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Test report of L1-SAIF experiment

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ABSTRACT

The MICHIBIKI satellite transmits the L1-SAIF signal. Since 2014, UNSW has hosted an L1-SAIF receiver (provided by the Electronic Navigation Research Institute, Japan) in order to collect continuous L1-SAIF data over a three month period. In this paper, a report on the L1-SAIF augmented positioning accuracy is presented. Kinematic or static real-time position estimation could not be undertaken as the broadcast ionospheric correction is only valid for Japan. However, epoch-by-epoch post-processed solutions could verify the positioning accuracy. For this paper, 90 days of observation and navigation data from an MGEX station located in Japan was analysed.

Results indicate that there is up to 60% improvement of the position solution when using the correction information broadcast by the L1-SAIF signal. For example, single point positioning solutions from DOY 320 indicate that the GPS-only solution has a 2D RMS of 4.3m, whereas using the L1-SAIF augmentation brings the 2D RMS down to about 1.6m. The height estimate is improved by 40%. The RMS of the pseudorange residuals is 0.628m (using L1-SAIF) whereas the GPS-only solution RMS of the residuals is 1.187m. These results indicate that the L1-SAIF augmented solutions can be used to improve the quality of positioning.

KEYWORDS: QZSS, L1-SAIF, single point positioning.

1. INTRODUCTION

The L1-SAIF (Submeter-class Augmentation with Integrity Function) development is undertaken by ENRI (Electronic Navigation Research Institute, Japan), and is intended to provide wide area differential correction information to GPS uses with a target accuracy of 1m (horizontal). In addition to the messages being fully compatible with those of SBAS, L1-SAIF transmissions includes additional special messages. The L1-SAIF messages have a structure as shown in Figure 1.

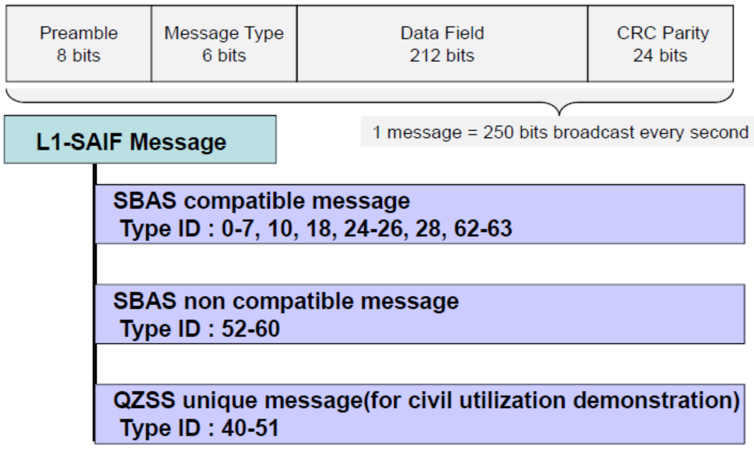

Figure 1. Structure of L1-SAIF messages (SPAC, 2012)

This research aims to investigate potential augmentation by L1-SAIF services in Australia. The L1-SAIF messages from QZSS (Quasi-Zenith Satellite System) and MSAS (MTSAT Satellite-based Augmentation System) and QZSS (Quasi-Zenith Satellites System) were collected at two stations in Sydney and Melbourne during the project period. In particular there is a continuous data collection period during September to November in 2014. As a first step of this investigation, the visibility of the QZSS and MSAS satellites in Australia had to be evaluated from the collected data. This study can provide a pattern of the real L1-SAIF signals in Australian region – what the transmitting satellite visibility is, and what is its signal strength.

The magnitude of the ionospheric delay depends on the latitude of the receiver, the elevation of the satellite in view at the time of observation, the season, the time of day, and the level of solar activity. Delay from satellites overhead can be as high as several tens of metres. The elevation angle to the satellite is quite significant since delay increases with lower elevation angles; up to about five times greater near the horizon than overhead (UNAVCO, 2014). This is largely due to the longer signal path through the ionosphere.

Provided that a MSAS or QZSS satellite is visible to the MSAS/QZSS reference station network for tracking purposes, orbit and timing error corrections will be available for that satellite. Ionosphere corrections for that satellite are only available if the signal passes through the ionospheric map provided by MSAS or QZSS (eg. the L1-SAIF ionospheric map covers Japan and nearby region). As QZSS and MSAS satellites are visible in the northwestern quadrant of sky in Australia, the transmitting satellite has a low elevation angle. This may cause additional difficulty in estimating ionospheric corrections in the Australian region because of the phenomenon of the "Equatorial Anomaly".

This study is part of an investigation of methodologies to extend the service area of the Japanese MSAS and QZSS L1-SAIF to the wider Asian region. The MSAS geostationary satellites and the IGSO (Inclined Geosynchronous Satellite Orbit) satellites of QZSS cover both hemispheres, including Australia, therefore both systems could provide augmentation to the Asia and Oceania regions simultaneously. Among problems to be investigated are the reception characteristics of the MSAS and L1-SAIF signals.

2. EXPERIMENT SETUP

The JAVAD ALPHA GNSS receivers were used for the tests in Sydney. The JAVAD NetView program (Javad, 2012) was used to configure the receivers and to store the data onto the hard disk of the host computer via a serial port. The Leica AS10 SmartTrack antenna was installed at the Sydney station. This compact antenna with built-in ground plane enables GPS, GLONASS, Galileo, BeiDou and SBAS signal tracking for a wide range of precision applications. The setup is shown in Figure 2 and Figure 3.

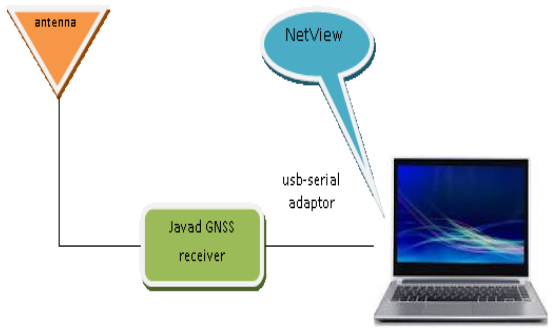

Figure 2. Devices configuration in the data collection tests

Figure 3. Antenna setup at Sydney station

The GNSS raw measurements were recorded in the binary format of the JAVAD protocol (Javad 2012), and included GPS, GLONASS, Galileo, QZSS, and MSAS data. The update rate was configured as 1Hz. Measurements and other data, such as GPS time, signal level for GPS and L1-SAIF signals, carrier phase observations for GPS and L1-SAIF signals, pseudorange for GPS and L1-SAIF signals, PRN for GPS and L1-SAIF signals, navigation message for GPS signals and augmentation message for L1-SAIF signal were recorded.

Three-month continuous data logging was conducted in Sydney and Melbourne at the same time during the period 1 September – 30 November 2014. The operation was mostly running smoothly, except for some data collection interruptions due to a power outage. In this work, the Sydney station's data is processed and analysed.

3. DATA ANALYSIS

3.1.SAIF visibility and signal level analysis

The SNR (signal-to-noise) level, code-phase multipath, and elevation are plotted against time using RTKPlot (an application of RTKLib software (Takasu, 2009), as shown in Figure 4 to 9. The dates are 01/09/2014, 01/10/2014 and 01/11/2014.

From these plots it can be seen that the SNR and MP (code-phase multipath) of the L1-SAIF and L1C are similar. They have the same trend – the lower the elevation the smaller the SNR, and the lower the SNR the higher the MP. This is as expected. The same results are were obtained for all other days at the Sydney station. There were multiple instances of data gaps, largely due to missing observations in the RINEX files, obtained after conversion from the logged L1-SAIF data. Data gaps on 2014-11-01 at the Sydney station for L1-SAIF are a data transmission issue. According to the JAXA (Japan Aerospace Exploration Agency) website, SPAC-provided L1-SAIF should be transmitted. After converting this day's logged data file to RINEX, it was found that there were no L1-SAIF observations and all L1-SAIF messages contained null information. Furthermore it can be seen that the L1-SAIF data experienced more interrupts than the L1C data. Interrupts of the L1-SAIF and L1C data are similar, which were caused by QZSS satellite J01's setting down below the horizon. The visibility of QZSS is indicated in **Table 1**.

Date/invisibility	Sydney
2014-09-01	visible over 24 hours
2014-10-01	7:00 – 9:00am
2014-11-01	4:00 – 7:30am

Table 1. Visibility of QZSS J01 from Sydney

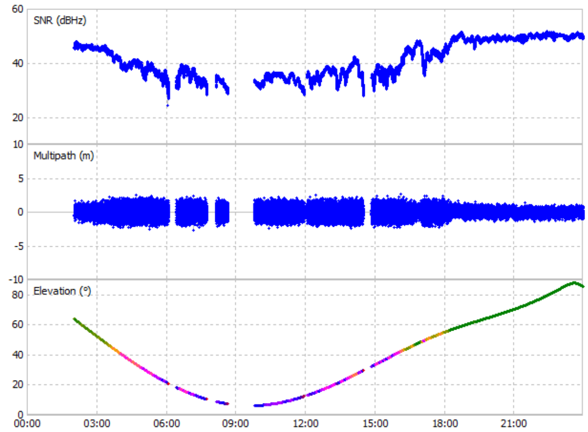

Figure 4. Visibility of L1-SAIF of QZSS J01 on 2014-09-01 at the Sydney station

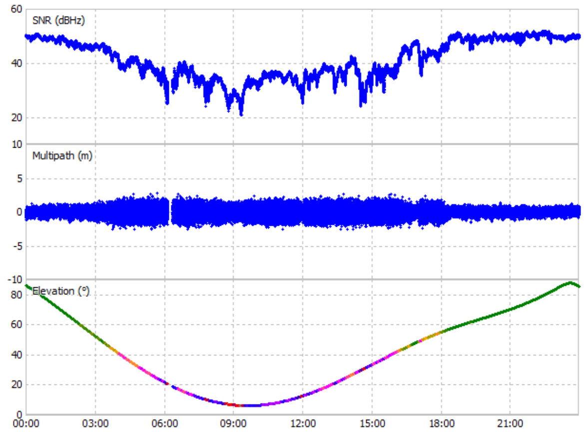

Figure 5. Visibility of L1C of QZSS J01 on 2014-09-01 at the Sydney station

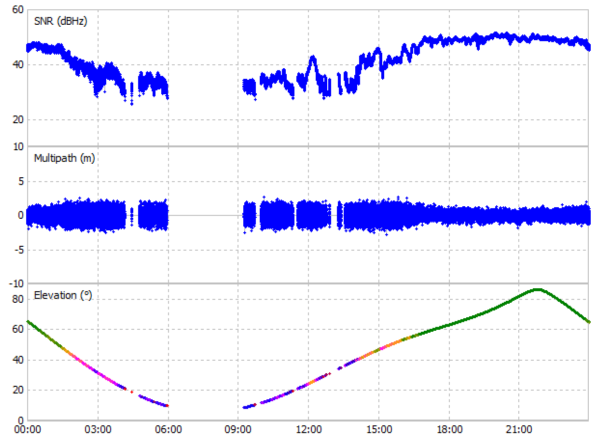

Figure 6. Visibility of L1-SAIF of QZSS J01 on 2014-10-01 at the Sydney station

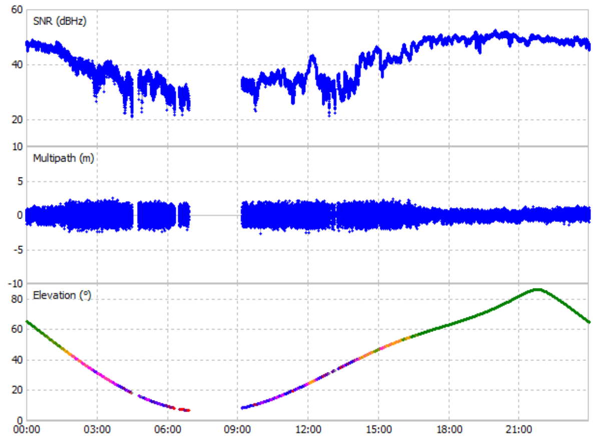

Figure 7. Visibility of L1C of QZSS J01 on 2014-10-01 at the Sydney station

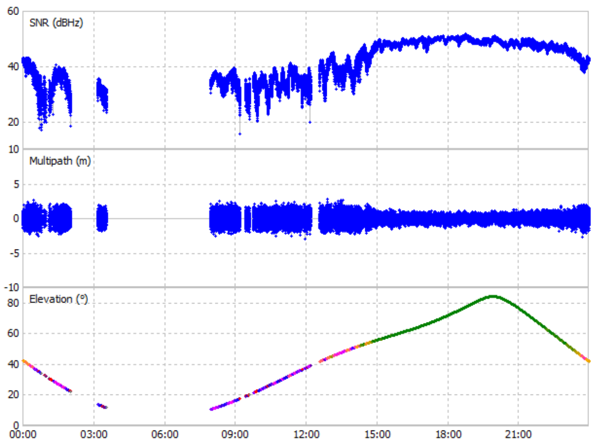

Figure 8. Visibility of L1C of QZSS J01 on 2014-11-01 at the Sydney station

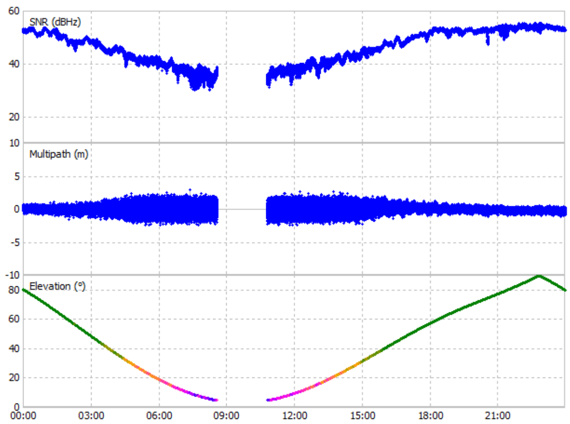

Figure 9. Visibility of L1-SAIF of QZSS J01 on 2014-09-01 at the Sydney station

3.2.Positioning accuracy

The corrections from L1-SAIF are only useful in Japan as the L1-SAIF correction messages presently are only valid for Japan. As a result, a trial was conducted with the observation data (i.e. RINEX files) from 1st September 2014 to 30th November 2014 from the CHOF IGS MGEX station (Latitude = 35.674544627°, Longitude = 139.531062437° Height=93.943m) in Tokyo, Japan. It is worth noting that the L1-SAIF correction data was not transmitted every day during the experiment period. As a result only those solutions when the L1-SAIF correction messages were available were analysed. Position solution is estimated using the single point positioning method (SPP) with the parameters as listed in Table 2.

	Standard	L1-SAIF
Software:	RTKLIB V2.4.2 (Takasu, 2009)	
Positing mode	Single point	
Ionosphere Correction	Broadcast	L1SAIF
Troposphere correction	Saastamoinen	Saastamoinen
Satellite Ephemeris	Broadcast	Broadcast +L1SAIF

Table 2. Data processing parameters

Figure 10 and Figure 11 show position comparisons with L1-SAIF correction (i.e. SPP+L1SAIF) and without L1-SAIF correction (i.e. SPP). The improvement in position quality using the L1-SAIF augmentation is clearly seen. From three months of data, the SPP solution results in 3.4±2.5m (1σ standard deviation) 3D (East, North and Height) accuracy, whereas the L1-SAIF corrected position solution results in 1.8 m± 0.8 (1σ level) 3D accuracy. Improvement of 62.5% is observed for the 2D (East-North) accuracy: 2D accuracy is 0.66±0.5m and 1.76±1.4m with L1-SAIF corrections and without L1-SAIF corrections, respectively. In addition to 2D, the height determination is also improved by approximately 93% when using L1-SAIF corrections. The height accuracy was 0.66±1.15m and 1.63±2.95m with L1-SAIF corrections and without L1-SAIF corrections, respectively. In addition the standard deviation improves significantly for both 2D and 3D solutions, which implies that using L1-SAIF corrections will generate a more precise solution than in the case of no L1-SAIF corrections.

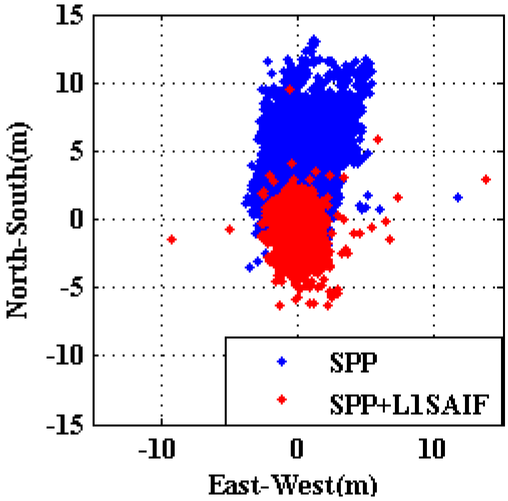

Figure 10. 2D position errors

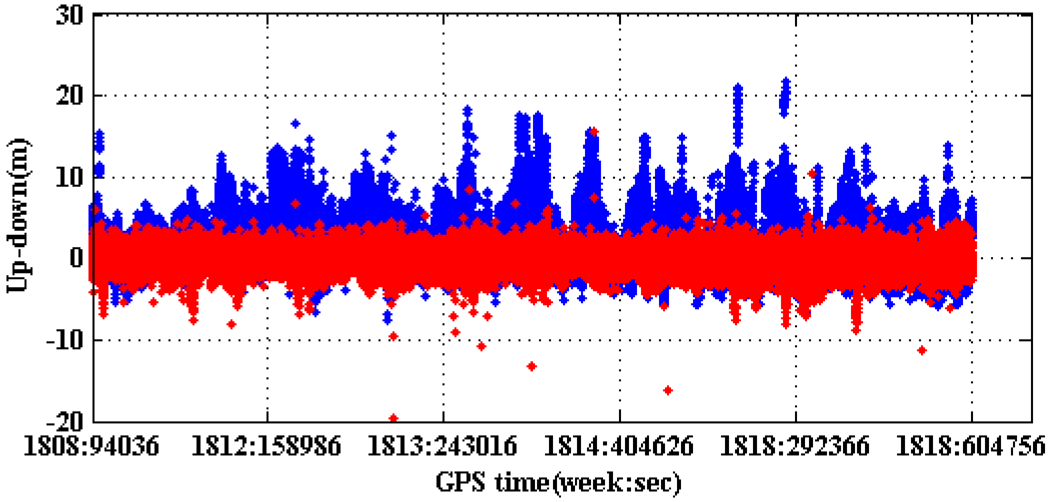

Figure 11. Height errors

The position quality in terms of measurement residuals for one day were analysed in order to gain a better understanding of the impact of the L1-SAIF correction information. For this purpose DOY (day of year) 244, in 2014 (1st September) was selected. Figure 12 shows the position accuracy. It can be seen that for all position components (i.e. East, North and Height) the L1-SAIF solution is more precise and more accurate. It should be noted that the L1-SAIF correction message were not available for 17.8% of the time due to the low elevation angle. The residuals of the solutions are shown in Figures 13 and 14. It can be seen that the residuals with the L1-SAIF corrections applied are smaller.

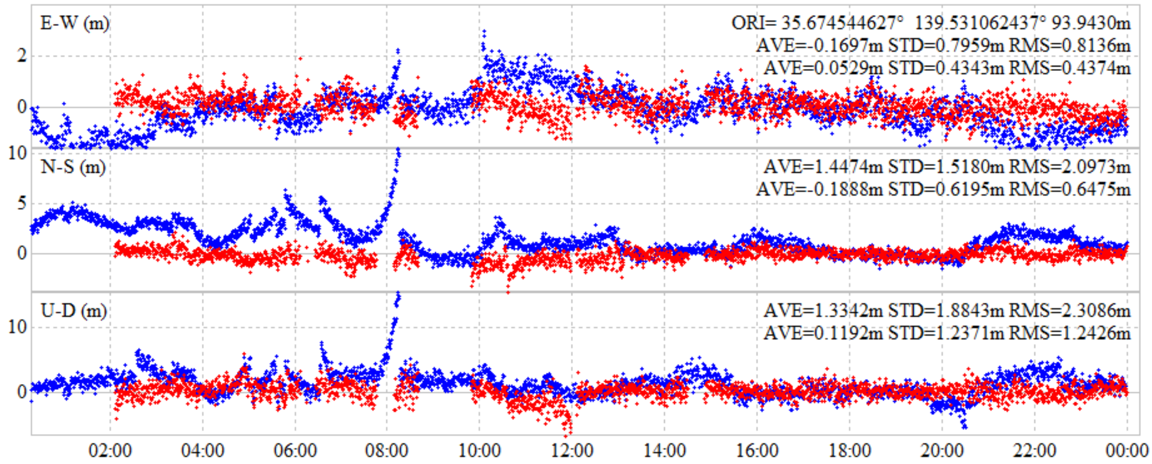

Figure 12. Single point position of the CHOF station. BLUE =without L1-SAIF, RED =L1-SAIF

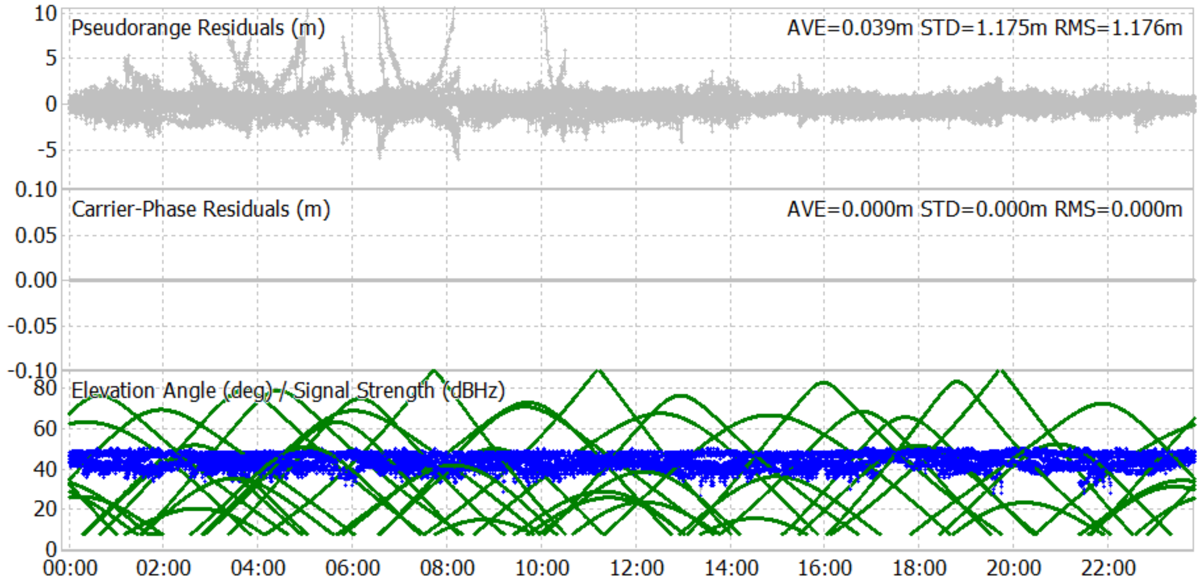

Figure 13. Pseudorange residuals of the position solution without L1-SAIF

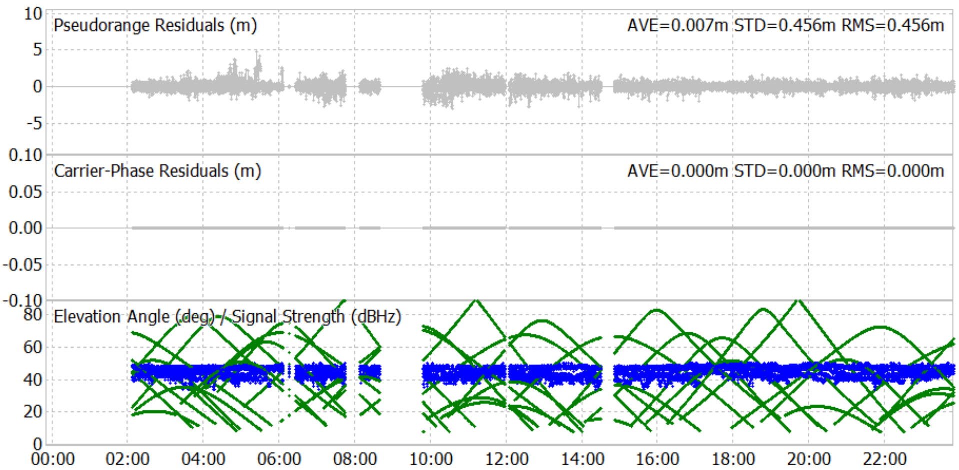

Figure 14. Pseudorange residuals of position solution with L1-SAIF

4. CONCLUDING REMARKS

The 3-month continuous data collection campaign was conducted during September to November 2014, in both Sydney and Melbourne. The data have been analysed in order to investigate the visibility and signal strength of the L1-SAIF signal in Australia. This data along with CHOF IGS MGEX station data are used to analyse the quality of L1-SAIF supported positioning. Some concluding remarks can be drawn:
(1) The L1-SAIF signals can be received for most of the day, except (a) when the QZSS satellite sets below the horizon; (b) a tree near the antenna at the Sydney station blocked low elevation signals from the north west direction.
(2) The L1-SAIF signal is strong, with SNR > 40dB for most of the time at the Melbourne station with an unobstructed sky view. SNR >40dB during the time when the QZSS satellite was at a high elevation was also observed at the Sydney station.
(3) The SNR and multipath of L1-SAIF and L1C are similar. They have the same trend – the lower the elevation the smaller the SNR, and the lower the SNR the larger the MP.
(4) The ionospheric delay as broadcast by the L1-SAIF signal from QZSS can improve the position solution quality.

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