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PPP-AR with GPS and Galileo: Assessing diverse approaches and satellite products to reduce convergence time

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04 May 2020

Objective

- Comparison of PPP-AR[1] results calculated with satellite products from different institutions
- Focus on GPS + Galileo solution
- Conclusion shortly:

$$\mathbf{CODE} \geq \mathbf{TUG} > \begin{matrix}\mathbf{CNES} \\ \mathbf{SGG}_{\mathbf{CNES}}\end{matrix} > \mathbf{SGG}_{\mathbf{CODE}} \gg \mathbf{SGG}_{\mathbf{GFZ}}$$

- Prospects for PPP approaches different from the 2-frequency ionosphere-free linear combination

[1] Precise Point Positioning (PPP) with ambiguity resolution, also known as IPPP (integer-PPP) or PPP-RTK

Satellite products for PPP-AR

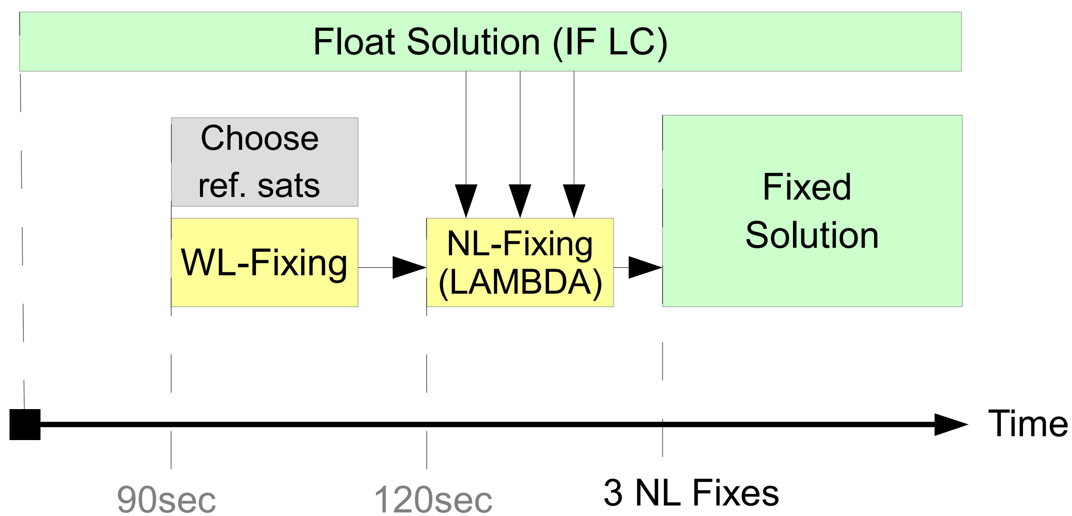
In this contribution:

Acronym	Institution	GNSS	Reference	Comment
TUG	Graz University of Technology	GE	[Strasser et al., 2018]	Raw observation approach
CODE	Center for Orbit Determination in Europe	GE	[Dach et al., 2018] [Prange et al., 2018] EGU2020-18142	CODE IGS MGEX product
CNES	Centre national d'études spatiales	GE	[Katsigianni et al., 2019] [Loyer et al., 2018]	CNES IGS MGEX product
SGG_{CODE} SGG_{CNES} SGG_{GFZ}	School of Geodesy and Geomatics, Wuhan University	GECJ	[Hu et al., 2020]	Addition to MGEX product of CODE, CNES or GFZ

- Other products: WHU[Geng et al., 2019] (GPS only), CNES postprocessed, corrections streams (e.g. CLK22, CLK93),…

Application

- These satellite products allow PPP-AR in different approaches [Teunissen and Khodabandeh, 2015] through splitting the ambiguity of the IF LC[1] into WL[2] and NL[3]



- The production of a combined IGS product (orbits, clocks, biases) is possible [Banville et al., 2020]

[1] IF LC ... ionosphere-free linear combination [2] WL ... Wide-Lane [2] NL ... Narrow-Lane

Processing Settings

Software: raPPPid (VieVS PPP)

Data: 38 IGS MGEX stations, January 2020

Observations: GPS L1, L2 and Galileo E1, E5a

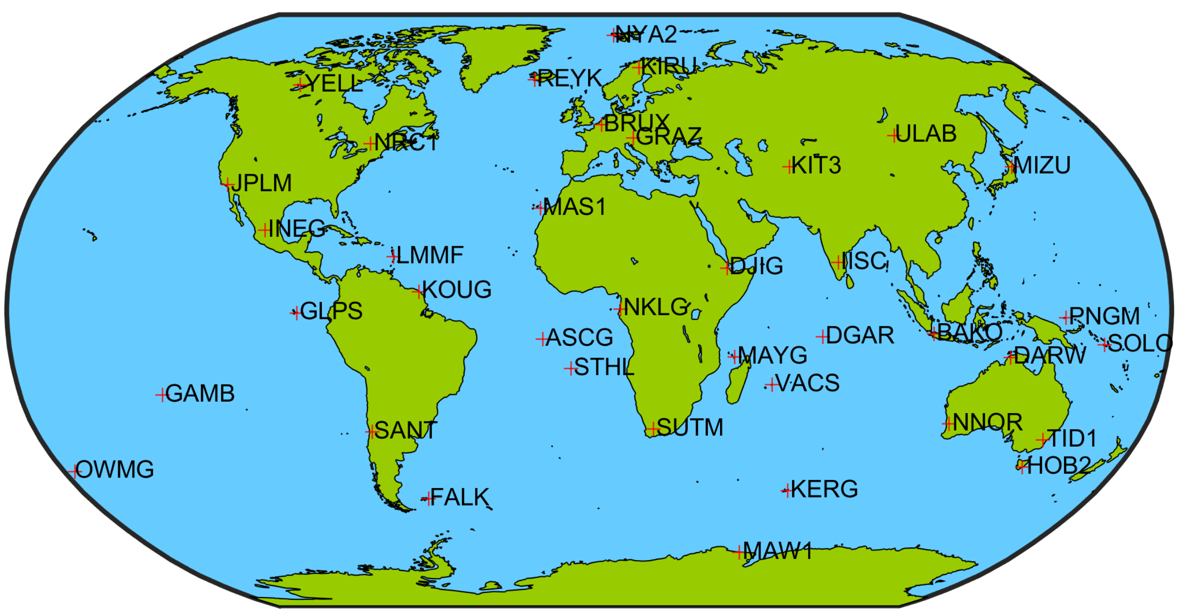
Observation interval: 30sec, reset of solution every 30min

Processing Mode: ionosphere-free linear combination, static receiver, Kalman-Filter

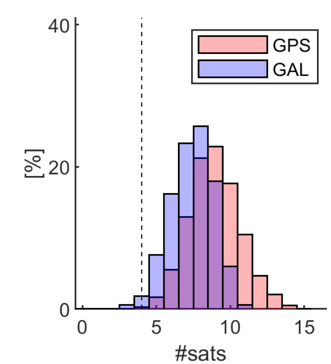
PPP-AR: Wide-Lane fixing after 90sec, Narrow-Lane fixing after 120sec

VieVS
Vienna VLBI and Satellite Software

More details in appendix

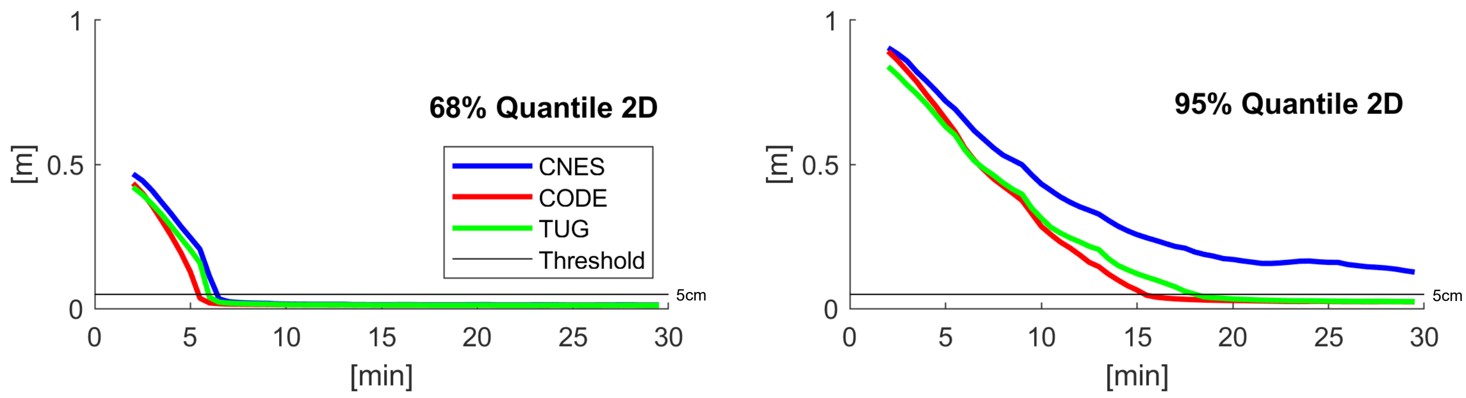


The used IGS MGEX stations

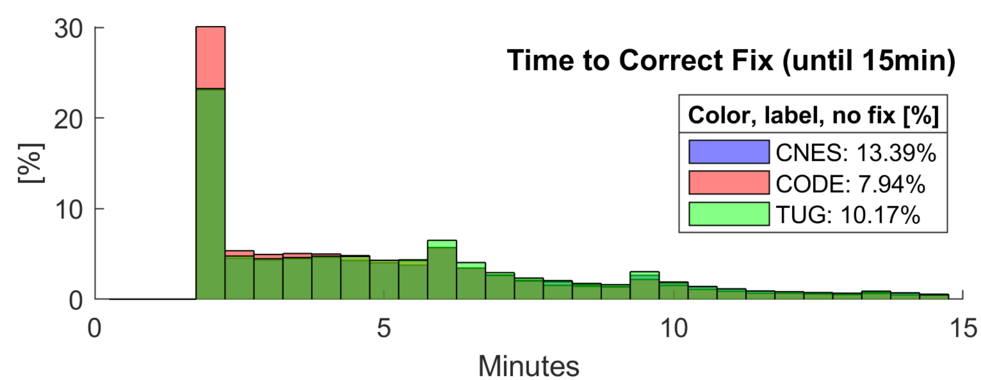


Used GNSS satellites,
2020/01/01 at all stations

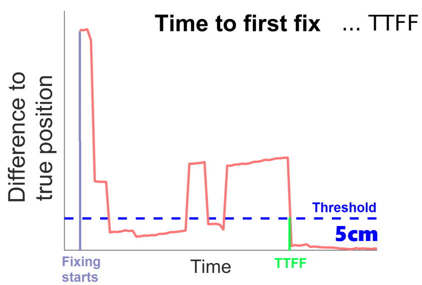
Results CNES vs. CODE vs. TUG



68% (left) and 95% (right) quantile of the horizontal position error for fixed PPP solutions with different PPP-AR products



Histogram of the time to first fix (TTFF, see bottom left corner).
TTFFs after 15min are summed up in the legend

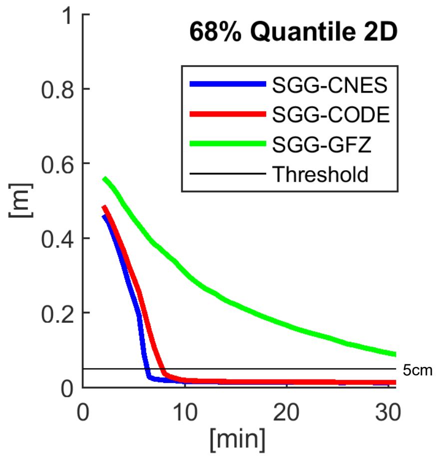


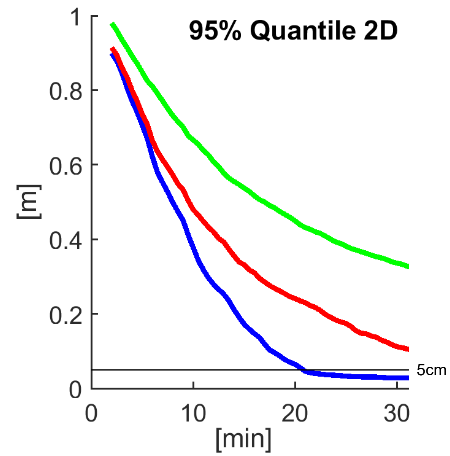
TTFF = fixed solution AND convergence is reached for the entire remaining convergence period

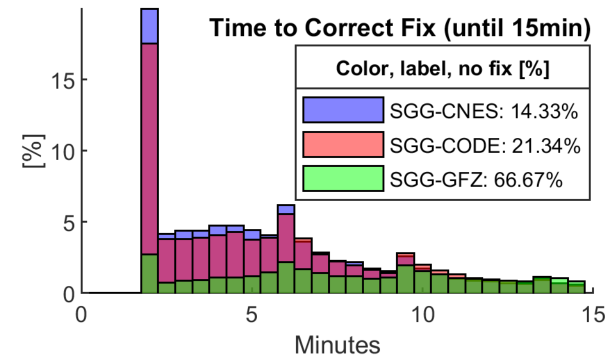
→ CODE ≥ TUG > CNES

Differences are found in the 95% quantile and the percentage of fixes after 15min

Results SGG vs. Analysis Center

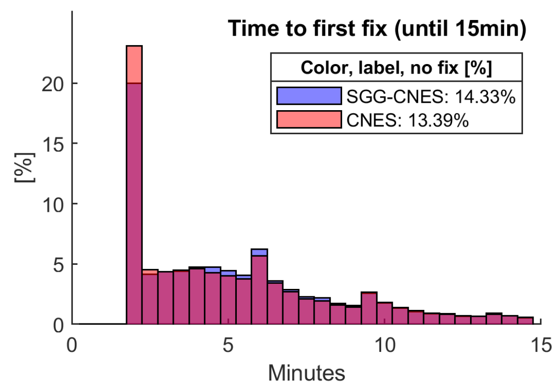


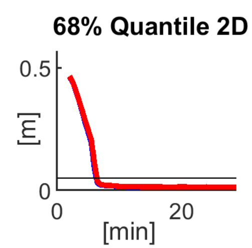




→ $\mathbf{SGG_{CNES} > SGG_{CODE} >> SGG_{GFZ}}$

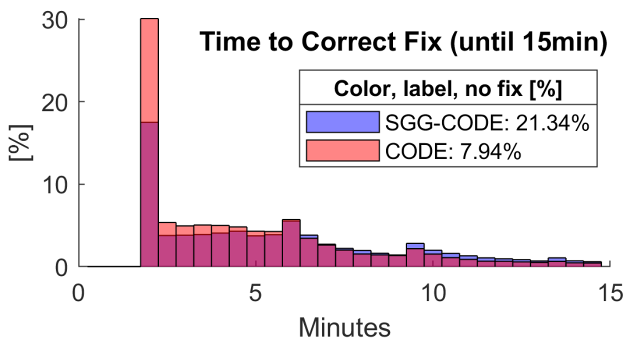
But GFZ is a rapid product with a delay of 9h only

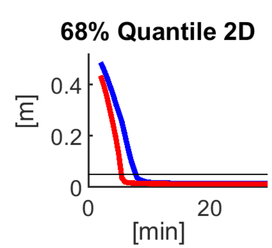




→ $\mathbf{CNES = SGG_{CNES}}$

Results are nearly identical



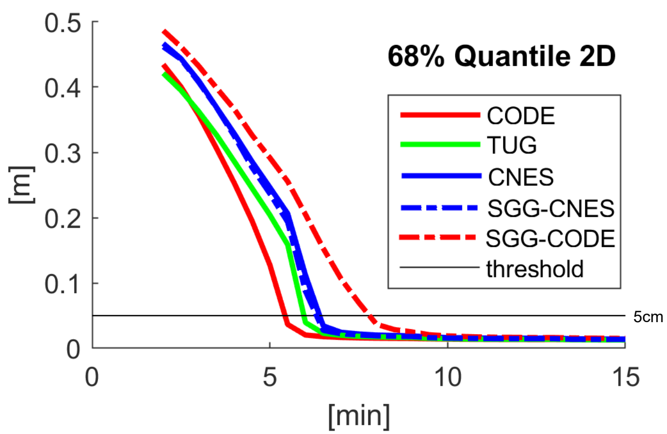


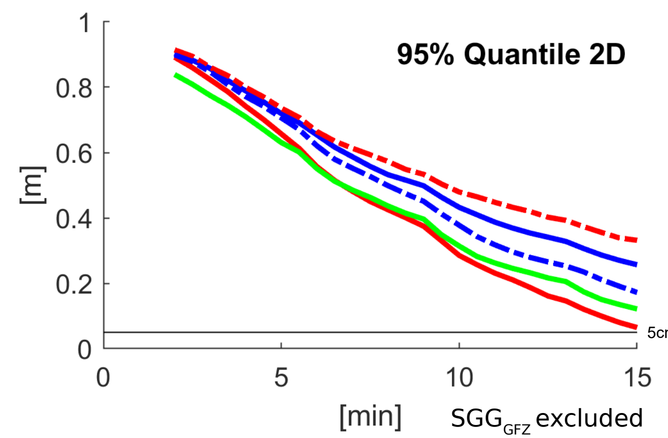
→ $\mathbf{CODE >> SGG_{CODE}}$

Especially clear in the percentage of fixes after 15min

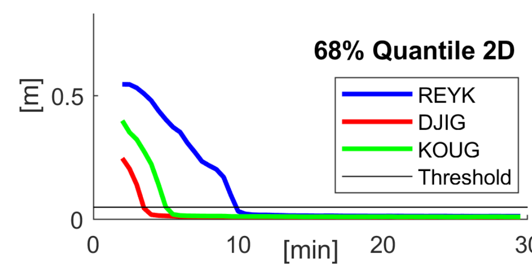
Conclusion

$$\textbf{CODE} \geq \textbf{TUG} > \begin{matrix}\textbf{CNES}\\ \textbf{SGG}_{\textbf{CNES}}\end{matrix} > \textbf{SGG}_{\textbf{CODE}} \gg \textbf{SGG}_{\textbf{GFZ}}$$





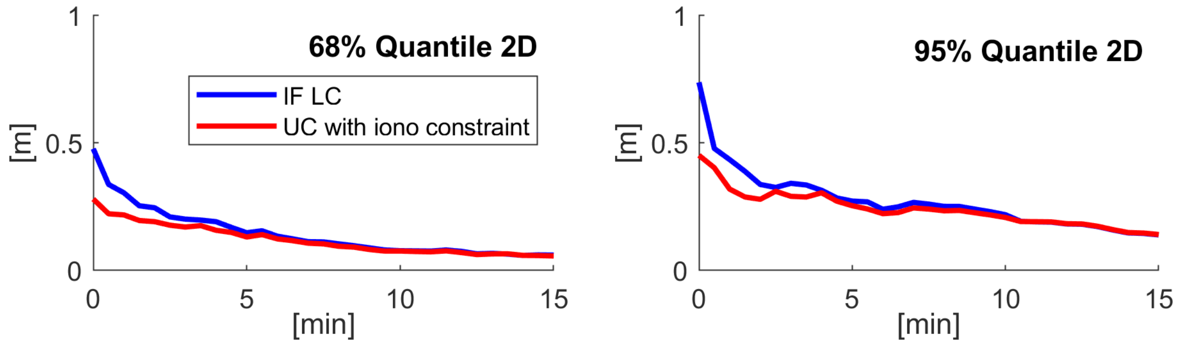
- Choice of satellite product influences TTFF
- After TTFF: no differences
- Big differences between stations:



Example for differences between stations (TUG)

Outlook

- All tested products enable PPP-AR for one 2-frequency IF LC only, except for TUG
- TUG makes other approaches possible
- For example: 2x2-frequency IF LC or uncombined model with ionospheric constraint (future work)



Float solution for IF LC (blue) and uncombined model with ionospheric constraint (red, better convergence) for the station MIZU on 2020/01/01.

GPS L1+L2, Galileo E1 + E5a, TUG products, final IGS ionosphere model, reset every 30min, first 15min are shown

Appendix: Detailed processing settings

Software: raPPPid (VieVS PPP) **Period:** January 2020

Stations: 38 IGS MGEX stations, randomly selected with global distribution with exclusion criterion on completeness of observation data and IGS coordinate estimation for every day

Observations: GPS L1, L2 and Galileo E1, E5a (weighted 1:1)

Observation ranking: GPS - WCDPSLXYMNDIQ and Galileo - BCIQXAZ

Observation interval: 30sec, reset solution every 30min → about 56 500 convergence periods

Processing Mode: ionosphere-free linear combination, static receiver

Raw observation noise: code 30cm, phase 2mm

Observation weighting: elevation weighted, $\sin(elev)^2$, cutoff angle: 5°

Troposphere model: VMF3 [Landskron and Böhm, 2018], residual ZWD is estimated

Correction models: Phase Wind-Up, solid earth tides, relativistic effect, phase center offsets

Adjustment: Kalman-Filter **Reference Coordinates:** Final IGS solution

Receiver Clock GPS, Time Offset Galileo: white noise

Float ambiguities: constant, zero-difference, cycle-Slip Detection:dL1-dL2

PPP-AR: Ambiguity of IF LC is split into Wide-Lane and Narrow-Lane, single-difference to reference satellite (highest satellite), Fixing cutoff = 10°

Wide-Lane fixing: Melbourne-Wübbena LC, start after 90sec

Narrow-Lane fixing: LAMBDA method [Teunissen, 1995], start after 120sec

VieVS
Vienna VLBI and Satellite Software

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