GNSS Satellite Orbit Validation Using Satellite Laser Ranging

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GNSS Satellite Orbit Validation Using Satellite Laser Ranging

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

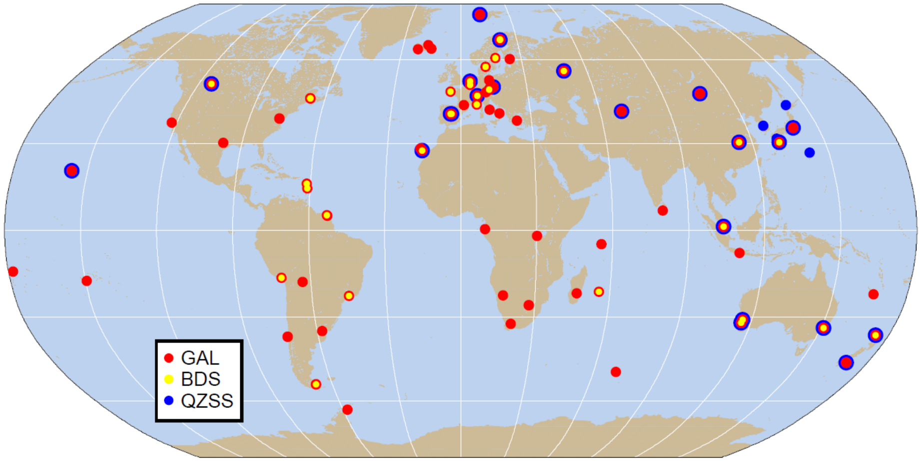
New GNSS Constellations

- 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)

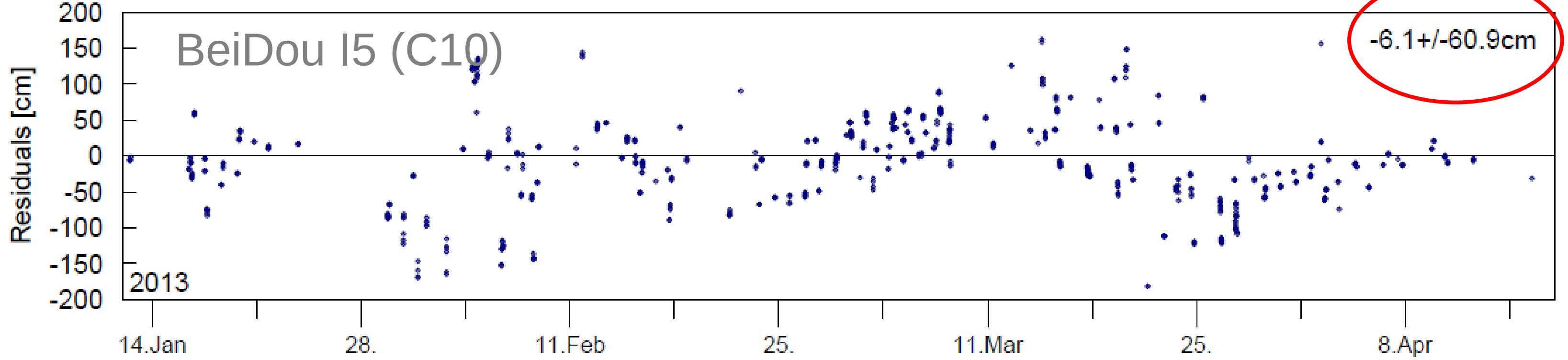
IGS

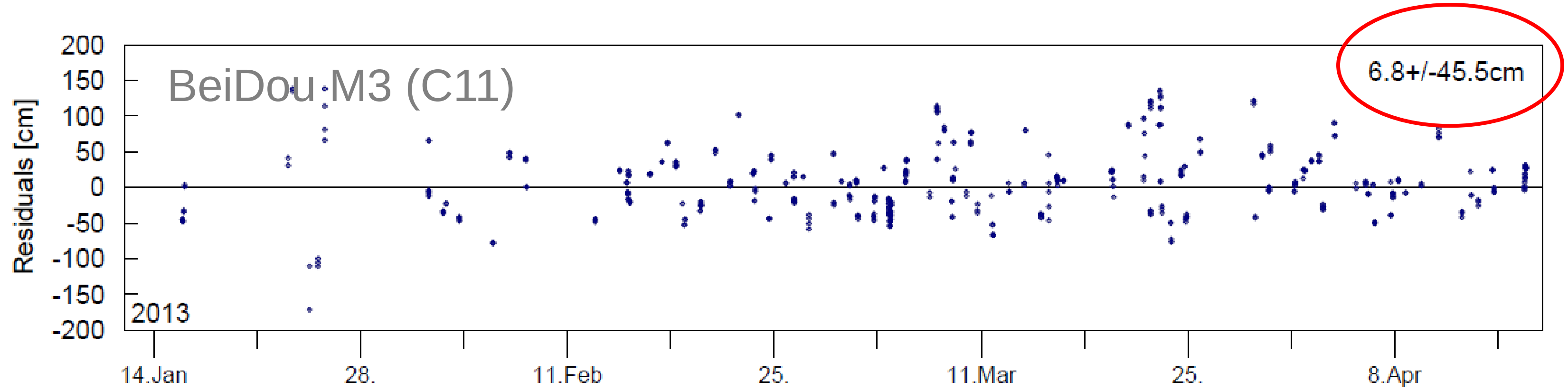
- Preparation of International GNSS Service (IGS) for support of new signals and constellations
- New global tracking network
  - Galileo, BeiDou, QZSS
  - ~90 stations (Sep. 2013)
  - Real-time streams (~70 stations)
- First precise orbit and clock products
  - Galileo (CODE, TUM, CNES/CLS, GFZ)
  -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



How does SLR tracking support our understanding of the new GNSSs?

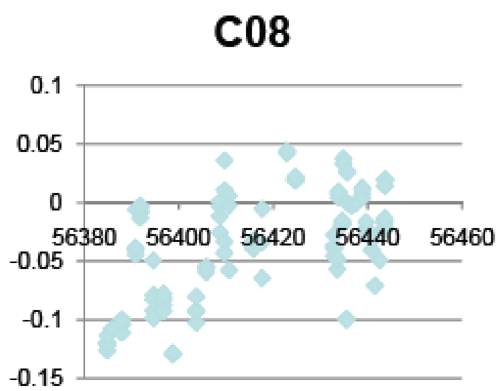
BeiDou (Broadcast Orbits)

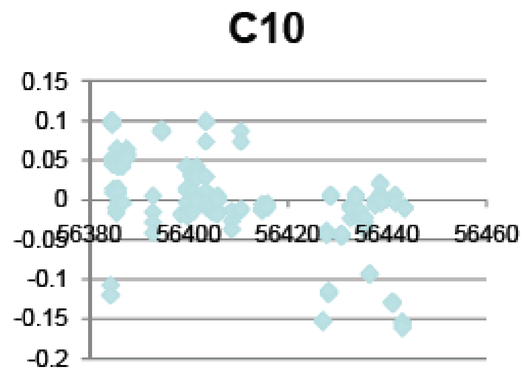


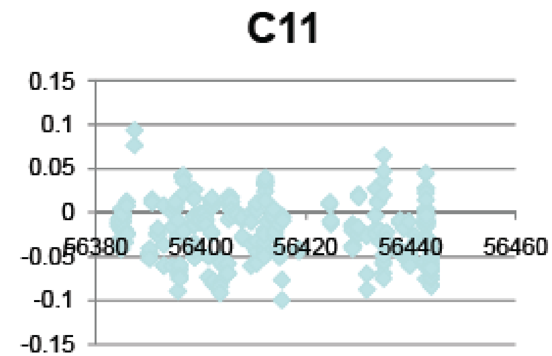


Montenbruck O., Steigenberger P.; *The BeiDou Navigation Message*; IGNSS Symposium 2013, 16-18 July 2013, Outrigger Gold Coast, Qld, Australia (2013).

BeiDou (Precise Orbits, Wuhan University)





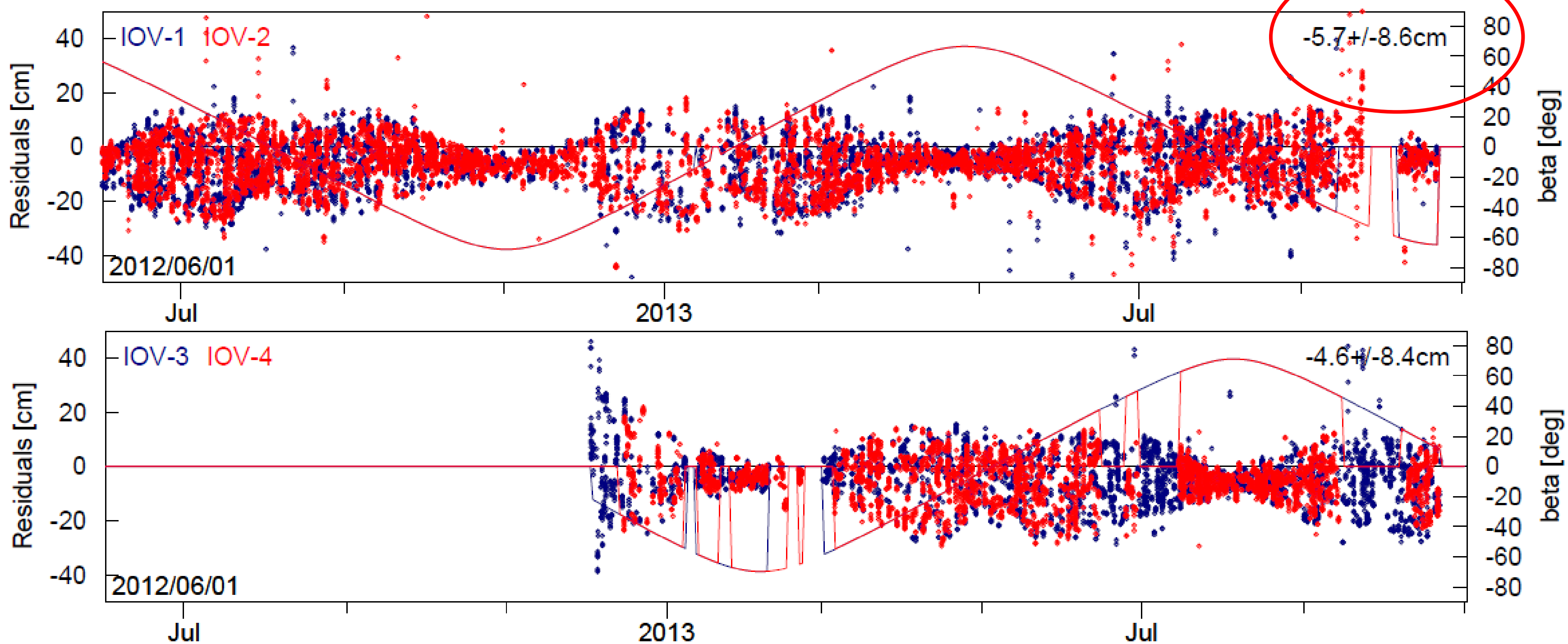


SVN	PRN	Average [cm]	RMS [cm]
I03	C08	-3.6	5.8
I05	C10	-0.3	5.8
M03	C11	-2.1	3.9

Figures & table from:
Qile ZHAO, Zhigang Hu, Jing Guo, Ming Li, Xing Shu, Guo Chen, Chuang Shi, Jinglan Liu; *Positioning Performance of BeiDou Navigation Satellite System*; IGNSS Symposium 2013, 16-18 July 2013, Outrigger Gold Coast, Qld, Australia (2013).

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

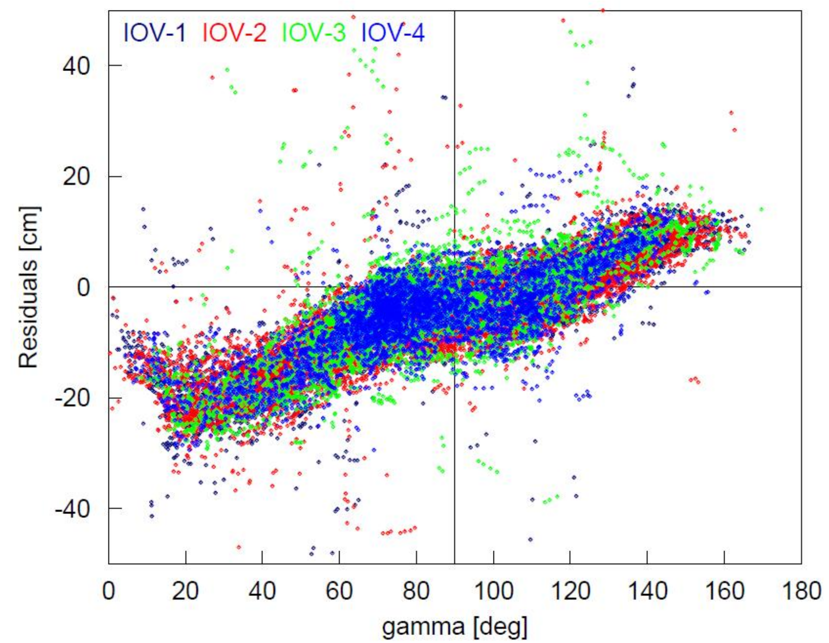
Galileo-IOV

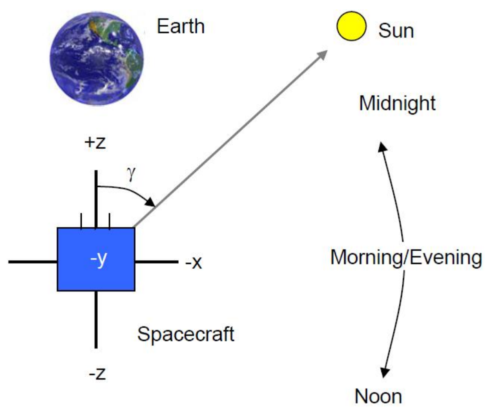


- Combined CODE+TUM products for ~ 1.5 years
- 1/rev radial orbit errors with up to +/- 20 cm
- Amplitude varies with Sun-angle above orbital plane (β-angle)

Galileo-IOV (cntd.)

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

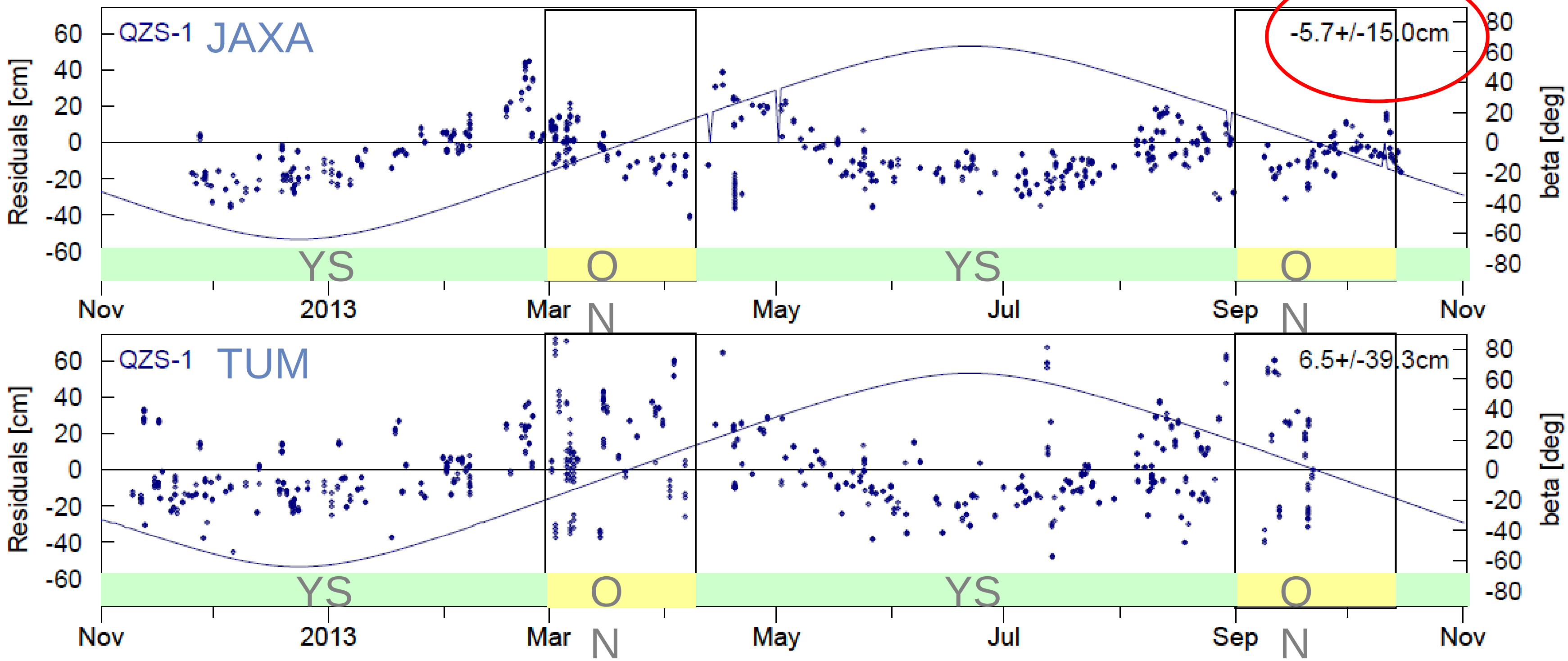




$$
\begin{aligned}
\boxed{\Delta\ddot{R}} - 2n\Delta\dot{T} - 3n^2\boxed{\Delta R} &= \Delta a_R \\
\Delta\ddot{T} + 2n\boxed{\Delta\dot{R}} &= \Delta a_T
\end{aligned}
$$

?

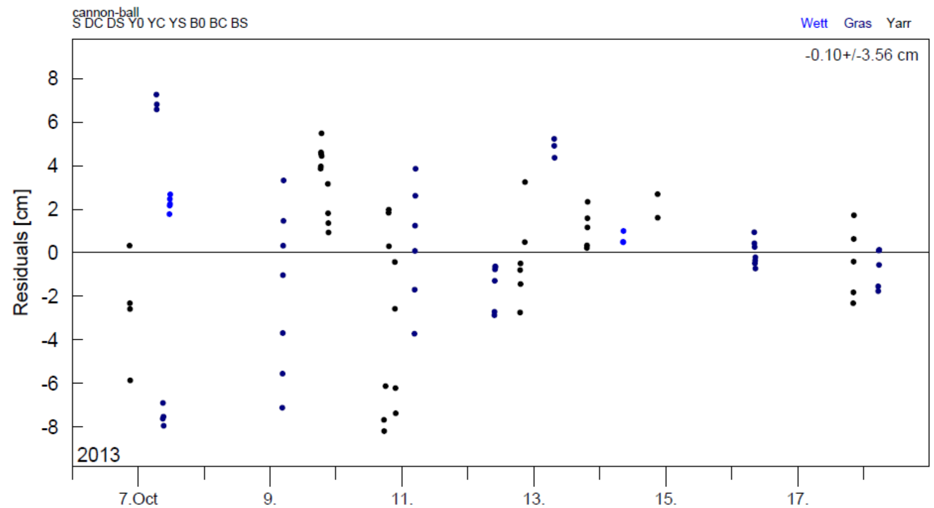
QZSS

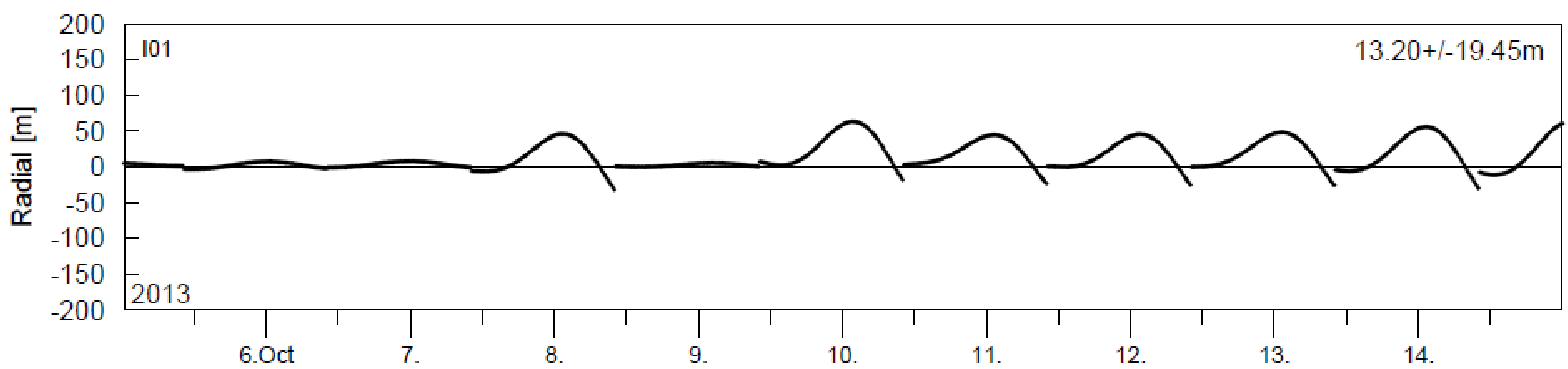


- Best quality of JAXA product (more stations, proper handling of orbit-normal mode, ON)
- Systematic variations (-20…+30 cm) during yaw-steering mode (YS) indicate radiation pressure modeling problems

IRNSS-1A

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



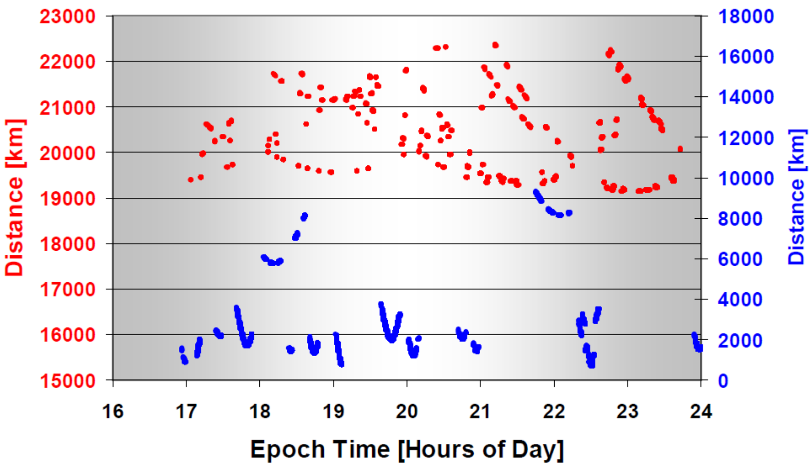


Operational Aspects

- 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 indispensible 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