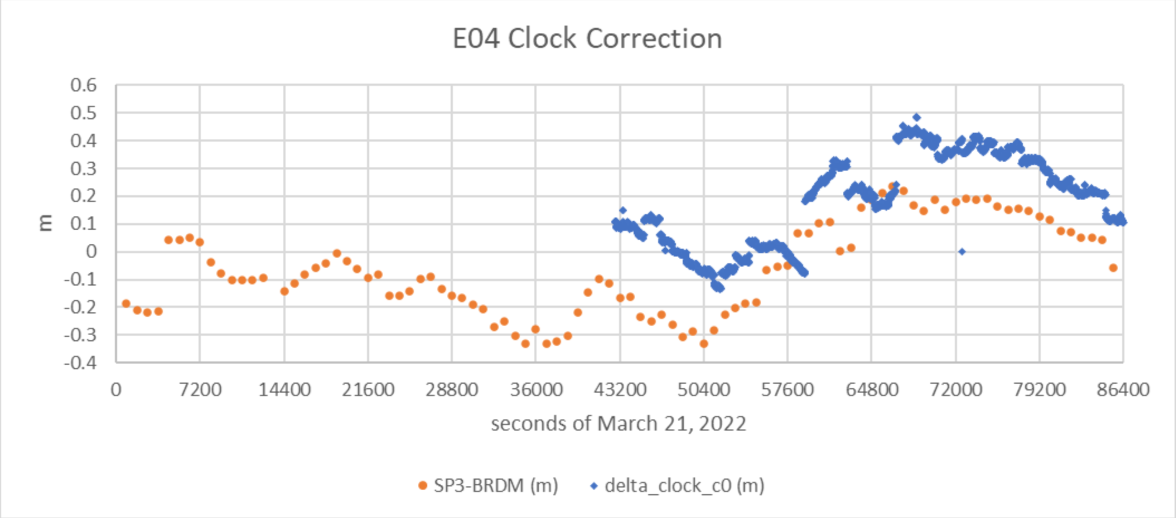


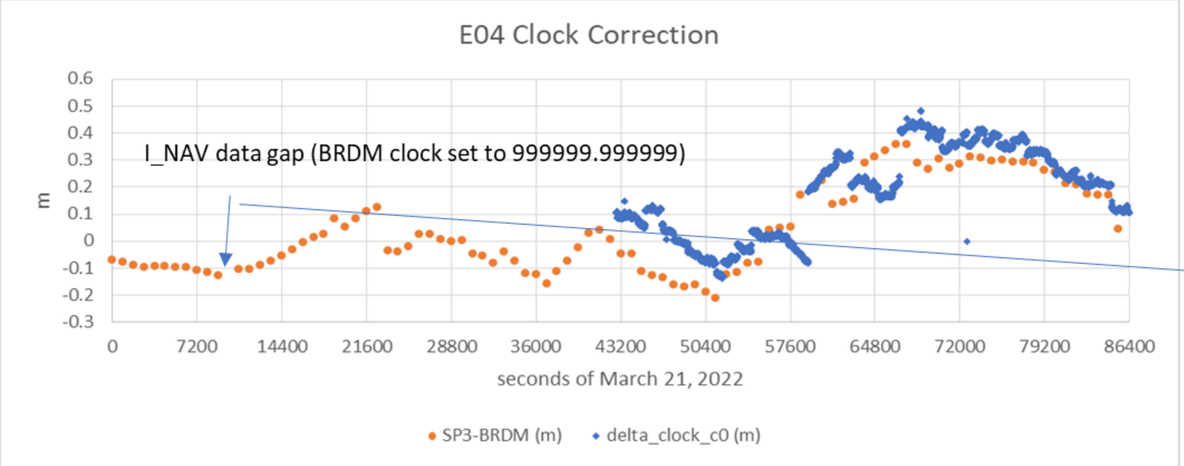




… and now the good news!

Clock (I/NAV eph. validity time 7200)

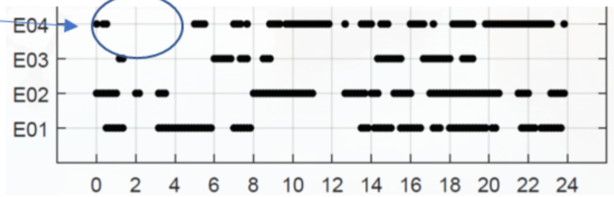




- HAS corrections are provided every 10 sec
- The corrections tend to remain constant for ca. 1 minute
- SP3 IGS clocks refer to F-NAV, by 'silent' convention (O. Montenbruck, private comm. of Apr. 28, 2021)

F_NAV clock: HAS appears biased probably because HAS is calibrated on the I_NAV ionofree linear combination

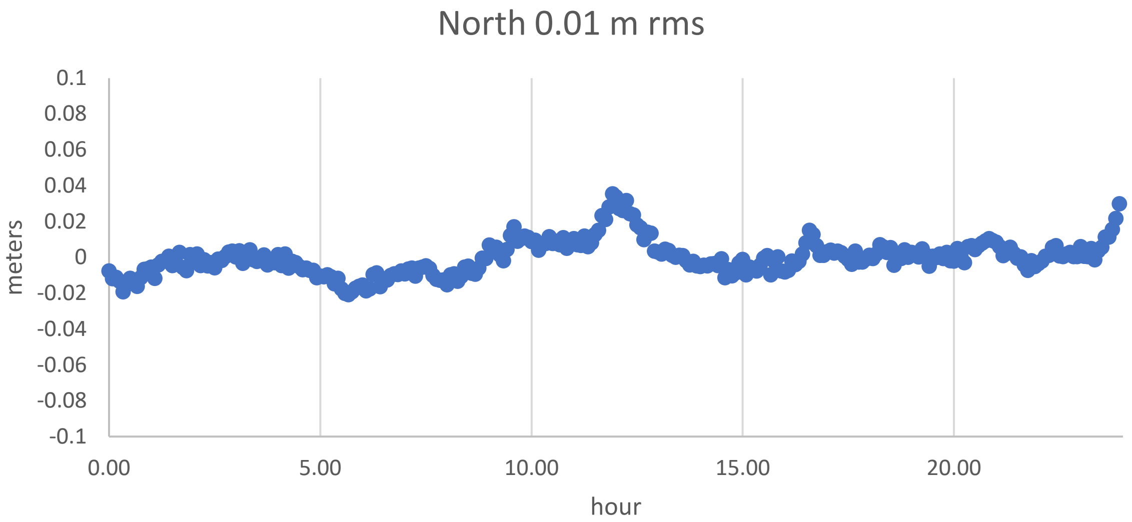
I_NAV clock: better agreement of SP3-BRDM.I_NAV with the HAS clock which is calibrated on I_NAV
I/NAV ephemeris blocks available for E04, doy 080:

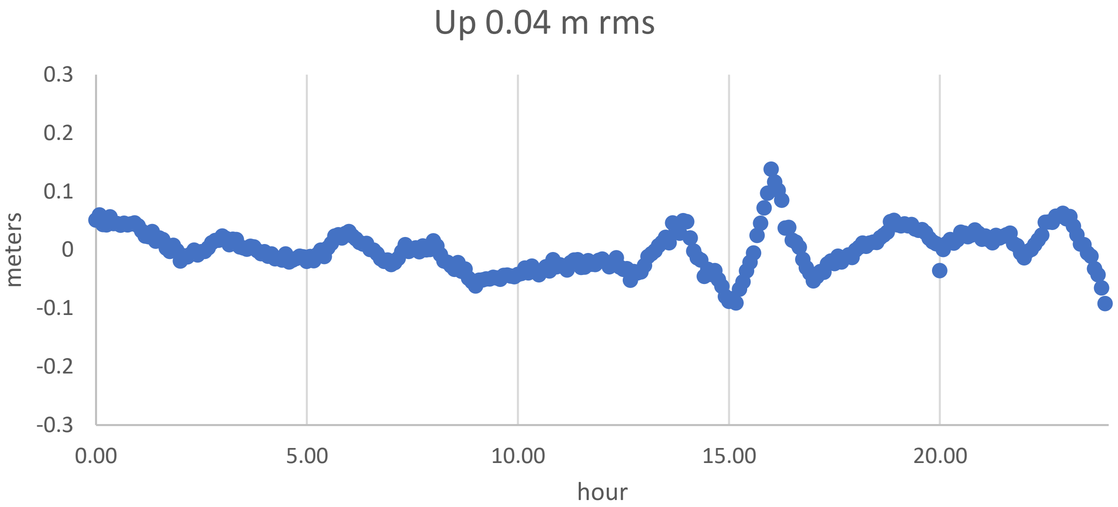


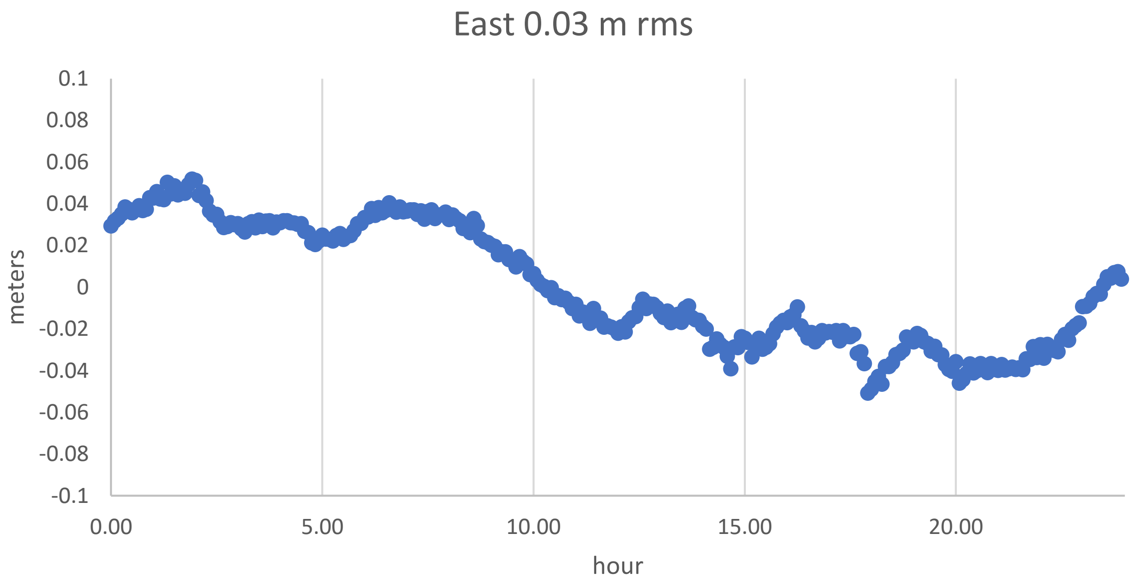
Positioning with PPP+HAS: strategy for a test

- Start from a final SP3 orbit (e.g. CNES or CODE) and replace the XYZT values with those resulting from the Broadcast+HAS procedure (Matlab)
- Start from a RINEX 3.0x obs file (e.g. PADO) and replace the GPS and Gal phase data with those corrected with HAS (no code correction because reference signal combinations are used for G and E) (Matlab)
- Process in PPP mode (kinematic) with BSW52 the data and compare the resulting coordinates with those obtained with the original orbit and rinex/obs data
- Resulting coordinates are in ITRF

Kinematic PPP using BRDM+HAS @5 min (GRE): PADO station







Summary and conclusions

- The available data form a good basis to practice and understand the HAS corrections for Galileo and GPS
- We find that BRDM+HAS and final SP3 orbits and clocks are very nearly unbiased and have a subdecimetric rms.
- Kinematic PPP with BSW5.2 shows rms < 5 cm @ 5 min using BRDM+HAS orbits and clocks for the PADO site
- PPP analysis of daily datasets shows that using CNES orbits or BRDM+HAS @5min results in subdecimetric differences relative to a network Double Difference solution (EPN)
- Used HAS files relate to orbit, clock and phase corrections. Code bias n.a. because INAV and L1 C/A-L2P were used for E and G, respectively.
- Some open questions:
  - HAS corrections are available at irregularly spaced epochs with gaps of several tens of seconds → reference orbit and clock maybe unsmoothed → noisy coordinates of end user
  - Novatel and Septentrio receivers yield HAS data with mismatched epochs: decoder issue?
  - Uncertainty of HAS corrections and algorithm to compute them is not known.
  - Code biases and phase biases are given only for the epochs of orbit corrections. Unclear what should be done for observations at intermediate epochs e.g. each second (used in precision navigation)