GNSS Satellite Orbit Validation
Using Satellite Laser Ranging

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GNSS Satellite Orbit Validation
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- Motivation
  - New GNSS Constellations
  - The IGS MGEX Project
- SLR Orbit Validation
  - BeiDou
  - Galileo
  - QZSS
  - IRNSS
- Operational Aspects
- Summary and Conclusions
New GNSS Constellations

- **BeiDou**
  - 14 operational satellites (GEO/IGSO/MEO)
  - Initial operational service (regional) since Dec. 2012

- **Galileo**
  - 4 satellites (in-orbit validation)
  - Non-operational broadcast ephemerides

- **QZSS**
  - 1 IGSO satellite (operational) since 2010

- **IRNSS**
  - First IGSO satellite launched July 2013
  - No ICD
The IGS Multi-GNSS Experiment (MGEX)

- Preparation of International GNSS Service (IGS) for support of new signals and constellations
- New global tracking network
  - Galileo, BeiDou, QZSS
  - ~90 stations (Sep. 2013)
  - Real-time streams (~70 stations)
- First precise orbit and clock products
  - Galileo (CODE, TUM, CNES/CLS, GFZ)
  - QZSS (TUM, JAXA)
- Cumulative broadcast ephemerides

How does SLR tracking support our understanding of the new GNSSs?
BeiDou (Broadcast Orbits)

BeiDou (Precise Orbits, Wuhan University)


- Very encouraging results
- Independent confirmation pending (data/products not publically available)
Galileo-IOV

- Combined CODE+TUM products for ~ 1.5 years
- 1/rev radial orbit errors with up to +/- 20 cm
- Amplitude varies with Sun-angle above orbital plane (β-angle)
Galileo-IOV (cntd.)

- SLR residuals depend only on Sun-satellite-Earth angle ($\gamma$)
- Solar radiation pressure modeling? (see Svehla et al., IAG 2013)
- Problem
  - SLR yields (mainly) radial position error
  - $\Delta R(\gamma(t))$ is insufficient to determine radial acceleration error!

\[
\Delta \ddot{R} - 2n\Delta \dot{T} - 3n^2 \Delta R = \Delta a_R \\
\Delta \ddot{T} + 2n\Delta \dot{R} = \Delta a_T
\]
QZSS

- Best quality of JAXA product (more stations, proper handling of orbit-normal mode, ON)
- Systematic variations (-20…+30 cm) during yaw-steering mode (YS) indicate radiation pressure modeling problems
IRNSS-1A

- (Almost) no GNSS tracking yet
- SLR tracking enables independent orbit determination
- Initial broadcast ephemeris assessment
Operational Aspects

Increasing overall number of GNSS satellites with laser retroreflector arrays
- Galileo: 4 → 24…27
- BeiDou: 14 → 30 (?)
- GPS: ?
- QZSS: 1 → 4…7
- IRNSS: 1 → 7
- GLO: 24 →?

Large number of geostationary (GEO) and inclined geosynchronous (IGSO) satellites over Asia
- Large distance, weak returns
- Few supporting stations in area of interest

High-rate stations („kHz Laser“)
- Fast collection of normal points with sufficient echoes (<< 5 min)
- Allows rapid switching between objects
- Example GRAZ:
  - 20 LEO+14 HEO in 7 h
  - Supports 24 GLO, 2 GPS, 4 GAL, 1 IRNSS

Only small subset of Beidou constellation supported by ILRS
- No support request
- No predictions (but: CPFs can be generated from broadcast ephemerides!)
Summary and Conclusions

- SLR tracking offers indispensable tool for validation of GNSS orbit products and is gratefully acknowledged!

- Radial accuracy of GNSS precise orbit products is at 10 cm level
  - Galileo: ~10 cm, QZSS: ~20 cm, BeiDou: ~10 cm (TBC)
  - Mean offsets at 5 cm level

- SLR tracking can help to overcome limitations of GNSS-only orbit determination
  - Constrain MEO orbits (Galileo!)
  - Constrain GEO longitude

- Tracking of “all” GNSS satellites desired
  - Multiple satellites per orbital plane
  - Different orbit types (MEO, IGSO, GEO)

- More high-rate stations encouraged
  - Fast normal point generation
  - Increased tracking capacity