IGS-MGEX: QZSS Orbit and Clock Determination

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Quasi-Zenith Satellite System (QZSS)

- Japanese regional augmentation System for GPS in the Asia and Pacific region
- Launch of QZS-1 in September 2010, PRN J01
- Inclined Geosynchronous Orbit (IGSO)
QZSS Attitude Modes

Yaw Steering Mode

- Varying yaw angle to enable Sun pointing solar panels
- Similar to GPS, but +x to deep space

Orbit Normal Mode for $|\beta|<20^\circ$

- Solar panel axis normal to orbital plane

Current Status and Future Plans

- Application demonstrations and R&D activities have being conducted using the first satellite.
  - JAXA is developing the Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis (MADOCA) for PPP applications
- Japanese Government decided to move the QZSS program to the second stage
  - 2 additional IGSO satellites and 1 GEO satellite will be launched in 2017
  - No Orbital Normal mode on IGSO satellites
  - Starting practical operation with four satellite constellation in 2018
  - Quasi-Zenith Satellite System Services Inc. (QSS) is now establishing the operational system.
QZSS Signals

<table>
<thead>
<tr>
<th>QZSS</th>
<th>GPS</th>
<th>Galileo</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>L1</td>
<td>E1</td>
</tr>
<tr>
<td>1575.42 MHz</td>
<td>1575.42 MHz</td>
<td>1575.42 MHz</td>
</tr>
<tr>
<td>LEX</td>
<td></td>
<td>E6</td>
</tr>
<tr>
<td>1278.75 MHz</td>
<td></td>
<td>1278.75 MHz</td>
</tr>
<tr>
<td>L2</td>
<td>L2</td>
<td>E5b</td>
</tr>
<tr>
<td>1227.60 MHz</td>
<td>1227.60 MHz</td>
<td>1207.14 MHz</td>
</tr>
<tr>
<td>L5</td>
<td>L5</td>
<td>E5a</td>
</tr>
<tr>
<td>1176.45 MHz</td>
<td>1176.45 MHz</td>
<td>1176.45 MHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E5 AltBOC</td>
</tr>
</tbody>
</table>

L-Band EXperimental Signal

Submeter-class Augmentation with Integrity Function

http://igs.org

MGEX QZSS Tracking Stations

L1/L2/L5: 19
L1/L2/L5/LEX: 8
dormant: 2
no QZSS tracking: 4
MGEX QZSS Analysis Centers

- **QZF**: Japan Aerospace Exploration Agency (JAXA)
  - MGEX: GPS+QZS since 215/2013 with some gaps
  - JAXA: QZS, GPS+QZS since 330/2012 with some gaps

- **TUM**: Technische Universität München, Germany
  - QZS+GAL since 295/2012

- 5 min orbits and clocks in sp3 format
Satellite Laser Ranging to QZS-1

Time period 330/2012 – 140/2014: 2111 normal points
SLR Residuals: QZF

Offset: -8.4 cm     STD: 13.7 cm

Orbit-Normal Mode

http://igs.org
SLR Residuals: TUM

Offset: 4.5 cm     STD: 27.6 cm

Orbit-Normal Mode
Orbit Comparison: QZF vs. TUM

3D-RMS: 1.32 m

Orbit-Normal Mode

http://igs.org
• MGEX broadcast product \texttt{brdm} available since 1/2013
• Vertical antenna offset of 3.515 m applied (ionosphere-free offset of L1 and L2 antenna offsets provided by JAXA)
Orbit Comparison: Broadcast vs. QZF

3D-RMS: 1.65 m

Orbit-Normal Mode

http://igs.org
Clock Stability

Median Modified Allan Deviation for GPS week 1773
TUM 30 s clock solution

- Modified Allan Deviation vs Integration Time
- Clock vs Time
- Amplitude vs Period

16.3 min
## Differential Code Biases

<table>
<thead>
<tr>
<th>Receiver</th>
<th>GPS L1</th>
<th>GPS L2</th>
<th>QZSS L1</th>
<th>QZSS L5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trimble NetR9</td>
<td>C1C</td>
<td>C2W</td>
<td>C1C</td>
<td>C5X</td>
</tr>
<tr>
<td>Javad TRE_G3TH</td>
<td>C1W</td>
<td>C2W</td>
<td>C1X</td>
<td>C5X</td>
</tr>
</tbody>
</table>

**Graph:**
- **Trimble NetR9**
- **Javad TRE_G3TH**

**Time Periods:**
- **2013**
- **2014**
Summary, Outlook, and Open Issues

- Two MGEX analysis centers provide QZSS orbit and clock products.
- Orbit accuracy currently at the several decimeter level
- Systematic errors related to attitude modeling
  - Need consistent YS/ON modeling for all analysis centers
  - Need proper bookkeeping (and advance notice) of all mode transitions
  - Need common convention for s/c axes (ANTEX!)
• Deficiencies in solar radiation pressure modeling
  – Dependency of SLR residuals on $\beta$-angle

• Need for improved solar radiation pressure model
  – Box-wing-hat style model
  – Initial work by Ikari et al. (ION GNSS+ 2013)

• Other MGEX analysis centers are encouraged to include QZSS in their solutions.
<table>
<thead>
<tr>
<th>Processing Strategies</th>
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<thead>
<tr>
<th></th>
<th>QZF</th>
<th>TUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>QZSS stations</td>
<td>9</td>
<td>11-15</td>
</tr>
<tr>
<td>GPS stations</td>
<td>33</td>
<td>11-15</td>
</tr>
<tr>
<td>Frequencies</td>
<td>L1 and L2</td>
<td>L1 and L5</td>
</tr>
<tr>
<td>Differencing</td>
<td>Undifferenced</td>
<td>Undifferenced</td>
</tr>
<tr>
<td>Data interval</td>
<td>7 days</td>
<td>3 days (orbit)</td>
</tr>
<tr>
<td>Sampling</td>
<td>300 s</td>
<td>30 s</td>
</tr>
<tr>
<td>Elevation cutoff</td>
<td>10°</td>
<td>3°</td>
</tr>
<tr>
<td>Radiation pressure par.</td>
<td>Orbit normal mode: D0, Y0, B0, ZC, ZS Yaw steering: D0, Y0, B0, DC, DS, BC, BS, ZC, ZS, D(2/rev), X(2/rev)</td>
<td>D0, Y0, B0, BC, BS</td>
</tr>
</tbody>
</table>