Multi-GNSS SISRE Monitoring – Methodology and Results

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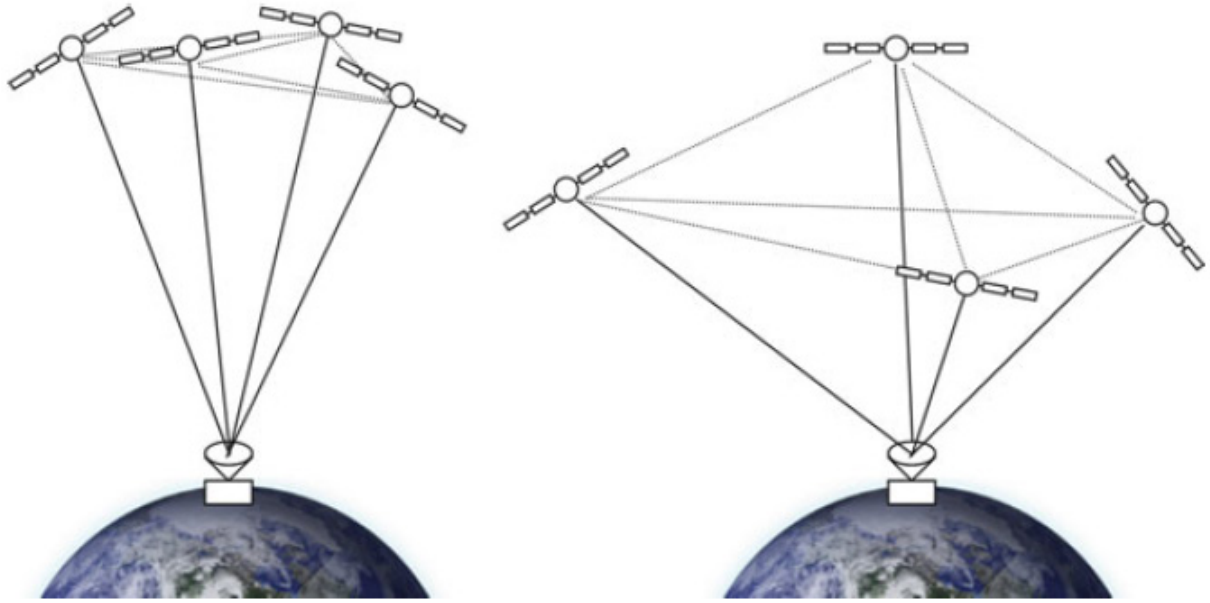
GNSS Positioning Accuracy



Schüttler (2014)

UERE: User Equivalent Range Error

- All measurement and modelling errors of a pseudorange

DOP: Dilution of Precision

- Mapping of range error to position error σ for given geometry

SISRE: Signal-in-Space Ranging Error

- Errors of broadcast orbits and clocks

UEE: User Equipment Error

- Receiver noise, multipath, uncorrected atmospheric delays

$$\sigma = \text{UERE} \cdot \text{DOP}$$

$$\text{UERE} = \text{SISRE} + \text{UEE}$$

- Assumes uncorrelated errors with zero mean
- Only valid in a statistical sense

Signal-in-Space Ranging Error (SISRE)

- SISRE is a **key indicator** for **GNSS performance monitoring**
- Depending on
  - **Space segment capabilities**: clock stability, predictability of orbital motion
  - **Control segment capabilities**: orbit and clock determination performance, distribution of monitoring stations, upload capacity
- Evaluated by comparison of broadcast ephemerides with precise reference products

Reference orbit and clock product

- IGS combined orbit and clock product for GPS
- No combined clock product for GLONASS
  - Use (orbits and) clocks of one particular IGS analysis center
- No combined orbit and clock products for Galileo, BeiDou, QZSS
  - Use orbits and clocks of one particular MGEX analysis center
- No products for IRNSS at all

Reference DCB product

- MGEX

SISRE Computation

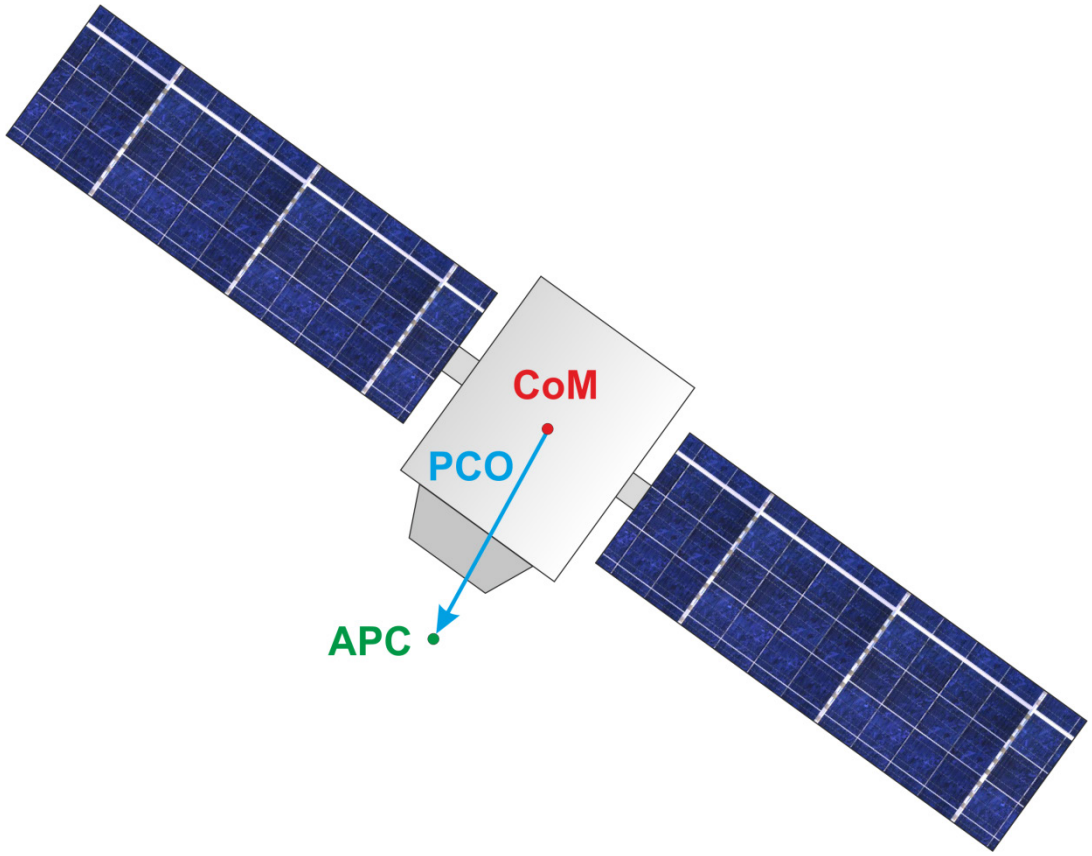
1. Translate orbit and clock data to center of mass
2. Evaluate orbit difference in radial (R), along-track (T) and cross-track (N)
3. Translate precise clock solution using MGEX DCBs
   - to E1/E5b for Galileo INAV
   - to B3 for BDS D1/D2
4. Evaluate clock differences; remove epoch-wise constellation mean
5. Compute per-epoch (i) and per-satellite (k) SISRE contribution from root-sum-square of weighted orbit and clock errors (broadcast – precise)

$$\mathrm{SISRE}_{i,k} = \sqrt{\left(w_R \cdot \Delta r_{R,i,k} - \left(\Delta cdt_{i,k} - \overline{\Delta cdt_i}\right)\right)^2 + w_{T,N}^2 \cdot \left(\Delta r_{T,i,k}^2 + \Delta r_{N,i,k}^2\right)}$$

6. Outlier screening
7. Compute SISRE from root-mean-square over all satellites and epochs

$$\mathrm{SISRE} = \sqrt{\left(\sum_{i,k} \mathrm{SISRE}_{i,k}^2\right) / \left(\sum_{i,k} 1\right)}$$

Satellite Antenna Phase Center Offsets



- **Precise orbits** refer to the **center of mass (CoM)** of the satellite
- **Broadcast orbits** refer to the **antenna phase center (APC)**
- Precise and broadcast clocks refer to different APCs
- Estimation of broadcast antenna phase center z-offsets as **radial difference** between precise and broadcast orbits

Block	Satellites	z [cm]
GLONASS-M	SVN 715, 716, 717, 719	245.0
GLONASS-M	SVN 720 – 747, 851, 853, 854	205.0
GLONASS-M+	SVN 855	205.0
GLONASS-K1	SVN 802	165.0

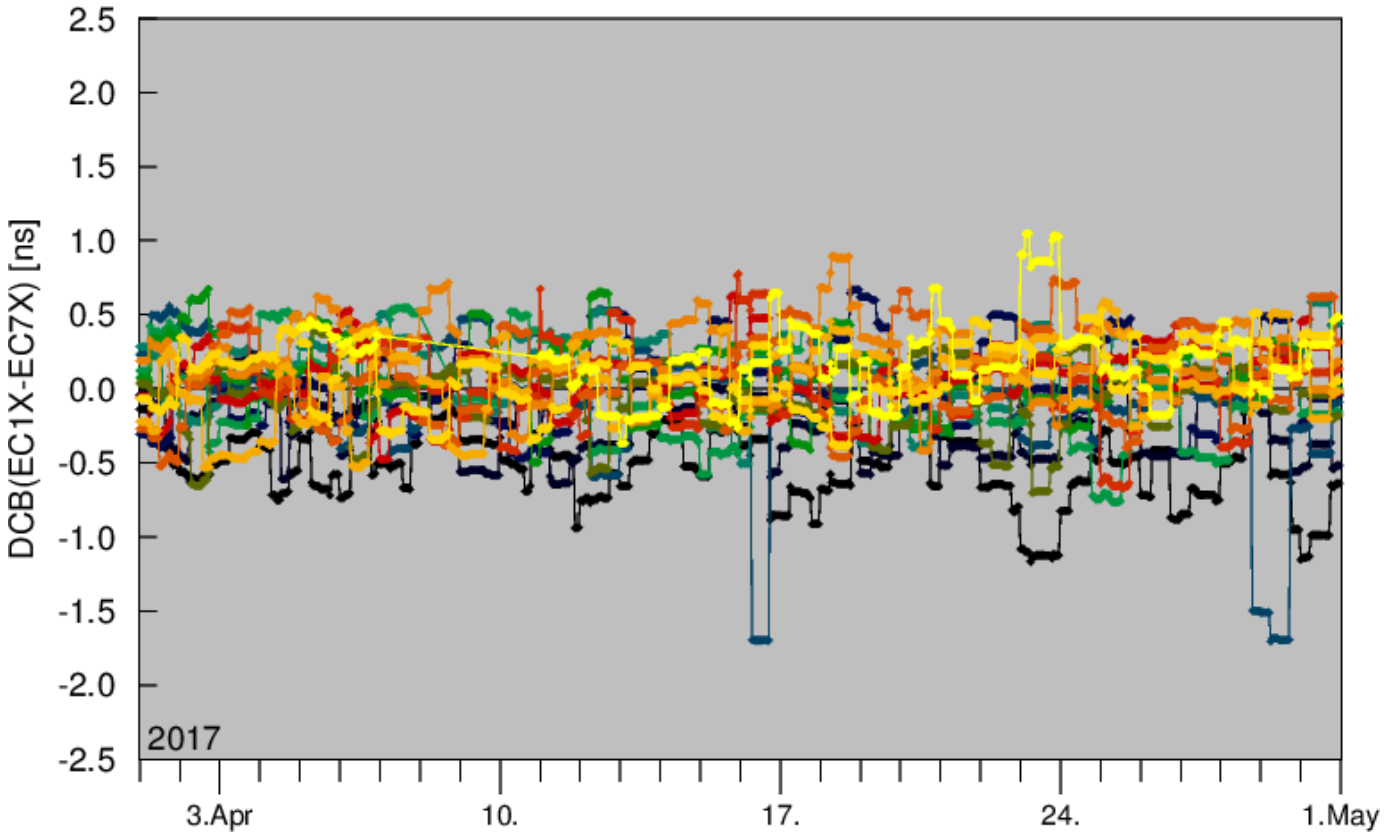
Block	Validity	z [cm]
Galileo IOV	1/2013 – 120/2013	165.0
	121/2013 – 59/2015	85.0
	since 60/2015	75.0
Galileo FOC		75.0

BGD/DCB SISRE Contribution

- Broadcast Group Delays (BGDs) or more generally Differential Code Biases (DCBs) translate clock conventions
- Standard deviation of BGD/DCB values contributes to computed SISRE values if conventional clock signal of broadcast and precise product disagrees
- Concept can be extended to single-frequency SISRE

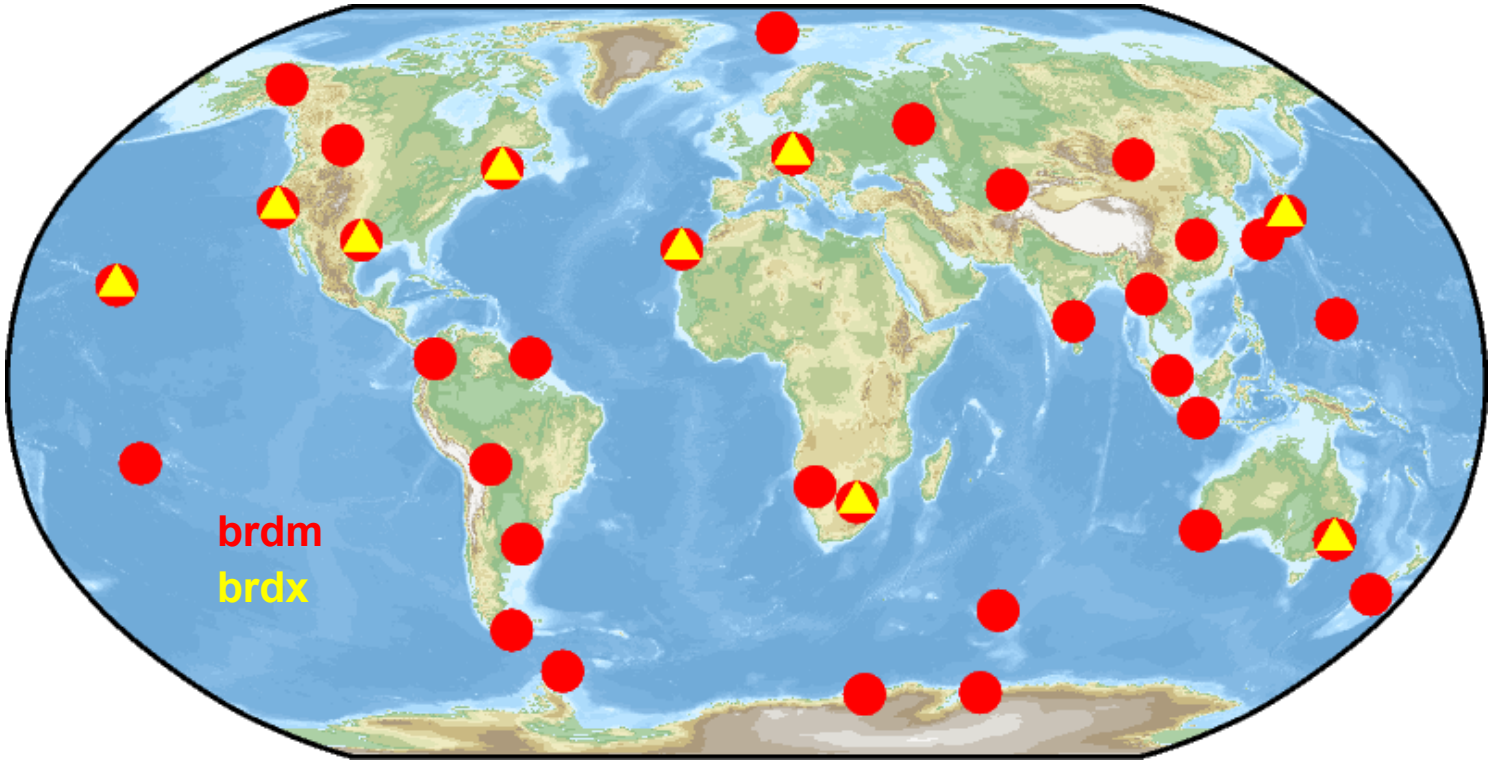
Galileo signals	STD [ns]	STD [cm]
E1/E5a	0.36	11
E1/E5b	0.32	9

Galileo E1/E5b DCB comparison: broadcast vs. MGEX

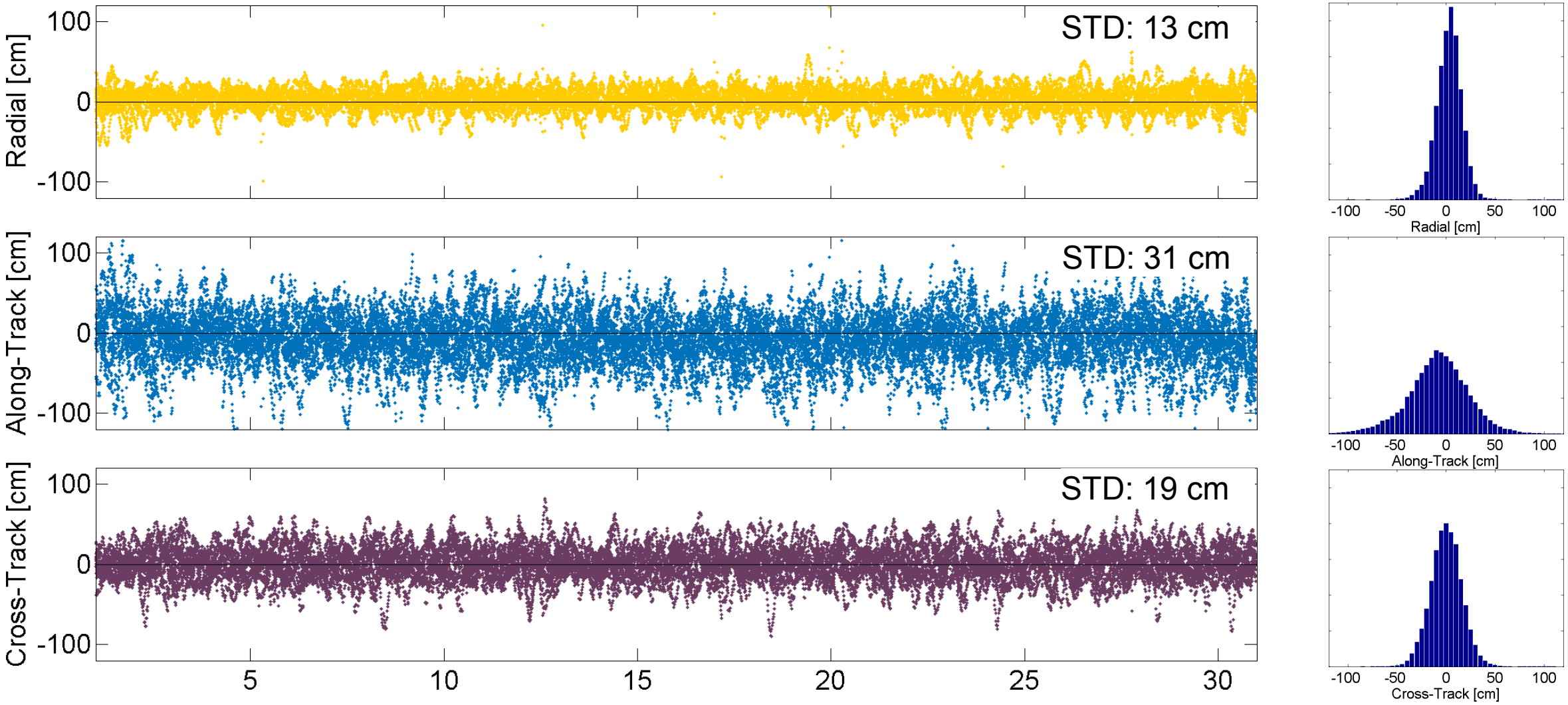


IGS MGEX Broadcast Ephemerides Product

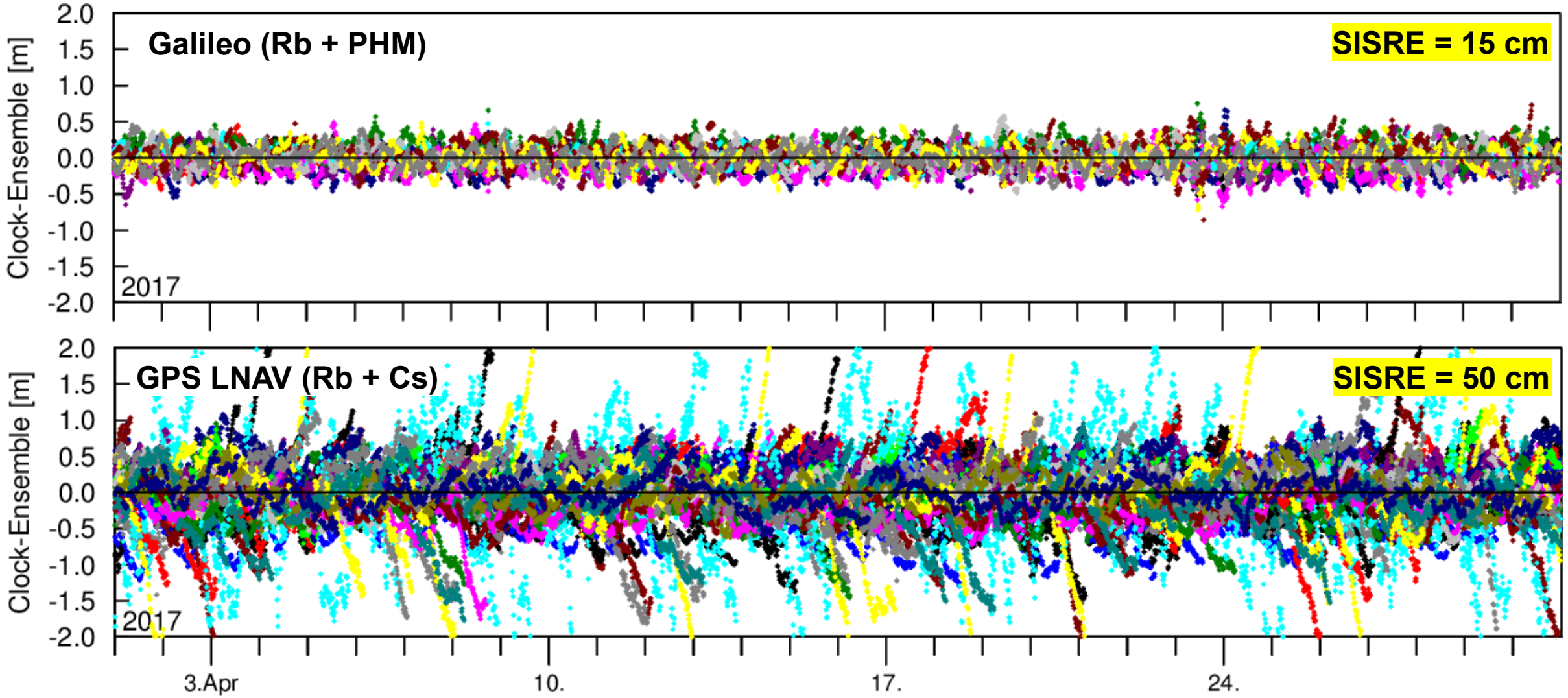
- Merged broadcast ephemerides product generated by DLR for the Multi-GNSS Pilot Project (**MGEX**)
- Based on 37 real-time streams and one offline station (`brdm`)
  - GPS LNAV
  - GLONASS
  - Galileo INAV and FNAV
  - BeiDou
  - QZSS
  - IRNSS
  - SBAS
- MGEX CNAV product (`brdx`) from raw navigation data of 9 Javad receivers



Orbit Comparison: Galileo FNAV April 2017

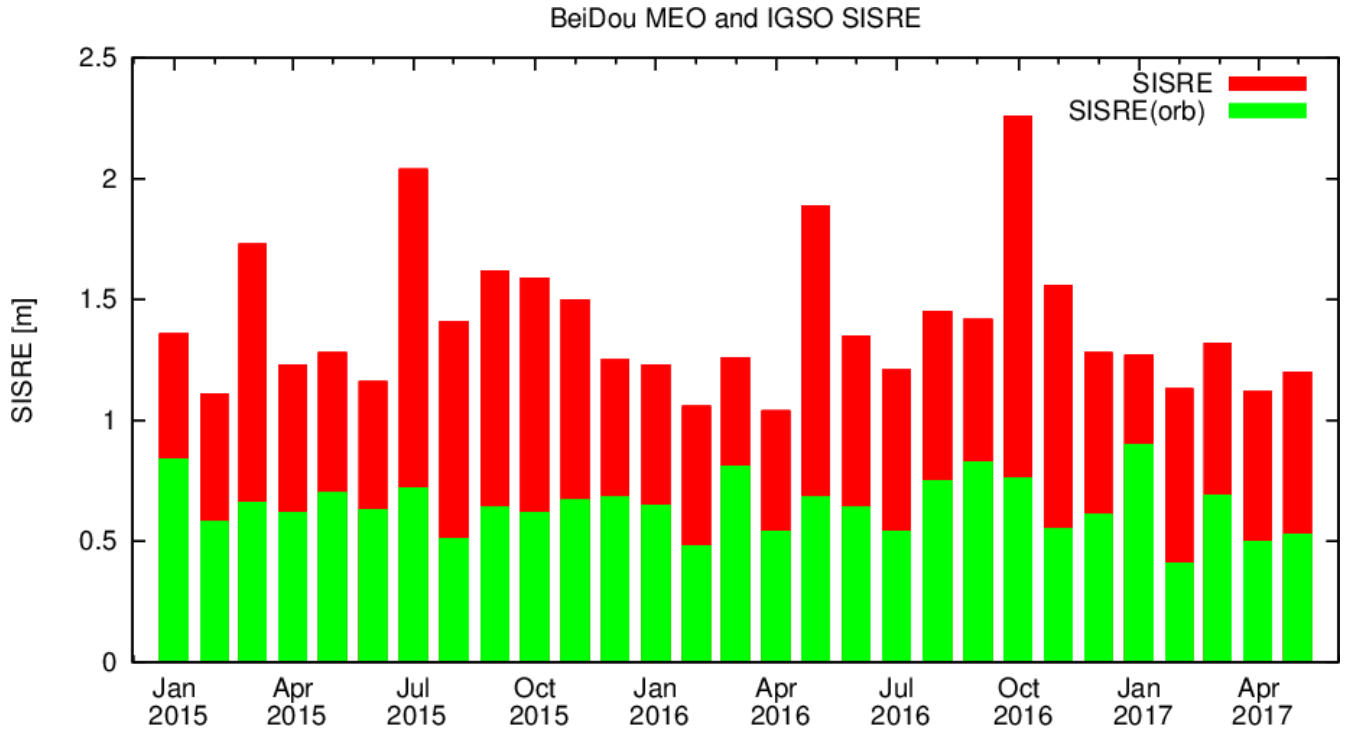


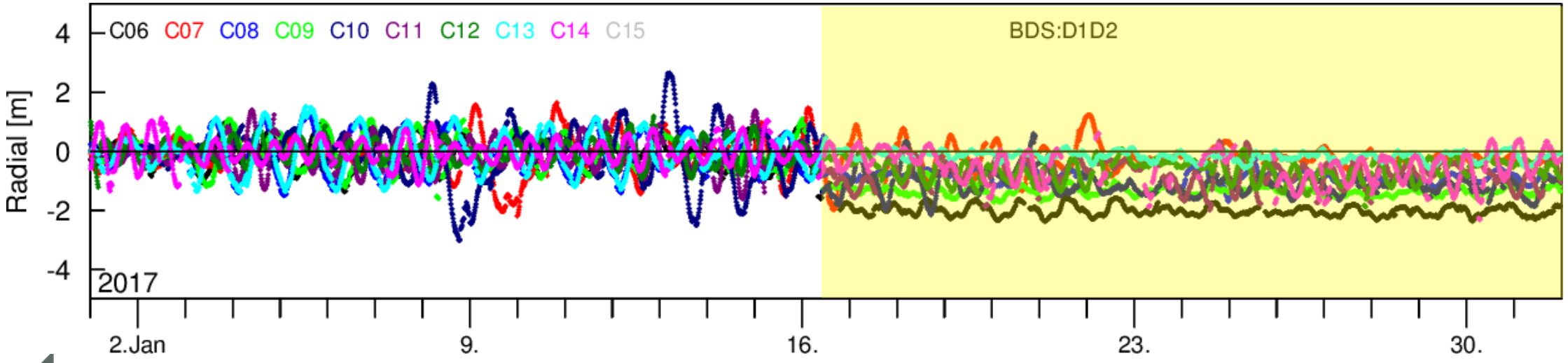
Clock Comparison: Galileo and GPS



BeiDou Broadcast Ephemerides

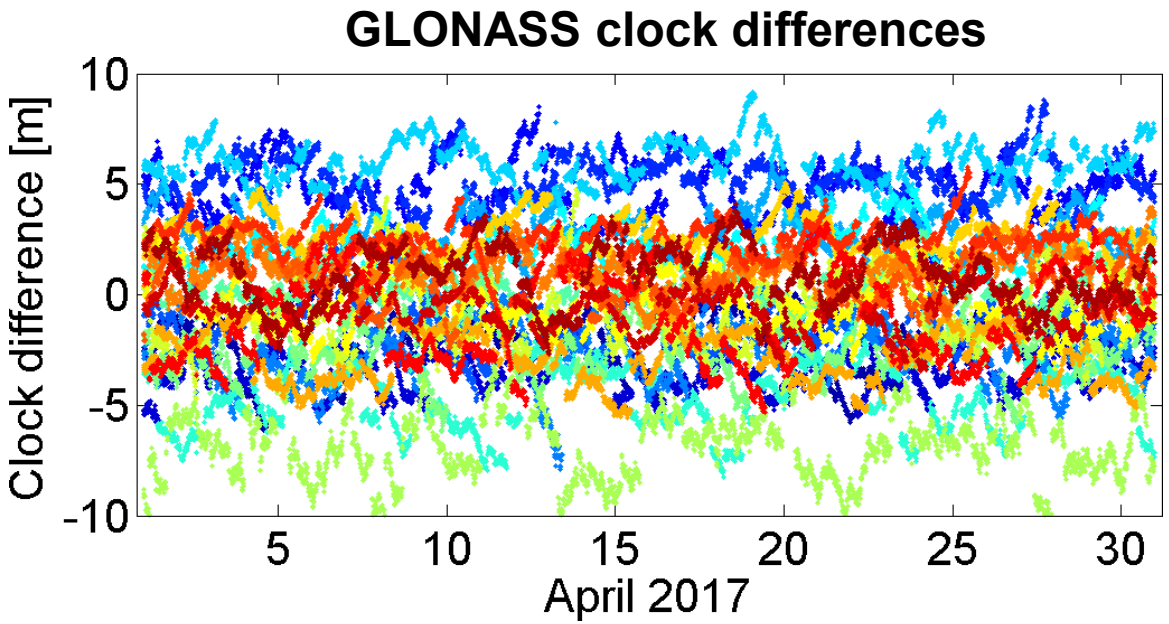
- Revised broadcast generation since mid of January 2017
- Goal: improved SISRE
- Comments:
  - changed PCOs (unknown, time-variable?)
  - non-physical orbit representation?
  - discontinuities





SISRE Overview (April 2017)

Constellation	Type	Group	SISRE [cm]	SISRE(orb) [cm]
GPS	LNAV	all	50	22
		Rb	45	22
		IIF/Rb	40	24
	CNAV	all	53	22
		IIF/Rb	39	23
GLONASS		all	309	51
Galileo	INAV	all	14	14
	FNAV	all	15	14
BeiDou-2		all	162	66
		MEO	86	63
		IGSO	100	35
		GEO	198	84



- Inter-frequency biases not considered for GLONASS
- Daily IFB estimation reduces SISRE to about 100 cm

Summary and Conclusions

- Signal-in-Space Ranging Error (SISRE) is a **key indicator** for **GNSS performance monitoring**
- No combined IGS multi-GNSS reference product available
- Currently no quality control for IGS combined broadcast ephemeris products
- Common set of **broadcast satellite antenna phase center offsets** needed
  - Values used by system operators desired for SISRE(orb) monitoring
  - Alternative: estimation of broadcast PCOs from comparisons with precise orbits
- Discussion on outlier screening for SISRE computation needed: fixed limit vs. fixed percentile

Galileo navigation message outage 14-16 May 2017

- NAGU 2017015: NAVIGATION MESSAGES NOT REFRESHED FOR ALL SATELLITES SINCE 2017-05-14 15:50 UTC UNTIL FURTHER NOTICE.