Trimble RTX™ Orbit Determination and User Positioning Performance with BeiDou Satellites

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Outline

- Motivation
- Trimble RTX™ Correction Services
- BeiDou Orbit Determination
- Rover Positioning Performance with BeiDou
- Summary
Motivation

- BeiDou satellites provide enhanced global coverage for high precision positioning

- Focus of BeiDou IGSO and GEO satellites over Asia-Pacific region

- GEO satellite orbit determination is recognized as problematic

- Potential improvements in RTX rover performance from the inclusion of all BeiDou satellites
Trimble RTX™
Correction Services
Trimble RTX™ Correction Services
Satellite Delivery
Trimble RTX™ Correction Services
Worldwide IP / Cellular Delivery
## Trimble RTX™ Correction Services

<table>
<thead>
<tr>
<th>Service</th>
<th>Horizontal Performance (95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ViewPoint® RTX™</td>
<td>39” / 1 m in 5 minutes</td>
</tr>
<tr>
<td>RangePoint® RTX™</td>
<td>20” / 50 cm in 5 minutes</td>
</tr>
<tr>
<td>FieldPoint® RTX™</td>
<td>8” / 20 cm in 15 minutes, 1-5 minutes in Europe</td>
</tr>
<tr>
<td>CenterPoint® RTX™ Fast</td>
<td>1.5” / 3.8 cm in 30 minutes, 1-5 minutes in selected regions</td>
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</tbody>
</table>
Trimble CenterPoint RTX - general overview

Global Trimble tracking network with > 110 stations

L-band satellite link coverage

Convergence to < 4cm: 10-20 min

CenterPoint RTX Standard (globally)

Convergence to < 4cm: 1 min

CenterPoint RTX Fast (Central US and Europe)
Trimble RTX Compatible Devices

Agriculture
- TMX-2050
- FmX
- CFX-750
- Ag-372
- MMX-070

Survey
- R10
- R9s
- R2
- R1/PG200
- Geo 7x
- NetR9 Geospatial

Seismic
- Kestrel
- SNS Systems

GIS
- CenterPoint® RTX
- CenterPoint® RTX Fast
- FieldPoint RTX™
- RangePoint® RTX
- ViewPoint RTX™
- Enhanced xFill® / xFill® Premium

Infrastructure
- SPS855
- SPS852
- SPS985 & SPS985L
- SPS585

Applanix
- Land and Airborne Solutions

OEM
- ProMark 700
- Mobile Mapper 300
- ProXRT

Spectra Precision
- BD982
- MB-TWO
- SP60
- SP80

Land Administration
- BX982

Construction
- Trimble Leap
- SPS585

Trimble Outdoors
- SPS855
- SPS985 & SPS985L

Architectural Systems
-(Transforming the Way the World Works)
BeiDou Orbit Determination
BeiDou GEO Orbit Determination

- Precise orbit determination challenging for GEO satellites
- Weak and almost invariable tracking geometry w.r.t. ground stations:
  - Altitude of ~36,000 km (~20,000km for MEO)
  - Satellite position almost fixed with respect to the Earth
- Lack of apparent satellite motion induces strong correlations between estimated parameters such as:
  - Satellite position, velocity, clock
  - Receiver clock, troposphere
  - Multipath (code & phase)
BeiDou GEO Orbit Determination

- Stabilize the solution with GPS as aiding system
- Enhance tracking geometry, e.g. by:
  - Use of code observations
  - Low elevation cutoff
- Tailored solar radiation pressure model for GEOs:
  - Proper parameterization to reduce correlation
  - Orbit normal attitude mode considered
- Geostationary satellites perform frequent station-keeping manoeuvres:
  - Approximately every 4 to 10 weeks
  - Shown in next slides based on broadcast ephemerides
  - Orbit processor states need to reconverge after manoeuver
Change of semi-major axis over time

C01 - BRDC ephemerides

C04 - BRDC ephemerides
Change of semi-major axis over time

C09 - BRDC ephemerides
- Semi-major axis (minus 42164 km)
- Unhealthy flag

C14 - BRDC ephemerides
- Semi-major axis (minus 27906 km)
- Unhealthy flag
Real-Time MEO Orbit Performance – Comparison to external IGS-MGEX orbits

GFZ
German Research Centre for Geosciences

RMS all days [m]:
- Along-T. 0.154
- Cross-T. 0.075
- Radial 0.052

WUHAN
University, GNSS Research Center

RMS all days [m]:
- Along-T. 0.155
- Cross-T. 0.077
- Radial 0.053

CODE
Center for Orbit Determination in Europe

RMS all days [m]:
- Along-T. 0.138
- Cross-T. 0.065
- Radial 0.051

Excluded periods in orbit-normal attitude mode
Real-Time IGSO Orbit Performance – Comparison to external IGS-MGEX orbits

GFZ
German Research Centre for Geosciences

WUHAN
University, GNSS Research Center

CODE
Center for Orbit Determination Europe

Excluded periods in orbit-normal attitude mode

RMS all days [m]:
- Along-T. 0.134
- Cross-T. 0.157
- Radial 0.090

RMS all days [m]:
- Along-T. 0.208
- Cross-T. 0.178
- Radial 0.105

RMS all days [m]:
- Along-T. 0.145
- Cross-T. 0.104
- Radial 0.121
Real-Time GEO Orbit Performance – Comparison to external IGS-MGEX orbits

GFZ
German Research Centre for Geosciences

WUHAN
University, GNSS Research Center

Trimble vs GFZ orbits (RMS over all BeiDou GEO satellites)

RMS all days [m]:
Along-T. 2.860
Cross-T. 2.465
Radial 0.881

Trimble vs WUHAN orbits (RMS over all BeiDou GEO satellites)

RMS all days [m]:
Along-T. 1.990
Cross-T. 0.188
Radial 0.280
Real-Time BeiDou Orbit Performance – Internal consistency

- 15-min orbit prediction error
  - RMS over all satellites and all epochs [m]
  - 17 weeks (Jul 10 – Nov 5, 2016)

15-minute Prediction Error [m]

- Along-track
- Cross-track
- Radial
Rover Positioning Performance with BeiDou
Rover RTX Performance with/without BeiDou

- **Data**
  - 14 Stations (Australia, China, New Zealand, Japan, Taiwan)
  - 4 months (July-November 2016)
  - RTX realtime data stream

- **Positioning solutions**
  - GPS-GLONASS versus GPS-GLONASS-BeiDou (Dual-Frequency)
  - Kinematic positioning in post-processing

- **Analysis**
  - Convergence
    - Convergence time to achieve < 4 cm horizontal error
    - Convergence runs with reset every hour
  - Position error after convergence
Horizontal Convergence Comparison

Number of possible runs: 40008
Number of counted runs: 38205 (GPS+GLN); 38274 (GPS+GLN+BDS)

- 68%: 14.3min GPS+GLN
- 68%: 10.2min GPS+GLN+BDS
- 95%: 29.3min GPS+GLN
- 95%: 20.6min GPS+GLN+BDS

- 29% Reduction
- 30% Reduction

4cm Threshold
Vertical Convergence Comparison

- 68%: 11.2min GPS+GLN
- 68%: 8.3min GPS+GLN+BDS
- 95%: 23.9min GPS+GLN
- 95%: 17.8min GPS+GLN+BDS

Number of possible runs: 40008
Number of counted runs: 38205 (GPS+GLN); 38274 (GPS+GLN+BDS)

26% Reduction

9cm Threshold
Horizontal Position Error after Convergence

2D-pos. offset [m]

- TPS\|GPS+GLN
- TPS\|GPS+GLN+BDS

- 90%:
  - TPS\|GPS+GLN: 0.0229
  - TPS\|GPS+GLN+BDS: 0.0198
- 95%:
  - TPS\|GPS+GLN: 0.0269
  - TPS\|GPS+GLN+BDS: 0.0231
- 99%:
  - TPS\|GPS+GLN: 0.0362
  - TPS\|GPS+GLN+BDS: 0.0306
Vertical Position Error after Convergence
All BeiDou satellites now included in RTX transmissions and rover processing:

- BeiDou GEO satellites provide the greatest challenge for precise orbit determination
- Internal consistency checks indicate that mean component RMS errors in BeiDou orbits are: 2cm for GEO, and 1cm for ISGO / MEO satellites
- BeiDou orbits from RTX system, agree with external sources to cm/dm-level for MEO / ISGO satellites and meter-level for GEO satellites.

Adding BeiDou satellites to Trimble RTX™ positioning:

- Reduced convergence times by 25-30% over the Asia Pacific test region
- Improved (95%) Horizontal and Vertical position errors improved by 18% and 7% respectively
Thank you for your attention!