New ambiguity-fixed IGS clock analysis products at CODE

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Outline

- New clock products at CODE
- GPS and Galileo widelane fractional biases
- Clock generation procedure
- Phase bias representation
- Properties of the new clock and phase bias products
- Validation
- Summary and conclusions
New GNSS clock analysis products and their characteristics

- **CODE rapid, GR, 30 sec clocks, 5° min.el., 120 stations, wk 2004**
- **CODE final, GR, 5 sec clocks, 5° min.el., >300 stations, wk 2004**
- **CODE MGEX, GRECJ, 30 sec clocks, 5° min.el., 140 stations, wk 2006**
GPS and Galileo satellite widelane fractional bias results

![Graph showing GPS WL FCB: CODE final (OSB: C1W/C2W) vs. GRG/CNES (WSB)]
GPS and Galileo satellite widelane fractional bias results

GPS WL FCB reproducibility based on CODE final phase bias generation
GPS and Galileo satellite widelane fractional bias results
GPS and Galileo satellite widelane fractional bias results

Galileo WL FCB reproducibility based on CODE MGEX phase bias generation

Galileo WL FCB standard deviation (cyc)

Day of 2018

1 day lag
GPS and Galileo satellite widelane fractional bias results

![Galileo WL FCB reproducibility based on CODE MGEX phase bias generation](chart)

- 1 day lag
- 2 days
- 3 days
- 4 days
- 5 days
- 10 days
- 15 days
- 30 days

Day of 2018

Galileo WL FCB standard deviation (cyc)
GPS and Galileo satellite wide-lane fractional bias results

Galileo ground track repetition of 10 days
WL and NL phase bias determination, between-satellite ambiguity resolution (AR), and generation of ambiguity-fixed clock products

WL and NL phase bias determination and ambiguity resolution:
1. WL phase bias determination (WLB)
2. WL integer fixing (WLI)
3. NL bias determination (NLB)
4. NL integer fixing (NLI)
5. OSB values for L1 and L2 (IAR)
Narrowlane phase bias representation (specifically for GPS)

- Ionosphere-free LC of **code observations C1W/C2W**
- Ionosphere-free LC of **code observations C1C/C2W**
- Ionosphere-free LC of **phase observations L1W/L2W**
- Ionosphere-free LC of **phase observations L1W/L2W**

Ref. clock C1W/C2W

Redef. clocks

Range
Narrowlane phase bias representation (specifically for GPS)

- Ionosphere-free LC of **code observations** C1W/C2W
- Ionosphere-free LC of **code observations** C1C/C2W
- Ionosphere-free LC of **phase observations** L1W/L2W

Ref. clock C1W/C2W

CC-OSB

IRC

Redef. clocks

Range

Ref. clock L1W/L2W

C1W-C1C DCB

NL FCB

NL cyc

NL cyc

NL cyc
New GNSS clock analysis products and their characteristics

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GPS satellite clock properties (1/2): Comparison CODE final vs. CODE rapid
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1 NL cyc = 356.8 ps = 107.0 mm

1 ns = 0.300 m
GPS satellite clock properties (1/2): Comparison CODE final vs. CODE rapid

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1 NL cyc = 356.8 ps = 107.0 mm

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35.1 ps std. dev.
GPS satellite clock properties (1/2):
Comparison CODE final vs. CODE rapid

GPS satellite clock differences (day 256, 2018): CODE final vs. CODE rapid; C1W/C2W (R:1/B:0)
GPS satellite clock properties (1/2): Comparison CODE final vs. CODE rapid

GPS satellite clock differences (day 256, 2018): CODE final vs. CODE rapid; C1W/C2W (R:1/B:0)

26.3 ps std. dev.
GPS satellite clock properties (1/2): Comparison CODE final vs. CODE rapid

GPS satellite clock differences (day 256, 2018): CODE final vs. CODE rapid; L1W/L2W (R:1/B:0)
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164.6 ps std. dev.
GPS satellite clock properties (1/2): Comparison CODE final vs. CODE rapid

GPS satellite clock differences (day 256, 2018): CODE final vs. CODE rapid; L1W/L2W (R:1/B:1)
GPS satellite clock properties (1/2): Comparison CODE final vs. CODE rapid

GPS satellite clock differences (day 256, 2018): CODE final vs. CODE rapid; L1W/L2W (R:1/B:1)

209.8 ps std. dev.
GPS satellite clock properties (1/2): Comparison CODE final vs. CODE rapid

GPS satellite clock differences (day 256, 2018): CODE final vs. CODE rapid; L1W/L2W (R:1/B:2)
GPS satellite clock properties (1/2): Comparison CODE final vs. CODE rapid

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7.3 ps std. dev.
New GNSS clock analysis products and their characteristics

- **CODE rapid**, GR, 30 sec clocks, 5° min.el., 120 stations, wk 2004
- **CODE final**, GR, 5 sec clocks, 5° min.el., >300 stations, wk 2004
- **CODE MGEX**, G2ECJ, 30 sec clocks, 5° min.el., 140 stations, wk 2006

<table>
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<tr>
<th>Day i-1</th>
<th>Day i</th>
<th>Day i+1</th>
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<tbody>
<tr>
<td>Time</td>
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</table>
GPS satellite clock properties (2/2): Comparison CODE final at day boundaries

GPS satellite clock differences @ 24/00UT (day 256, 2018): CODE final; C1W/C2W (R:1/B:0)
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65.8 ps std. dev.
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176.0 ps std. dev.
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-15.3 ps std. dev.
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Clock difference (ps)

Time (hours)

8.3 ps std. dev.
Validation 1/3: Daily PPP vs. daily IPPP

Median (Q0.50) daily repeatability (mm)

Daily PPP; CODE final product; September 2018;
295 (of 337) stations

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Ambiguity-float PPP</td>
<td>1.18</td>
<td>1.86</td>
<td>4.15</td>
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Median (Q0.50) daily repeatability (mm)
Validation 2/3: K-band range (KBR) performance comparison using GRACE data (of April 2007)

Please be referred to the poster PS13-07 by Arnold et al. on:

Undifference ambiguity resolution for GPS-based precise orbit determination of low Earth orbiters using the new CODE clock and phase bias products

IGSWS2018 – PS13
International GNSS Service Workshop 2018 29 Oct-02 Nov. 2018, Wuhan, China
Validation 3/3: IGS rapid and final clock combination and comparison

Rapid Clocks (AC solutions compared to IGS Rapid)
Validation 3/3: IGS rapid and final clock combination and comparison

Rapid Clocks (AC solutions compared to IGS Rapid)

Clock Std Dev [ps]

Time [GPS weeks]
Validation 3/3: IGS rapid and final clock combination and comparison

Final Clocks (AC solutions compared to IGS Final)

Clock Std Dev [ps]

Time [GPS weeks]

(weekly means)
Validation 3/3: IGS rapid and final clock combination and comparison

Final Clocks (AC solutions compared to IGS Final)

Clock Std Dev [ps]

Time [GPS weeks]

Geoscience Australia/MIT, 6.10.2018 00:017 (GMT)
Validation 3/3: IGS rapid and final clock combination and comparison

Rapid Clocks (AC solutions compared to IGS Rapid)
Validation 3/3: IGS rapid and final clock combination and comparison

Final Clocks (AC solutions compared to IGS Final)

Time [GPS weeks]

Clock RMS [ps]

(weekly means)
Summary and conclusions (1/2)

• CODE has established the generation of a high-quality signal-specific phase bias (OSB) product and a fully consistent ambiguity-fixed clock product within its rapid and final IGS-related processing (since wk 2004/2006). Our multi-GNSS clock product contribution to MGEX (covering GRECJ) does include ambiguity fixing not only for GPS but also for Galileo.
Summary and conclusions (1/2)

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• All presented developments are part of the current development version of the Bernese GNSS Software.
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- All presented developments are part of the current development version of the Bernese GNSS Software.

- This quantum leap in GNSS clock analysis at CODE could be accomplished due to successful *between-satellite ambiguity fixing* using undifferenced observation data of IGS receiver network. The new CODE clock products reveal a notably improved quality and, in the end, allow for single-receiver ambiguity resolution, thus enabling *integer-PPP (IPPP)*.
Summary and conclusions (2/2)

- Our new clock and bias products are conditioned in a way that maximum consistency may be ensured for (i) ambiguity-float, (ii) ambiguity-fixed, and (iii) pseudorange-supported (or pseudorange-only) PPP applications.
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• In any case, the clock product (following a CC-OSB representation strategy) has to be used in conjunction with the associated phase and pseudorange bias product in order to achieve best possible performance.
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• 24UT clock values permit (NLC-)integer-corrected connection of subsequent days of CODE final clock information (48/72 hours or more).
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• 24UT clock values permit (NLC-)integer-corrected connection of subsequent days of CODE final clock information (48/72 hours or more).

• Redefined clock \( \text{Obs1/Obs2} = \text{Reference clock (C1W/C2W)} - \text{IF LC OSB correction (Obs1/Obs2)} \)
# How to use the CODE clock and phase bias analysis products ➔ Bias-SINEX V1.00

<table>
<thead>
<tr>
<th>OSB</th>
<th>G063 G01</th>
<th>C1C</th>
<th>2018:256:00000 2018:257:00000 ns</th>
<th>11.0960</th>
<th>0.0065</th>
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<tbody>
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Thank you for your attention