PRECISE ORBIT DETERMINATION OF QZS-1

G41B-0734

Peter Steigenberger[1], **Urs Hugentobler**[1], **Carlos Rodriguez-Solano**[1], **André Hauschild**[2]

[1] Institut für Astronomische und Physikalische Geodäsie, Technische Universität München, Germany [2] Deutsches Zentrum für Luft- und Raumfahrt, Oberpfaffenhofen, Germany

Contact: Peter Steigenberger, TU München, Arcisstraße 21, D-80333 München, Germany, steigenberger@bv.tum.de

Introduction

QZS-1, the first satellite of the Japanese Quasi Zenith Satellite System (QZSS) was launched in September 2010. Transmission of the standard codes started in December 2010 and the satellite was declared healthy in June 2011. QZS-1 transmits GNSS navigation signals in the L1, L2, L5, and E6 band. The COoperative Network for GIOVE Observation (CONGO) network is a global real time GNSS network operated by Deutsches Zentrum für Luft- und Raumfahrt (DLR), Bundesamt für Kartographie und Geodäsie (BKG), Deutsches GeoForschungsZentrum (GFZ), and Centre National d'Etudes Spaciales (CNES) in cooperation with a number of local station hosts. Five of the currently 22 CONGO stations were upgraded to provide QZSS tracking capability of the L1, L2, and L5 signals. The stations in Chofu, Singapore and Sydney allow continuous QZS-1 tracking whereas the stations in Maui and Tahiti have a visibility interval of 17 and 10 hours per day, respectively.

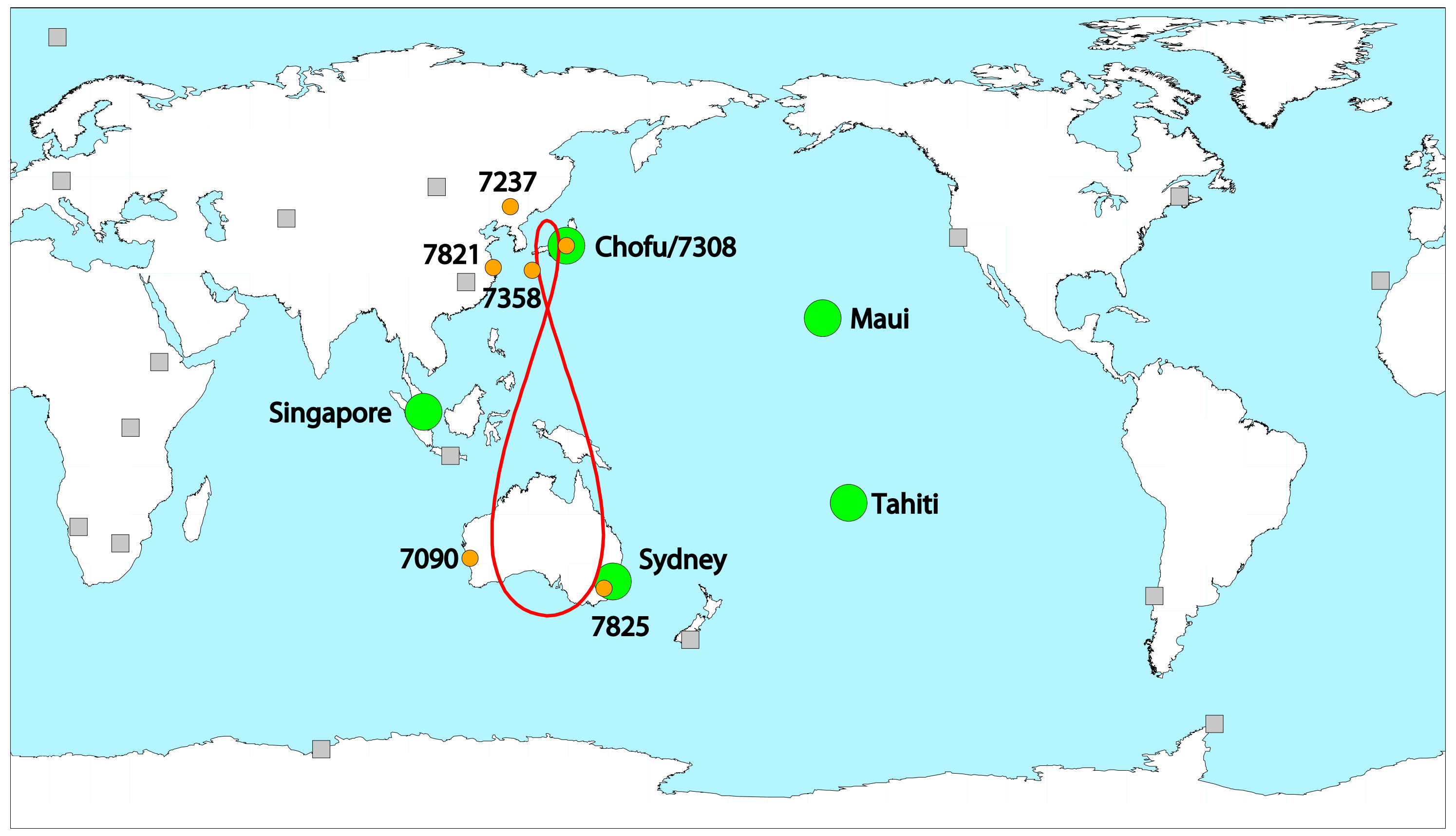

FIGURE 1: Tracking stations of the Cooperative Network for GIOVE Observation (CONGO). QZSS-capable stations are shown as green circles. The QZS-1 ground track is plotted in red, SLR stations tracking QZS-1 in orange.

QZSS Data Processing

The processing scheme for the QZS-1 orbit determination is similar to that of GIOVE-B described in *Steigenberger et al.* (2011). A modified version of the Bernese GPS Software is used to process dual frequency GPS and QZSS tracking data. In a first step, station positions, troposphere parameters, and epoch wise receiver clock offsets are estimated with GPS data only. Code and phase observations are processed simultaneously. The parameters estimated in the first step are kept fixed in the second step, the QZS-1 orbit and clock determination. Epoch wise QZS-1 satellite clock offsets, six Keplerian elements and three, five, or nine radiation pressure parameters of the model of *Beutler et al.* (1994) are estimated per day. The time period from 22 July until 7 September 2011 has been used for the following studies.

Orbit Precision and Accuracy

Different orbital arc lengthes and numbers of radiation pressure (RPR) parameters have been tested to find an optimal parameterization for the orbit determination. The following quantities are used as quality indicators:

Day Boundary Discontinuities: absolute value of the 3-dimensional difference of the orbit positions of two consecutive days at midnight.

2-day Orbit Fit RMS: mean RMS of a 2-day orbit with respect to the two independent orbital arcs.

SLR Residuals: mean and standard deviation of SLR normal points measured by the SLR stations shown in Figure 1.

Arc Length [days]	No. RPR Parameters	Day Boundary Discontinuities [cm]	2-Day Orbit Fits RMS [cm]	SLR Validation STD [cm]	SLR Validation Offset [cm]
3	3	24.3	3.2	36.4	-1.8
	5	16.4	3.1	32.5	−1.7
	9	35.3	7.6	61.9	−1.1
5	3	18.3	2.4	34.3	−0.4
	5	16.7	3.0	33.1	0.4
	9	17.3	4.0	50.1	34.2
7	3	12.7	1.5	34.2	−0.6
	5	16.3	2.6	34.7	3.4
	9	10.9	2.3	39.7	18.2
Broadcast		87.0	15.0	48.4	23.8

TABLE 1: Quality measures of QZS-1 orbits with different arc length and different number of radiation pressure (RPR) parameters. The worst value per column is given in red, the best in green (except for broadcast).

All solutions derived from the CONGO network show a better performance than the broadcast orbits. The number of nine RPR parameters is obviously too high for a network of five stations only: for each arc length, the SLR STD is the largest; largest day boundary discontinuities of the 3-day orbits; significant SLR offset of 5- and 7-day orbits. 3-day and 5-day orbits with 5 RPR parameters have a similar quality level with the best performance in the SLR validation and also good performance in the day boundary discontinuities and orbit fits.

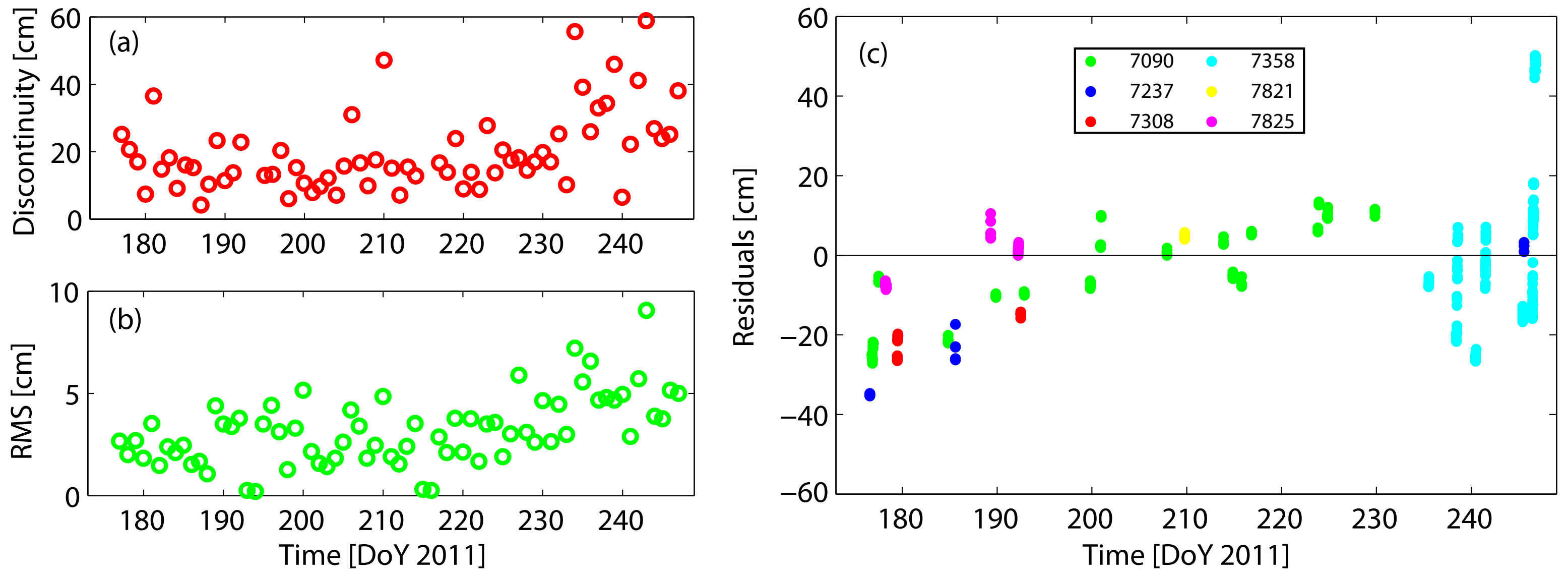

FIGURE 2: Quality measures of 5-day orbits with 5 RPR parameters: (a) day boundary discontinuities, (b) orbit fit RMS, (c) SLR residuals.

Different Frequencies

Ionosphere-free linear combinations of L1/L2 and L1/L5 have been used for the orbit determination. As different observables of GPS and QZSS as well as different frequencies are processed together, biases between the corresponding code observations have to be considered. This is done by estimating differential code biases (DCBs) for all stations except for Chofu, which is constrained to zero. The mean biases and their standard deviations are listed in Table 2. The biases are in the order of a few nanoseconds with a standard deviation usually better than 1.5 nanoseconds. All L1/L2 biases have a larger standard deviation than the corresponding L1/L5 biases.

Frequency	L1/L2		L1/L5	
Station	Mean [ns]	STD [ns]	Mean [ns]	STD [ns]
Maui	−0.95	1.35	−0.27	0.99
Singapore	0.06	1.49	0.19	0.40
Sydney	−1.25	0.65	0.20	0.59
Tahiti	0.12	1.53	2.60	0.97

TABLE 2: Differential code biases of QZS-1 for the ionosphere-free linear combinations of L1/L2 and L1/L5, respectively.

For a selected time interval of two weeks shown in Figure 3, the differences in the estimated orbit positions can reach up to 30 cm in the along-track direction with mean values of 3 cm in radial, −3 cm in cross-track, and 15 cm in along-track direction. The corresponding standard deviations are 3 cm, 12 cm, and 7 cm, respectively.

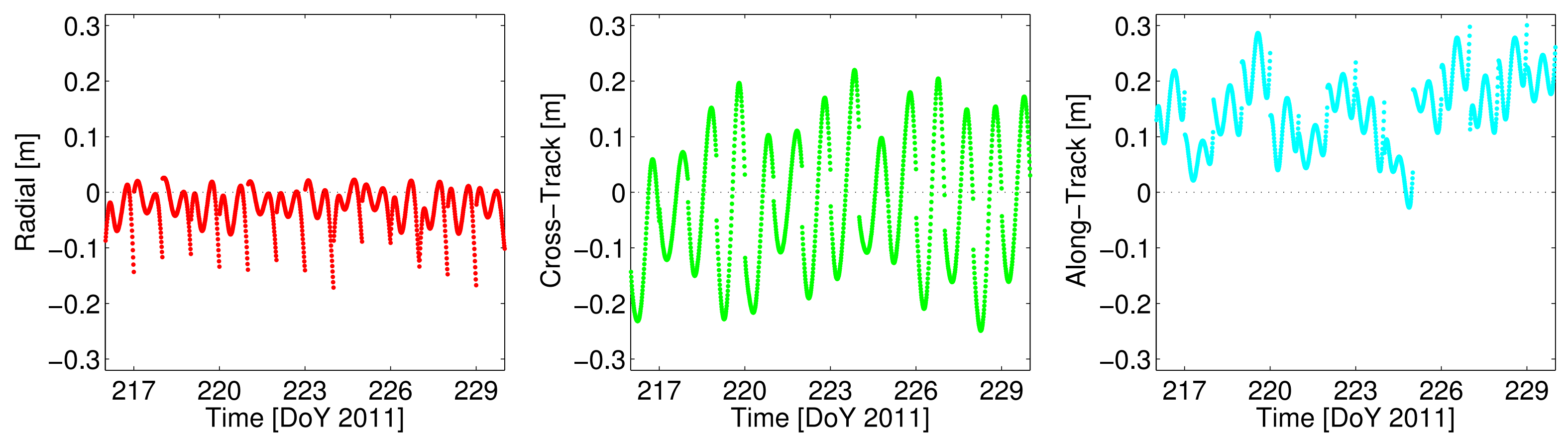

FIGURE 3: Differences between orbits estimated from the ionosphere-free linear combination of L1/L2 and L1/L5, respectively.

Attitude Determination

The Submeter-Class Augmentation with Integrity Function (SAIF) signal of QZSS is transmitted from a dedicated antenna, which is mounted with an offset of approximately 1.34 m from the main antenna. As a result, the yaw attitude of the spacecraft can be estimated, see *Hauschild et al.* (2011). Figure 4 depicts the estimated yaw angle over a period of 48 hours. During this period of time, the satellite performs an attitude maneuver at approximately 9:20 h on 8 September, after the attitude mode has been switched from yaw-steering to orbit-normal.

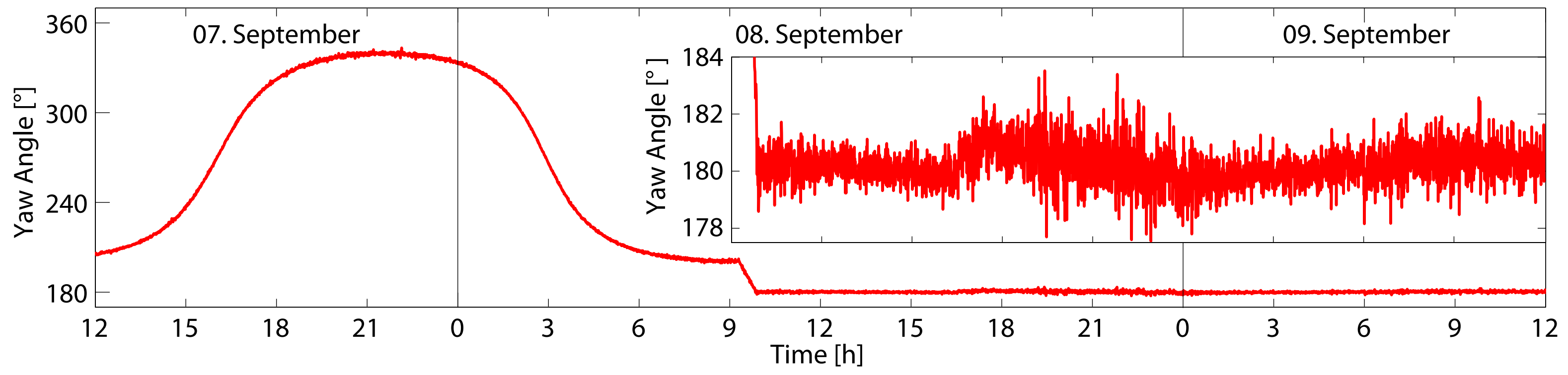

FIGURE 4: Estimated yaw angle of QZS-1 in September 2011.

During yaw-steering, the solar panel axis is oriented perpendicular to the Sun's direction. In orbit-normal mode, the panel axis is kept normal to the orbital plane, resulting in a constant yaw angle. The QZSS satellites switch to orbit normal mode when the angle elevation angle of the Sun with respect to the orbital plane is between −20° and +20° (*Inaba et al.*, 2009). Figure 4 also shows a zoom of the yaw angle estimates during orbit-normal mode to demonstrate the estimation accuracy. Due to the limited number of only 5 stations, the accuracy is in the order of a few degrees and varies over time depending on the station coverage.

Conclusions

QZS-1 orbits were estimated from tracking data of five CONGO stations. Compared to previous studies, the orbit quality could be improved to sub-meter level. The estimated differential code biases have a magnitude of a few nanoseconds. Signal transmission via different antennas allows for an attitude determination with an accuracy of a few degrees.

References

Beutler, G., E. Brockmann, W. Gurtner, U. Hugentobler, L. Mervart, M. Rothacher, and A. Verdun (1994), Extended orbit modeling techniques at the CODE processing center of the international GPS service for Geodynamics (IGS): theory and initial results, *Manuscripta Geodaetica*, *19*, 367–386.

Hauschild, A., P. Steigenberger, and C. Rodriguez-Solano (2011), QZS-1 Yaw Attitude Estimation Based on Measurements from the CONGO Network, in *ION GNSS 2011*, Portland, Orgeon, Georgia, USA, September 20-23 2011.

Inaba, N., A. Matsumoto, H. Hase, S. Kogure, M. Sawabe, and K. Terada (2009), Design concept of Quasi Zenith Satellite System, *Acta Astronautica*, *65*, 1068–1075, doi:10.1016/j.actaastro.2009.03.068.

Steigenberger, P., U. Hugentobler, O. Montenbruck, and A. Hauschild (2011), Precise orbit determination of GIOVE-B based on the CONGO network, *Journal of Geodesy*, *85*(6), 357–365, doi:10.1007/s00190-011-0443-5.