IGS-MGEX:
QZSS Orbit and Clock Determination

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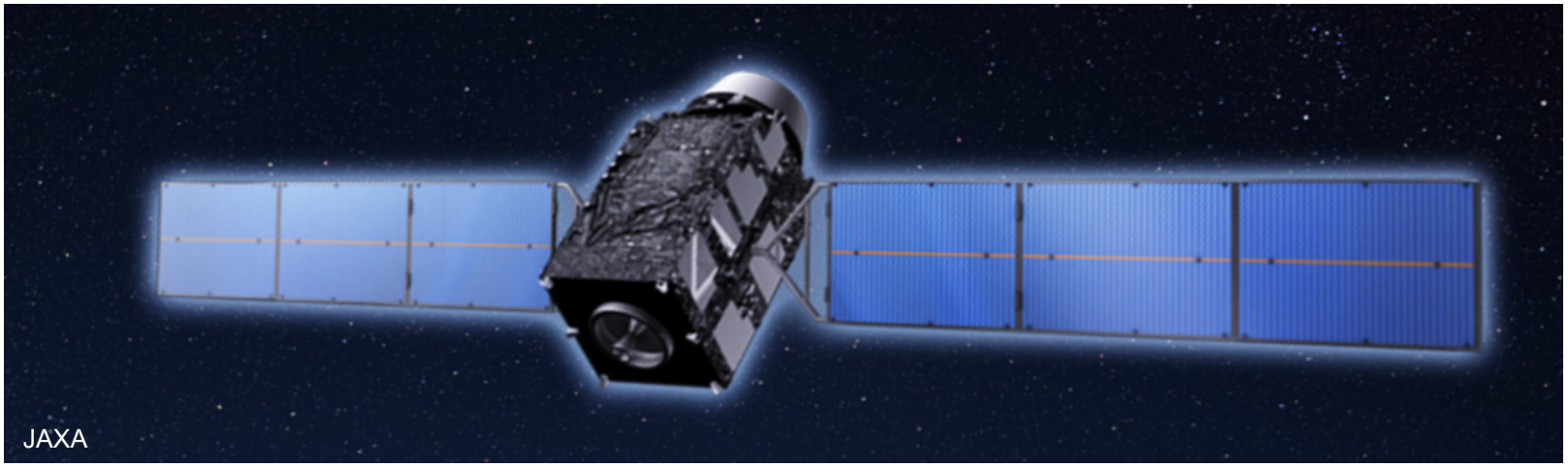
Quasi-Zenith Satellite System (QZSS)

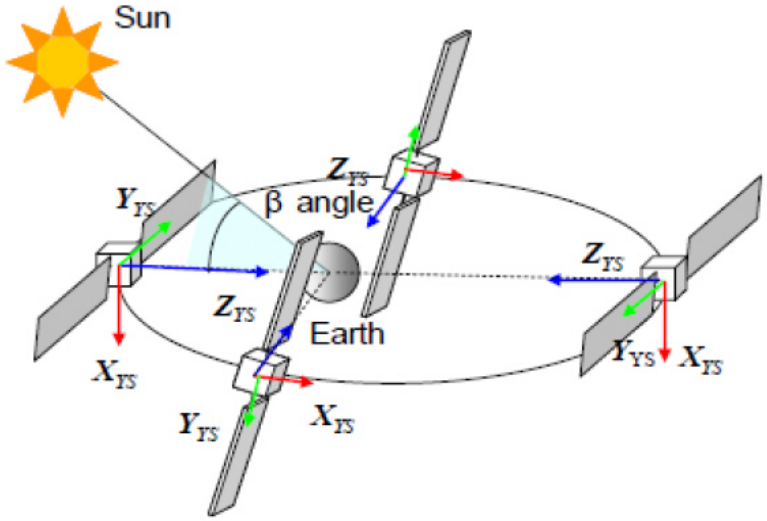
- Japanese regional augmentation System for GPS in the Asia and Pacific region
- Launch of QZS-1 in September 2010, PRN J01
- Inclined Geosynchronous Orbit (IGSO)



QZSS Attitude Modes

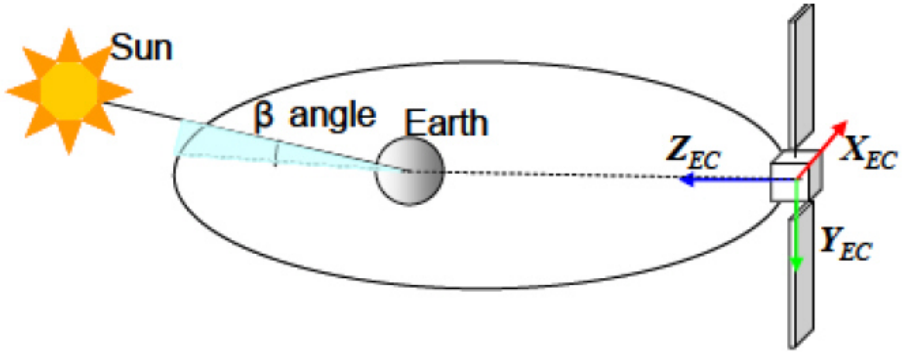
Yaw Steering Mode

- Varying yaw angle to enable Sun pointing solar panels
- Similar to GPS, but +x to deep space



Orbit Normal Mode for |β|<20°

- Solar panel axis normal to orbital plane



Y. Ishijima, N. Inaba, A. Matsumoto, K. Terada, H. Yonechi, H. Ebisutani, S. Ukawa, T. Okamoto, "Design and Development of the First Quasi-Zenith Satellite Attitude and Orbit Control System"

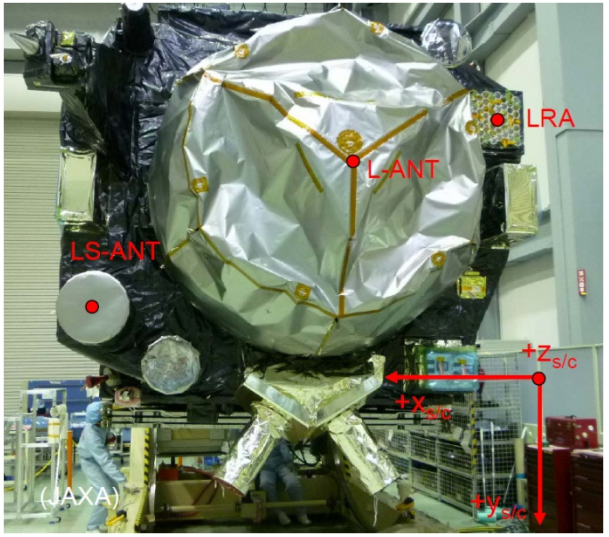
Current Status and Future Plans

- Application demonstrations and R&D activities have being conducted using the first satellite.
  - JAXA is developing the Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis (MADOCA) for PPP applications
- Japanese Government decided to move the QZSS program to the second stage
  - 2 additional IGSO satellites and 1 GEO satellite will be launched in 2017
  - No Orbital Normal mode on IGSO satellites
  - Starting practical operation with four satellite constellation in 2018
  - Quasi-Zenith Satellite System Services Inc. (QSS) is now establishing the operational system.

QZSS Signals

QZSS	GPS	Galileo
L1 1575.42 MHz	**L1** 1575.42 MHz	**E1** 1575.42 MHz
LEX 1278.75 MHz		**E6** 1278.75 MHz
L2 1227.60 MHz	**L2** 1227.60 MHz	
		E5b 1207.14 MHz
L5 1176.45 MHz	**L5** 1176.45 MHz	**E5a** 1176.45 MHz

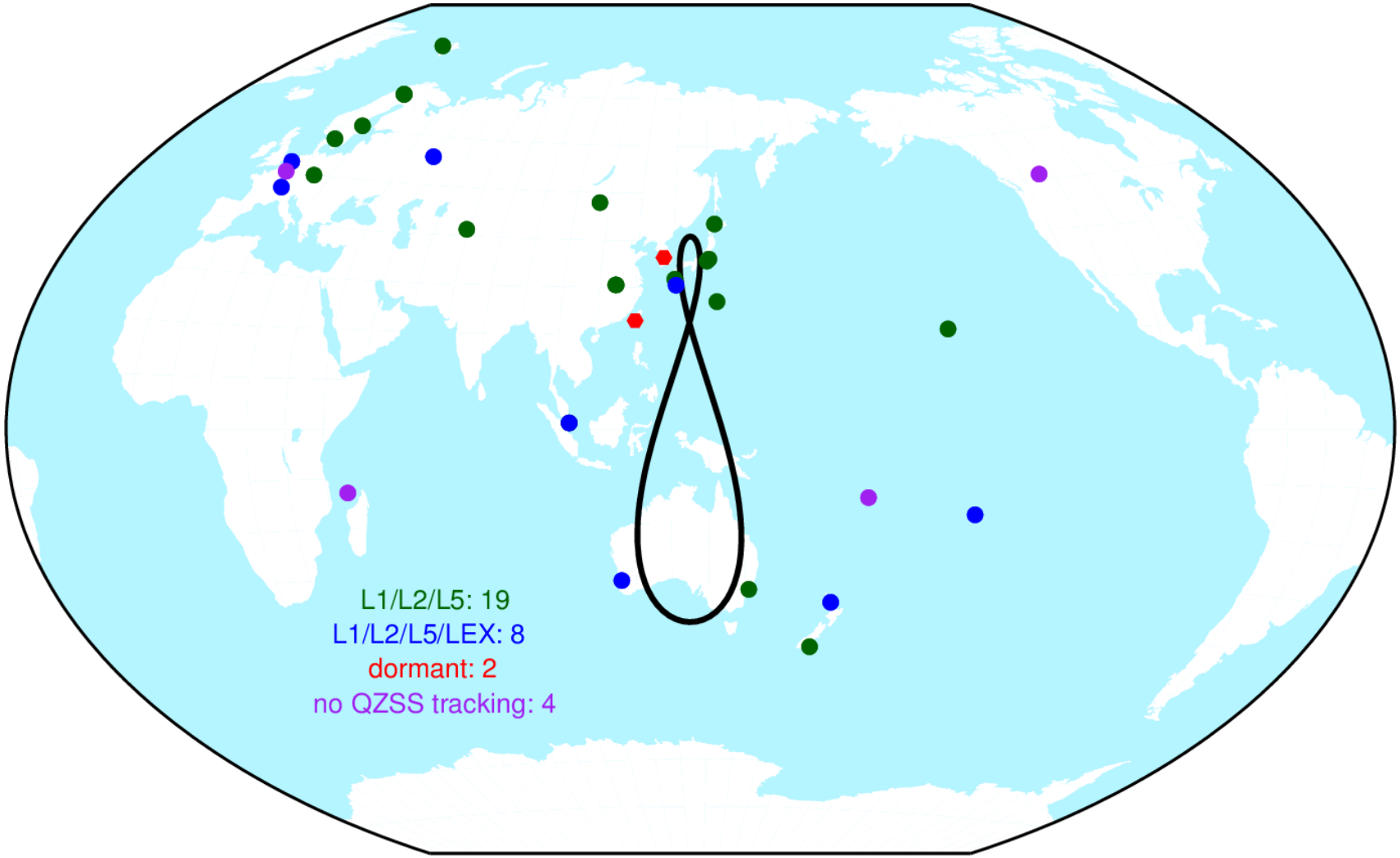
E5 AltBOC



L-Band **EX**perimental Signal

Submeter-class **A**ugmenta-tion with **I**ntegrity **F**unction

MGEX QZSS Tracking Stations

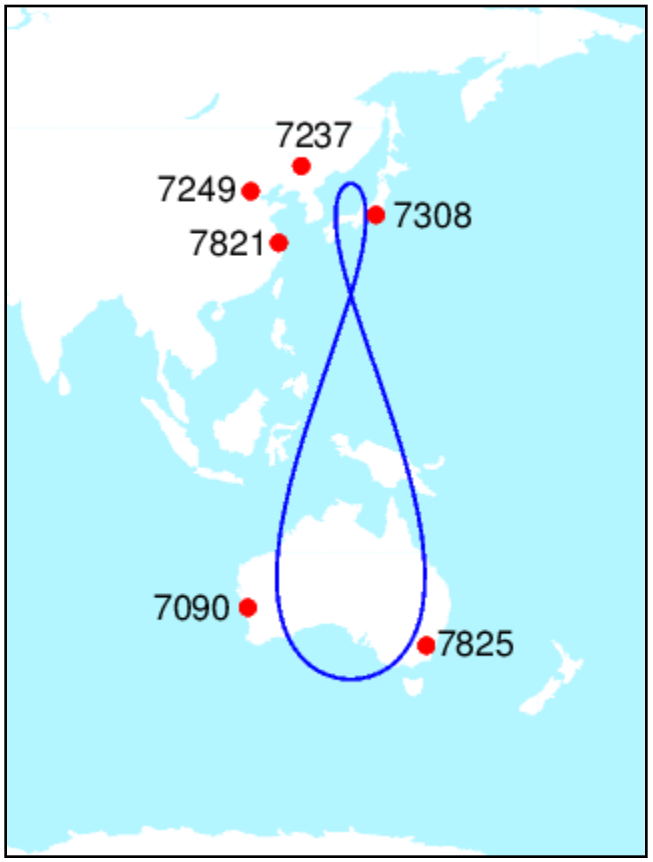


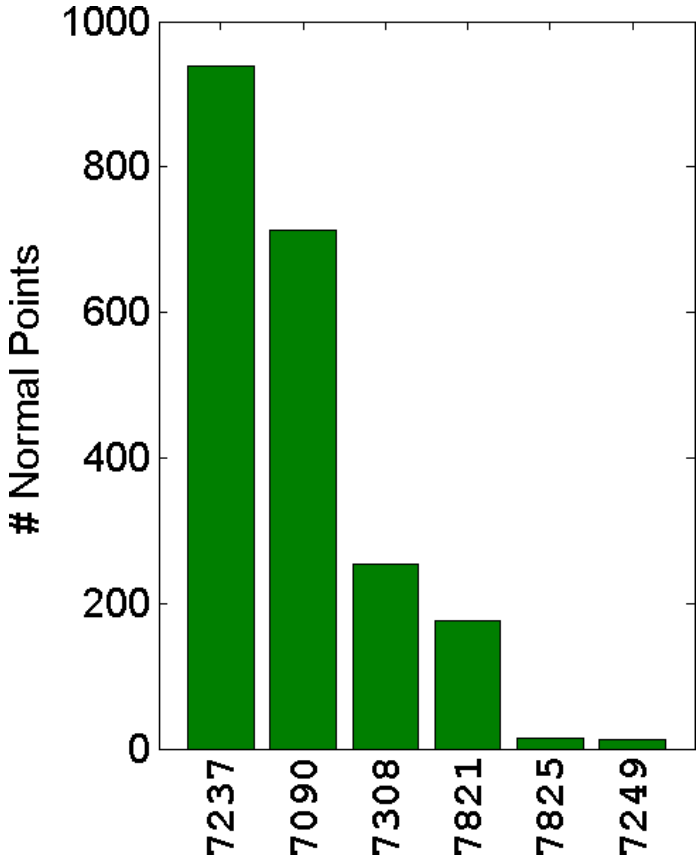
MGEX QZSS Analysis Centers

- **QZF**: Japan Aerospace Exploration Agency (JAXA)
  - MGEX: GPS+QZS since 215/2013 with some gaps
  - JAXA: QZS, GPS+QZS since 330/2012 with some gaps
- **TUM**: Technische Universität München, Germany
  - QZS+GAL since 295/2012
- 5 min orbits and clocks in sp3 format

Satellite Laser Ranging to QZS-1

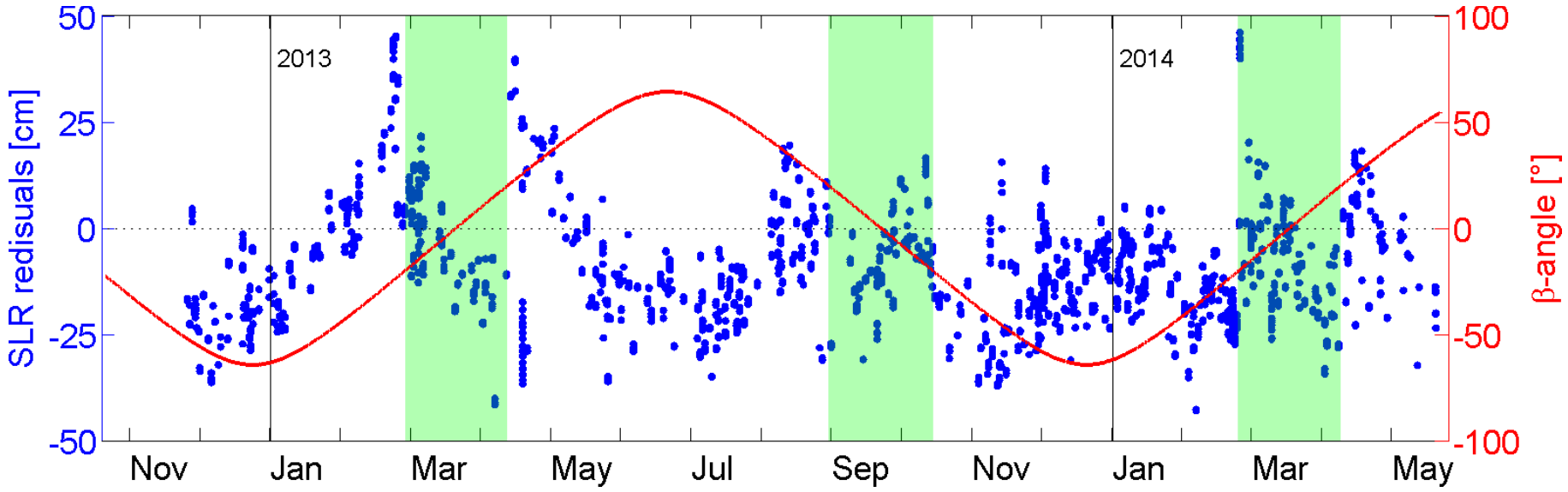
Time period 330/2012 – 140/2014: 2111 normal points



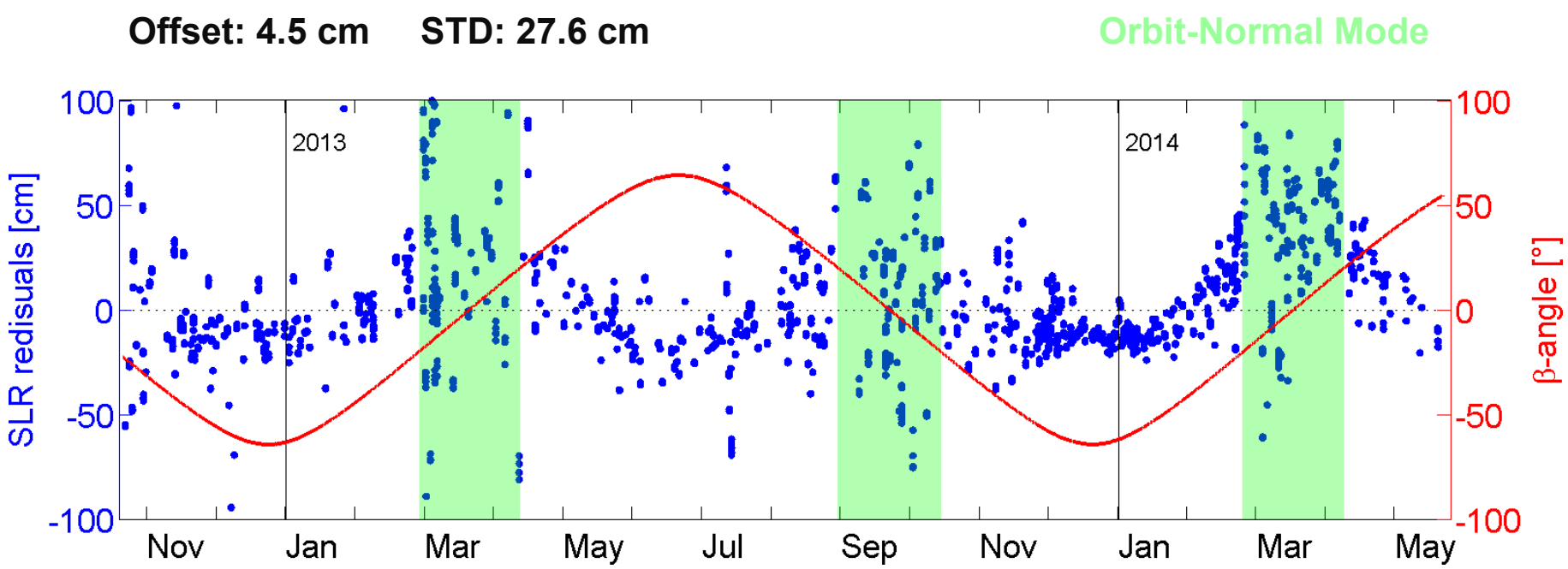


SLR Residuals: QZF

Offset: -8.4 cm **STD: 13.7 cm** Orbit-Normal Mode



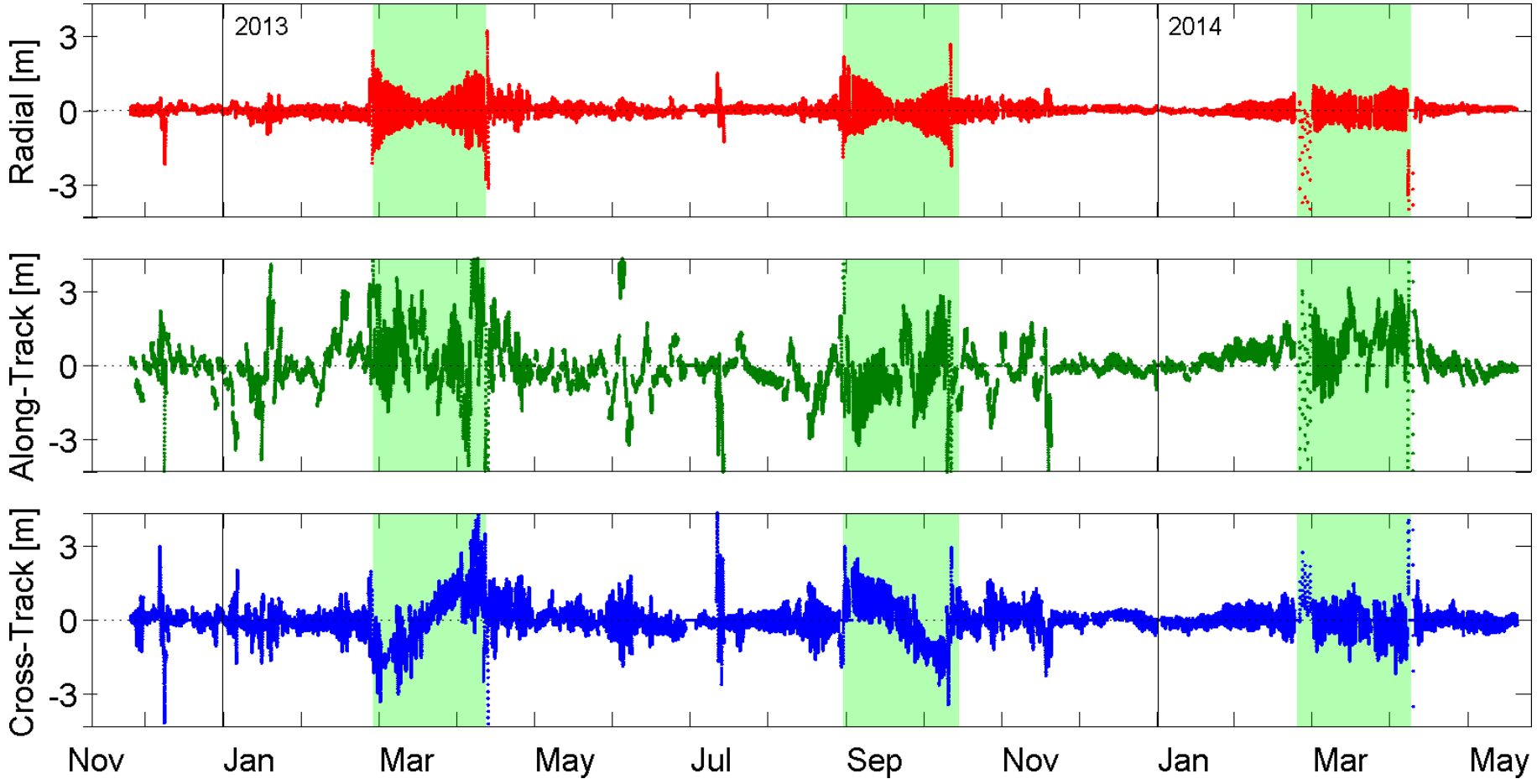
SLR Residuals: TUM



Orbit Comparison: QZF vs. TUM

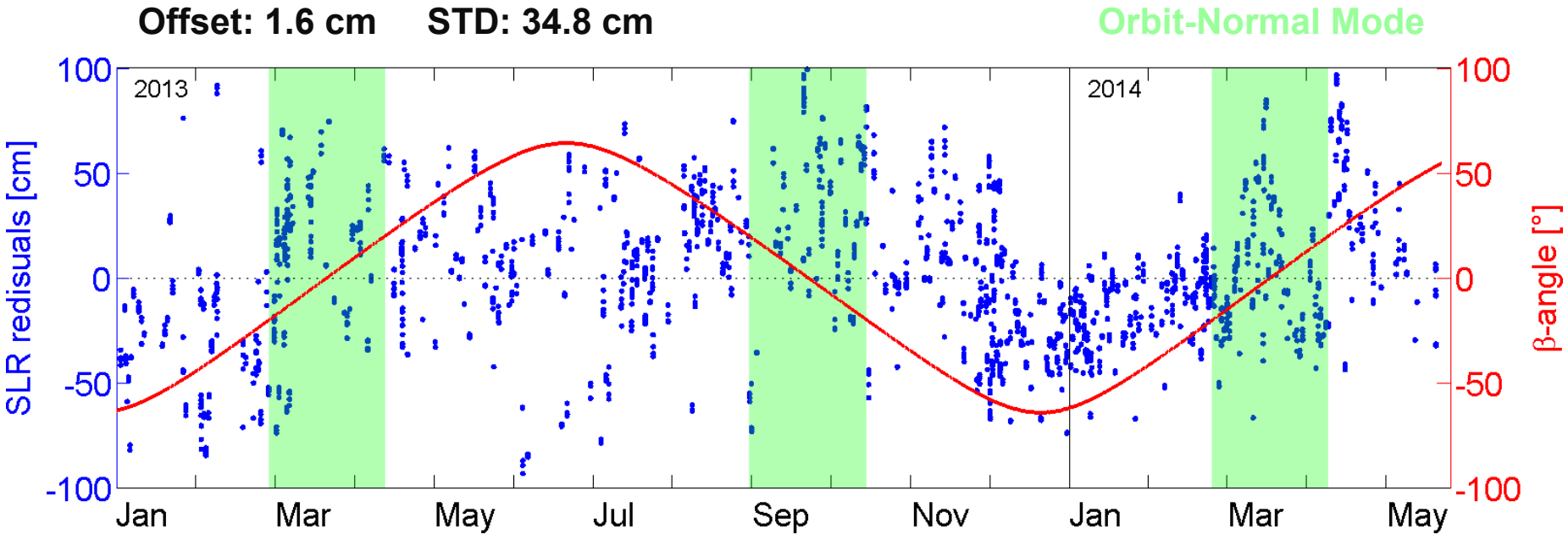
3D-RMS: 1.32 m

Orbit-Normal Mode



SLR Residuals: Broadcast Orbits

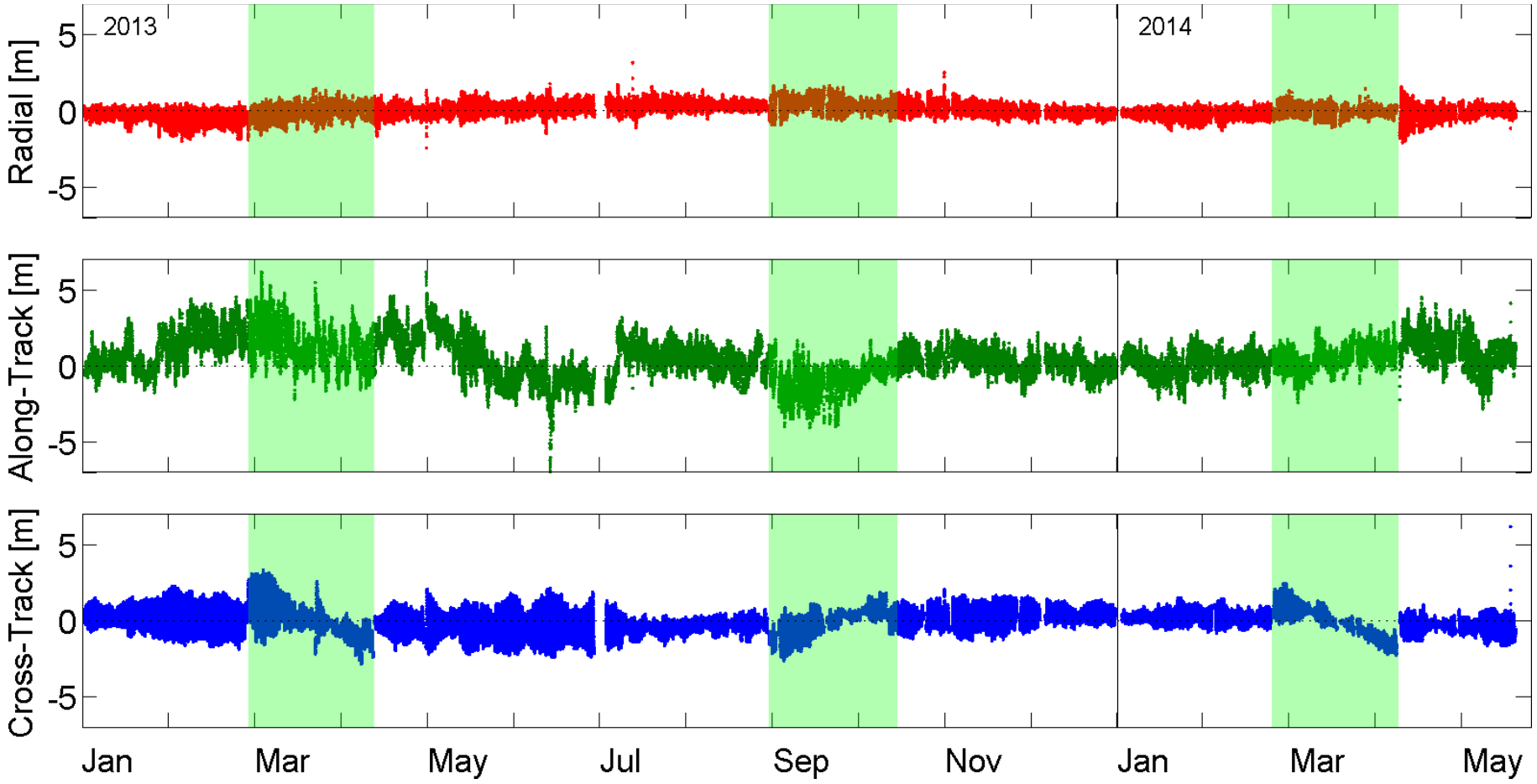
- MGEX broadcast product **`brdm`** available since 1/2013
- Vertical antenna offset of 3.515 m applied (ionosphere-free offset of L1 and L2 antenna offsets provided by JAXA)



Orbit Comparison: Broadcast vs. QZF

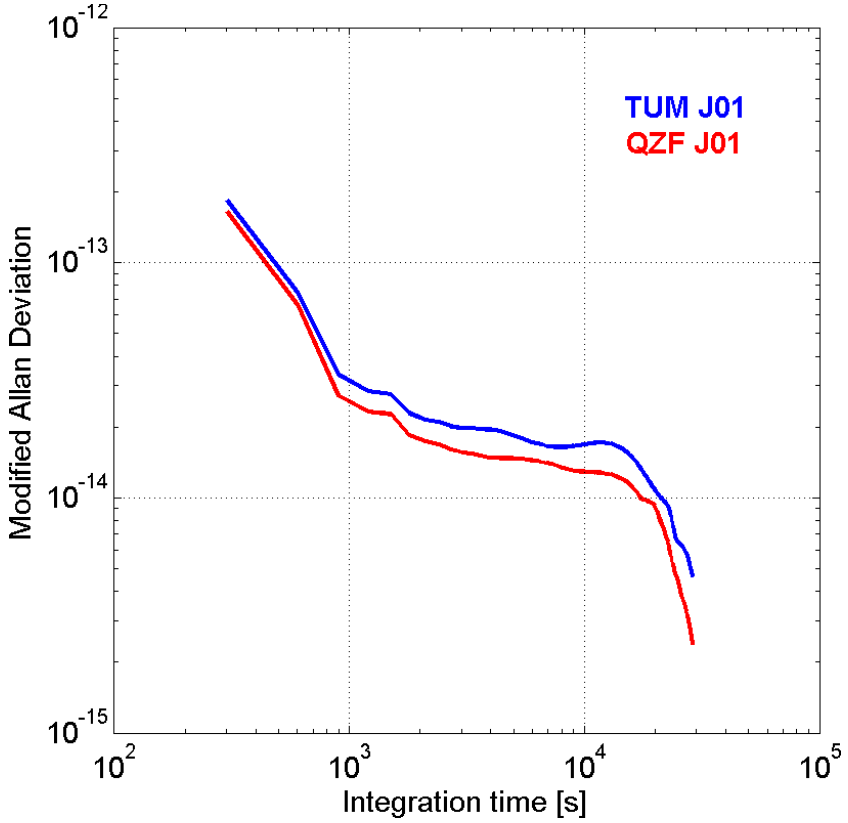
3D-RMS: 1.65 m

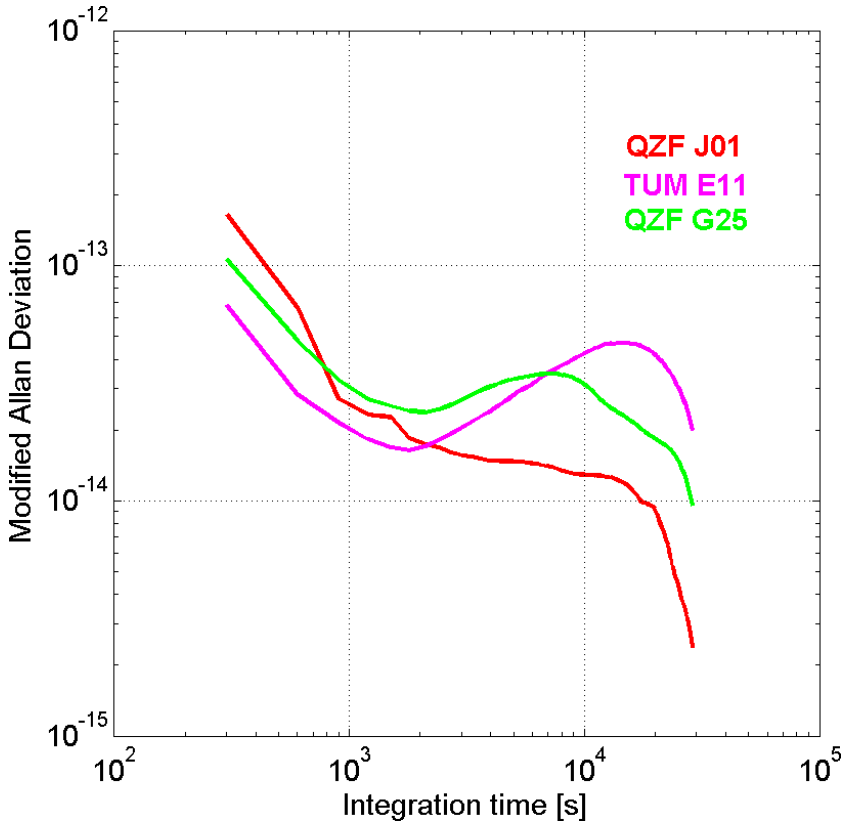
Orbit-Normal Mode



Clock Stability

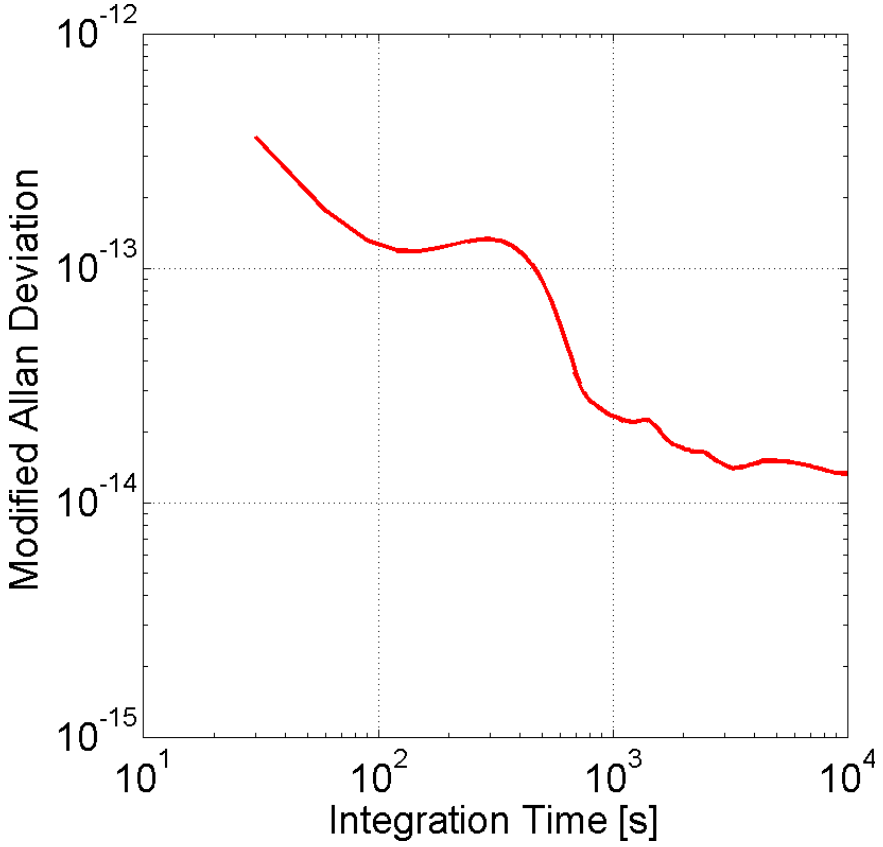
Median Modified Allan Deviation for GPS week 1773

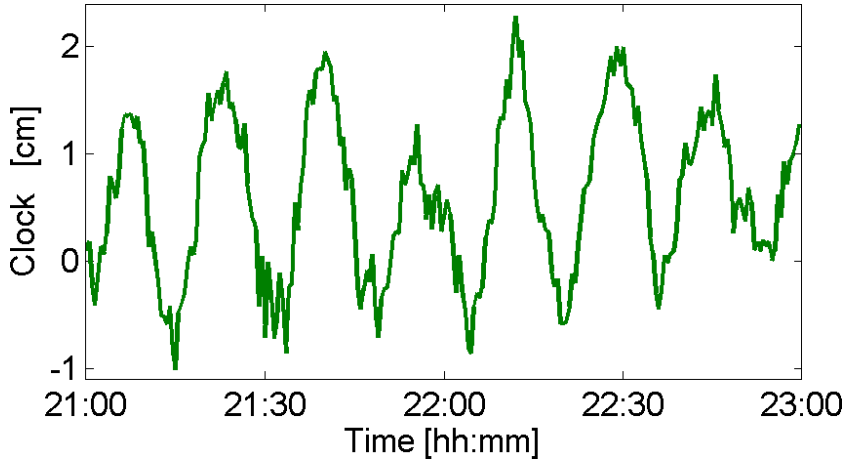


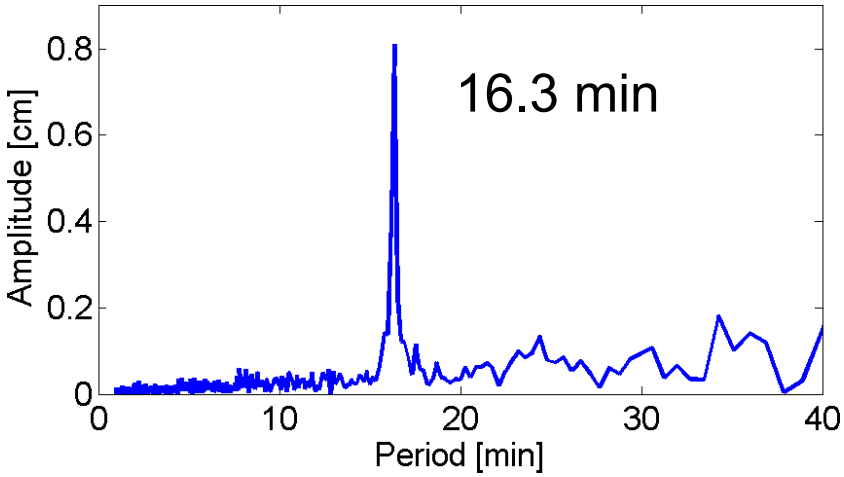


Short-period Clock Variations

TUM 30 s clock solution

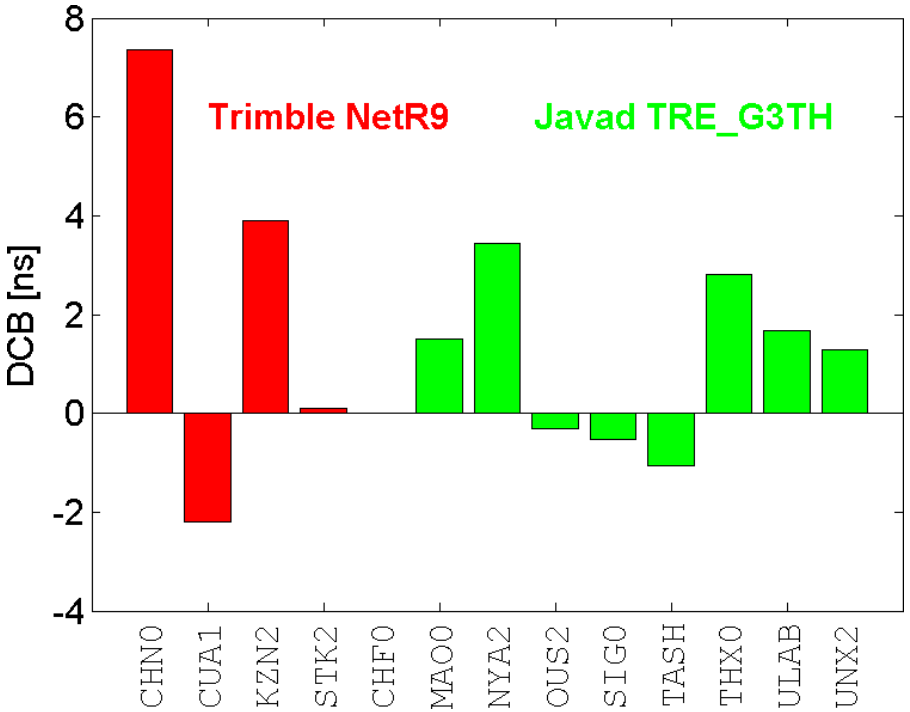


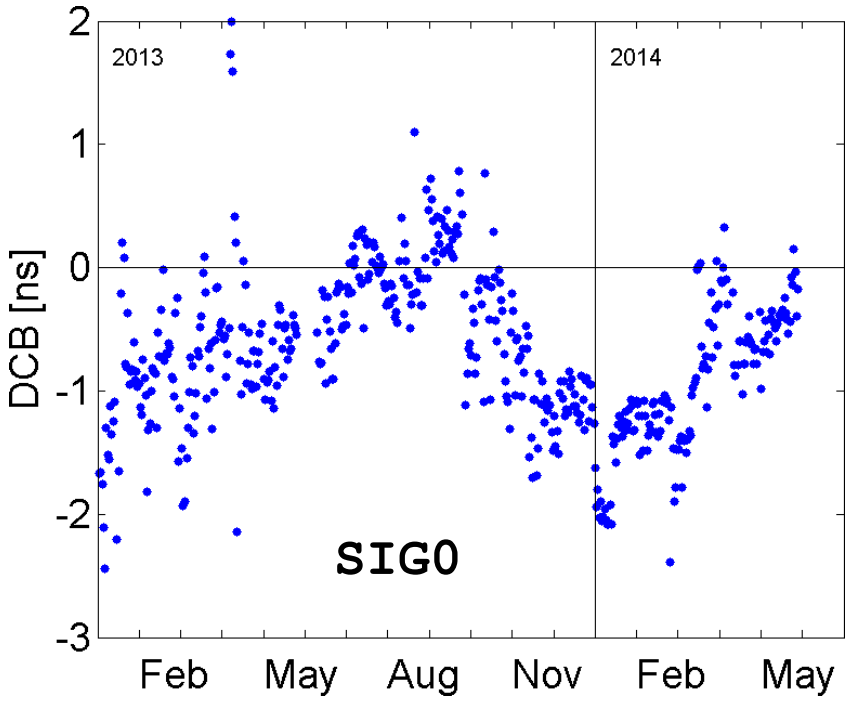




Differential Code Biases

Receiver	GPS L1	GPS L2	QZSS L1	QZSS L5
Trimble NetR9	C1C	C2W	C1C	C5X
Javad TRE_G3TH	C1W	C2W	C1X	C5X



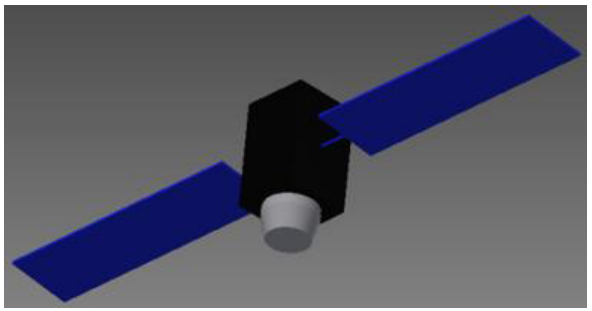


Summary, Outlook, and Open Issues

- Two MGEX analysis centers provide QZSS orbit and clock products.
- Orbit accuracy currently at the several decimeter level
- Systematic errors related to attitude modeling
  - Need consistent YS/ON modeling for all analysis centers
  - Need proper bookkeeping (and advance notice) of all mode transitions
  - Need common convention for s/c axes (ANTEX!)

Summary, Outlook, and Open Issues

- Deficiencies in solar radiation pressure modeling
  - Dependency of SLR residuals on β-angle
- Need for improved solar radiation pressure model
  - Box-wing-hat style model
  - Initial work by Ikari et al. (ION GNSS+ 2013)



- Other MGEX analysis centers are encouraged to include QZSS in their solutions.

Processing Strategies

	QZF	TUM
QZSS stations	9	11-15
GPS stations	33	11-15
Frequencies	L1 and L2	L1 and L5
Differencing	Undifferenced	Undifferenced
Data interval	7 days	3 days (orbit) 1 day (clock)
Sampling	300 s	30 s
Elevation cutoff	10°	3°
Radiation pressure par.	Orbit normal mode: D0, Y0, B0, ZC, ZS Yaw steering: D0, Y0, B0, DC, DS, BC, BS, ZC, ZS, D(2/rev), X(2/rev)	D0, Y0, B0, BC, BS