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Towards new CODE analysis products based on GPS L1/L5 signals

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Introduction

To meet increasingly stringent requirements for positioning accuracy and signal availability, GPS has introduced the modern L5 signal, which is compatible with the Galileo E5a signal. The L5 signal was designed to mitigate the multipath and poor performance in harsh environments such as indoor, forests, and areas affected by jamming. As the L2 signal will become obsolete in the future, it is time to take advantage of the modern signal type which is currently broadcast by 18 (of 32) GPS satellites. This transition is particularly critical for upcoming Low Earth Orbit (LEO) missions such as EUMETSAT Polar System Second Generation (EPS-SG) that will rely exclusively on L1/L5 combinations for GNSS-based orbit determination. In response, the Center for Orbit Determination in Europe (CODE) is developing a prototype processing chain dedicated to generating high-precision clock and bias products based on L1/L5 observations, in parallel with its established L1/L2-based processing lines.

Generation of the L1/L5 products: processing setup

To enable PPP with ambiguity resolution (PPP-AR), it is crucial to model satellite related errors, particularly satellite clock biases and observable-specific signal biases (OSBs). Satellite clock corrections compensate for temporal variations in the onboard clocks of GNSS satellites, while OSBs address signal-specific hardware-induced biases that impact GNSS observations.

To support this, corresponding L1/L5-based products were generated using the operational CODE processing routines configured with the following options:

SATELLITES

- GPS (block **IIIA**, block **IIF** with antenna calibrations for L5 copied from L2)
- GLONASS (all available)
- Galileo (all available: E1/E5 signals used)

STATIONS

- 100 stations with L1/L2/L5 observations and L1/L2/L5 antenna "ROBOT" calibrations

ORBITS

- fixed (CODE operational product based on L1/L2 processing)

ESTIMATED PARAMETERS

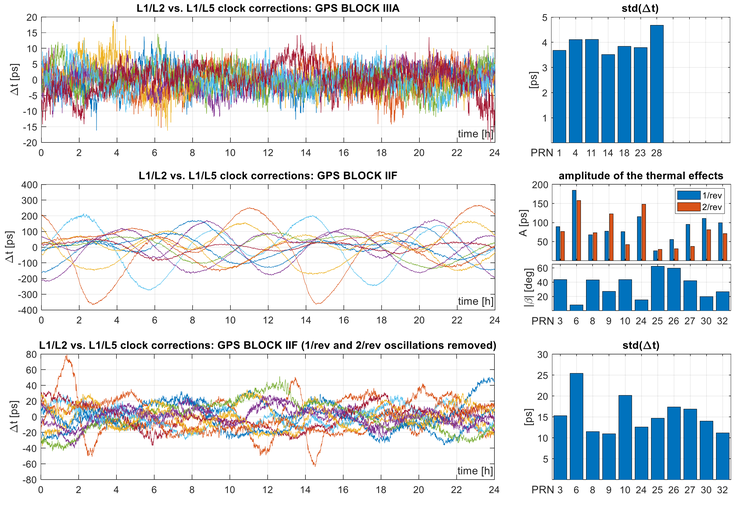
- epoch-wise clock corrections for satellites
- observable specific code/phase biases
- tropospheric parameters
- station coordinates (constrained)

} input for **PPP** and **LEO POD** with single receiver ambiguity resolution

Satellite clock corrections: GPS L1/L2 vs. L1/L5

A comparison of satellite clock corrections was conducted for 18 GPS satellites (11 BLOCK IIF and 7 IIIA), all transmitting on the L5 frequency. Consistent with findings from previous studies (Montenbruck et al. 2011), the BLOCK IIF satellites exhibit a pronounced time-dependent inter-frequency bias, primarily attributed to thermal effects. This bias manifests itself as 1/rev and 2/rev oscillations, with amplitudes strongly correlated to the satellite's β angle - the angle between the orbital plane and the Sun. Notably, lower β angles are associated with more significant thermal influences.

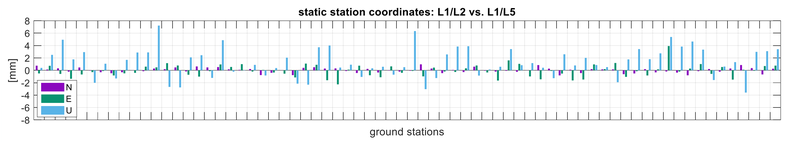
In contrast, the clock estimates derived from L1/L2 and L1/L5 combinations for BLOCK IIIA satellites demonstrate remarkable consistency, differing by only few picoseconds.



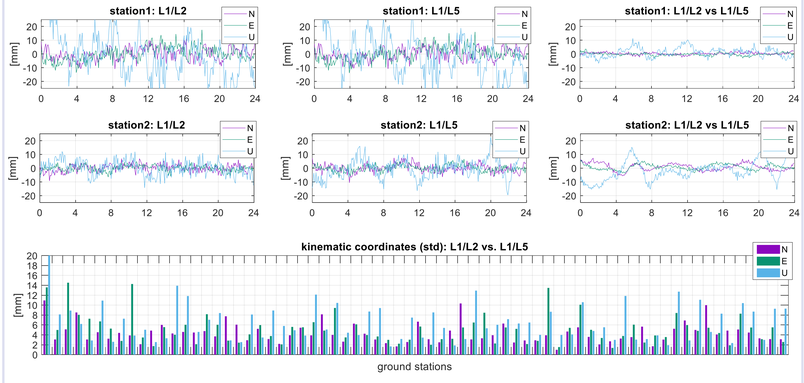
Precise Point Positioning based on GPS L5 signal

As a direct comparison between the GPS L1/L2 and GPS L1/L5-based results would not provide a realistic picture due to limited number of satellites transmitting on L5 frequency, the E1/E5-based observations of GALILEO satellites were also incorporated to enhance reliability of the validation analysis. This increases the total number of satellites considered to 47 (18 GPS + 29 GALILEO), which is still significantly lower than those typically used in the operational CODE processing. Nevertheless, any differences observed due to the transition from GPS L1/L2 to GPS L1/L5 are more pronounced and remain identifiable.

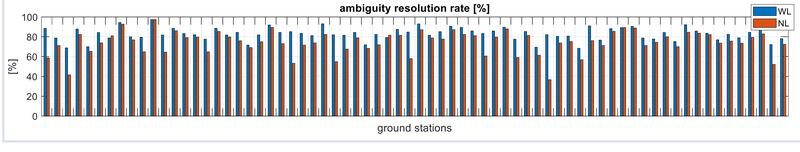
The comparison of static station coordinates, computed over a 24-hour period, shows good agreement between the L1/L2 and L1/L5-based solutions. However, the differences in the "Up" component are generally positive, which may suggest modeling deficiencies possibly related to antenna phase center corrections for the GPS IIF L5 signals (copied from L2). Note that a few stations exhibiting significant outliers are excluded from the following figures.



A more detailed analysis of the **kinematic coordinates** for two arbitrarily selected stations shows that, in general, the scatter within each solution type (L1/L2 and L1/L5) is greater or at the same level than the difference between them. In most cases, the standard deviation of the differences between the kinematic solutions does not exceed 10 mm in the "Up" component.



For the PPP processing discussed, the ambiguity resolution rates are nearly identical for both solution types (L1/L2 and L1/L5), with differences of less than 1%. The average resolution rate for wide-lane (WL) ambiguities is approximately 83%, while for narrow-lane (NL) ambiguities it is around 74%.



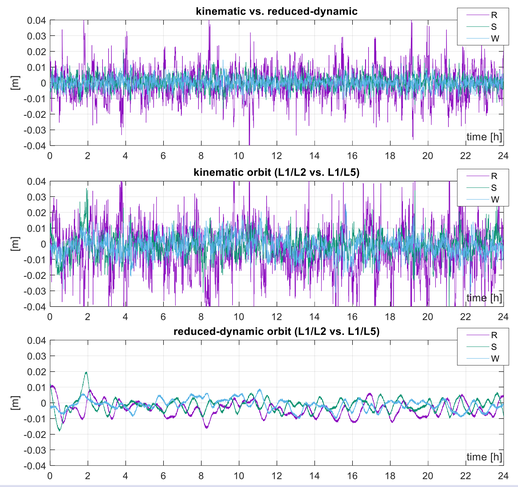
The data processing presented in this poster was carried out using the **Bernese GNSS Software**

LEO POD based on GPS L5 signal: Sentinel-6A

Precise Orbit Determination (POD) of Sentinel-6A was performed using two configurations:

1. S6AR: redundant antenna (PCV for L5 copied from L2), GPS (**IIF** and **IIIA**) **L1/L5**, Galileo **E1/E5**
2. S6AN: nominal antenna, GPS (**IIF** and **IIIA**) **L1/L2**, Galileo **E1/E5**

The quality of LEO POD is typically evaluated by comparing the kinematic and reduced-dynamic orbit. In this context, the L1/L5-based solution demonstrates a performance comparable to that of the standard L1/L2-based processing. Moreover, the use of L1/L5 observations enhances the ambiguity resolution rate.



Ambiguity resolution rate [%]

	GPS(L1/L2) GAL (E1/E5)		GPS(L1/L5) GAL (E1/E5)	
GNSS	WL	NL	WL	NL
GPS	81.1	79.4	97.6	93.4
Galileo	96.9	96.5	98.5	98.1
TOTAL	90.8	89.9	98.1	96.3

Conclusions

- Assessment of the L1/L5-based results remains limited as only 18 GPS satellites transmit L5 signals. Therefore, to enhance the solution strength and reliability, GALILEO satellites utilizing E1/E5 signals were incorporated alongside GPS L1/L2 and L1/L5 observations for comparative analysis.
- PPP for ground stations and LEO POD results that partially rely on GPS L1/L5 signals are equivalent to those derived entirely from L1/L2 observations. However, effective use of L1/L5-based PPP requires that analysis centers provide dedicated products, including satellite clock corrections and observable-specific signal biases.
- L1/L5-based clock corrections for GPS IIIA satellites are equivalent to L1/L2 ones at the level of picoseconds, while for GPS IIF satellites L1/L5 clocks are inconsistent with respect to L1/L2 clocks due to periodic 1/rev and 2/rev thermal effects. The clock corrections for IIF satellites are crucial.
- Based on the analysis of data from one day, the ambiguity resolution performance for Sentinel-6A improves when using GPS L1/L5 observations instead of L1/L2, indicating potential benefits of incorporating L1/L5 signals in operational processing.
- Availability of the antenna calibration for the L5 frequency band of the GPS block IIF satellites would likely enhance the consistency between L1/L2- and L1/L5-based results.
- In the study presented here, we were able to demonstrate that an extra clock/bias analysis (with GPS L1/L5) is sufficient to complement an existing operational orbit, clock, and bias product line (based on GPS L1/L2), thus enabling users to consistently expand their GPS application range (to L1/L5). We now have a prototype for this additional step at CODE, which will be transferred into an operational mode as the next step of this development. Of course, it would be conceivable to consider also different signal frequency combinations for the other constellations (specifically for Galileo).

Reference

Montenbruck O, Hugentobler U, Dach R, Steigenberger P, Hauschild A, (2011) Apparent clock variations of the Block IIF-1 (SVN62) GPS satellite. GPS Solutions, 16(3), pp. 303-313. Berlin: Springer 10.1007/s10291-011-0232-x

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