Orbit and Attitude Determination of the First QZSS Satellite

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Introduction

The Japanese Quasi-Zenith Satellite System (QZSS) is a regional augmentation system for Global Positioning System (GPS) users in Asia and the Pacific. QZSS satellites transmit navigation signals in the L1, L2, and L5 band interoperable with GPS. Furthermore, a SAIF (Submeter-class Augmentation with Integrity Function) signal on the L1 frequency and a LEX (L-band EXperimental) signal at 1278.25 MHz (E6) are transmitted. The first QZSS satellite QZS-1 was launched in September 2010 and started to transmit its standard codes in December 2010.

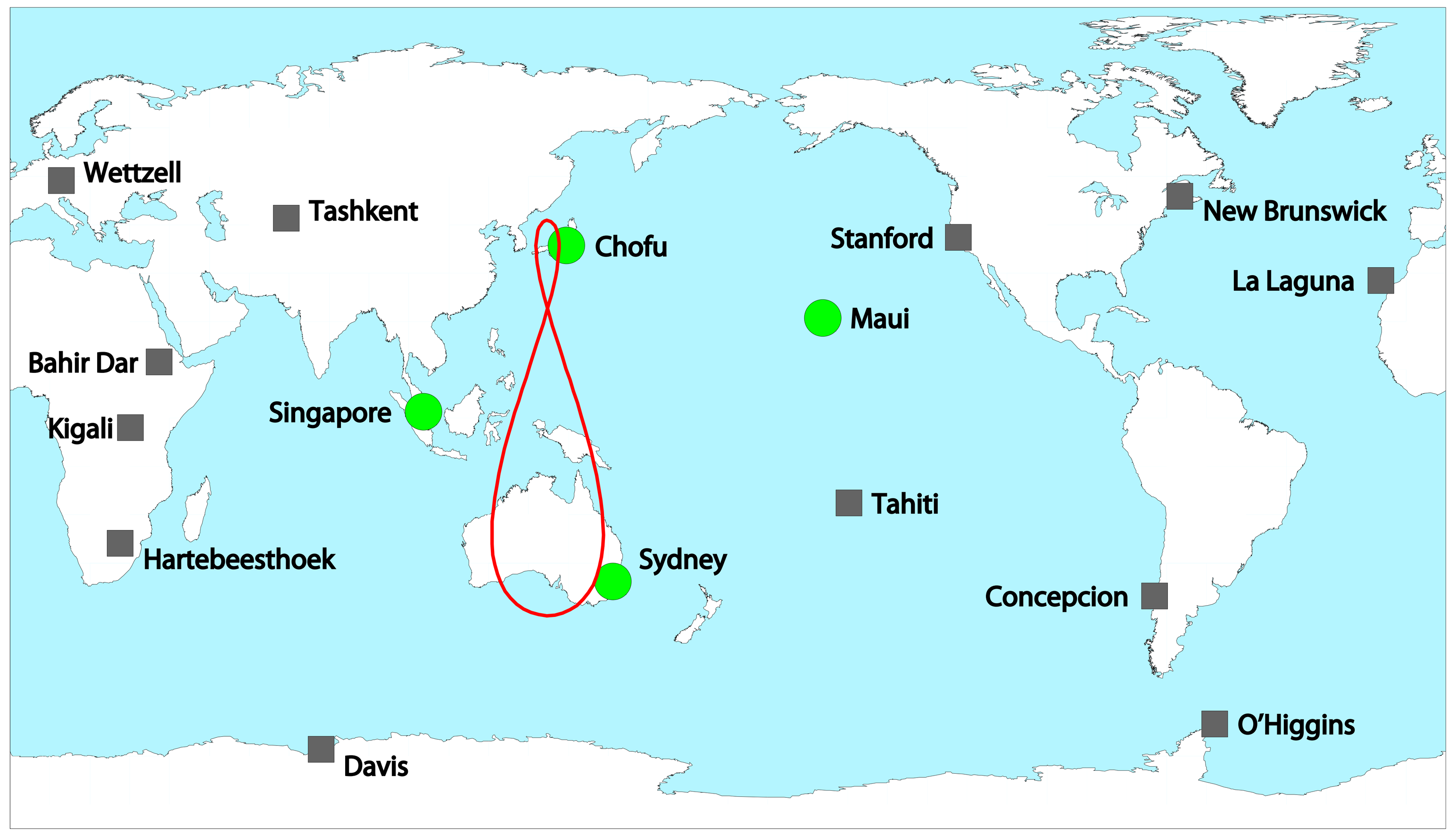

FIGURE 1: Tracking stations of the Cooperative Network for GIOVE Observation (CONGO). QZSS-capable stations are given in green. The QZS-1 groundtrack is plotted in red.

The Cooperative Network for GIOVE Observation (CONGO) was primarily established for GIOVE signal analysis, orbit, and clock determination. It is a global real-time GNSS tracking network of currently 16 stations jointly operated by Deutsches Zentrum für Luft- und Raumfahrt (DLR, Oberpfaffenhofen, Germany), Bundesamt für Kartographie und Geodäsie (BKG, Frankfurt, Germany), and Deutsches GeoForschungsZentrum (Potsdam, Germany) in cooperation with a number of local station hosts. Four Javad Triumph receivers of the CONGO network were recently upgraded with a prototype firmware providing QZSS tracking capability. These receivers are able to track all QZSS signals except for the LEX signal.

Orbit and Clock Determination

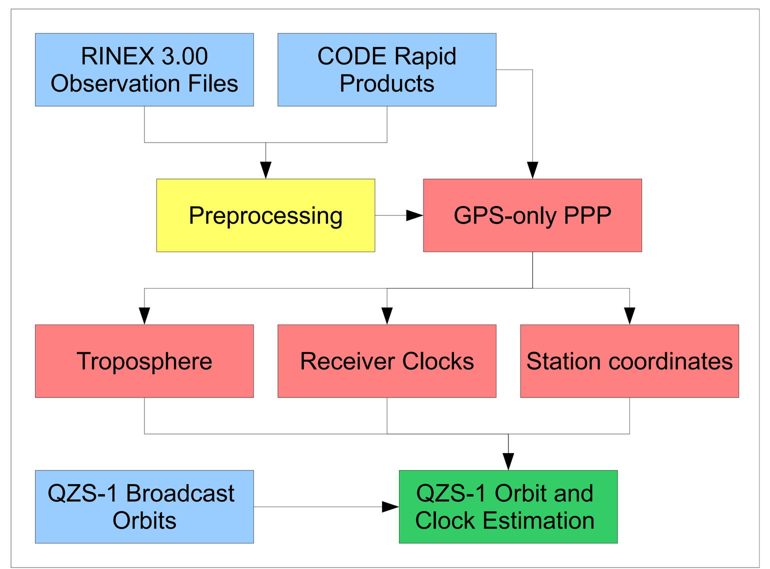

FIGURE 2: QZSS processing scheme.

In a first step, troposphere zenith delays, station coordinates and receiver clock parameters are estimated in a GPS-only precise point positioning (PPP) using the rapid products of the Center for Orbit Determination in Europe (CODE).

These parameters are kept fixed for the QZS-1 orbit and clock estimation based on the ionosphere free linear combination of L1 and L5. In addition, differential code biases are estimated for all stations but one. Normal equations of these 1-day solutions are combined to get 5-day orbital arcs.

Orbit Quality

Satellite Laser Ranging (SLR) residuals provide an independent validation of the broadcast ephemeris (BCEs) transmitted by QZS-1. Altogether 232 normal points are available for the time period 30 November 2010 until 6 March 2011 shown in Figure 3. A clear improvement in the BCEs can be seen at the end of 2010. Whereas the SLR residuals in 2010 can reach several tens of meters, they do not exceed 3 m in 2011 having a standard deviation of 1.02 m. When excluding the solutions affected by an orbit maneuver on 16 February 2011, the standard deviation of the SLR residuals in 2011 for the CONGO-derived orbits is with 1.09 m only slightly worse.

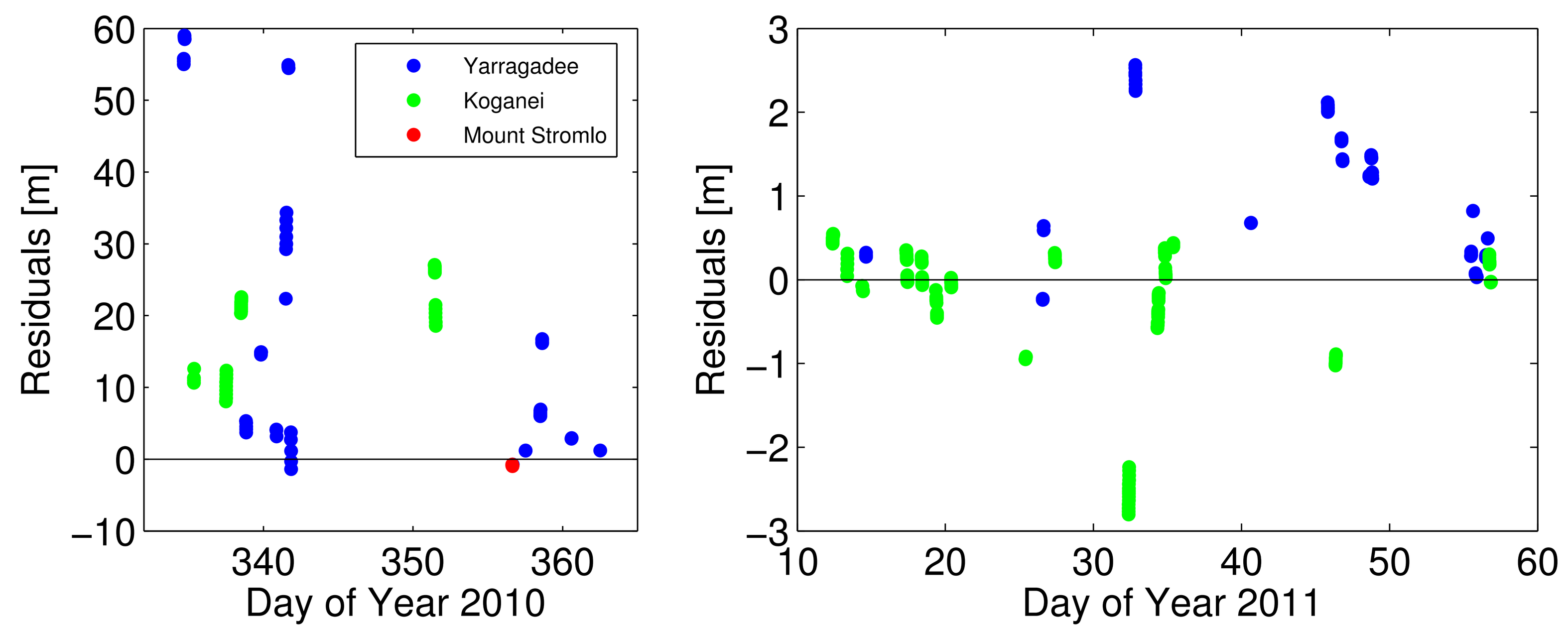

FIGURE 3: SLR residuals of QZS-1 broadcast ephemeris for the stations Yarragadee (Australia), Koganei (Japan), and Mount Stromlo (Australia).

Differences between the orbits determined from the CONGO network and the broadcast orbits for the time period 5 January until 6 March 2011 are shown in Figure 4. The differences are on the several meter level with standard deviations of 2.2 m in radial, 2.4 m in cross-track, and 4.4 m in along-track direction.

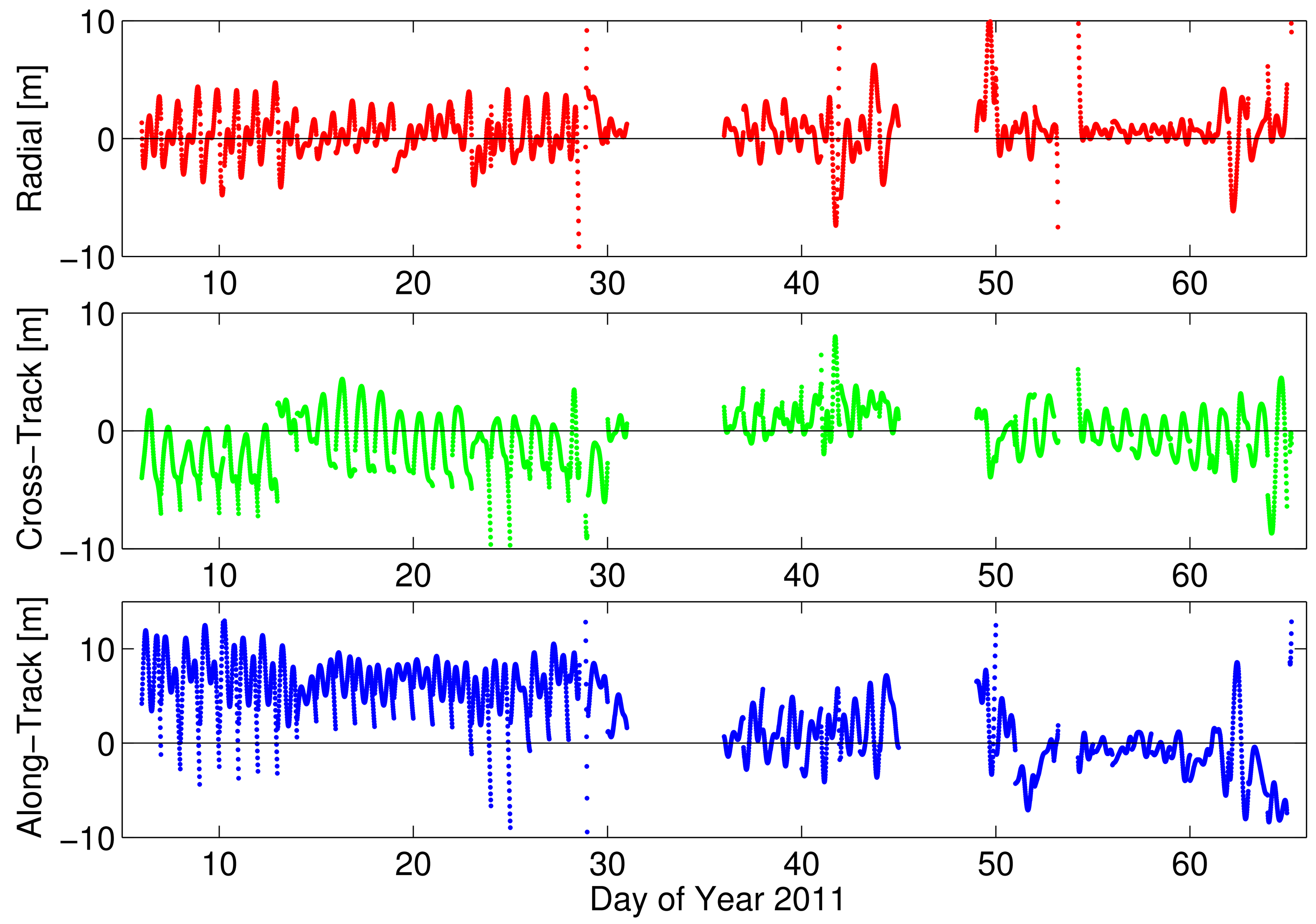

FIGURE 4: Differences between central day of CONGO 5-day orbits and broadcast ephemeris. Days with maneuvers as well as days with QZS-1 transmitting non-standard codes were excluded.

Attitude Determination

QZS-1 transmits the L1 and the L1-SAIF signal via different antennas. The difference between these signals ΔL_i can be used as observable for attitude determination:

$$\Delta L_i = \vec{b} \cdot \vec{e}_i + N_i$$

- i station index
- ΔL_i L1 – L1-SAIF phase observation
- $\vec{b}$ vector pointing from the L1 to the L1-SAIF antenna
- $\vec{e}_i$ unit vector pointing from station i to the satellite
- N_i ambiguity term

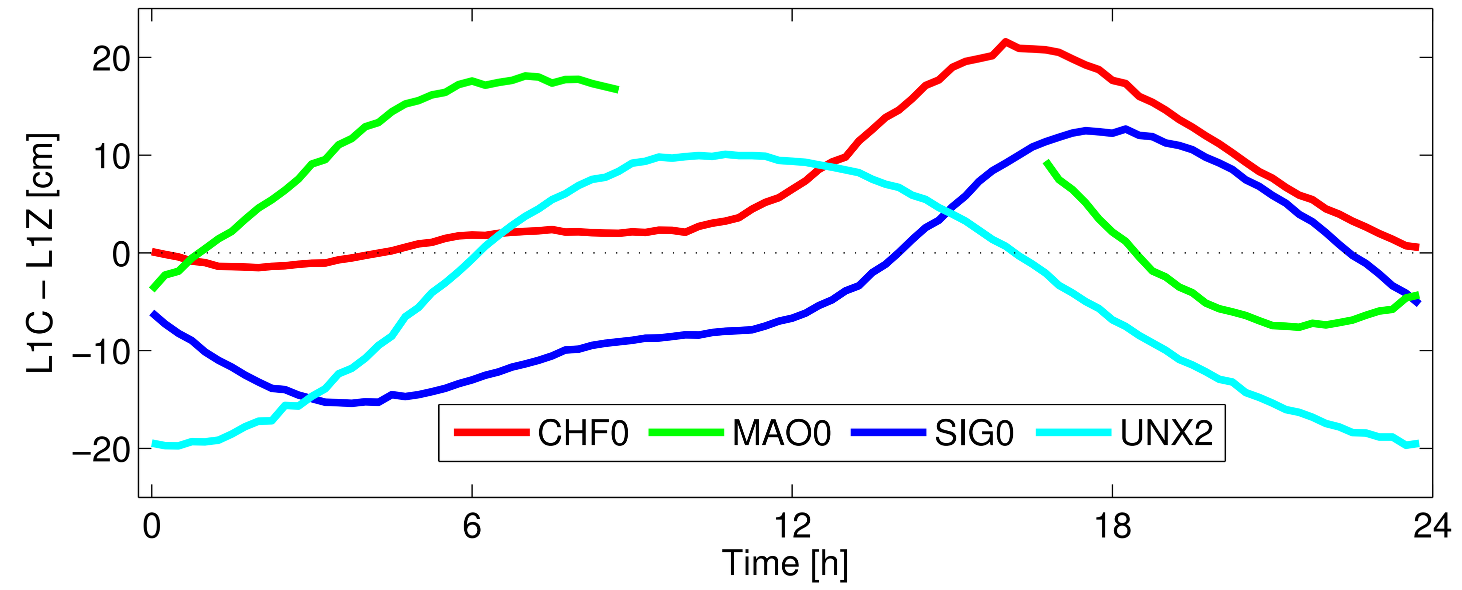

FIGURE 5: ΔL_i = L1 – L1-SAIF for the stations Chofu (CHF0), Maui (MAO0), Singapore (SIG0), and Sydney (UNX2). The observations are already corrected for the ambiguity term.

To stabilize the equation system, a weak constraint of 10 cm is applied, forcing the vector $\vec{b}$ to be perpendicular to the satellite vector. Figure 6 shows the estimated yaw angle as well as the vector length for 5 days in January 2011. The mean vector length is 1.338 m with a standard deviation of 1.8 cm.

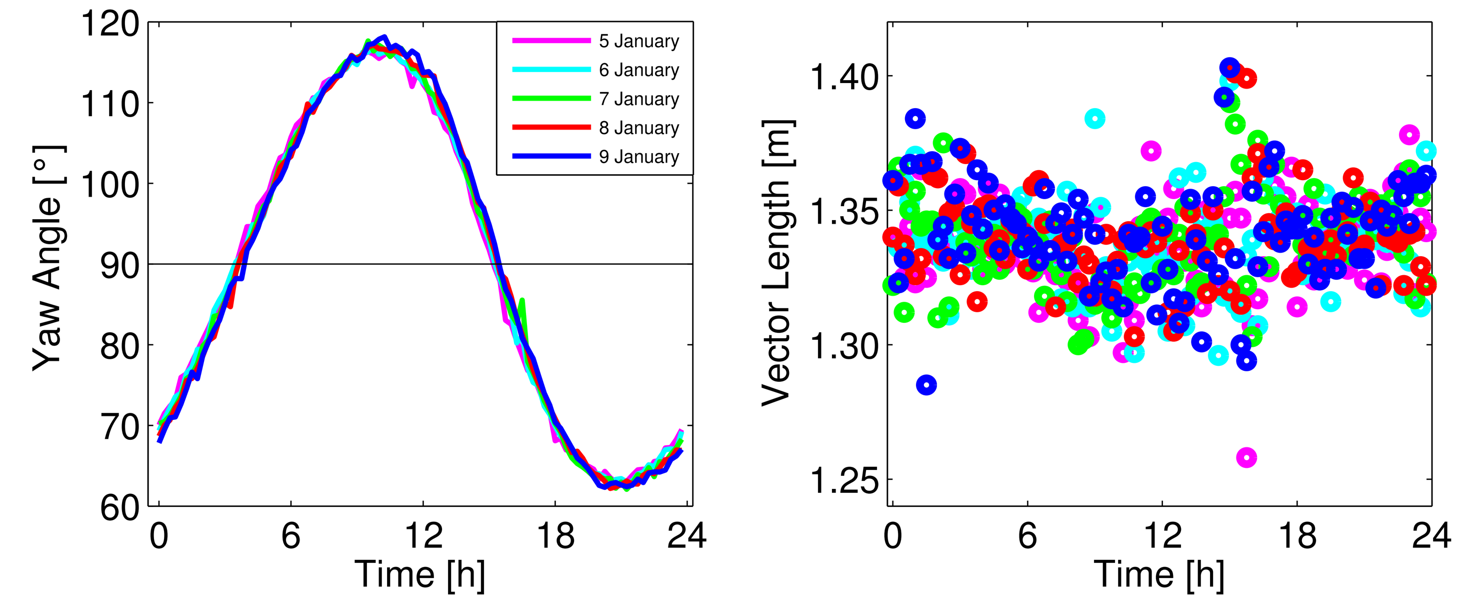

FIGURE 6: Estimated yaw angle (left) and vector length (right) for 5 days in January 2011.

Conclusions

A QZS-1 orbit accuracy of a few meters could be achieved with a tracking network of only four stations. Current orbit determination is degraded by frequent configuration changes of QZS-1 including transmission of non-standard codes, maneuvers, and transmission outages. Signal transmission via two different antennas allows for a direct attitude determination of the satellite. An upgrade of the Tahiti station to provide QZSS tracking capability is planned for the near future.