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Trimble Terrasat GmbH

IGNSS 2016, SYDNEY, AUSTRALIA

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

Outline

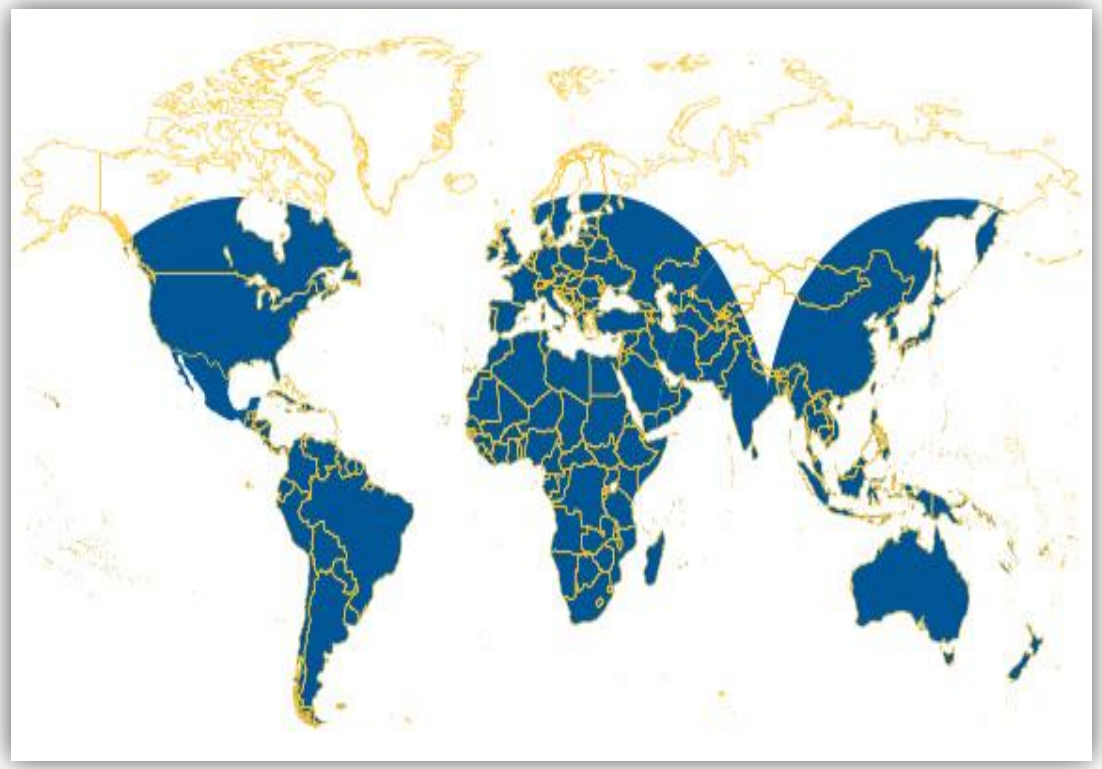
- Motivation
- Trimble RTX™ Correction Services
- BeiDou Orbit Determination
- Rover Positioning Performance with BeiDou
- Summary

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

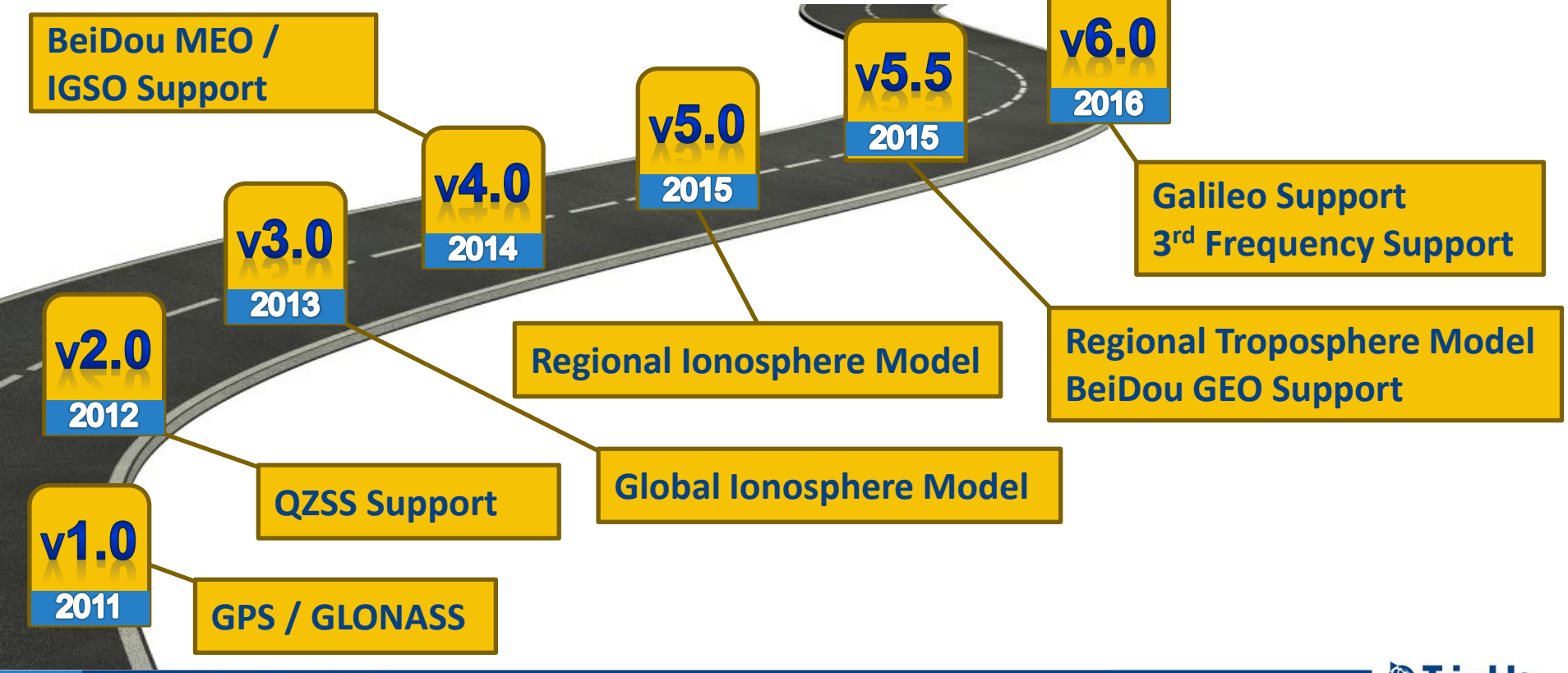


Trimble RTX™ Correction Services Worldwide IP / Cellular Delivery

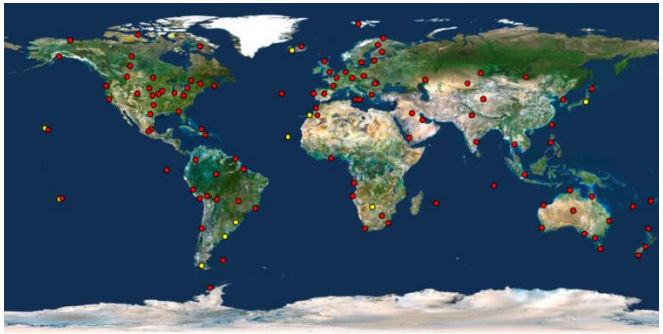
Trimble RTX™ Correction Services

Service	Horizontal Performance (95%)
ViewPoint® RTX™	39″ / 1 m in 5 minutes
RangePoint® RTX™	20″ / 50 cm in 5 minutes
FieldPoint® RTX™	8″ / 20 cm in 15 minutes 1-5 minutes in Europe
CenterPoint® RTX™ CenterPoint® RTX™ Fast	1.5″ / 3.8 cm in 30 minutes 1-5 minutes in selected regions

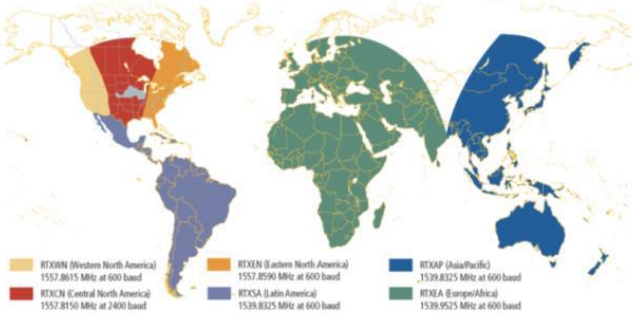
RTX Service History



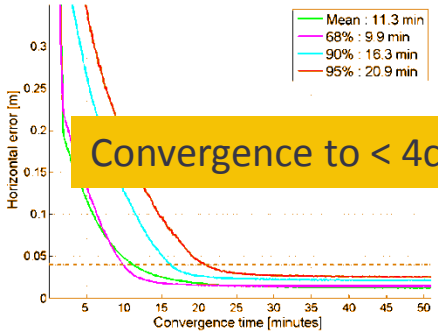
Trimble CenterPoint RTX - general overview



Global Trimble tracking network with > 110 stations

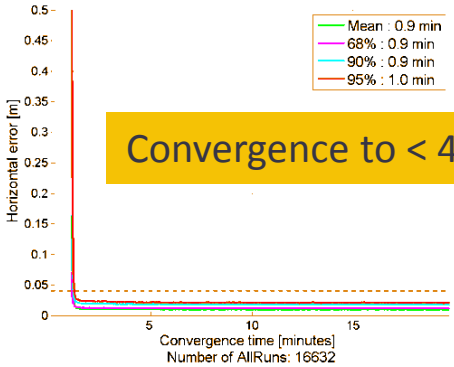


L-band satellite link coverage



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

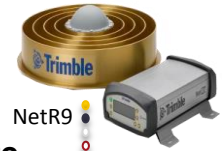

R2

GIS


R1/PG200


Geo 7x


NetR9 Geospatial


NetR9

Infrastructure

Seismic


Kestrel


SNS Systems

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

Spectra Precision


ProMark 700


Mobile Mapper 300


SP60


SP80

Land Administration


ProXRT

Trimble Outdoors


Trimble Leap

Construction


SPS855
SPS852


SPS985 & SPS985L


BX982


SPS585

Applanix


Land and Airborne Solutions

OEM


BD982


MB-TWO

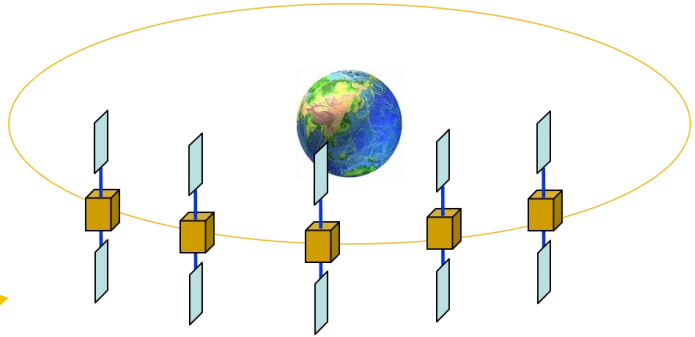
BeiDou Orbit Determination

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

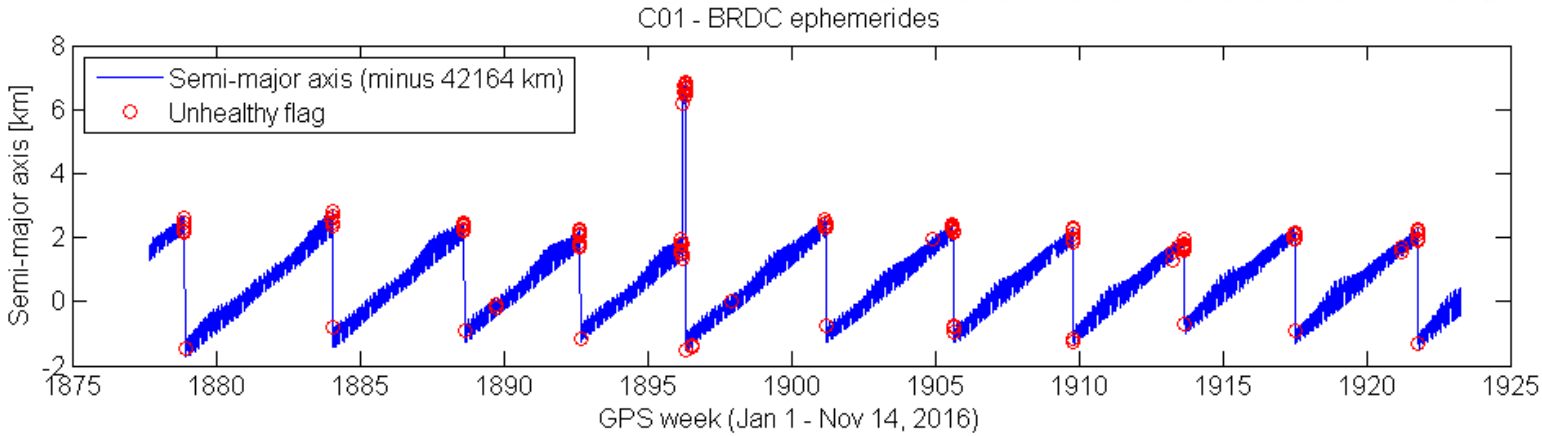
- Stabilize the solution with GPS as aiding system
- Enhance tracking geometry, e.g. by:
  - Use of code observations
  - Low elevation cutoff
- Tailored solar radiation pressure model for GEOs:
  - Proper parameterization to reduce correlation
  - Orbit normal attitude mode considered



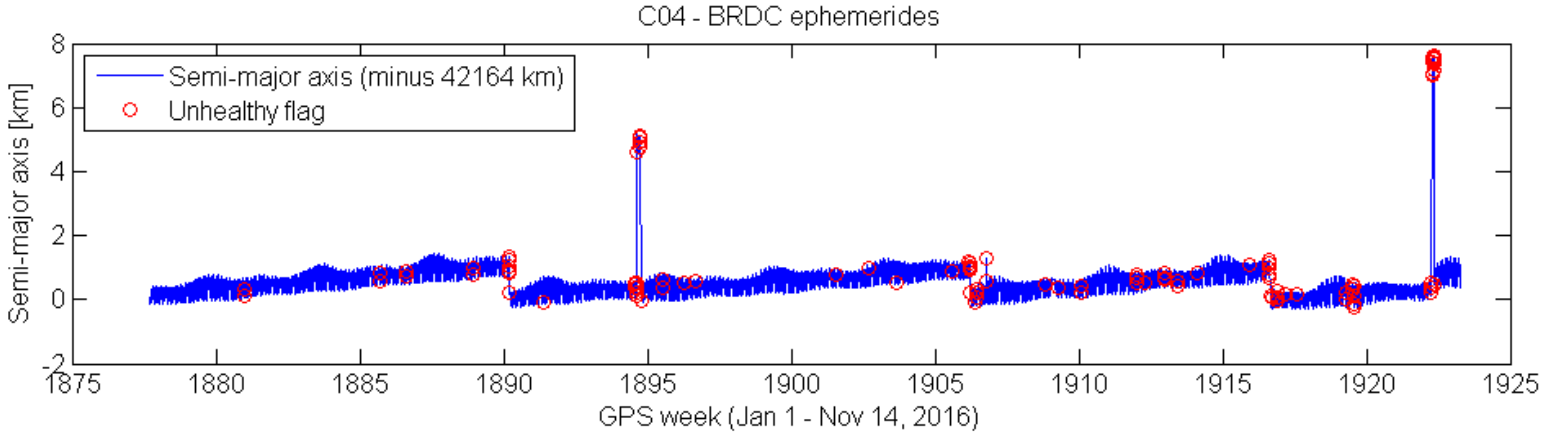
- Geostationary satellites perform frequent station-keeping manoeuvres:
  - Approximately every 4 to 10 weeks
  - Shown in next slides based on broadcast ephemerides
  - Orbit processor states need to reconverge after manoeuver

Change of semi-major axis over time

C01 GEO

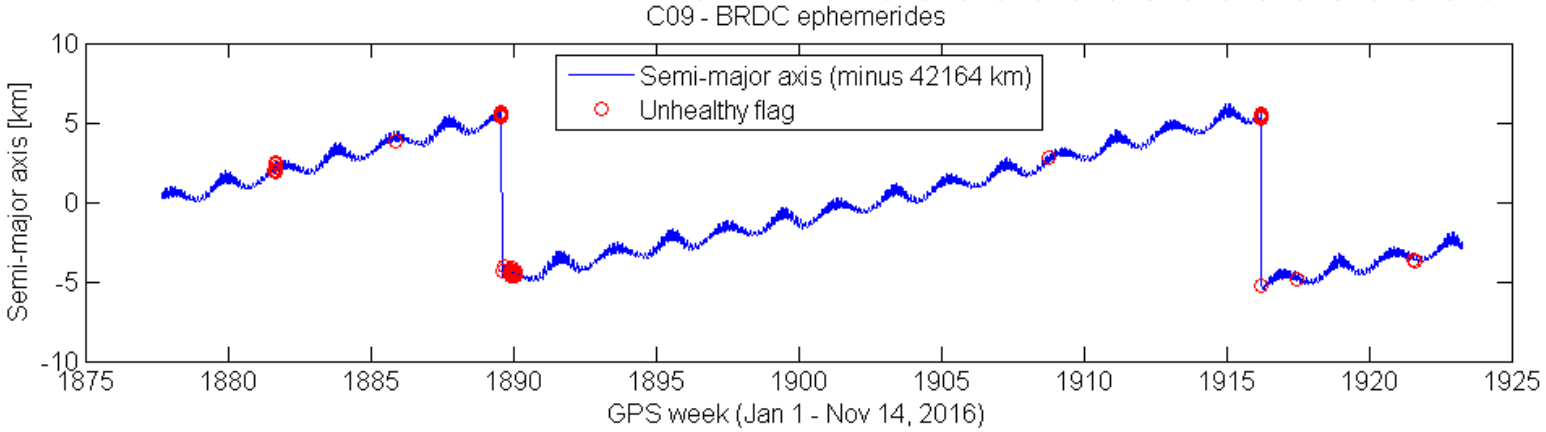


C04 GEO

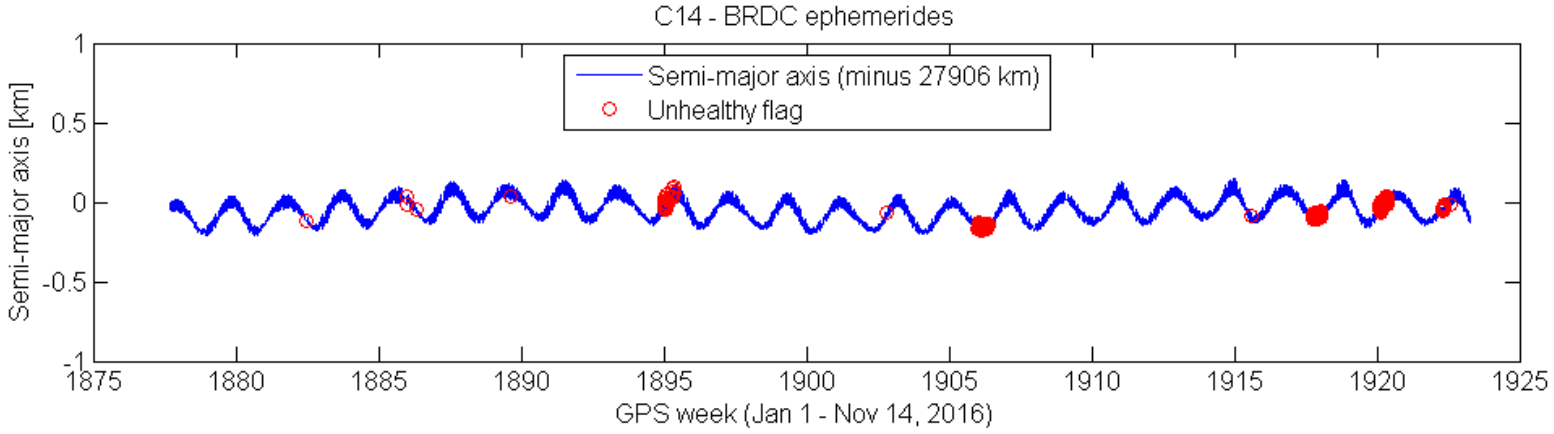


Change of semi-major axis over time

C09
IGSO

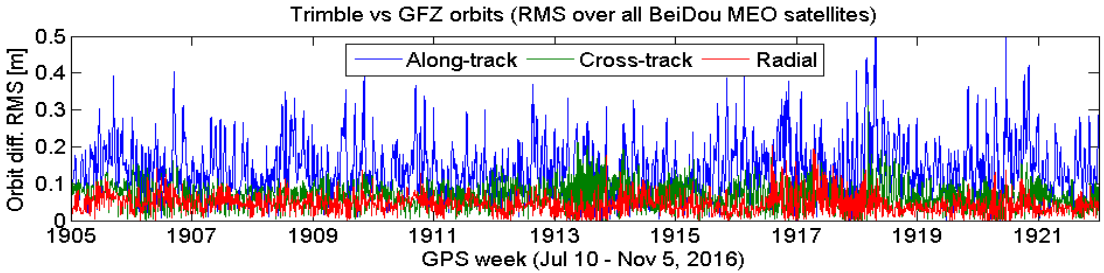


C14
MEO



Real-Time MEO Orbit Performance –
Comparison to external IGS-MGEX orbits

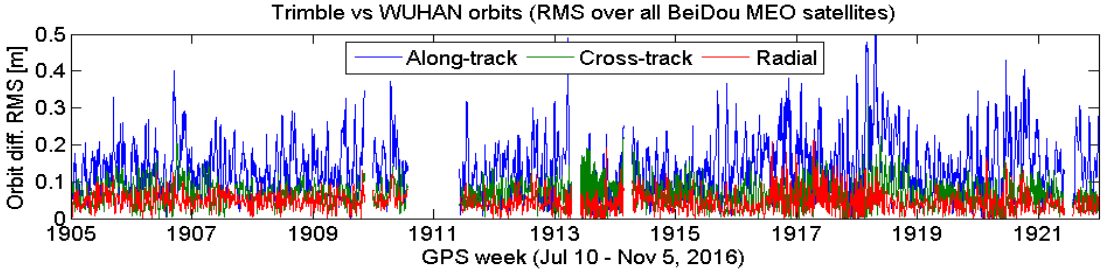
GFZ
German Research Centre for Geosciences



RMS all days [m]:

Along-T.	0.154
Cross-T.	0.075
Radial	0.052

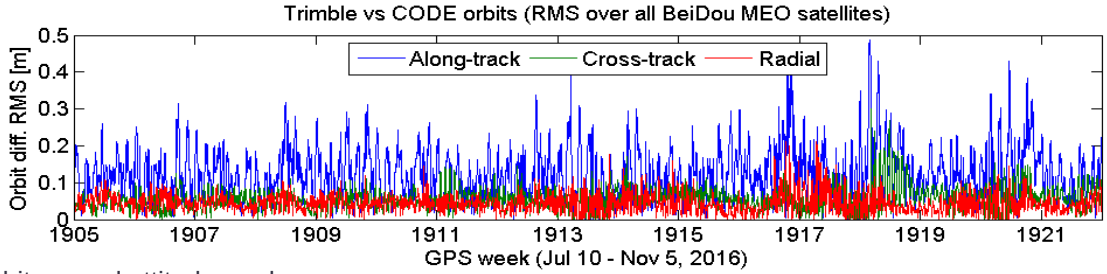
WUHAN
University, GNSS Research Center



RMS all days [m]:

Along-T.	0.155
Cross-T.	0.077
Radial	0.053

CODE
Center for Orbit Determination in Europe



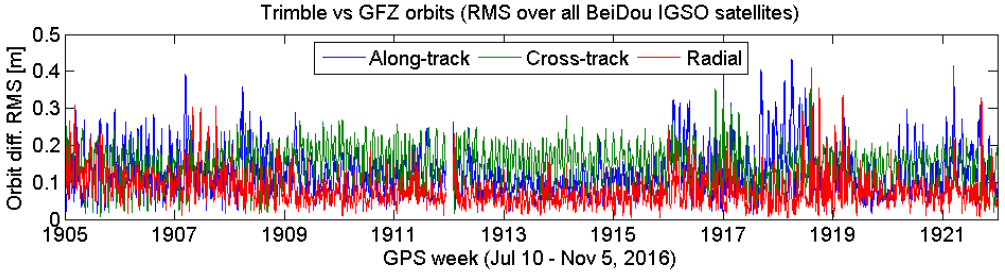
RMS all days [m]:

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

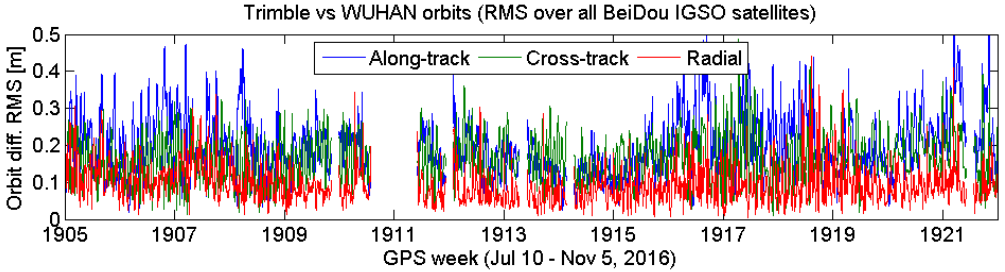
GFZ
German Research Centre for Geosciences



RMS all days [m]:

Along-T.	0.134
Cross-T.	0.157
Radial	0.090

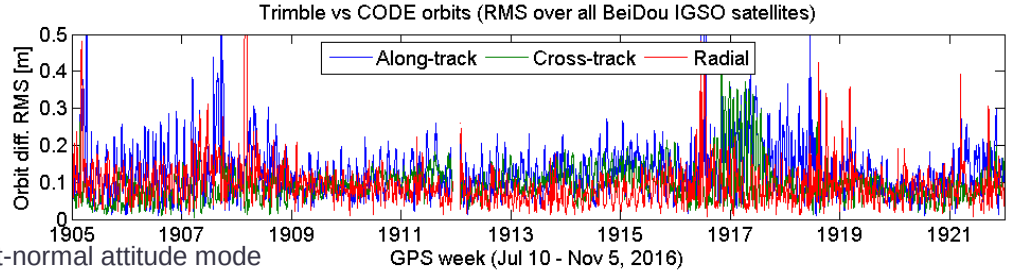
WUHAN
University, GNSS Research Center



RMS all days [m]:

Along-T.	0.208
Cross-T.	0.178
Radial	0.105

CODE
Center for Orbit Determination Europe



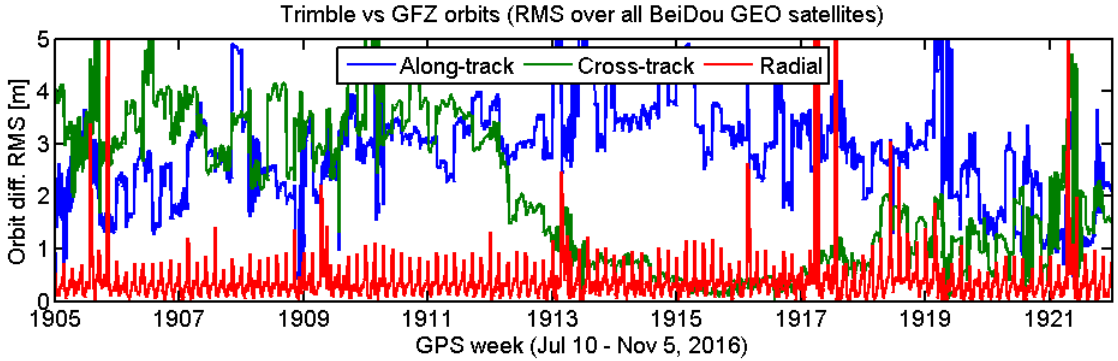
RMS all days [m]:

Along-T.	0.145
Cross-T.	0.104
Radial	0.121

Excluded periods in orbit-normal attitude mode

Real-Time GEO Orbit Performance –
Comparison to external IGS-MGEX orbits

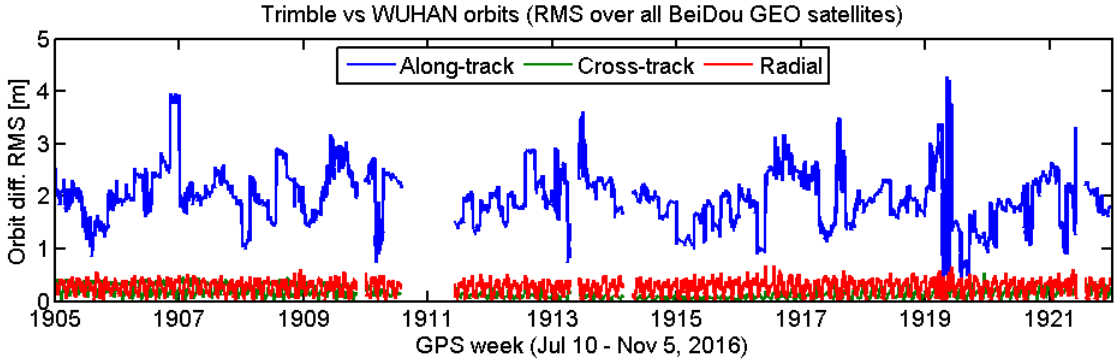
GFZ
German Research Centre for Geosciences



RMS all days [m]:

Along-T.	2.860
Cross-T.	2.465
Radial	0.881

WUHAN
University, GNSS Research Center

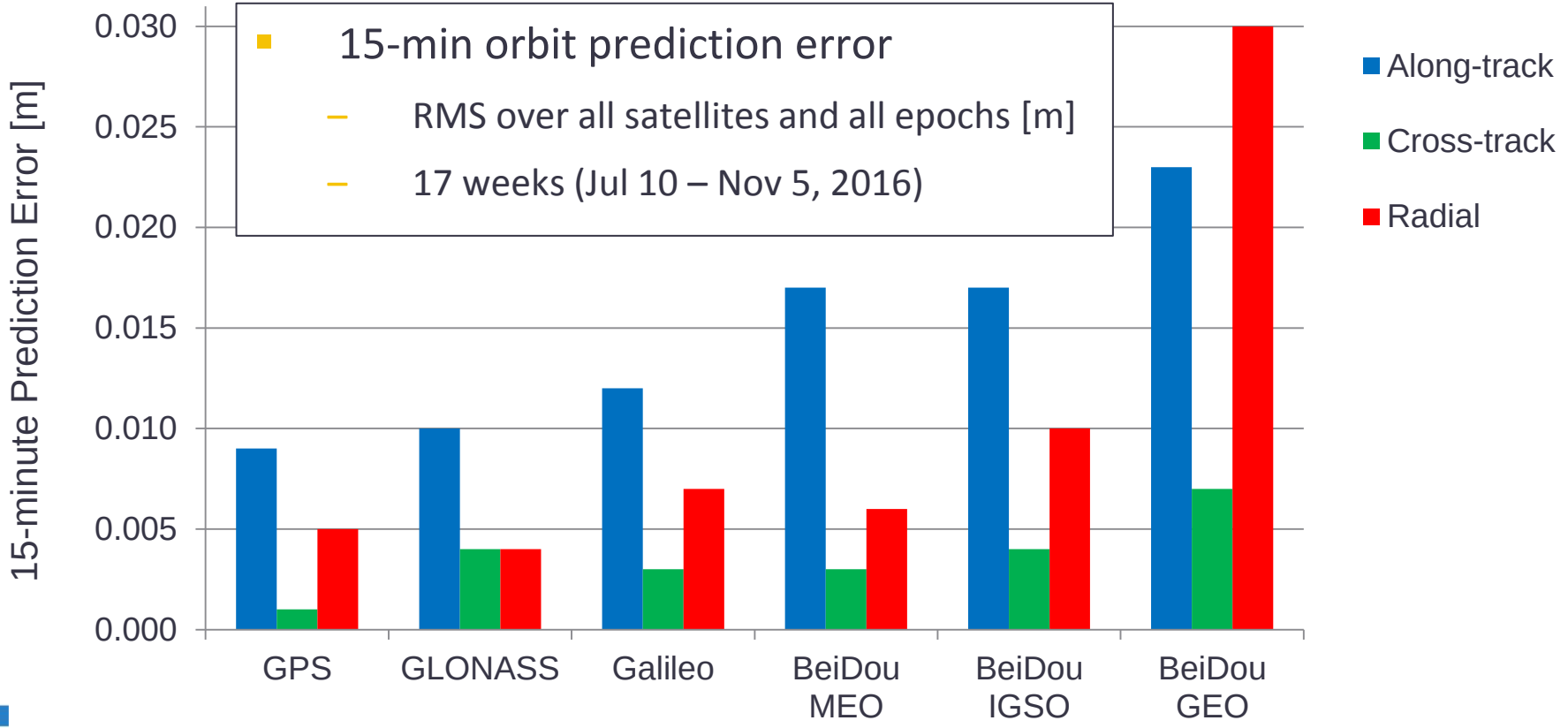


RMS all days [m]:

Along-T.	1.990
Cross-T.	0.188
Radial	0.280

Trimble

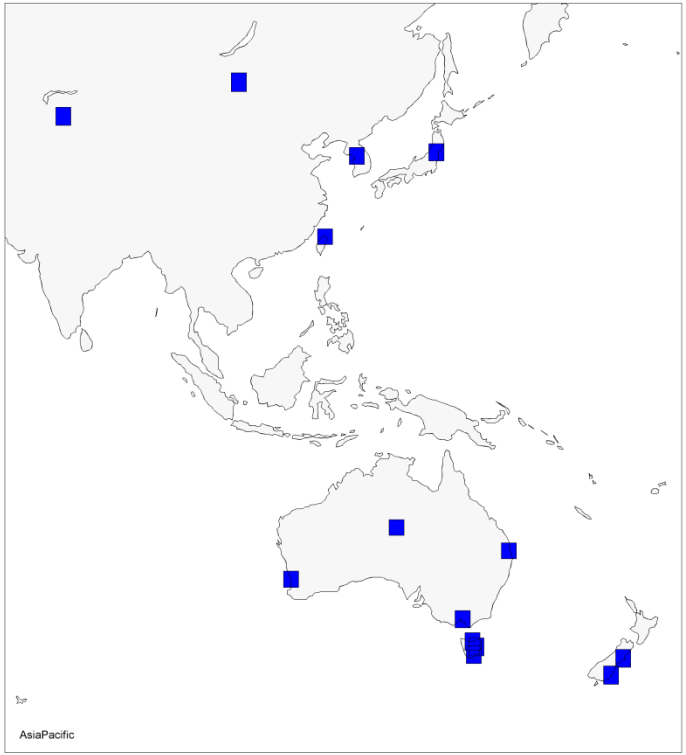
Real-Time BeiDou Orbit Performance –
Internal consistency



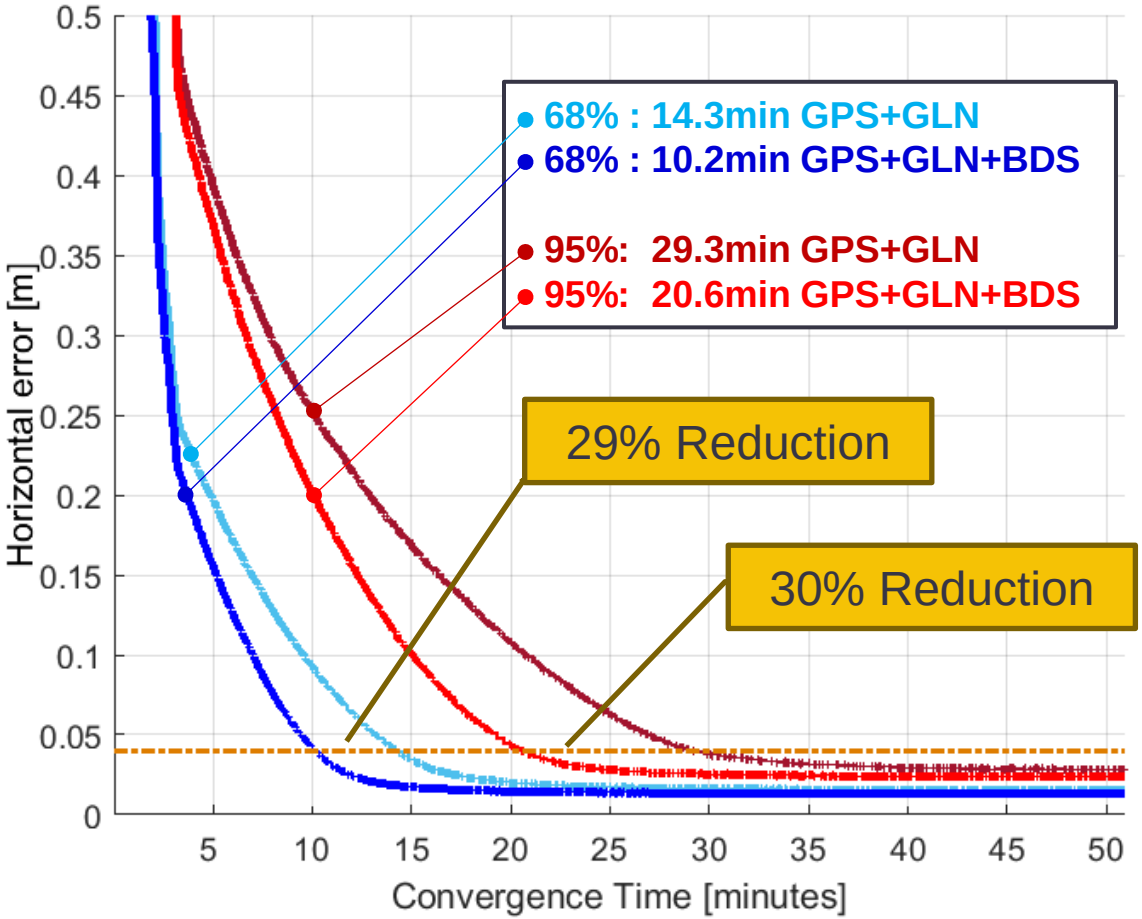
Rover Positioning Performance with BeiDou

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

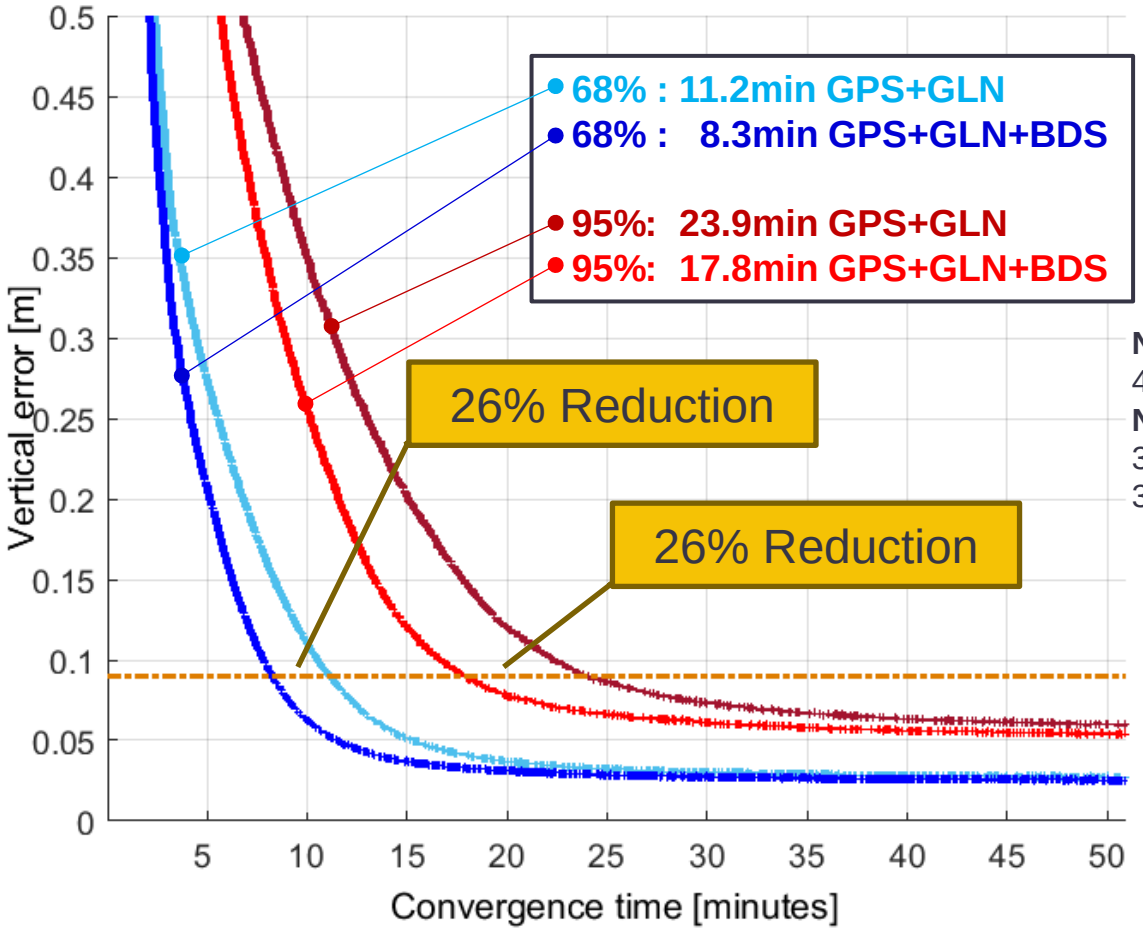


Horizontal Convergence Comparison



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

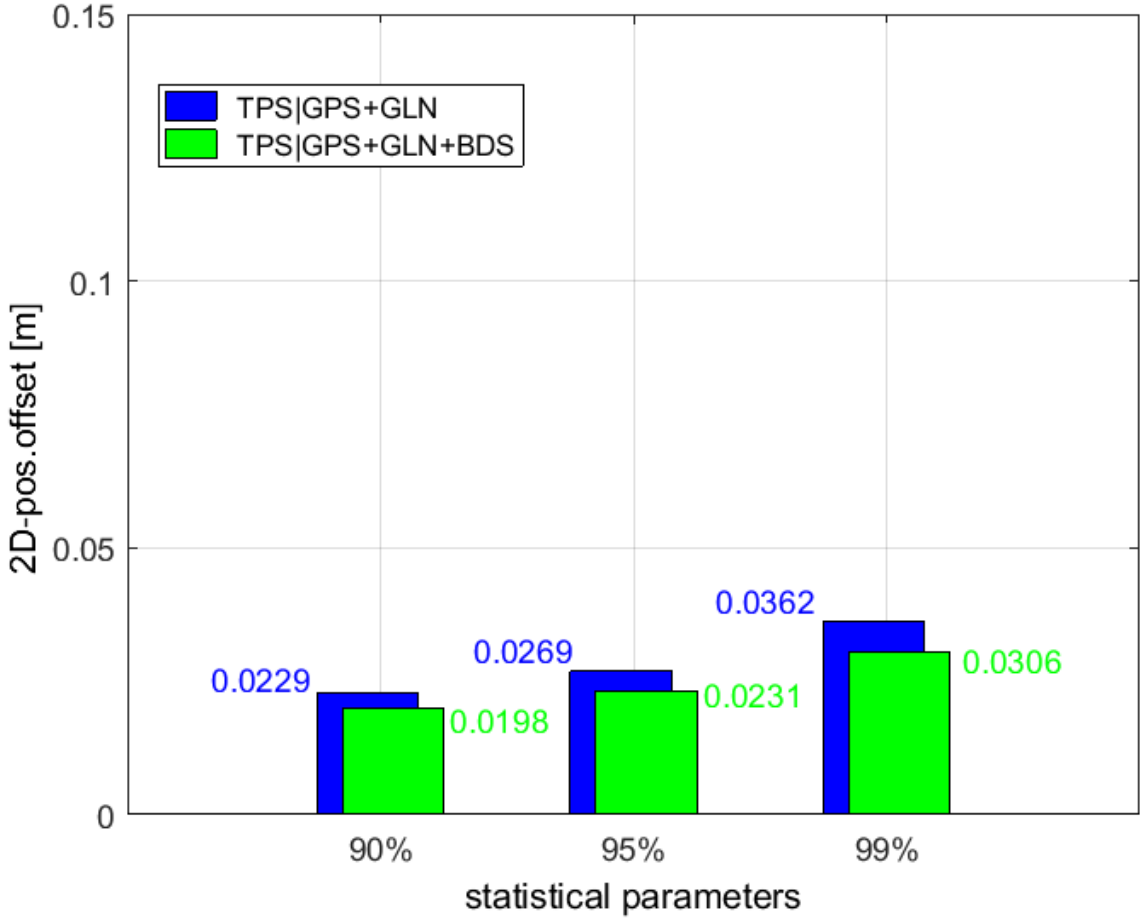
Vertical Convergence Comparison



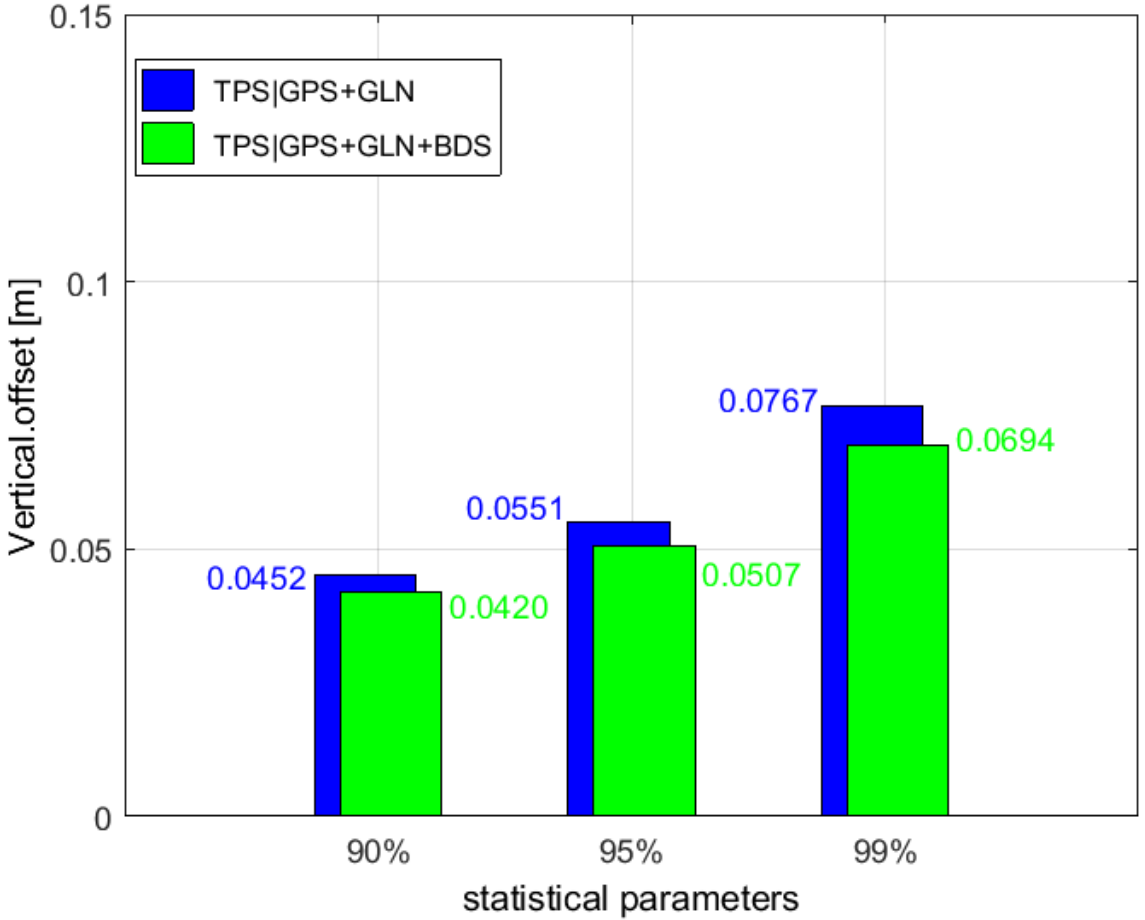
Number of possible runs: 40008
Number of counted runs: 38205 (GPS+GLN); 38274 (GPS+GLN+BDS)

Trimble

Horizontal Position Error after Convergence



Vertical Position Error after Convergence



Summary

- 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!