BDS Real-time Precise Products from WHU and its application in NBASS

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GNSS Research Center of Wuhan University, GRC
IGS Workshop 2017
July 3-7, 2017, Paris, France
Outline

- Overview
- BDS Real Time Precise Products
- Application of Real-time PPP
- Summary
# The Current Status of BDS

## BDS-2

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<thead>
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**Accuracy (95%)**

- **SPP**
  - Without IGSO-6: 3.54m
  - With IGSO-6: 3.34m
  - Improvement: 5.6%
  - Vertical: 6.09m
  - With IGSO-6: 5.83m
  - Improvement: 4.3%
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**PPP**

<table>
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<tr>
<th>Convergence time (95% &lt;1m)</th>
<th>Horizontal</th>
<th>Vertical</th>
</tr>
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<tbody>
<tr>
<td>without IGSO-6</td>
<td>142 min</td>
<td>146 min</td>
</tr>
<tr>
<td>with IGSO-6</td>
<td>116 min</td>
<td>120 min</td>
</tr>
</tbody>
</table>

**Improvement**

<table>
<thead>
<tr>
<th></th>
<th>Horizontal</th>
<th>Vertical</th>
</tr>
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<tbody>
<tr>
<td>18.3%</td>
<td>17.8%</td>
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<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEIDOU I1-S</td>
<td>C101</td>
<td>2015-019A</td>
<td>Operational</td>
<td>C31</td>
<td>launched 2015/03/30</td>
</tr>
<tr>
<td>BEIDOU M1-S</td>
<td>C102</td>
<td>2015-037A</td>
<td>Operational</td>
<td>C33</td>
<td>Slot A06, launched 2015/07/30</td>
</tr>
<tr>
<td>BEIDOU M2-S</td>
<td>C103</td>
<td>2015-037B</td>
<td>Operational</td>
<td>C34</td>
<td>Slot A01, launched 2015/07/30</td>
</tr>
<tr>
<td>BEIDOU I2-S</td>
<td>C104</td>
<td>2015-053A</td>
<td>Operational</td>
<td>C32</td>
<td>launched 2015/09/29</td>
</tr>
<tr>
<td>BEIDOU M3-S</td>
<td>C105</td>
<td>2016-006A</td>
<td>N/A</td>
<td>C35</td>
<td>Slot B01; launched 2016/02/01</td>
</tr>
</tbody>
</table>
National BDS Augmentation Service System (NBASS)

- **Object**
  - Improving the *positioning performance* of the BDS
  - Providing various precise location-based services

- **Infrastructure**
  - 150 BDS/GNSS reference stations as Nationwide frame.
  - About 1200 BDS/GNSS dense reference stations in special area.
  - National data processing center, application service centers.

- **Augmented Satellite System**
  - BDS, GPS, GLONASS, Galileo…
Tracking Station Network for BDS RT-PPP Service

~72 stations for BDS ORB, ~92 stations for BDS CLK, ~150 stations for regional products
Principle of processing system

Step 1
Multi-GNSS POD → Orbit Extrapolation → Real-time Orbit

Step 2
Real-time Clock Estimation (1s interval) → Real-time clock

Step 3
Real-time ionosphere modeling (30s interval) → Real-time ionosphere corrections

Step 4
Real-time troposphere modeling (1s interval) → Real-time troposphere corrections

Real-time PPP service
Outline

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Real-Time Satellite Orbit

<table>
<thead>
<tr>
<th>RMS (cm)</th>
<th>GEO</th>
<th>IGSO</th>
<th>MEO</th>
<th>GPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>50.0</td>
<td>17.6</td>
<td>21.0</td>
<td>5.9</td>
</tr>
<tr>
<td>C</td>
<td>5.1</td>
<td>6.8</td>
<td>4.2</td>
<td>2.6</td>
</tr>
<tr>
<td>R</td>
<td>13.5</td>
<td>7.7</td>
<td>4.0</td>
<td>2.3</td>
</tr>
</tbody>
</table>
Real-Time Precise Satellite Clock (URE)

\[ URE = \sqrt{\alpha \cdot (dA^2 + dC^2) + \beta (dClk - dR)^2} \]

\( \alpha = 0.01846081, \beta = 0.96308408 \)  
MEO

\( \alpha = 0.0078296, \beta = 0.99214524 \)  
GEO/IGSO

- Affect SPP accuracy
- Affect PPP accuracy
- Affect PPP convergence time
# Real-Time CIM (China Ionosphere Map)

## Strategy

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
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<tbody>
<tr>
<td>Stations</td>
<td>~100</td>
</tr>
<tr>
<td>Interval</td>
<td>30 second</td>
</tr>
<tr>
<td>Coverage</td>
<td>E70<del>140, N10</del>60</td>
</tr>
<tr>
<td>Format</td>
<td>SSR</td>
</tr>
<tr>
<td>Observable</td>
<td>Carrier-phase smoothed pseudo-range GF</td>
</tr>
<tr>
<td>Modeling</td>
<td>5 degree SHF</td>
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Real-Time CIM (China Ionosphere Map)

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**Assessment**

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<th>Value</th>
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<tr>
<td>Time</td>
<td>DOY 021~028, 2017</td>
</tr>
<tr>
<td>Station</td>
<td>~200</td>
</tr>
<tr>
<td>Reference</td>
<td>VTEC generated by PPP</td>
</tr>
<tr>
<td>RMS</td>
<td>3.4 TECU</td>
</tr>
</tbody>
</table>
Initial result of Real-time Tropospheric Grid Point model (TGP)
Initial result of Real-time Tropospheric Grid Point model (TGP)

<table>
<thead>
<tr>
<th>Season</th>
<th>TGP</th>
<th>GPT2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>0.79</td>
<td>2.42</td>
</tr>
<tr>
<td>Spring</td>
<td>1.02</td>
<td>3.29</td>
</tr>
<tr>
<td>Summer</td>
<td>1.38</td>
<td>4.33</td>
</tr>
<tr>
<td>Autumn</td>
<td>1.39</td>
<td>4.33</td>
</tr>
<tr>
<td>Average</td>
<td><strong>1.15</strong></td>
<td><strong>3.59</strong></td>
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Details of the Real-Time experiment

- Stations: 26, distributed over China
- Session time: 20170121-20170128
- Accuracy
  - DF-PPP/SF-PPP/SF-SPP
- Convergence
  - DF-PPP/SF-PPP/DF-PPP with TGP
Real-time BDS DF-PPP Accuracy

- Mean Up Error: 7.6 cm
- Mean North Error: 3.9 cm
- Mean East Error: 3.5 cm
Real-time BDS+GPS DF-PPP Accuracy

**Up Error**
- Mean: 3.4 cm

**North Error**
- Mean: 1.2 cm

**East Error**
- Mean: 1.5 cm
Real-time BDS SF-PPP Accuracy

Up Error
North Error
East Error

Up Error Distribution
North Error Distribution
East Error Distribution

mean: 0.6m
mean: 0.2m
mean: 0.3m
Real-time BDS+GPS SF-PPP Accuracy

**Up Error**
- Mean: 0.3m

**North Error**
- Mean: 0.1m

**East Error**
- Mean: 0.2m
Real-time BDS SF-SPP Accuracy

Mean values for different error distributions:
- Up Error: mean = 1.6 m
- North Error: mean = 0.9 m
- East Error: mean = 0.6 m
Real-time BDS+GPS SF-SPP Accuracy

- **Up Error:**
  - Mean: 1.0m

- **North Error:**
  - Mean: 0.5m

- **East Error:**
  - Mean: 0.4m
Result Analysis

- **DFPPP**
- **SFPPP**
- **SPP**
DF-PPP Convergence time

- BDS only
- GPS only
- GPS+BDS

Time since PPP start [minutes]

Horizontal error [m]

Vertical error [m]
SF-PPP Convergence time
BDS DF-PPP Convergence time with TGP

The graphs illustrate the convergence time for different methods using TGP. The traditional method shows a slower rate of convergence compared to the methods using TGP.
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Summary

- BDS Real-time Precise Products:
  - Real-time Orbit: GEO 15cm(R); IGSO/MEO 10cm(R), 30cm(3D)
  - URE (Clock): BIAS~1.0m, STD~2cm
  - Real-time Ionosphere: ~3TECU, The precision of boundary area is a bit poor
  - Real-time Troposphere: <1.5cm, Initial result

- BDS Real-time PPP:
  - DF-PPP: 10cm in horizontal, 20cm in vertical, convergence time ~60 mins
  - DF-PPP: 0.6m in horizontal, 1.2m in vertical, convergence time ~5 mins
  - SF-SPP: 2.0m in horizontal, 3.0cm in vertical, comparing with standard SPP, improvement is about 40% and ~50% in horizontal and vertical
  - BDS positioning accuracy distribution with regional characteristics, its accuracy is worse than GPS in marginal area

- The major Contribution of BDS/GPS Combination
  - DF-PPP: ~20mins; SF-PPP: ~2mins
Thank You for Your attention!

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