BDS and QZSS in CODE's Final Solution: Assessment of the Impact

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Multi-GNSS Processing at CODE Analysis Center

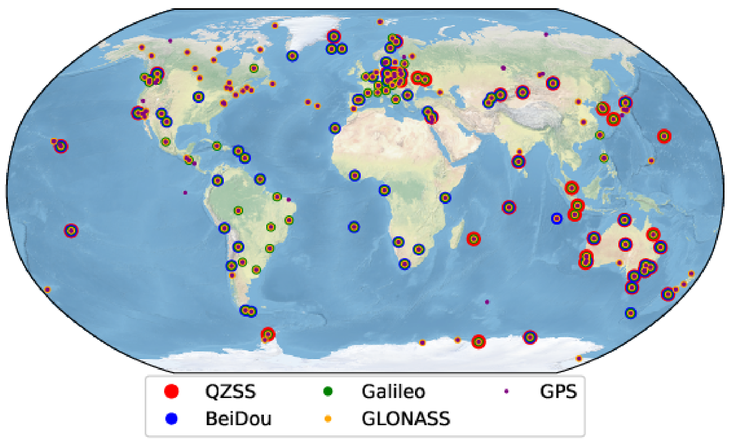
The Center for Orbit Determination in Europe acts as one of the Analysis Centers of the International GNSS Service (IGS, Johnston et al, 2017). The operational processing is carried out at AIUB. All activities are based on the latest development version of the Bernese GNSS Software (Dach et al, 2015).
CODE has a long tradition in establishing a rigorously combined processing of multiple GNSS. It includes the following systems into its product series since:

System	ultra	rapid	final	MGEX	repro
GPS	2001	1999	1992	2012	repro1
GLONASS	2003	2003	2003	2012	repro2
Galileo	2019	2019	2022	2012	repro3
BeiDou	???	???	???	2013	
QZSS	???	???	???	2013	

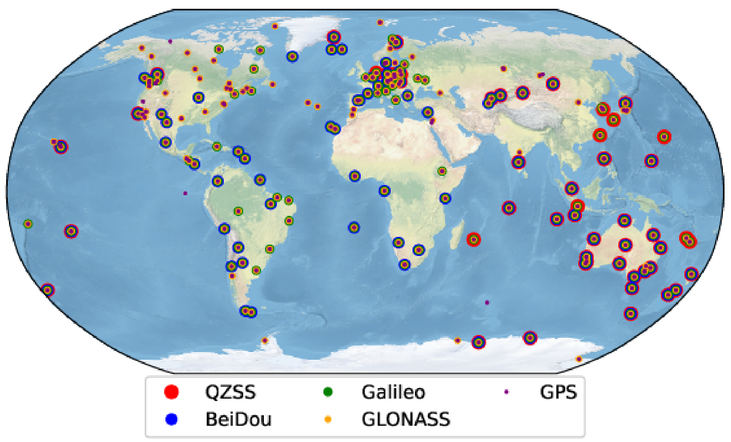
To which extent the Chinese BeiDou and Japanese QZSS systems can be included is the aim of this study.
The inclusion of additional satellite systems should not deteriorate any of the provided product series, in particular it should not degrade the access to the reference frame via the final series.
For this purpose the IGS calibration campaign for obtaining consistent satellite antenna corrections for all BeiDou 3 satellites is a prerequisite for this effort which was carried out by a number of IGS analysis centers in 2024 and where the results are provided to the contributing groups by P. Rebischung in February 2025.

The Experiment Setup

The CODE final process was extended by the BeiDou and QZSS satellite systems using the satellite antenna calibrations as provided by P. Rebischung in February 2025. Only those observations were considered for which the corresponding receiver antenna corrections were available in the IGS20 antenna file (as of GPS week 2353).



Situation in December 2021



Situation in December 2024

Figure 1: Map with stations of the CODE final solution with receiver calibrations for the selected satellite systems as considered for this experiment.

GPS (L1 and L2), GLONASS (L1 and L2), Galileo (E1 and E5a), BeiDou (only B1A and B2a signals from BeiDou-3) and QZSS (L1 and L5) have been considered from 2020 to end of 2024.

General Statistics of the Solutions

An initial evaluation of the solution quality is to check the a posteriori RMS of unit of weight for the parameter estimation process. Currently CODE is considering GPS, GLONASS and Galileo in its final processing series (green dots in the left panel of Figure 2). Adding the BeiDou and QZSS constellations does not change the picture (blue dots in the same panel).
It can be noticed that the GPS only solution (magenta dots in Figure 2) performs slightly better than the multi-GNSS solutions. For that reason the list of solutions was extended to a GPS and Galileo (green dots in the right panel of Figure 2) solution (CODE legacy final solution but without GLONASS). The effect is reduced in time when some of the GLONASS satellites have been decommissioned. For comparison, also a solution considering only GPS and BeiDou was added (again blue dots in the right panel) which confirms that adding the BeiDou satellites does not degrade the solution.

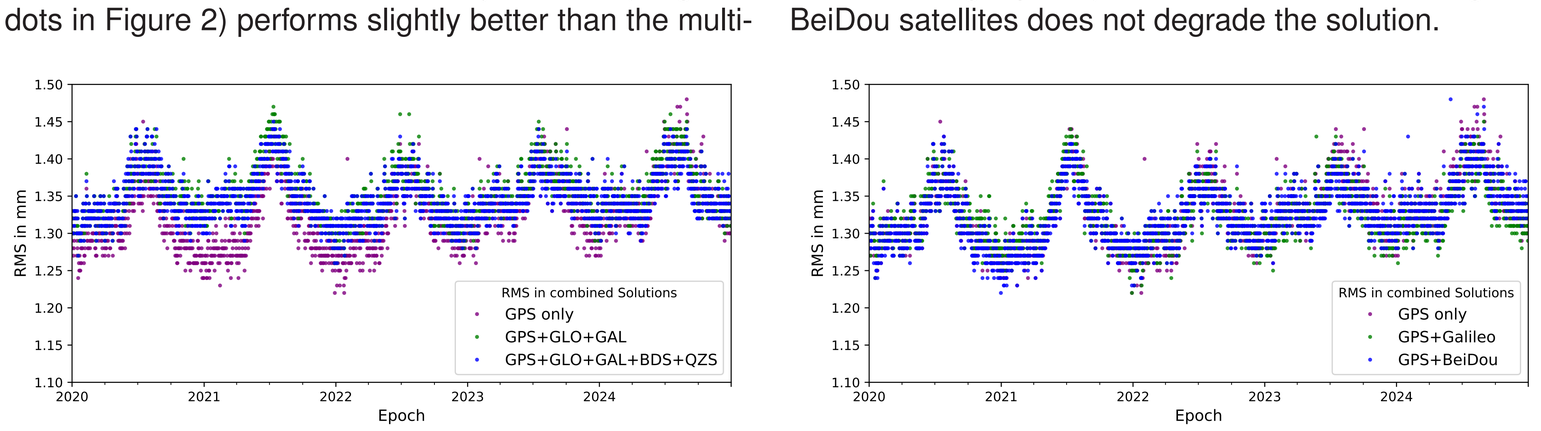


Figure 2: A posteriori unit of weight from the one day solution in different combinations of included satellite systems.

The left panel in Figure 3 shows the ambiguity resolution success rate per system in the fully developed five system configuration. The periods in 2021 and 2022 where QZSS shows a lower success rate for the ambiguity resolution are related to periods where the QZS-1 satellite was flying in orbit normal mode. Other periods are less pronnounced in this plot.
In addition in the right panel of Figure 3 it is verified that adding Galileo (green dots) and BeiDou (blue dots) does not degrade the ambiguity resolution rate for GPS compared to a GPS-only solution (purple dots). Interestingly, the combined GPS and Galileo solution helps for a slightly better ambiguity resolution rate – even compared to the GPS-only configuration. The GPS and BeiDou solution behaves like the GPS-only ambiguity resolution rate for the GPS constellation.

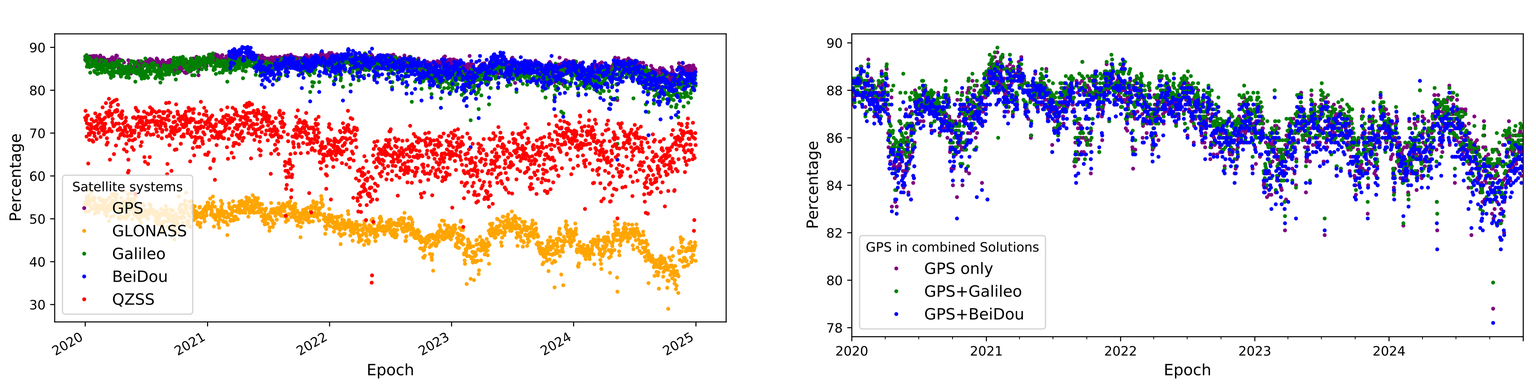


Figure 3: Ambiguity resolution success rates in the one day solution in different combinations of included satellite systems.

Global Parameters

Comparing various global parameters between the solutions generated as GPS-only (as reference), GPS+Galileo, GPS+BeiDou (both to have a maximal impact for a secondary GNSS), GPS+GLONASS+Galileo (current CODE's legacy setup), and the newly planned five system solution (GPS+GLONASS+Galileo+BeiDou+QZSS) we can state:

- There are no significant datum parameters (translations, rotations or scale) between these solutions and the introduced reference frame.
- The Earth rotation parameters agree better than $1\,\mu as$ between the different solutions. In Figure 4 the amplitude spectra of the differences with respect to the Bulletin A series are shown with slightly different behaviour for the combinations of satellite systems at periods around 120 days.

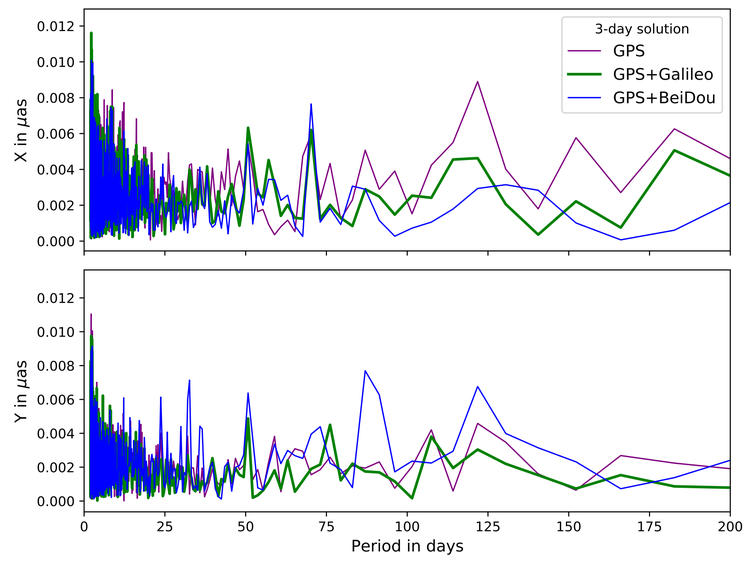


Figure 4: Amplitude spectra for polar motion differences obtained with different satellite constellations and Bulletin A as reference.

Conclusions

It has been demonstrated that the change from the current triple system solution (GPS+GLONASS+Galileo) to a five system solution by adding BeiDou and QZSS for generating the CODE legacy product series for the IGS has no negative impact.
Even if the used signals for the two additional systems share the same frequencies as Galileo E1 and E5a, the receiver antenna calbrations need to be checked carefully to allow an unlimited access to the reference frame.

References

Dach R, Lutz S, Walser P, Fridez P (eds) (2015) Bernese GNSS Software, Version 5.2. Astronomical Institute, University of Bern, Bern, Switzerland, doi: 10.7892/boris.72297, user manual.
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