Monitoring of GPS+GIOVE Inter-System Biases

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INTRODUCTION

Some GNSS systems, such as GPS and Galileo, have similar frequencies, i.e. the L1-E1 (1575.42 MHz) and the L5-E5a (1176.45 MHz) frequencies. These overlapping frequencies are beneficial for mixed RTK positioning, relying on integer ambiguity resolution. Instead of forming double-differenced phase and code observations for each GNSS separately (thereby choosing a pivot satellite for each system), with the overlapping frequencies it is possible to form the double differences with respect to the pivot satellite of just one system. As a consequence, additional parameters need to be estimated in the system of mixed observation equations: these are the differential Inter-System/Signal Biases (ISBs), accounting for the differential receiver hardware delay difference between the different systems' and signals phase and code observations on overlapping frequencies. This contribution presents results of differential ISBs estimated from GPS plus GIOVE data tracked in Western Australia.

DIFFERENTIAL GPS+GALILEO INTER-SYSTEM BIASES

Traditional single and double differencing

Traditionally, short-baseline RTK positioning applications are based on first forming single-differenced (SD) phase and code observation equations, eliminating satellite-dependent biases. Assume a rover receiver 2 with respect to a reference receiver 1, then the following SD observation equations can be set up, for satellite *s* and frequency *j,* for a multi-GNSS receiver tracking GPS as well as Galileo measurements:

$$\text{GPS SD}:\begin{cases} E(\phi^s_{12,j}) &= \rho^s_{12}+\bar{\delta}^G_{12,j}+\lambda_j M^{1_G s}_{12,j}\\ E(p^s_{12,j}) &= \rho^s_{12}+\bar{d}^G_{12,j}\end{cases}\qquad \text{Galileo SD}:\begin{cases} E(\phi^q_{12,j}) &= \rho^q_{12}+\bar{\delta}^E_{12,j}+\lambda_j M^{1_E q}_{12,j}\\ E(p^q_{12,j}) &= \rho^q_{12}+\bar{d}^E_{12,j}\end{cases}$$

$$s=1_G,\ldots,m_G \qquad\qquad q=1_E,\ldots,m_E$$

where $E(\cdot)$ denotes the expectation, λ_j the wavelength, m_G the number of GPS satellites and m_E the number of Galileo satellites. Furthermore:

$\phi^s_{12,j}$: SD phase observable; $\bar{\delta}^S_{12,j}=\delta^S_{12,j}+dt_{12}+\lambda_j M^{1_S}_{12,j}$: SD biased receiver phase delay

$p^s_{12,j}$: SD code observable; $\bar{d}^S_{12,j}=d^S_{12,j}+dt_{12}$: SD biased receiver code delay

ρ^s_{12} : SD receiver-satellite range; $M^{1_S s}_{12,j}=M^s_{12,j}-M^{1_S}_{12,j}$: DD integer ambiguity

dt_{12} : SD receiver clock error; $M^s_{12,j}$: SD non-integer ambiguity

with $S\in\{G,E\}$. The (biased) receiver hardware delays are different for both GPS and Galileo, despite that the signals are tracked inside one receiver [1]. For both GNSSs also a pivot satellite is used, i.e. 1_G for GPS and 1_E for Galileo, as to define the double-differenced (DD) ambiguities. Instead of solving the SD observation equations, DD observation equations can be formed by taking the difference of a SD observation with the SD of the pivot satellite, eliminating the receiver hardware biases:

$$\text{GPS DD}:\begin{cases} E(\phi^{1_G s}_{12,j}) &= \rho^{1_G s}_{12}+\lambda_j M^{1_G s}_{12,j}\\ E(p^{1_G s}_{12,j}) &= \rho^{1_G s}_{12}\end{cases}\qquad \text{Galileo DD}:\begin{cases} E(\phi^{1_E q}_{12,j}) &= \rho^{1_E q}_{12}+\lambda_j M^{1_E q}_{12,j}\\ E(p^{1_E q}_{12,j}) &= \rho^{1_E q}_{12}\end{cases}$$

$$s=2_G,\ldots,m_G \qquad\qquad q=2_E,\ldots,m_E$$

Galileo double differencing with respect to GPS: ISB estimation

Since GPS and Galileo have overlapping frequencies, i.e. GPS L1 and Galileo E1 (1575.42 MHz) and GPS L5 and Galileo E5a (1176.45 MHz), we can also form Galileo double differences relative to the *pivot satellite of GPS* [2]:

$$\text{GPS DD}:\begin{cases} E(\phi^{1_G s}_{12,j}) &= \rho^{1_G s}_{12}+\lambda_j M^{1_G s}_{12,j}\\ E(p^{1_G s}_{12,j}) &= \rho^{1_G s}_{12}\end{cases}\qquad \text{Galileo DD}:\begin{cases} E(\phi^{1_G q}_{12,j}) &= \rho^{1_G q}_{12}+\bar{\delta}^{GE}_{12,j}+\lambda_j M^{1_E q}_{12,j}\\ E(p^{1_G q}_{12,j}) &= \rho^{1_G q}_{12}+d^{GE}_{12,j}\end{cases}$$

$$s=2_G,\ldots,m_G \qquad\qquad q=1_E,\ldots,m_E$$

where we have one Galileo double-difference more for phase and code, but also one parameter more for both phase and code: the *differential Inter-System Biases* (ISB) :

$\bar{\delta}^{GE}_{12,j}=\delta^{GE}_{12,j}+\lambda_j M^{1_G 1_E}_{12,j}$: biased differential phase ISB

$\delta^{GE}_{12,j}=\delta^{E}_{12,j}-\delta^{G}_{12,j}$: differential phase ISB

$d^{GE}_{12,j}=d^{E}_{12,j}-d^{G}_{12,j}$: differential code ISB

The phase ISB parameter is only estimable as biased by the integer ambiguity between GPS and Galileo pivot satellites (the so-called *inter-system ambiguity*).

Galileo double differencing with respect to GPS: ISB correction

If the differential phase and code ISBs are known, we can *correct* the Galileo phase and code observation equations to improve the strength of the model and consequently ambiguity resolution and RTK positioning. Let us denote the phase and code ISB corrections as:

$$\begin{aligned} E(\tilde{\delta}^{GE}_{12,j}) &= \delta^{GE}_{12,j}+\lambda_j z_{12,j} &&= \bar{\delta}^{GE}_{12,j}-\lambda_j(M^{1_G 1_E}_{12,j}-z_{12,j})\\ E(\tilde{d}^{GE}_{12,j}) &= d^{GE}_{12,j} &&= d^{GE}_{12,j}\end{aligned}$$

with $z_{12,j}\in\mathbb{Z}$ the integer inter-system ambiguity for the dataset from which the ISBs are estimated. This notation is used as to discriminate this ambiguity from the inter-system ambiguity present in the observations that are corrected. The ISB-corrected single-differenced Galileo phase and code observation equations become:

$$\text{ISB-corr. Galileo SD}:\begin{cases} E(\tilde{\phi}^q_{12,j}) &= E(\phi^q_{12,j}-\tilde{\delta}^{GE}_{12,j}) &= \rho^q_{12}+\bar{\delta}^G_{12,j}+\lambda_j(M^{1_G q}_{12,j}-z_{12,j})\\ E(\tilde{p}^q_{12,j}) &= E(p^q_{12,j}-\tilde{d}^{GE}_{12,j}) &= \rho^q_{12}+\bar{d}^G_{12,j}\end{cases}$$

$$q=1_E,\ldots,m_E$$

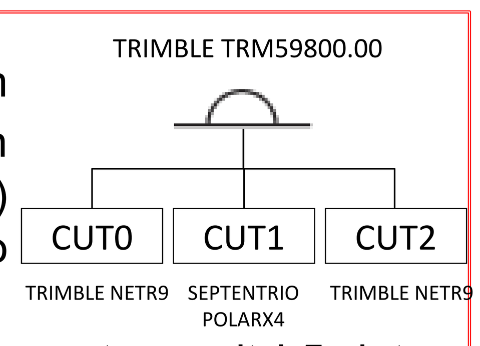
Due to the corrections, the Galileo single differences become parameterized into the (biased) receiver clocks of GPS, that thus can be eliminated by (double) differencing with respect to the GPS pivot satellite:

$$\text{ISB-corr. Galileo DD}:\begin{cases} E(\tilde{\phi}^{1_G q}_{12,j}) &= \rho^{1_G q}_{12}+\lambda_j(M^{1_G q}_{12,j}-z_{12,j})\\ E(\tilde{p}^{1_G q}_{12,j}) &= \rho^{1_G q}_{12}\end{cases}\qquad q=1_E,\ldots,m_E$$

Now both DD observables as well as the estimable integer ambiguity for Galileo are relative to the pivot satellite of GPS. The presence of $z_{12,j}$ is not an issue since it is integer and subtracted for every Galileo satellite. Thus, in this way the Galileo double-differences are fully interoperable with those of GPS.

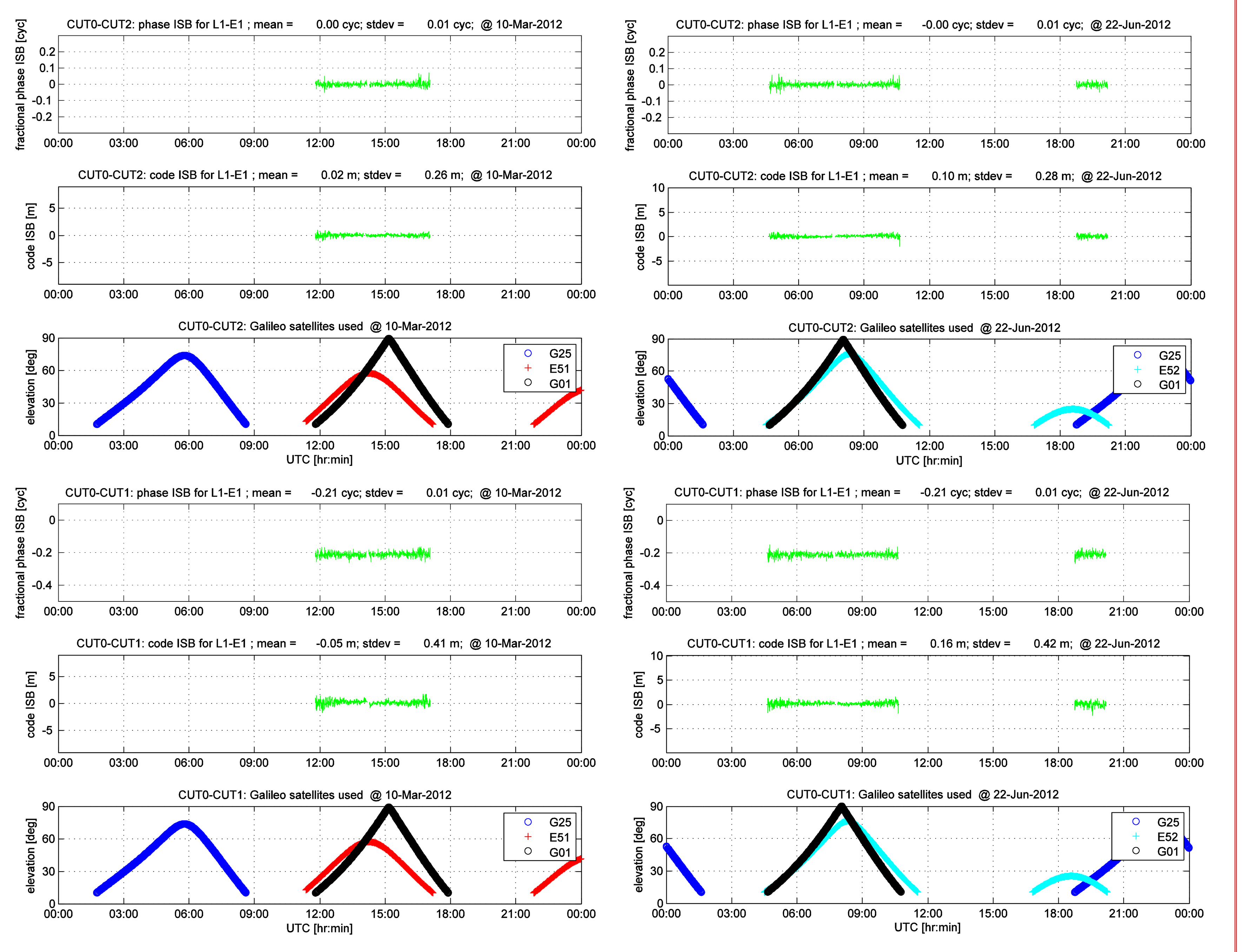
RESULTS

Differential ISBs have been estimated from GPS+GIOVE L1+E1 and L5+E5a data tracked at Curtin University's Bentley Campus. Two Trimble NetR9 (CUT0, CUT2) and one Septentrio PolaRx4 (CUT1) receivers are connected to the same Trimble antenna, forming zero baselines (see figure).

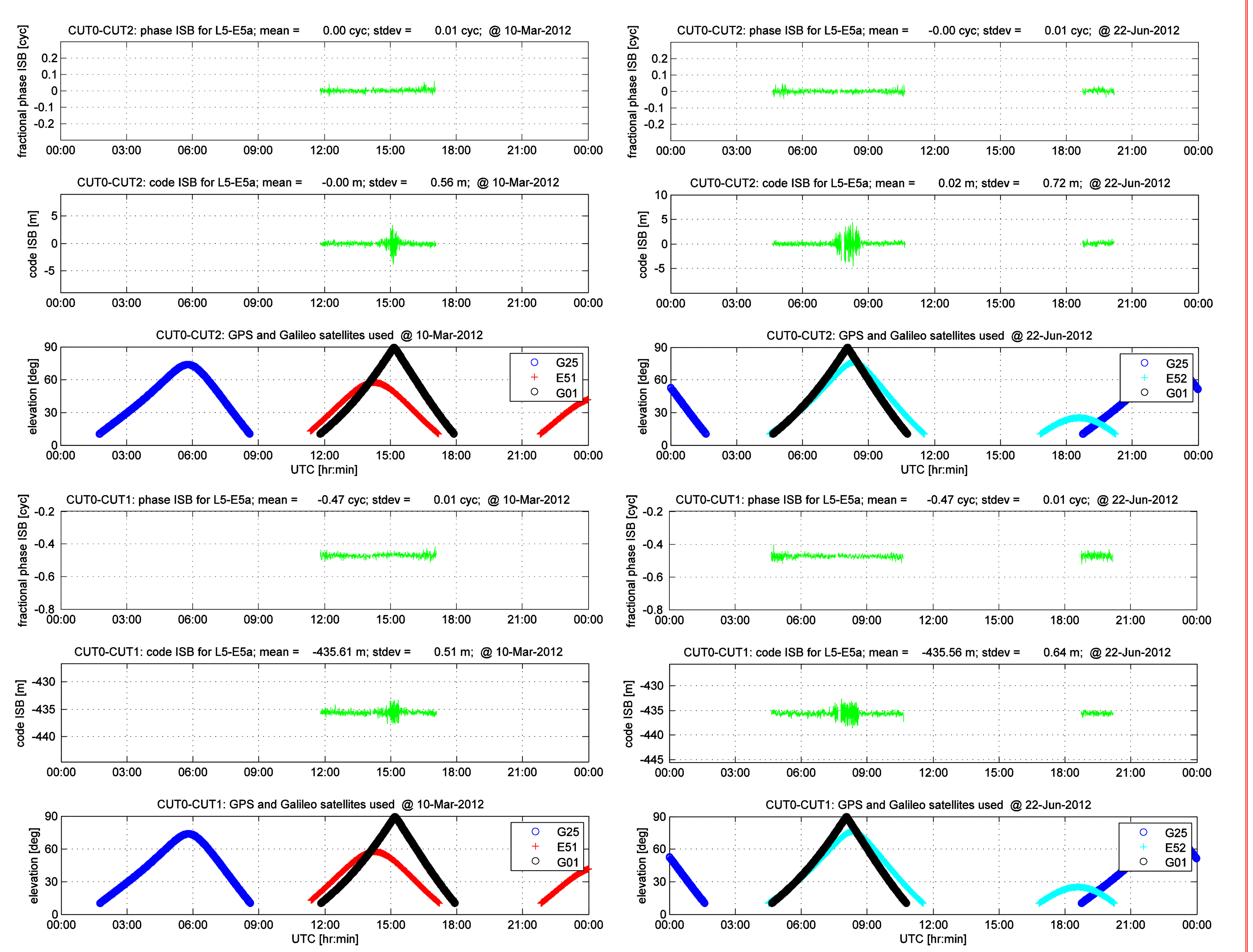


For GPS only PRN1 and PRN25 have been used, since only these transmit L5 data. E5a data is broadcast by GIOVE-A (E51) and GIOVE-B (E52). Below, differential L1-E1 and L5-E5a ISBs are plotted for CUT0-CUT2 (top), consisting of identical Trimble receivers and for CUT0-CUT1 (bottom), formed by a Trimble and Septentrio receiver.

Estimated differential L1-E1 ISBs: 10/03/2012 (GIOVE-A) vs. 22/06/12 (GIOVE-B)



Estimated differential L5-E5a ISBs: 10/03/2012 (GIOVE-A) vs. 22/06/12 (GIOVE-B)



DISCUSSION AND CONCLUSION

In this contribution monitoring results are presented of the differential ISBs between GPS and GIOVE, the two experimental Galileo satellites, estimated from permanent multi-GNSS receivers at Curtin University. The results show that the differential ISBs seem to be zero for the zero baseline consisting of two identical Trimble receivers, however they cannot be ignored for the zero baseline formed by receivers of different manufacturers, in this case Trimble and Septentrio. Despite their significance, the monitoring over three months indicate that the differential ISBs are stable in time, for both L1-E1 and L5-E5a phase and code. This stability may give rise for calibration of the Galileo double-difference (relative to the GPS pivot satellite) observations using the estimated differential ISBs. This would allow the Galileo data to be processed as if they were additional GPS data, thus strengthening the model as compared to a separate double differencing for each system.

REFERENCES

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