Performance Analysis of Compass Orbit and Clock Determination and Compass-only PPP

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Introduction

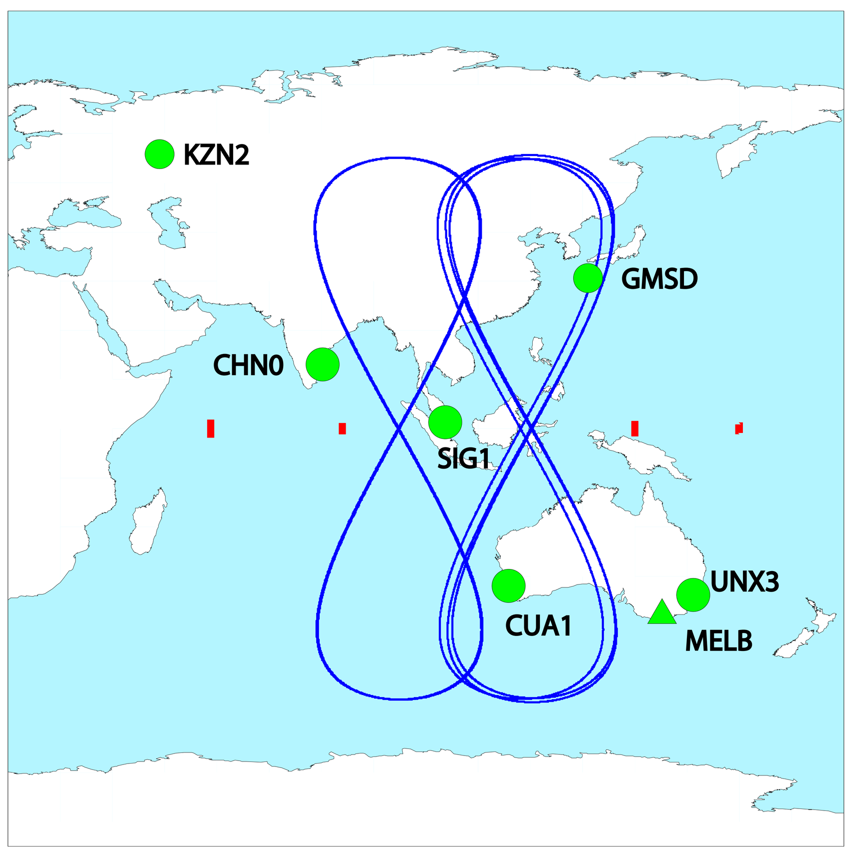

Figure 1: Compass IGSO (blue) and GEO (red) groundtracks as well as distribution of the Compass tracking stations.

The Compass constellation currently provides four usable satellites in geostationary Earth orbit (GEO) and five satellites in inclined geosynchronous orbit (IGSO). Based on a network of Compass-capable receivers from the IGS Multi-GNSS EXperiment (MGEX) and the Cooperative Network for GIOVE Observation (CONGO) orbit and clock parameters of the Compass GEO and IGSO satellites are estimated.
The orbit and clock analysis is based on up to 6 stations shown in Fig. 1: Kazan (KZN2, Russia), Chennai (CHN0, India), Singapore (SIG1), Tanegashima (GMSD, Japan), Curtin (CUA1, Australia), and Sydney (UNX3, Australia). The Melbourne station (MELB, Australia) was only used for precise point positioning, not for orbit and clock determination. More details on the tracking stations as well as Compass in general is given in Montenbruck et al (2012). The results discussed in this poster are based on the time period 79 – 128/2012.

Compass Data Processing

For the processing of dual-frequency GPS and Compass data, a modified version of the Bernese GPS Software is used. The general processing strategy is based on a GPS-only Precise Point Positioning (PPP) followed by a COMPASS-only step as discussed for GIOVE in Steigenberger et al (2011). Station coordinates, troposphere zenith delays and gradients as well as receiver clock parameters are estimated from GPS observations. These parameters are kept fixed when solving for Compass orbit and clock parameters.
For Compass, the ionosphere-free linear combination of B1 and B2 is used. To account for systematic differences of these observables w.r.t. the GPS L1 and L2 observations, differential code biases (DCBs) are estimated. The bias of the Singapore station is fixed to zero as a reference. Compass a priori orbits are taken from Two Line Elements (TLEs) provided by `https://www.space-track.org`. However, the orbit quality of these a priori orbits is quite bad (differences of several 10s of km). Therefore, three orbit iterations have to be done to get a converging solution. The observations are processed in daily batches and normal equations (NEQs) are saved to be able to generate multi-day solutions.

Orbit Analysis

Based on the normal equations orbit solutions with three, five, and seven days arc length are computed. In addition to the Keplerian elements, radiation pressure (RPR) parameters are estimated in a Sun-oriented system:
- **D**: direction to the Sun
- **Y**: direction along the solar panel axis
- **B**: completing a right-handed system

In each direction a constant, a sine, and a cosine term can be estimated resulting in up to nine RPR parameters. Due the static line-of-sight geometry the GEO orbit determination problem is less well conditioned than that of the IGSO satellites. Therefore, only a constant term in D-direction is estimated. For the IGSO satellites, three different sets of radiation pressure parameters were tested:
- **3 RPR**: direct terms in D-, Y-, and B-direction
- **5 RPR**: direct terms in D-, Y-, and B-direction, sine/cosine terms in B-direction
- **9 RPR**: direct and sine/cosine terms in D-, Y-, and B-direction

As a quality indicator for the internal consistency of the orbits day boundary discontinuities of two consecutive days are used, i.e., the 3D difference of the orbit positions at midnight. From the multi-day solutions, only the middle day of the arc is used. The results for orbital arc lengths of three, five, and seven days are summarized in Fig. 2.

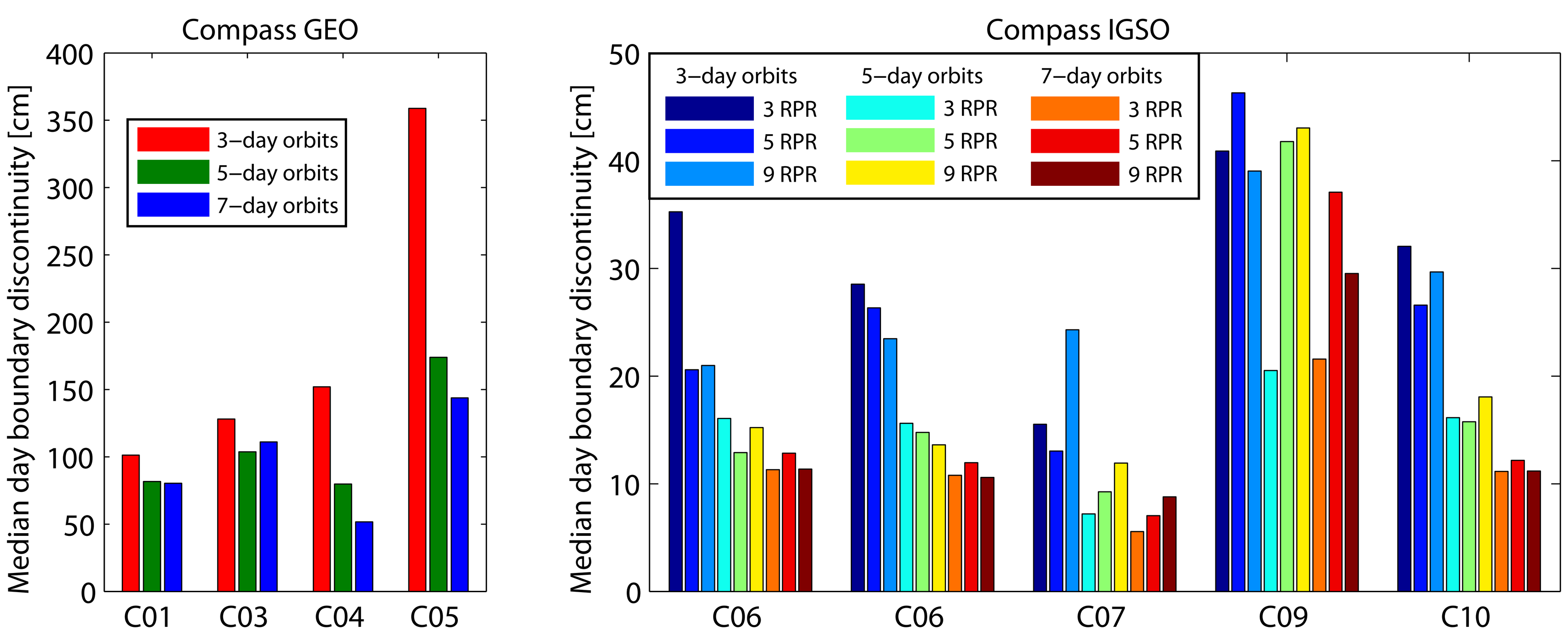

Figure 2: Median day boundary discontinuities of Compass GEO (left) and IGSO (right) satellites. Please note the different scale of the y-axis. For the GEO satellites only one direct radiation pressure (RPR) parameter was estimated.

The GEO satellite C05 is only tracked by three stations resulting in a fairly limited orbit quality. In general, the orbit quality improves with increasing arc length. For most satellites, a 7-day arc with three RPR parameters provides the best performance. Due to the bad observation geometry, the orbit quality of the GEOs is on the one meter level. It is worse by a factor of 5 – 7 compared to the IGSOs. The IGSO orbit quality is on the one to two decimeter level which is similar to results for the Japanese Quasi-Zenith Satellite System (QZSS) reported in Steigenberger et al (2012).

Clock Analysis

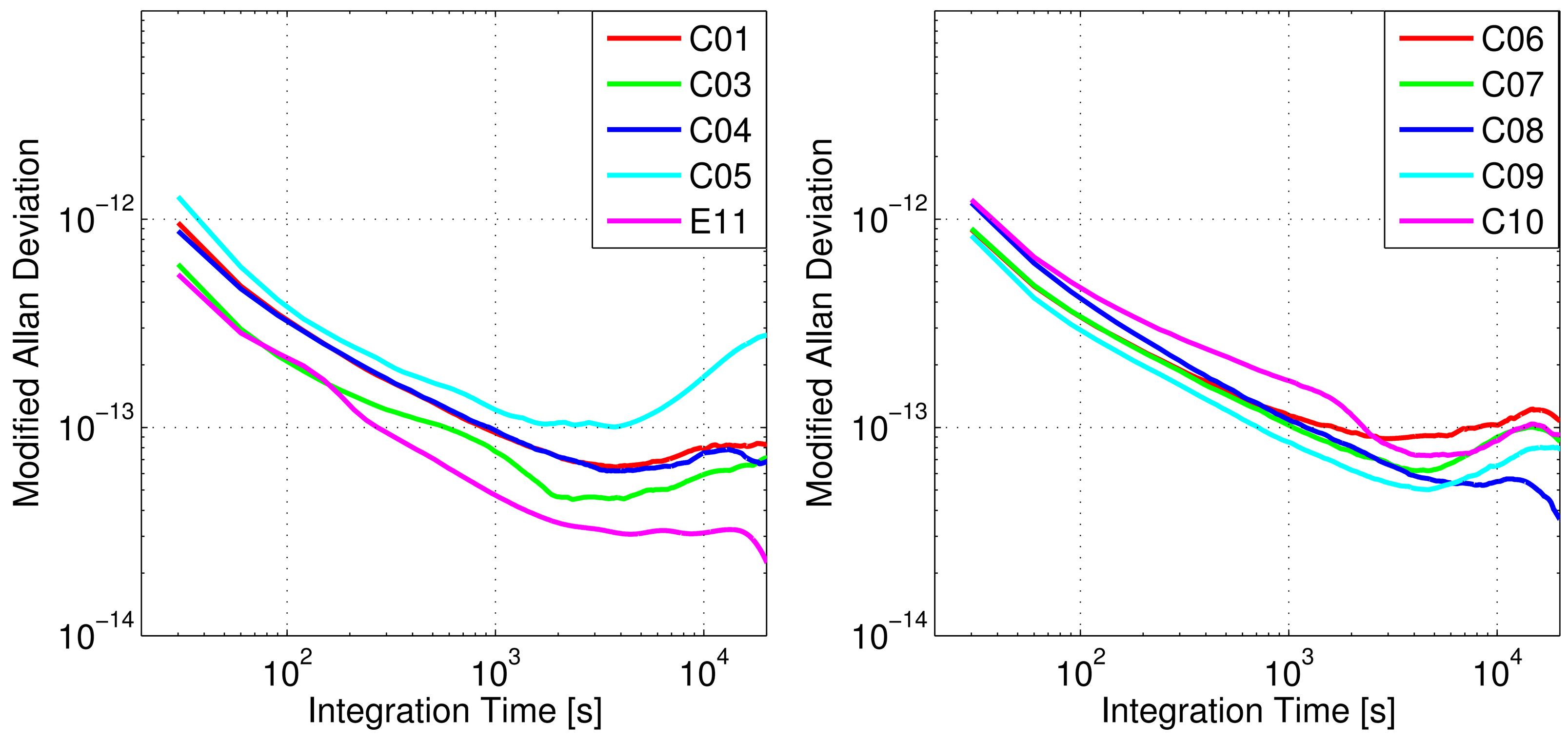

Figure 3: Modified Allan deviation of Compass GEO (left) and IGSO (right) satellites. Median values for the time period 79 – 128/2012 are shown. For comparison purposes, the performance of the first Galileo IOV satellite (E11) Rubidium clock is also shown in the left plot.

To assess the performance of the Compass on board clocks, modified Allan deviations are shown in Fig. 3. In general, the clock performance for the IGSO and GEO satellites is on the same level. The bad orbit performance of C05 reflects itself in an increased modified Allan deviation at longer integration times. Compared to the Rubidium clock of the Galileo IOV-1 satellite, the apparent performance of the Compass clocks is in general worse by a factor of about two, in particular at longer correlation times. However, at shorter periods the C03 clock seems to be competitive with the IOV-1 clock.

Differential Code Biases

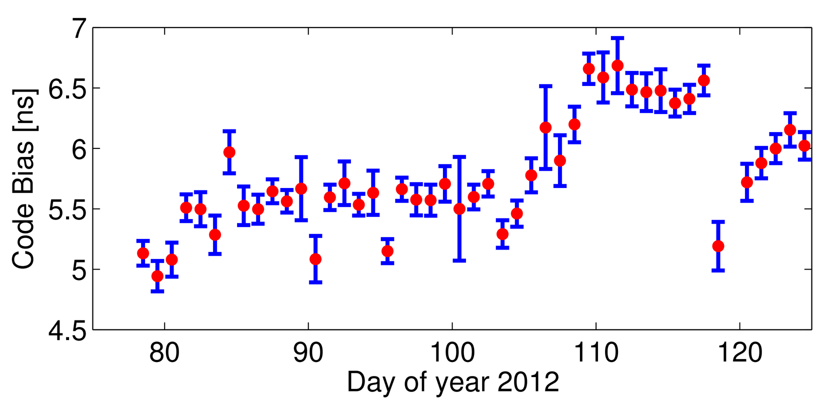

Figure 4: Differential code bias time series of GMSD. The blue errorbars indicate the threefold formal errors.

Receiver-specific differential code biases (DCBs) are estimated to account for systematic differences between different receiver types as well as intersystem biases between GPS and Compass. The code bias of the Singapore station (Trimble NetR9 with firmware 4.46/4.48) is fixed to zero. Large biases are present at CHN0 and UNX3 reaching almost 2 μs. This effect is related to a firmware-induced bias in the NetR9 4.4x firmware that was fixed in the 4.6x firmware.
The Septentrio receiver at UNX3 is not affected by this problem but as the biases are expressed w.r.t. the NetR9 at Singapore with firmware 4.4x, UNX3 also shows this large bias. After upgrading the Trimble receivers to firmware 4.60, all DCBs agree within several nanoseconds.

Station	Receiver	Firmware	DCB [ns]	STD [ns]
`CHN0`	NetR9	4.60	−1906.2	0.47
`CUA1`	NetR9	4.46/4.48	−7.0	0.82
`GMSD`	NetR9	4.46/4.48	5.8	0.47
`UNX3`	AsteRx3	unknown	−1938.1	0.34

Table 1: Differential code biases with respect to the reference receiver in Singapore. Mean values for the time interval 78 – 125/2012 are given.

Compass-only PPP

For five days, data of an additional tracking station in Melbourne (MELB, Australia) were provided by Trimble and Curtin University (Perth, Australia) to test the PPP performance of the orbit and clock products discussed above. The Compass visibility is quite limited at Melbourne with 5 to 8 satellites simultaneously visible mainly in the north west quadrant.

Satellites	North [cm]	East [cm]	Up [cm]
IGSO + GEO	1.7	4.1	6.4
IGSO	2.0	5.1	11.7

Table 2: Results of Compass-only PPP: RMS differences of five daily solutions w.r.t. GPS-only station coordinates.

The differences between GPS-only and Compass-only coordinate estimates are on the several centimeter level. Although the GEOs have a lower orbit accuracy compared to the IGSOs, they significantly improve the Compass-only positioning accuracy.
The troposphere zenith wet delays (ZWDs) derived from GPS and Compass show, in general, a similar behavior. However, due to the smaller and more variable satellite number, the Compass ZWDs are much more noisy. The GPS/Compass ZWD differences show a bias of 1.5 cm and have a standard deviation of 3.4 cm.

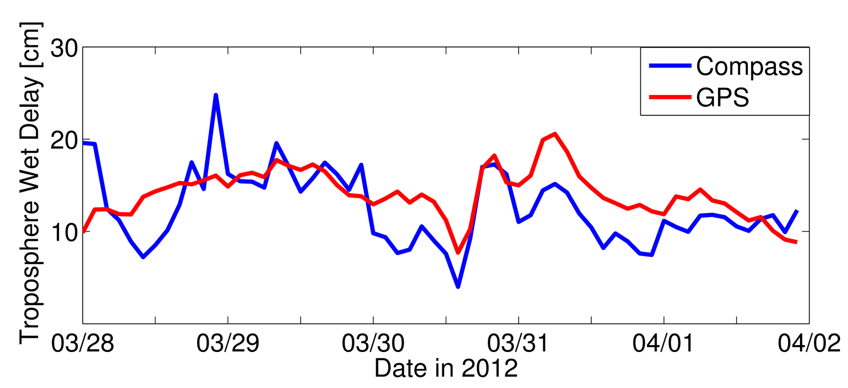

Figure 5: GPS-only and Compass-only troposphere wet delays of station Melbourne.

Further Reading

Montenbruck O, Hauschild A, Steigenberger P, Hugentobler U, Riley S (2012) A COMPASS for Asia: First Experience with the BeiDou-2 Regional Navigation System. IGS Workshop 2012, 23 – 27 July 2012, Olsztyn

Steigenberger P, Hugentobler U, Montenbruck O, Hauschild A (2011) Precise orbit determination of GIOVE-B based on the CONGO network. Journal of Geodesy 85(6):357 – 365

Steigenberger P, Hauschild A, Montenbruck O, Rodriguez-Solano C, Hugentobler U (2012) Orbit and Clock Determination of QZS-1 Based on the CONGO Network. Proceedings of ION ITM, pp 1265 – 1274