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SHORT COMMUNICATION

QZSS Regional Navigation System Visibility and Solution Experience from India

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Abstract In a multi-GNSS environment, users are exploiting the benefits of hybrid multi-constellation GNSS operation for redundancy and enhanced solution quality. The Indian geolocation helps in signal availability from all global and regional systems, but no study on the usability and advantages of the Japanese Quasi-Zenith Satellite System (QZSS) is made from India. This work presents the first results on the availability and advantages of QZSS from India based on simulations and real-time data. It is observed that 2–4 QZSS satellites can always be used from India. In static Single Point Positioning (SPS), QZSS in hybrid operation provides better solution quality over any single global constellation operation and GPS + Galileo + QZSS provides around 1 m 2-dimensional solution precision. The results would be useful for Indian GNSS user community.

Keywords GNSS · QZSS · Solution quality · Multi-GNSS

Significance Statement In multi-GNSS, users utilize hybrid operation to exploit the advantages. Based on the experience of regional navigation systems' advantages, for the first time the usability and advantages of the regional QZSS developed by Japan is explored from India. Potentials and advantages of QZSS from India are demonstrated through the results.

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Global Navigation Satellite System (GNSS) is currently being used in myriads of applications catering the needs of users for various precision, cost and capabilities. GPS (USA), GLONASS (Russia), Galileo (European Union) and BeiDou (China) provides Global Position, Navigation and Timing (PNT) services, while the Quasi-Zenith Satellite System (QZSS, Japan) and Navigation with Indian Constellation (NavIC/IRNSS, India) are designed to offer service to the regional users in and around the respective countries [1, 2]. In a multi-GNSS environment, users are interested in the concurrent use of two more systems to exploit the benefits of redundancy, improved satellite geometry and solution quality [3]. The regional systems provide opportunity of hybrid operation within the corresponding service areas with definite advantages [2–4]. India is situated in a typical geographical location, wherein signals from all the global and regional navigation systems are available [3]. Though the usability and benefits of GPS, GLONASS, Galileo and BeiDou from India has been studied [4, 5], no such detailed study can be found for QZSS. In [3] the advantage of QZSS from a global perspective has been presented together with IRNSS/NavIC. QZSS is a system that augments visibility using satellite placed in highly elliptical orbits and Geostationary Earth Orbit (GEO) [6]; therefore, it would be interesting to study the QZSS visibility and advantages from India, that has been done in this manuscript through well-validated simulation and real-time data. The manuscript is a novel study on the QZSS from India and is organized with a brief introduction on QZSS at the beginning, followed by the results of the simulation study on QZSS visibility over entire India. Finally, results on the advantages of using QZSS in hybrid operation with other global constellations are presented based on real-time data.

QZSS, a Japanese 4-satellite regional satellite system is developed to provide precise and stable PNT services in the Asia-Oceania regions with obvious focus over Japan. In 2002, government of Japan authorized the development as a 3-satellite regional augmentation system; the first satellite was launched on September 11, 2010. In March 2013, the expansion of QZSS to a 4-satellite system was announced and the basic 4-satellite system was declared operational on November 1, 2018. The QZSS consists of 3 periodic Quasi-Zenith Orbit (QZO) satellites with perigee and apogee altitudes of about 32,000 km and 40,000 km respectively, and 1 geostationary orbit satellite (QZS03). QZSS is designed to have at least 1 QZO satellite for more than 12 h a day with an elevation angle above 70° over Japan [7]. An operational GPS-independent regional system is planned for 2023 with 7 satellites and toward that direction, QZS1R satellite has been launched on October 26, 2021 and started operation in end of March 2022 [8]. Eight signals in 4 frequencies (L1, L2, L5 and L6) are transmitted from the QZSS satellites those include the conventional PNT, Submeter Level Augmentation Service (SLAS), Centimeter Level Augmentation Service (CLAS), Positioning Technology Verification Service (PTV) and Submeter-class Augmentation with Integrity Function (SAIF) services [7].

With this background, this unique study on the usability of QZSS from India is taken up. To begin with, an in-depth simulation on the visibility of QZSS from India is made. *Orbitron* [9] is a popular freeware for generation of accurate satellite visibility information from any location based on the current Two-Line Element (TLE) set file(s) in North American Aerospace Defense Command (NORAD) format for any satellite or constellation [10]. With the updated QZSS TLE files from the Celestrak Website [11] during mid-February 2022, the look angles of QZSS satellites from different locations of India are calculated using *Orbitron* and the consolidated results are presented in Figs. 1 and 2. As shown in Fig. 1, 8 points (1–8, shown as green circles) on the extreme geographical boundaries and point 9 in the central India are selected as simulation locations on the main Indian landmass. Using *Orbitron*, the maximum elevation angle contours for each of the QZSS satellites are shown over the Indian landmass and the maximum and minimum QZSS satellite visibility for the 9 simulation locations are calculated. In Fig. 2, the individual QZSS satellite visibility from each of the cardinal points (locations 1, 3, 5 and 7) are shown against UTC time for 10° elevation mask.

Close inspection of the simulated elevation contour lines of QZSS satellites over India, individual and cumulative QZSS visibility results presented in Figs. 1 and 2 reveals that, QZS3, placed in GEO has a constant visibility from most part of India above 20° elevation angle. The Figs also show that, at any time, 1 or more QZSS QZO satellites would be visible for use from most parts of India; the satellite visibility variation graphs in Fig. 1 confirms that except for the north-western part of India, at least 3 QZSS satellites are always available for use above 10° elevation angle; in the west to northern parts, only for small durations of the day, 2 satellites would be visible. As the QZSS constellation is designed to have the maximum satellite visibility from higher elevation angles from the QZO orbits, from India, most of the time these satellites would be visible for use

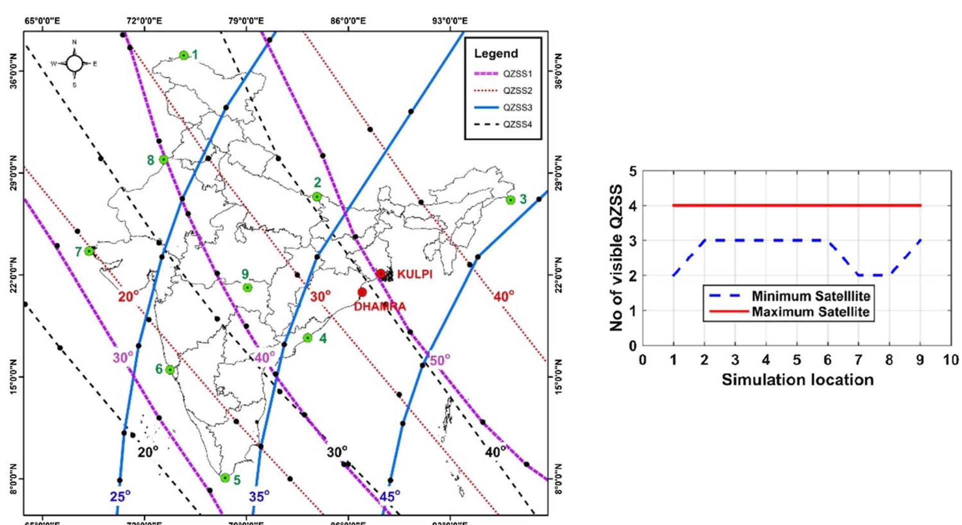

Fig. 1 Maximum Elevation angle contours of QZS1, 2, 4 (QZO) and QZS3 (GEO) satellites over India, simulation locations (green circles with numbers) and two data recording locations (red circles without number) (left) and QZSS satellite visibility plots for the simulation locations (right) (color figure online)

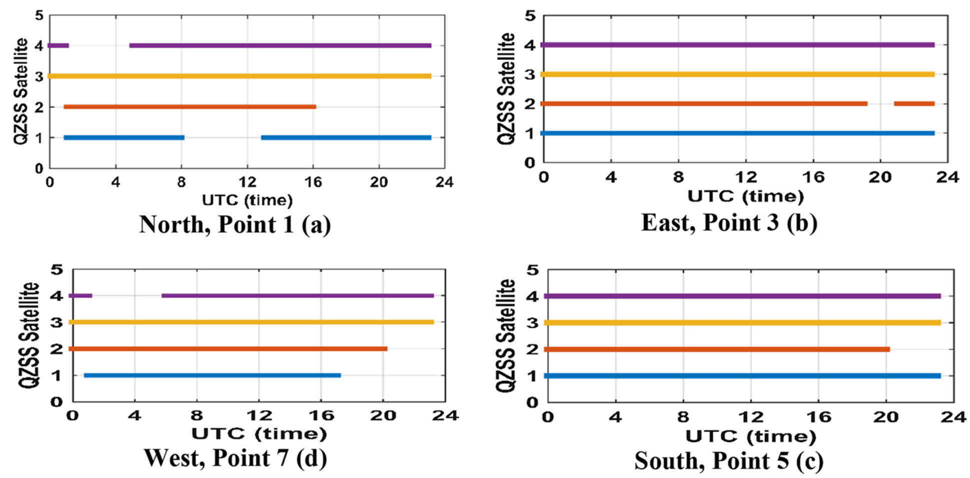

Fig. 2 QZSS individual satellite visibility simulation (10° elevation mask) for 4 extreme points of India (clockwise from top) **a** North **b** East **c** South and **d** West

with other constellations concurrently. This extensive and well-planned simulation study presents the QZSS satellite visibility from India for the first time.

The next part of the work is based on real-life data collected from two locations in eastern India- Kulpi (22.0832° N, 88.2442° E, −42.5 m) and Dhamra (20.7966° N, 86.9064° E, −52.95 m) as shown as red circles without number in Fig. 1, by combining global constellations with QZSS to study the benefits in position quality. A compact (~10 gm, 4 cm × 2 cm), low-cost (<100 USD), single frequency (CLS) GNSS module (uBLOX M8T) [12] with a commercial patch antenna is used at both the locations to collect multi-GNSS, data @1 Hz for different GNSS constellation combinations. Data for standalone and hybrid GNSS modes using QZSS with each of the GPS, GLONASS and Galileo constellations were collected between February and July 2021. Precision parameters of Horizontal (2 dimensional (2d)) and 3-dimension (3d) are calculated as per [13]; maximum and standard deviation of East, North and Up errors for different constellation combinations results are shown in Table 1.

The real-time data from the two locations firstly confirms the applicability of the simulated results. From Table 1, it may be witnessed that QZSS when used in tandem with any global constellation in static single point positioning (SPS) purpose, provides better solution quality. It is also seen that,

Table 1 Static GNSS solution quality parameters for standalone and hybrid GNSS solutions from Kulpi and Dhamra, India, Data volume: 3600 epochs @1 Hz in each mode, February-July, 2021

Location (Max/Min QZSS used)	Mode	Precision (m)				Standard deviation (m)			Peak to peak deviation (m)		
		Vertical		Horizontal							
		2DRMS	CEP	SEP	MRSE	East	North	Up	East	North	Up
Kulpi (4/3)	GPS	1.43	0.58	1.26	1.66	0.34	0.62	1.50	5.955	6.037	9.3
	GPS + QZSS	1.06	0.44	1.09	1.49	0.38	0.36	1.39	3.707	4.960	6.8
	GLONASS	2.58	1.03	1.95	2.42	1.09	0.68	2.04	6.350	7.611	19.9
	GLONASS + QZSS	1.98	0.83	3.78	6.10	0.61	0.77	6.02	5.869	6.815	43.1
	Galileo	1.40	0.58	1.32	1.74	0.48	0.50	1.59	6.389	7.796	18.2
	Galileo + QZSS	1.38	0.56	1.08	1.36	0.35	0.59	1.17	3.827	4.704	9.0
	GPS + Galileo + QZSS	1.02	0.40	0.69	1.18	0.39	0.45	1.02	1.870	1.870	5.9
	GPS + GLONASS + Galileo + QZSS	1.44	0.60	1.22	1.89	0.50	0.49	1.40	4.582	5.444	7.399
Dhamra (4/3)	GPS	1.37	0.55	1.02	1.27	0.31	0.61	1.07	3.359	3.555	6.2
	GPS + QZSS	1.14	0.47	0.93	1.06	0.27	0.19	0.57	2.111	3.515	4.3
	GLONASS	1.67	0.63	0.99	1.49	0.76	0.32	0.86	10.631	3.852	17.1
	GLONASS + QZSS	1.29	0.54	1.10	1.37	0.43	0.47	1.24	5.177	5.426	8.299
	Galileo	1.65	0.68	1.06	1.24	0.65	0.51	0.92	3.497	4.426	8.2
	Galileo + QZSS	1.38	0.53	1.01	1.75	0.34	0.23	0.63	3.445	1.148	4.70
	GPS + Galileo + QZSS	1.09	0.38	0.59	1.22	0.20	0.27	0.47	1.333	1.018	2.200
	GPS + GLONASS + Galileo + QZSS	1.43	0.59	1.11	1.38	0.54	0.46	1.17	5.818	2.259	6.4

even using a low-cost GNSS module-antenna combination, in GPS + Galileo + QZSS hybrid operation, around 1 m 2d solution precision is achievable. Another important observation is relatively worse performance when GLONASS is included in such solutions; for channel-constraint GNSS hardware operation, the results would be useful for selection of best possible GNSS constellation combination.

GNSS is extensively used for real-time applications which requires precise position solution quality in a competitive price. Therefore, the system developers on one hand may exploit the benefit of multi-constellation SPS using the CLS GNSS modules or may use techniques like Precise Point Positioning (PPP) that requires external augmentation data to enhance the local solution accuracy. This novel study on the QZSS usability from India presented here clearly shows that, QZSS as a regional service can offer both types of advantages. When used together with any other global constellations, QZSS would help in obtaining higher precision in SPS mode at a lowcost. QZSS is planned to provide Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis (MADOCA) [14] service for higher precision through real-time PPP, wherein the correction information would be provided through the L6 satellite signal, and higher precision would be achievable at a lower cost and latency than conventional PPP. This study confirms the availability of QZSS signal from entire India to exploit the benefit for low-cost, real-time PPP in future. Therefore, the results of this unique effort would be beneficial to the GNSS user community of India.

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