

IGS-related multi-GNSS activities at CODE

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CODE: who we are?

- **CODE = Center for Orbit Determination in Europe**
- joint venture between
 - Astronomisches Institut der Universität Bern (AIUB)
 - Bundesamt für Landestopographie swisstopo
 - Bundesamt für Kartographie und Geodäsie (BKG)
 - Institut für Astronomische und Physikalische Geodäsie, TU München (IAPG, TUM)
- operational since 1992, located at the University of Bern
- contributions to all product lines of the **IGS** from a rigorous multi-GNSS processing (also contributing to the **EPN** and **ILRS**)
- all products are generated using the *Bernese GNSS Software* developed and maintained by the AIUB

Outline

1. Introduction: IGS–MGEX
2. CODE–MGEX orbit solution
3. CODE–MGEX clock solution
4. PPP
5. Summary and outlook

IGS: International GNSS Service

- **IGS-MGEX: IGS Multi-GNSS Experiment**

- **Scope:** (from www.igs.org/mgex)

*The Multi-GNSS Experiment (MGEX) has been set-up by the IGS to **track, collate and analyze** all available GNSS signals. This includes signals from the **BeiDou, Galileo and QZSS** systems, as well as from **modernized GPS and GLONASS** satellites and any **space-based augmentation system (SBAS)** of interest. Analysis centers will attempt to estimate **inter-system calibration biases**, compare equipment performance and further develop processing software capable of handling multiple GNSS observation data.*

IGS MGEX history

- Call for Participation in August 2011
- Start of the project in February 2012
- First results have been exchanged at the IGS workshop in Olsztyn, Poland (end of July 2012).
- In important update is expected at the next IGS workshop in Pasadena, USA (end of June 2014).
- **Further information about MGEX:**
Montenbruck O., Steigenberger P., Khachikyan R., Weber G., Langley R.B., Mervart L., Hugentobler U., "IGS–MGEX: Preparing the Ground for Multi–Constellation GNSS Science", InsideGNSS 9(1):42–49 (2014).

IGS-MGEX network (from www.igs.org/mgex)

Network

An overview of the current MGEX network is shown in the map below. For detailed information on individual stations see the [MGEX station list](#). The latest site logs are available from the [IGS MGEX site log archive](#).

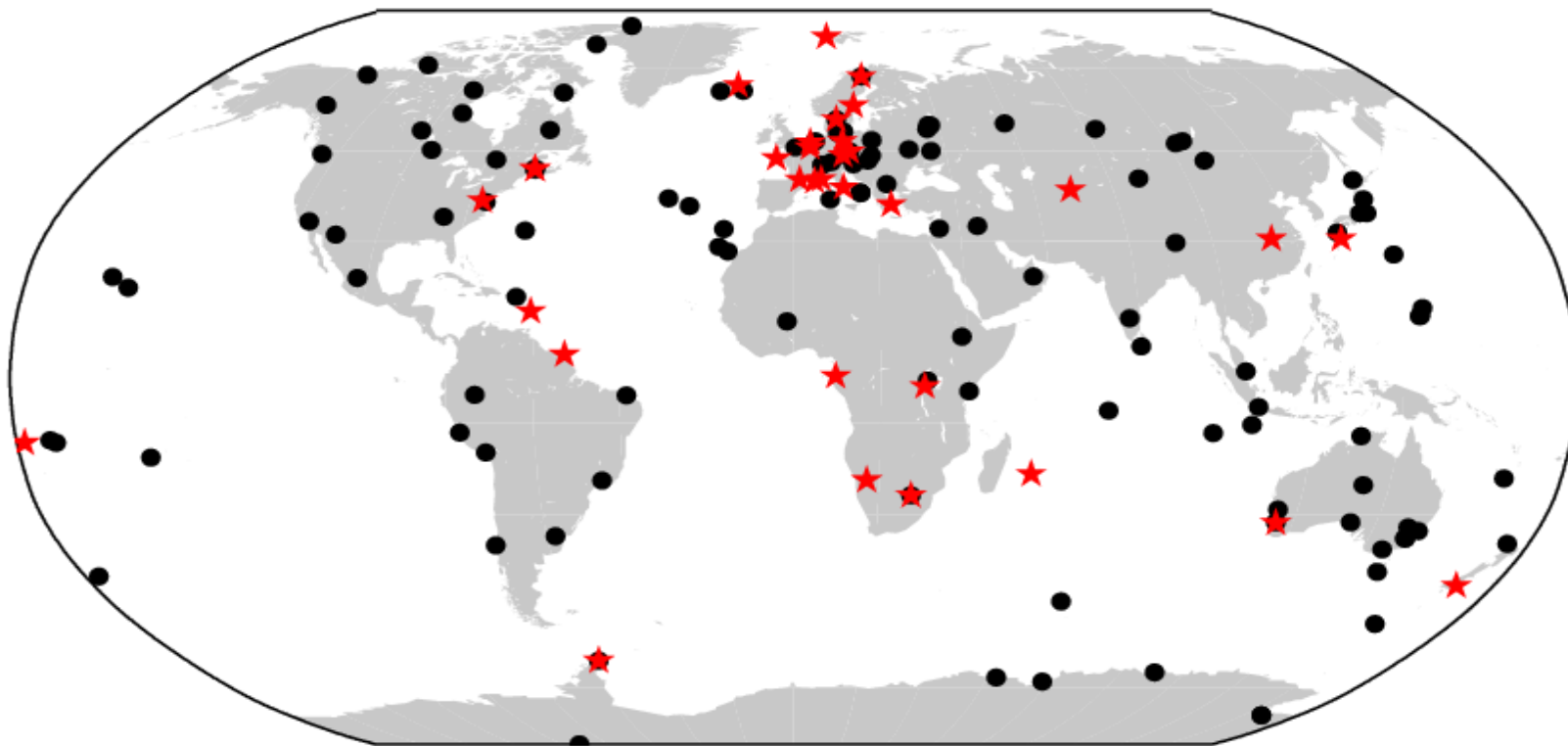


The CODE MGEX solution

- All available Galileo tracking stations are included. (Some selection is only done in Europe.)
- The network is completed by the GPS+GLONASS tracking sites typically used in the CODE rapid solution for the IGS (about 120 stations).
- CODE MGEX solution is rigorous triple-system solution with GPS+GLONASS+Galileo.
- *Important note:*
The CODE MGEX solution is updated in batches – no operational processing. Each batch is carefully studied before the publication; next steps for the development is derived from this evaluation.

CODE MGEX solution: station selection

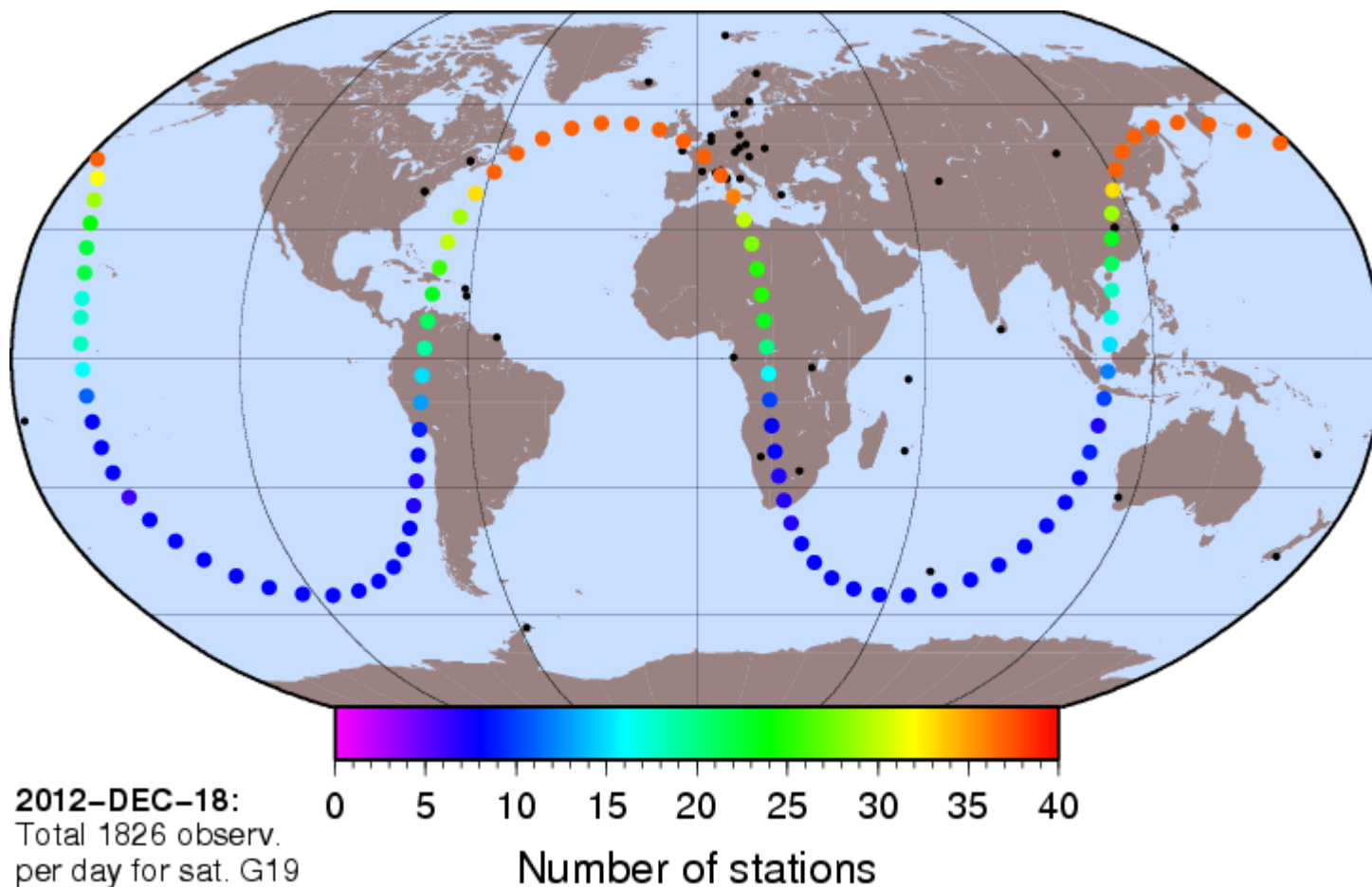
Number and distribution of tracking stations contributing to the CODE MGEX orbit solution (*late 2012*)



Num. of stations:	GPS: 145–150	GLONASS: 125	Galileo: 30–35
Num. of observ. per sat. and day	22,000–25,000	18,000–20,000	1,500–5,000

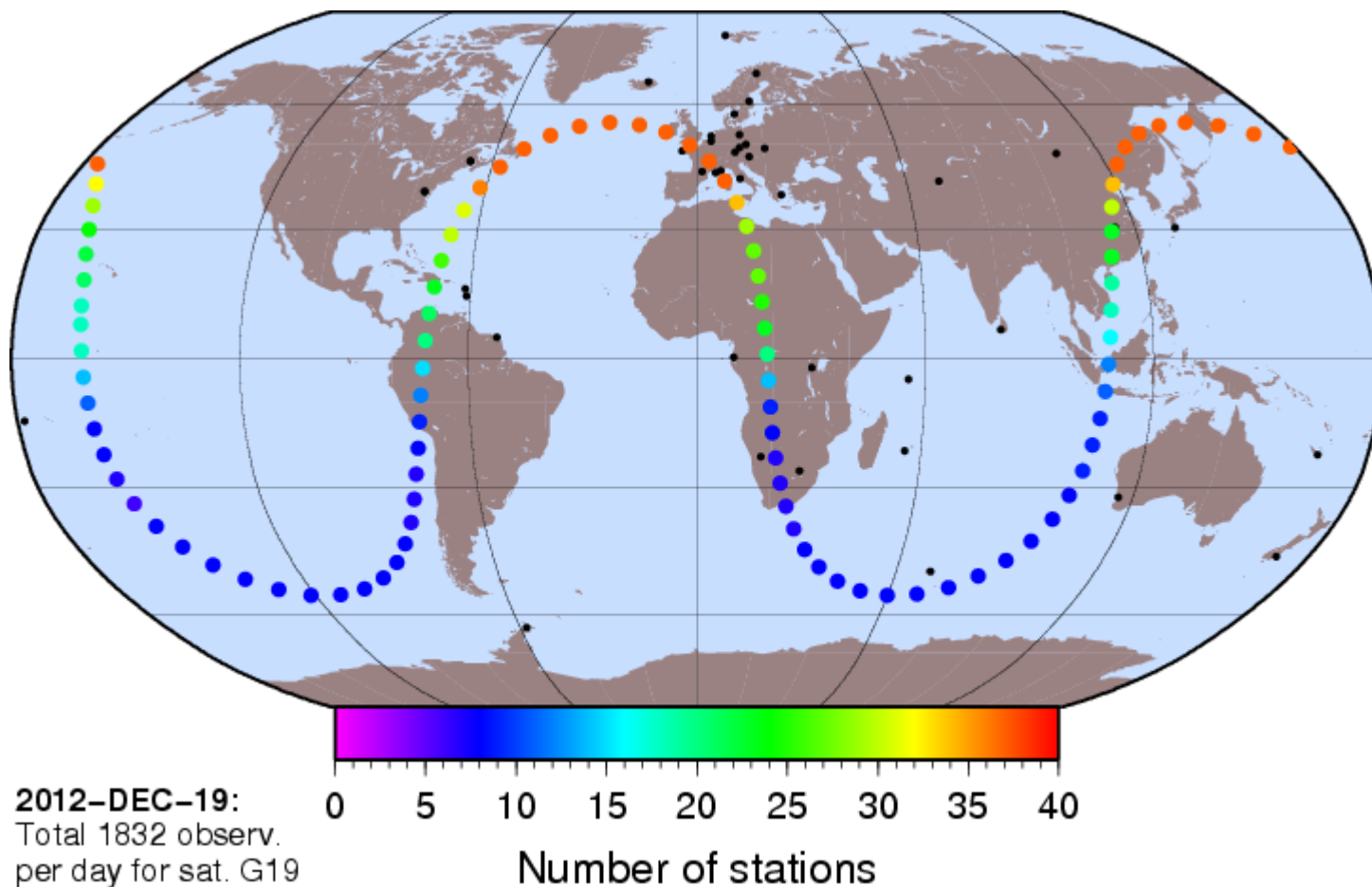
CODE MGEX solution: ground tracks

Number of MGEX stations tracking: **G19**



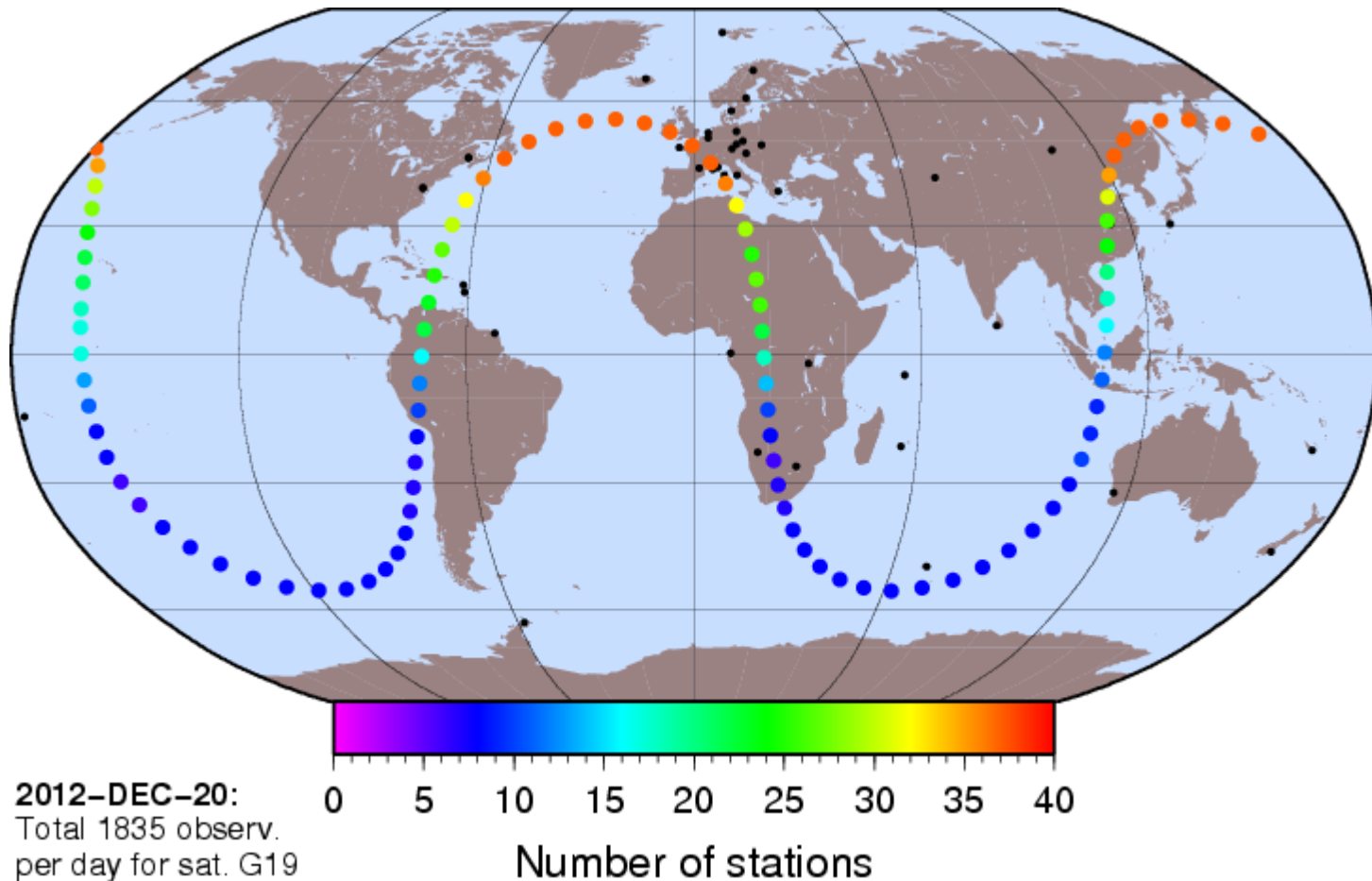
CODE MGEX solution: ground tracks

Number of MGEX stations tracking: **G19**



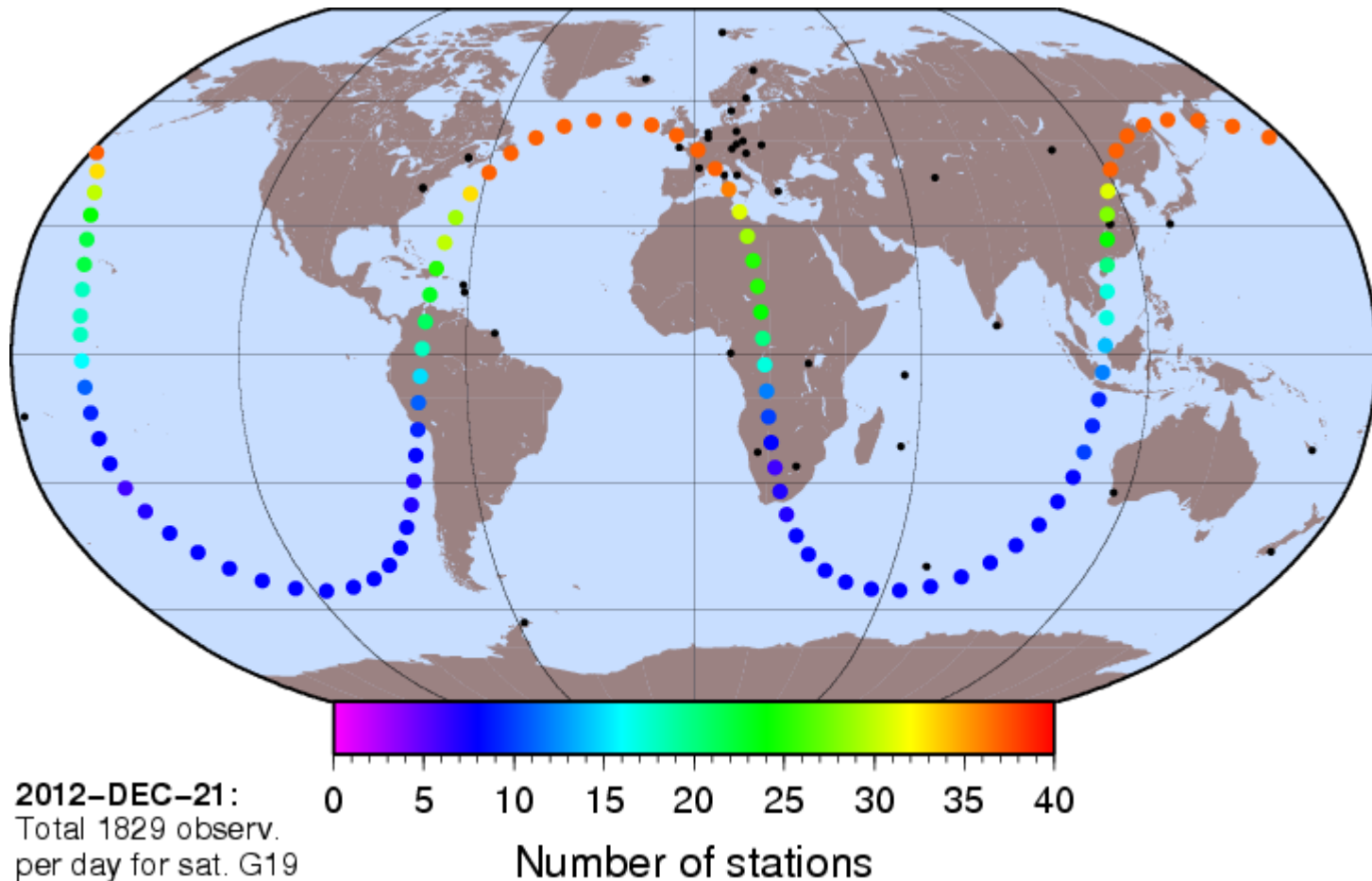
CODE MGEX solution: ground tracks

Number of MGEX stations tracking: **G19**



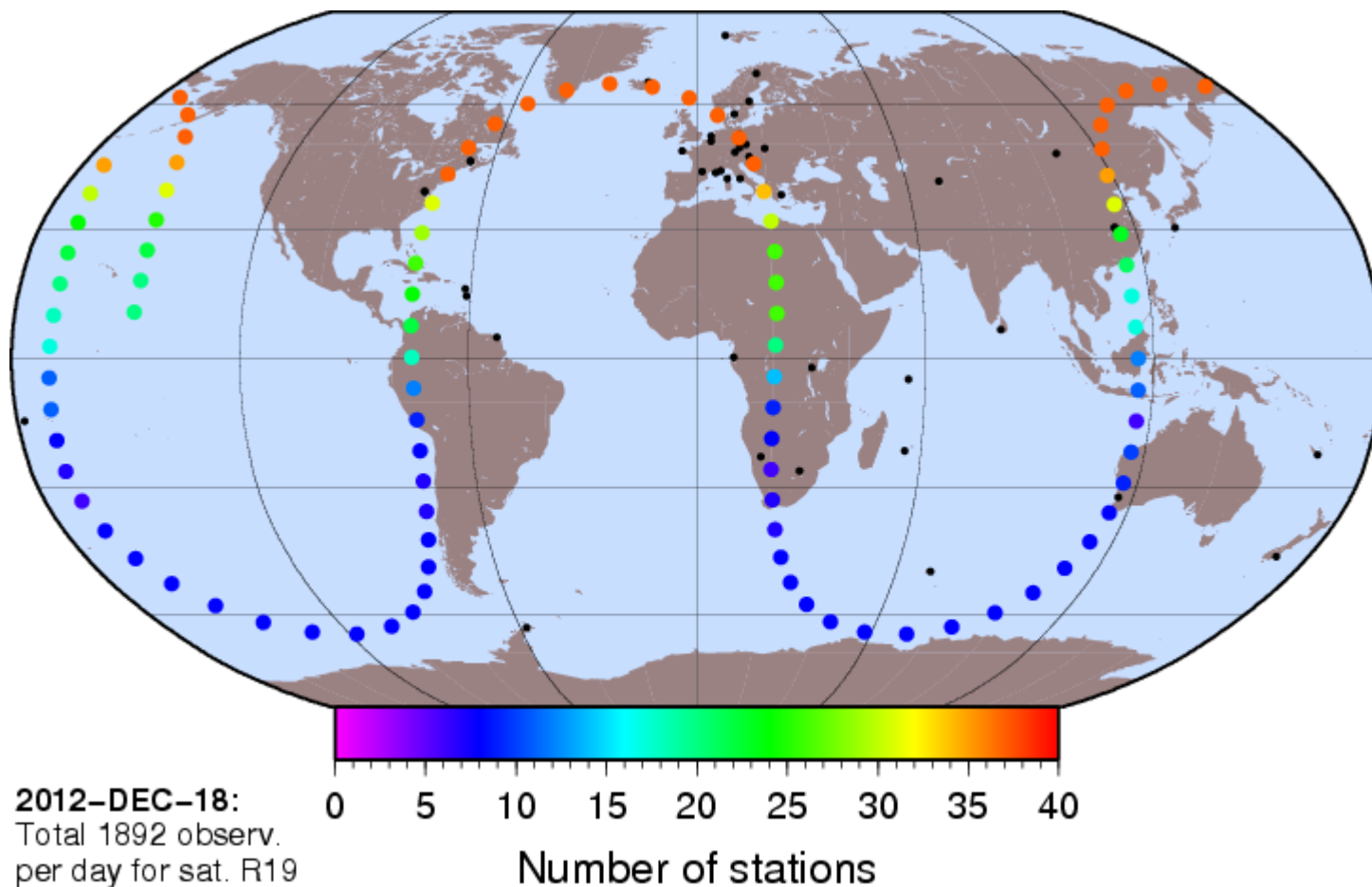
CODE MGEX solution: ground tracks

Number of MGEX stations tracking: **G19**



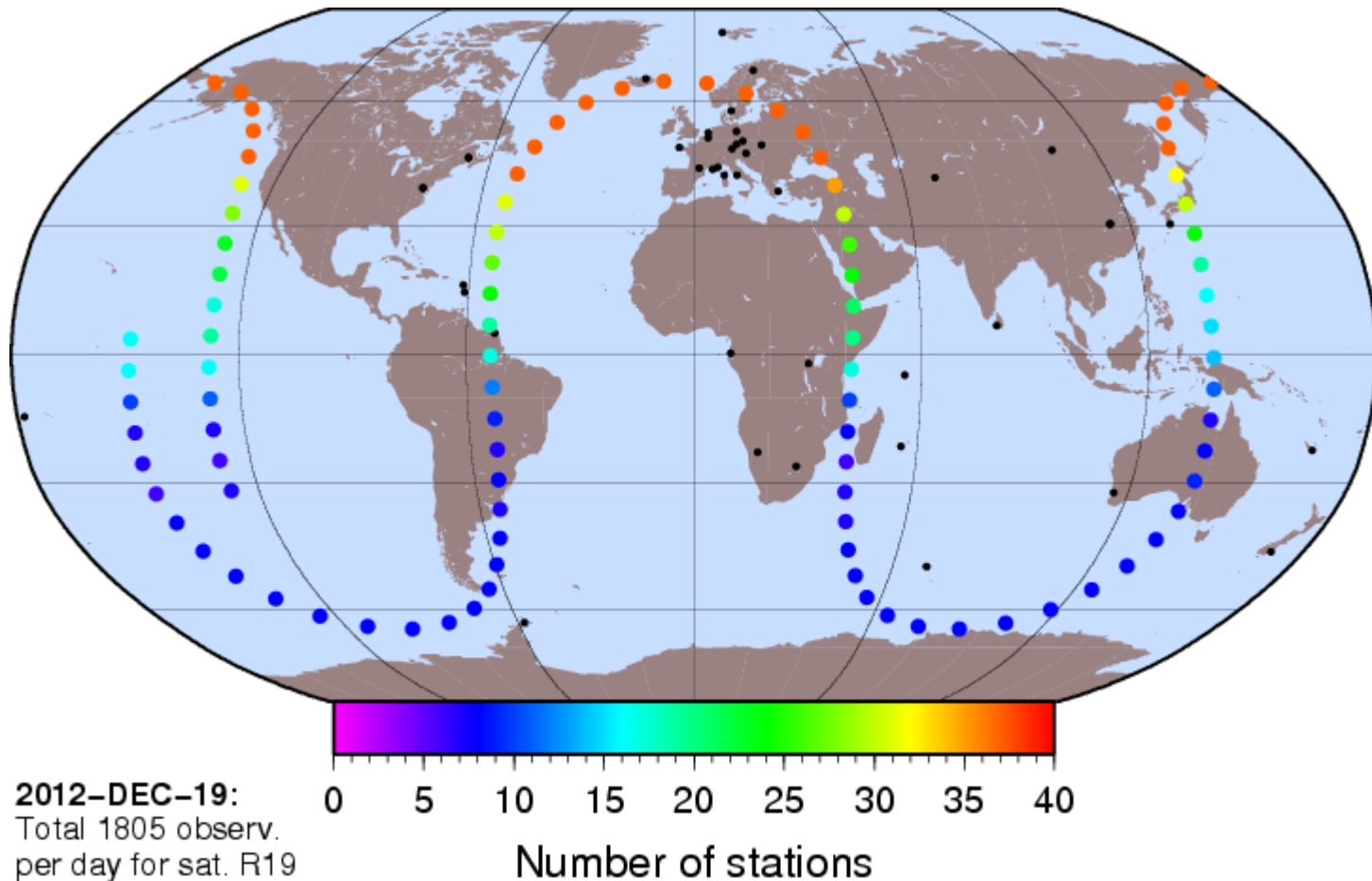
CODE MGEX solution: ground tracks

Number of MGEX stations tracking: **R19**



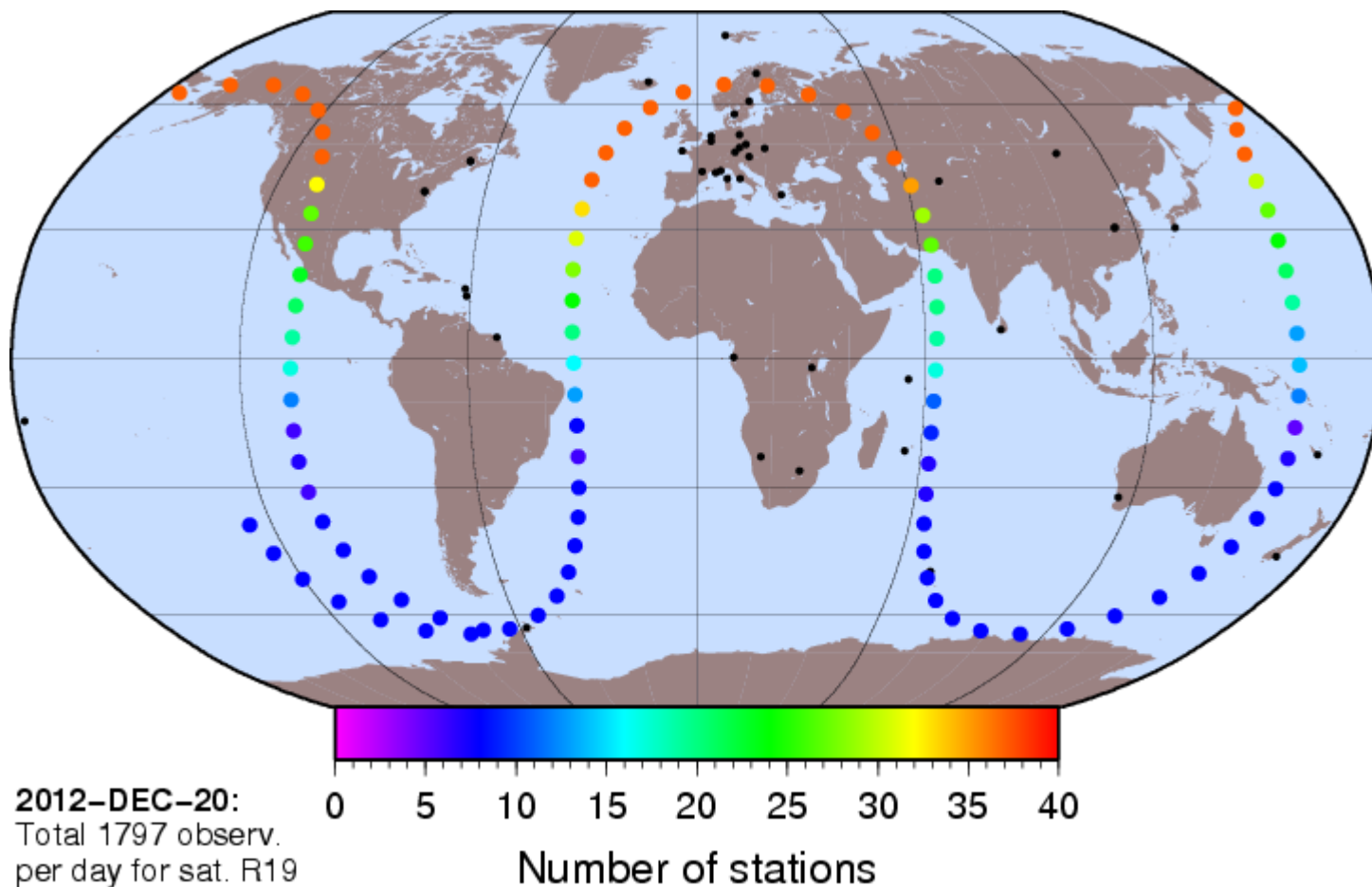
CODE MGEX solution: ground tracks

Number of MGEX stations tracking: **R19**



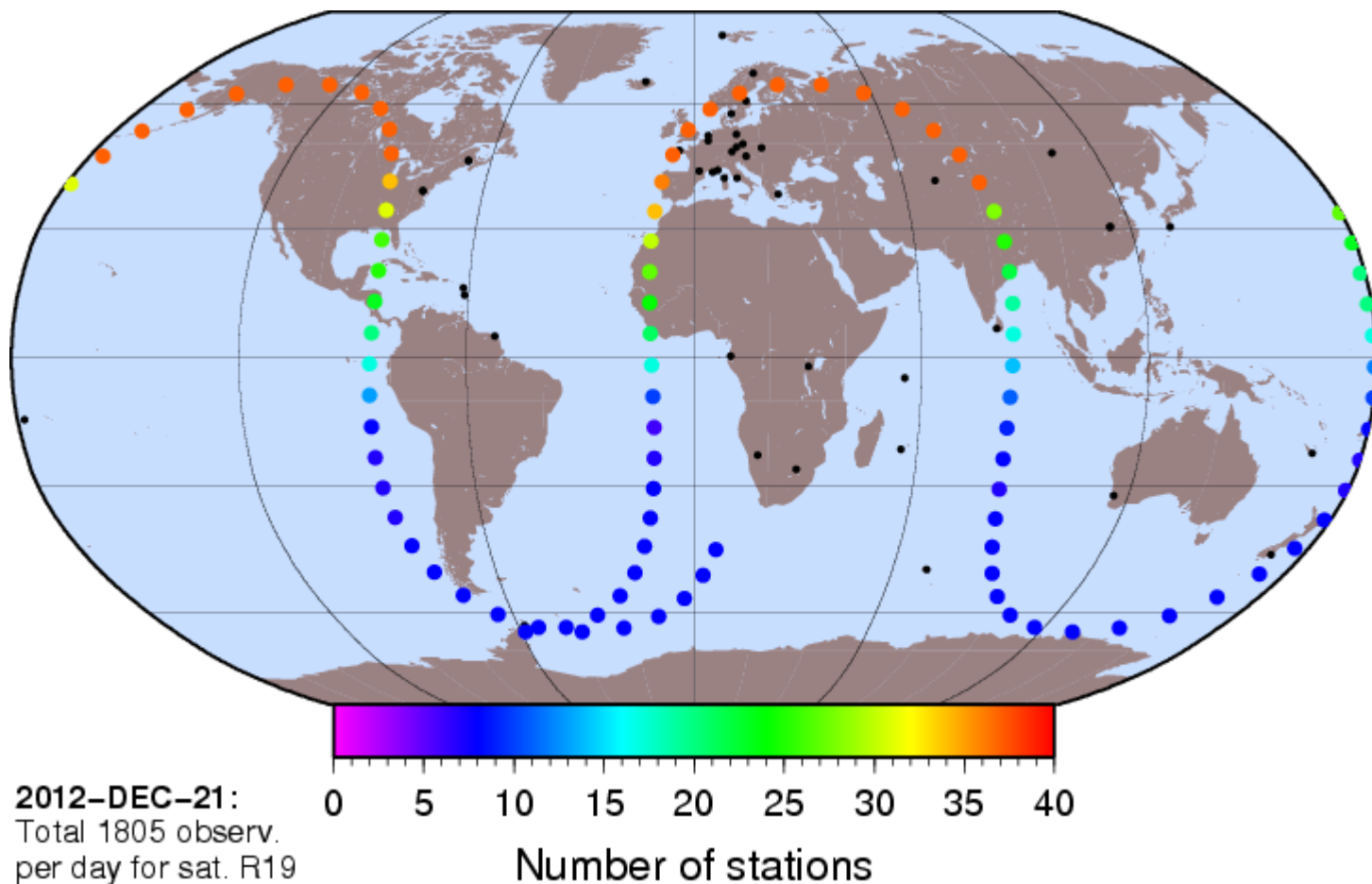
CODE MGEX solution: ground tracks

Number of MGEX stations tracking: **R19**



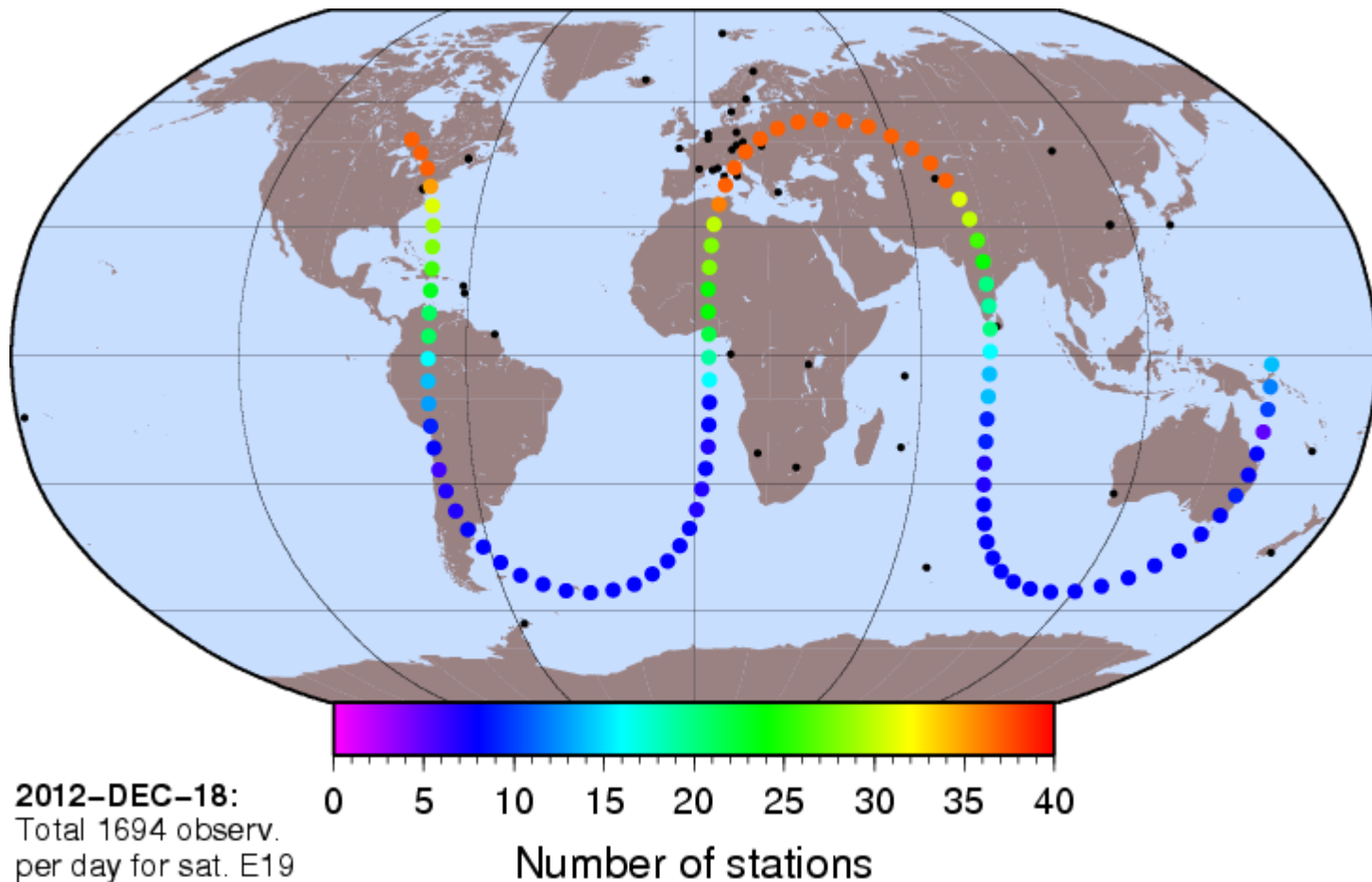
CODE MGEX solution: ground tracks

Number of MGEX stations tracking: **R19**



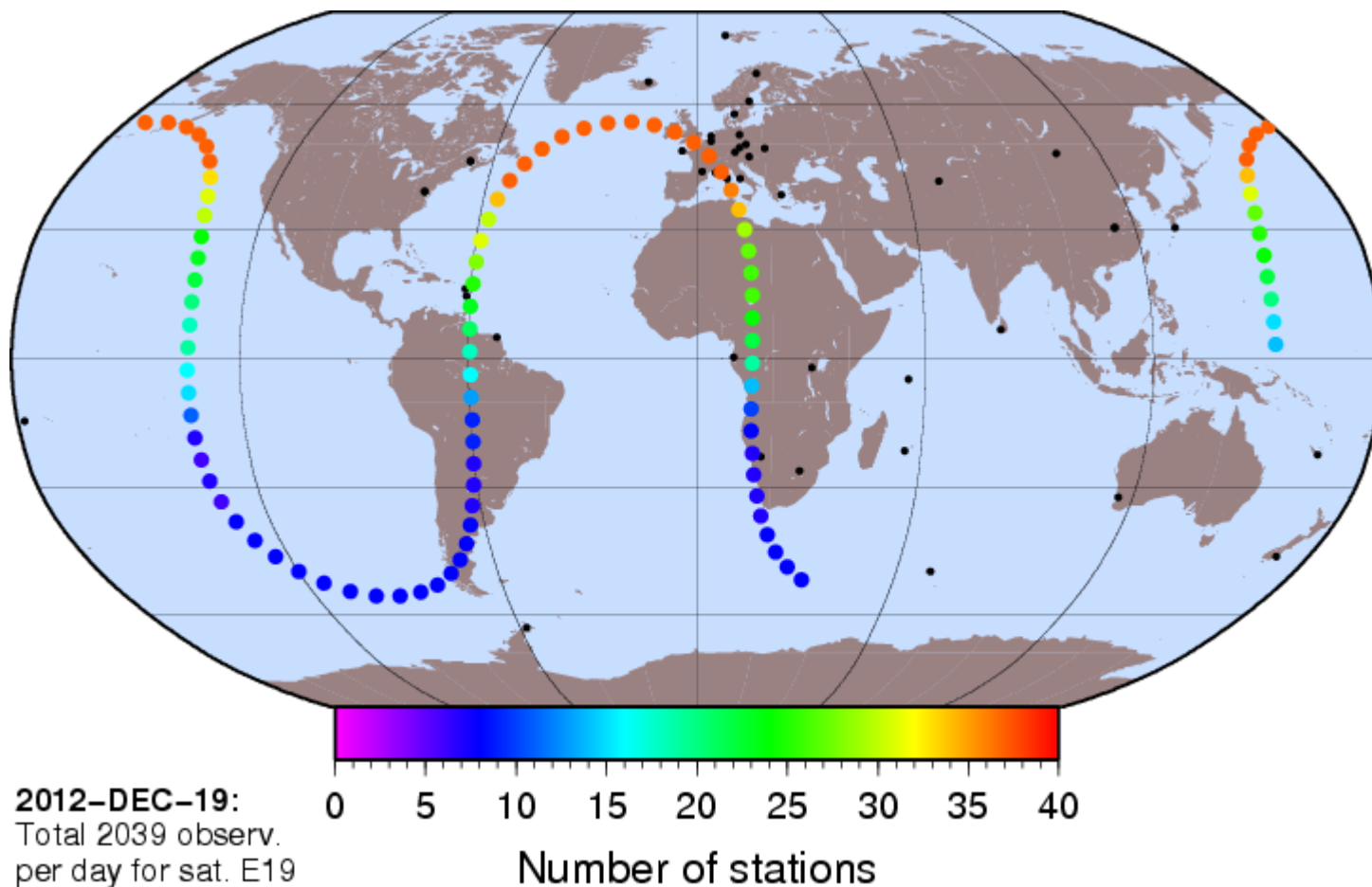
CODE MGEX solution: ground tracks

Number of MGEX stations tracking: **E19**



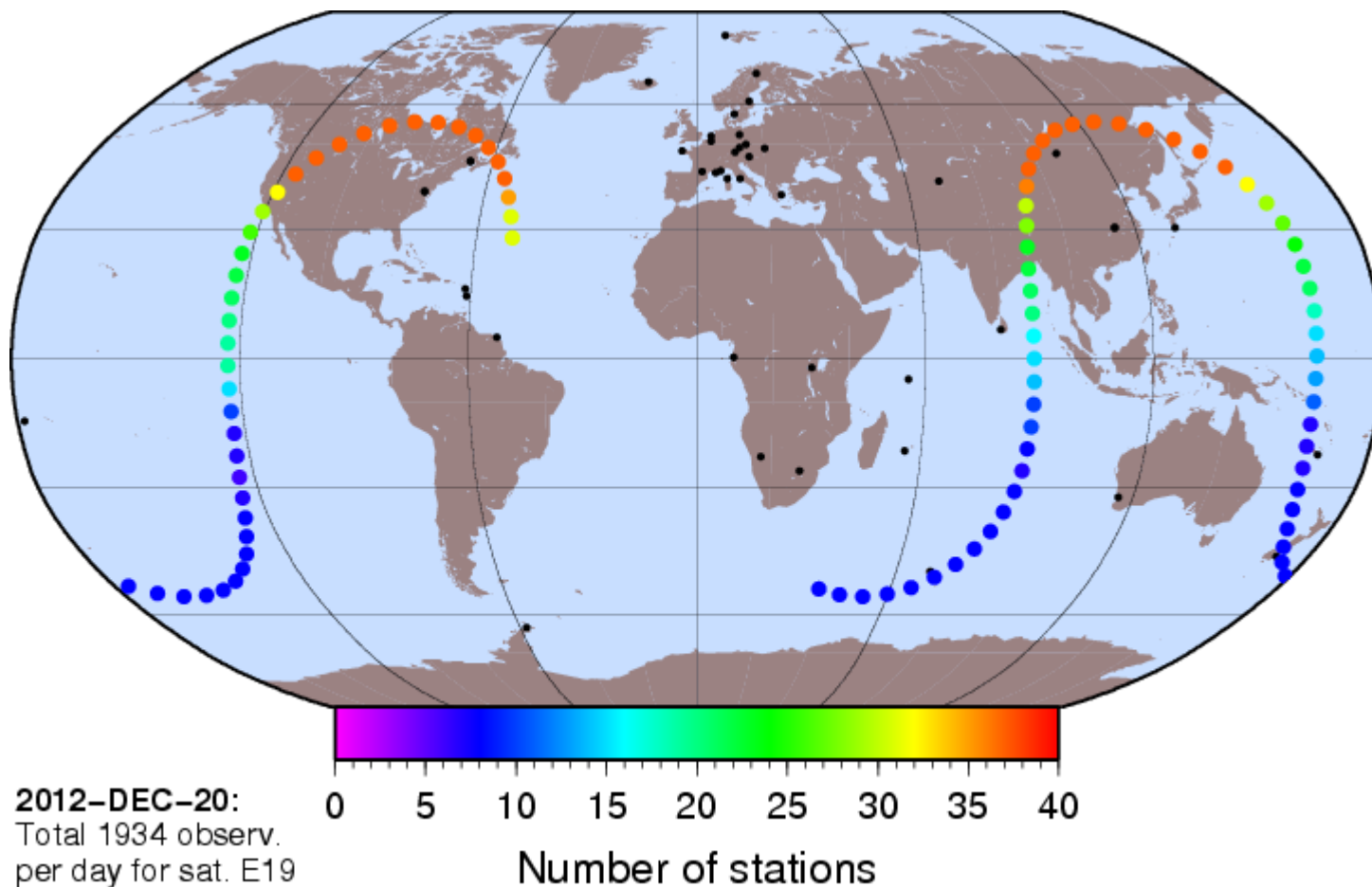
CODE MGEX solution: ground tracks

Number of MGEX stations tracking: **E19**



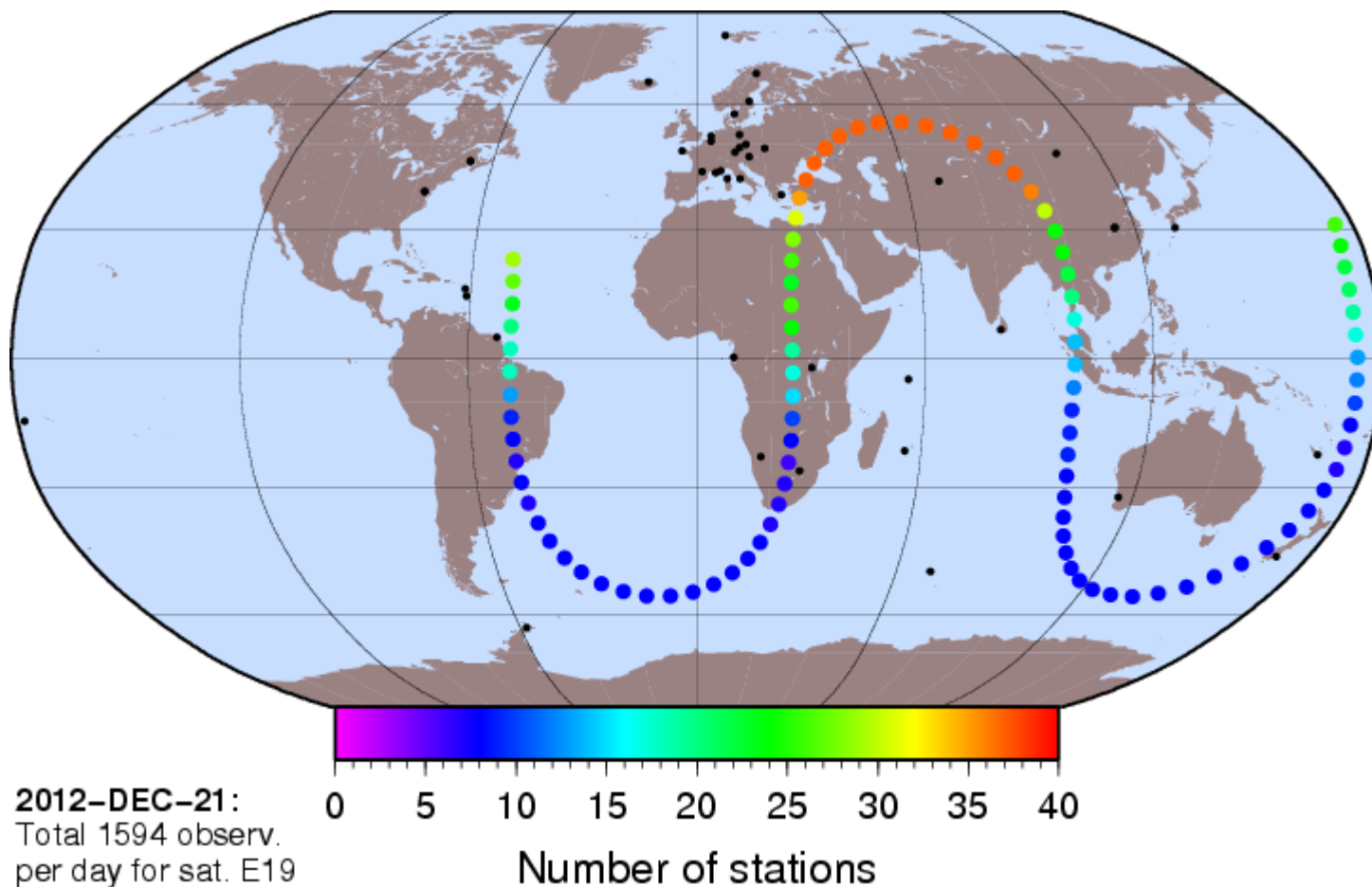
CODE MGEX solution: ground tracks

Number of MGEX stations tracking: **E19**



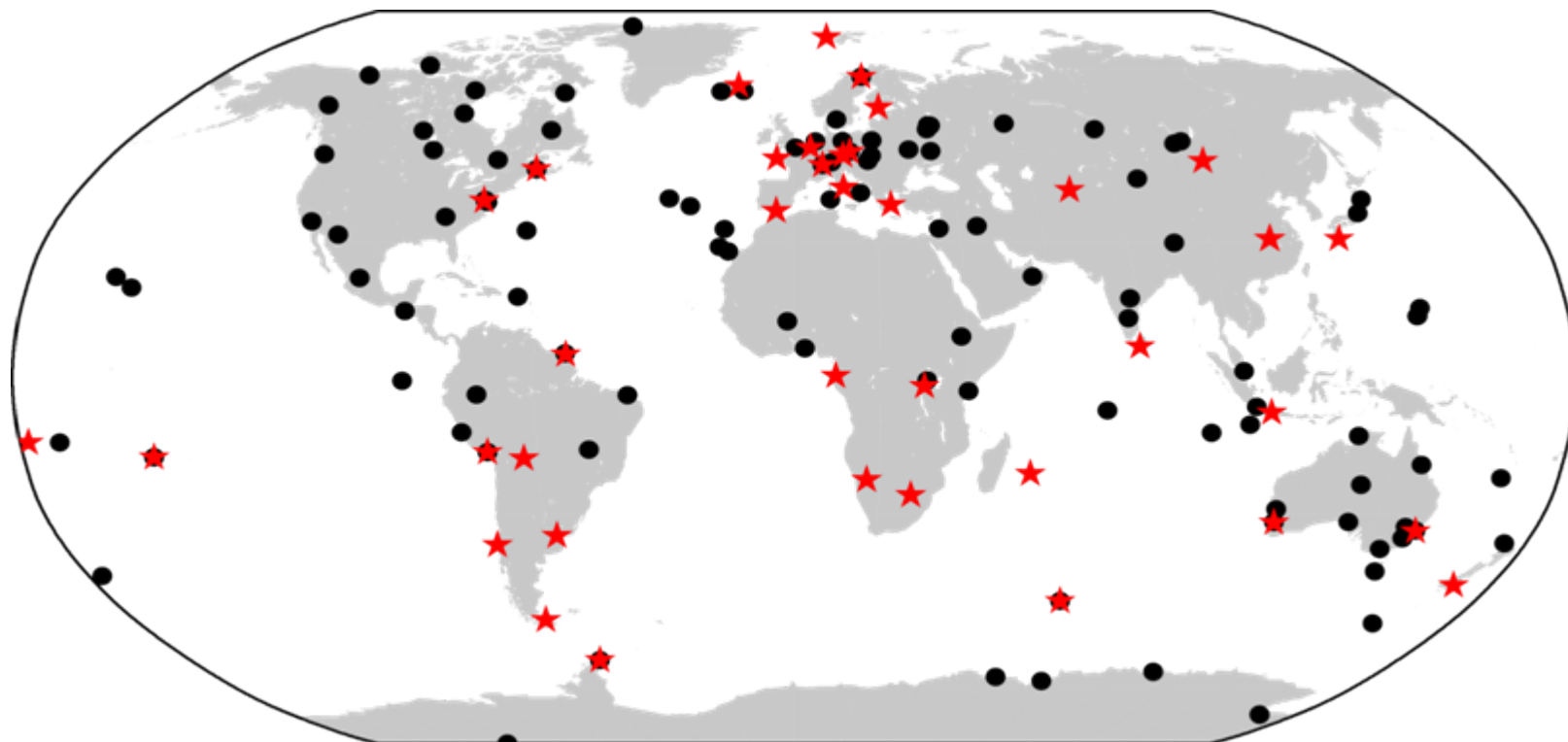
CODE MGEX solution: ground tracks

Number of MGEX stations tracking: **E19**



CODE MGEX solution: station selection

Number and distribution of tracking stations
contributing to the CODE MGEX orbit solution (*mid 2013*)



Num. of stations:	GPS: 145–150	GLONASS: 125	Galileo: 30–40
Num. of observ. per sat. and day	22,000–25,000	18,000–20,000	4,000–6,500

CODE MGEX orbit solution: overview

GNSS considered: **GPS + GLONASS + Galileo** (up to 60 satellites)

Processing mode: post-processing

Timespan covered: GPS-weeks 1689–1746 (DOY 12/146–13/180)

Number of stations: 150 (GPS + GLONASS), 30 – 40 (Galileo)

Processing scheme: double-difference network processing
(observable: phase double differences)

Signal frequencies: L1 + L2 (GPS + GLONASS),
E1 (L1) + E5a (L5) (Galileo)

Orbit characteristic: 3-day long arcs

Reference frame: IGS08 (until week 1708); IGB08 (since week 1709)

IERS conventions: IERS2003 (until 1705); IERS2010 (since 1706)

Product list: daily orbits (SP3) and ERPs

Distribution: <ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/>

Designator: comwwwwd.???.Z

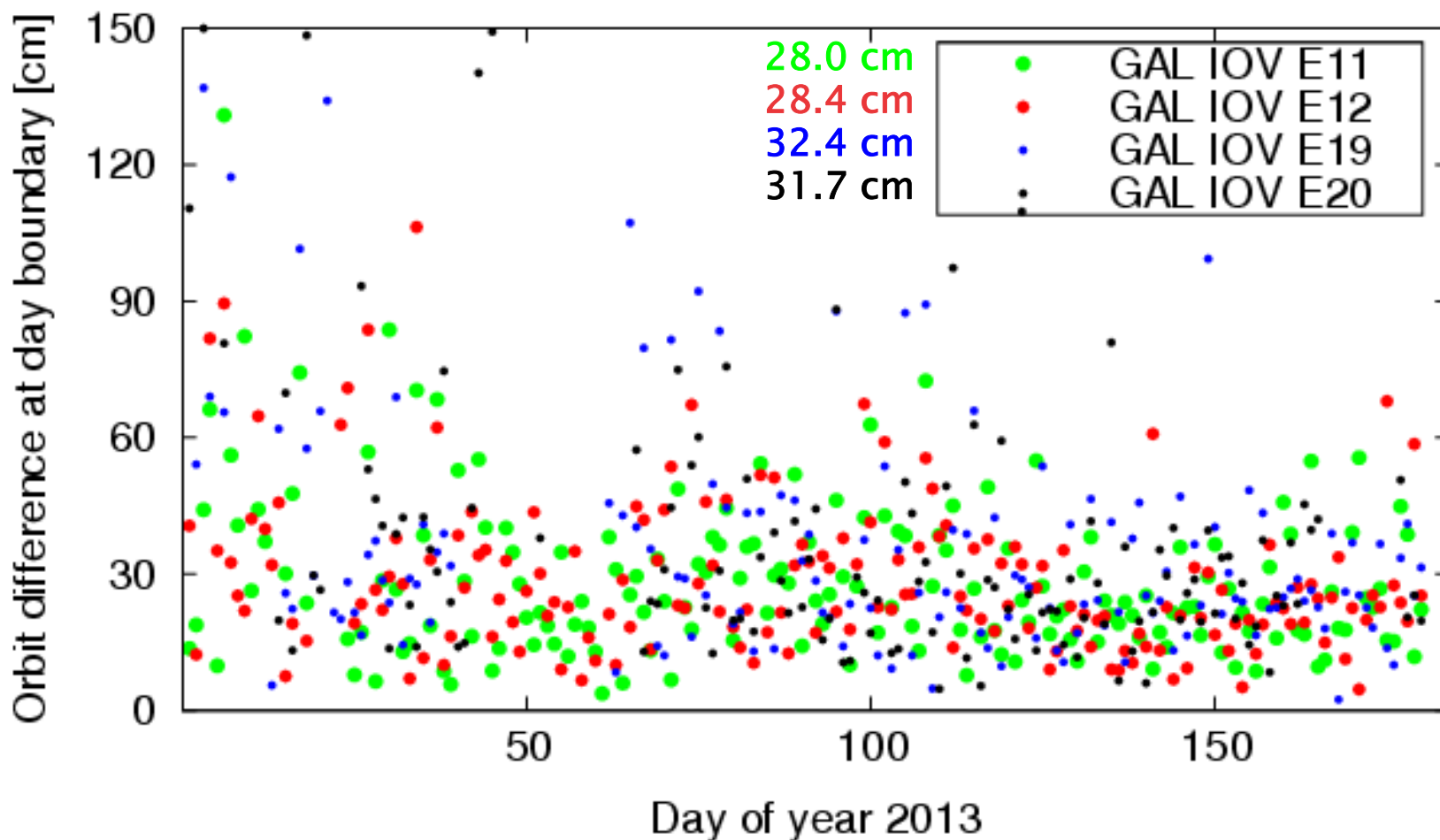
Methods for orbit validation

1. Orbit overlaps



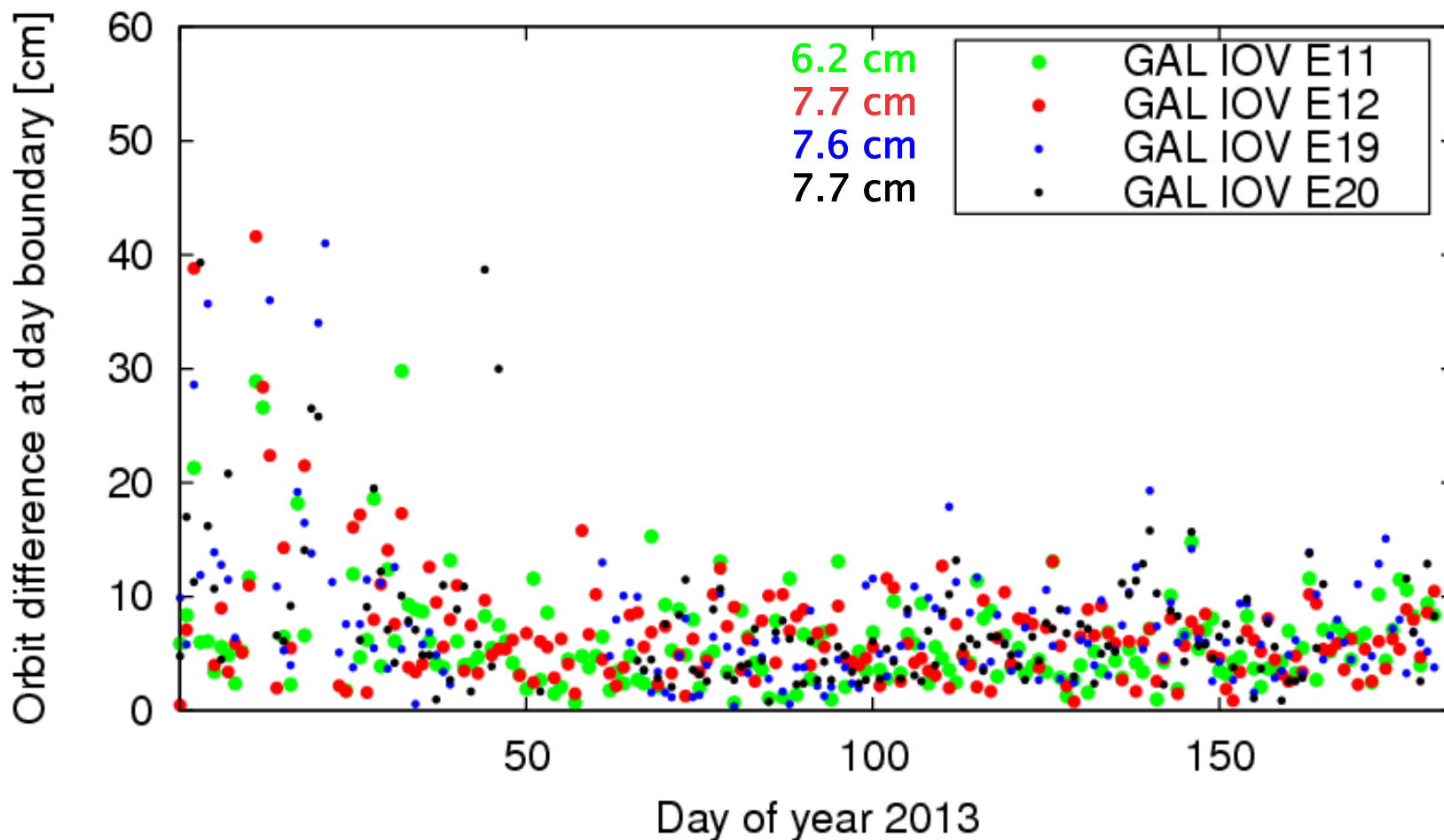
Orbit validation: overlaps

Arc length: 1 day



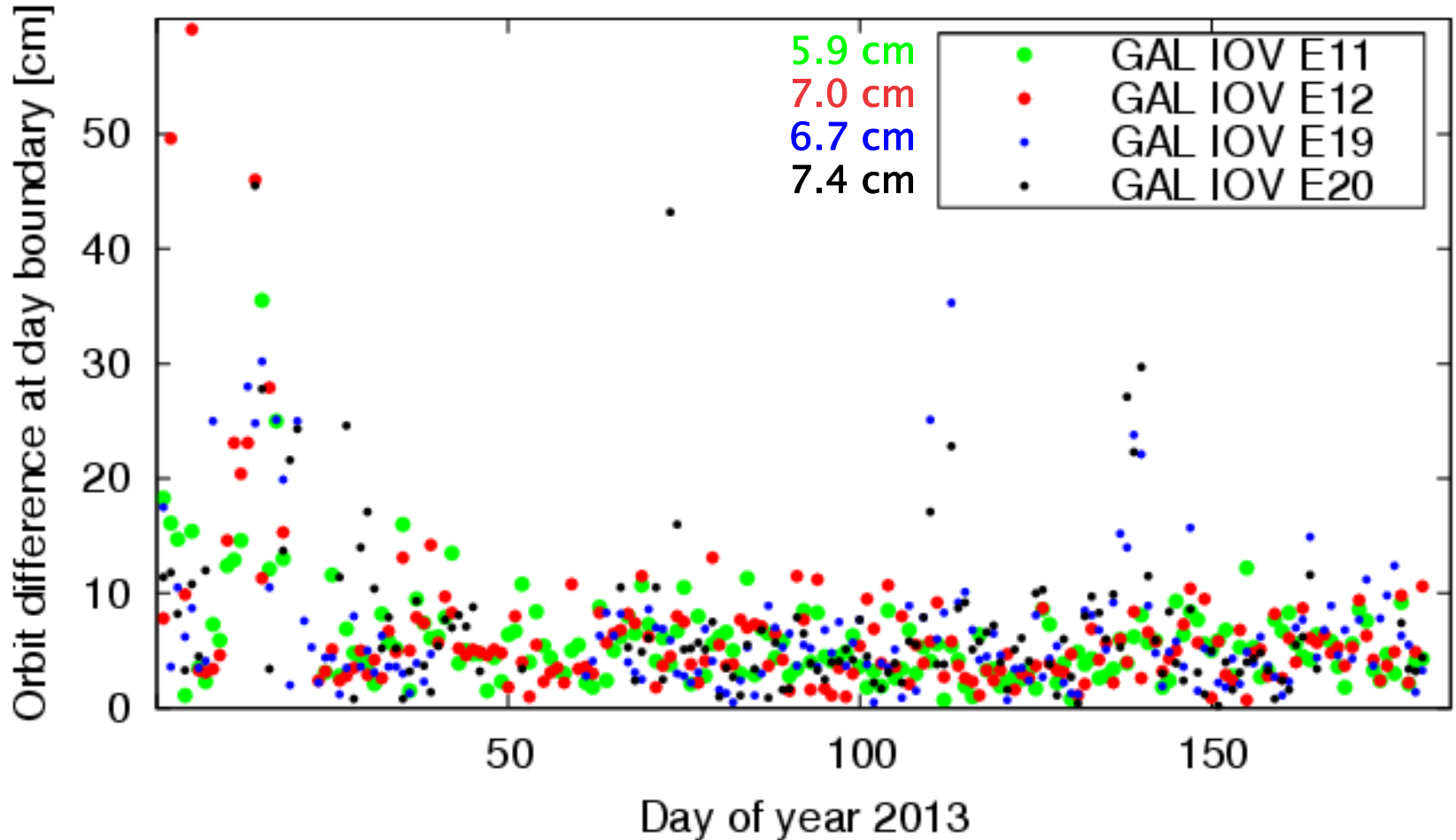
Orbit validation: overlaps

Arc length: 3 days



Orbit validation: overlaps

Arc length: 5 days



Methods for orbit validation

1. Orbit overlaps



2. Fitting long-arcs



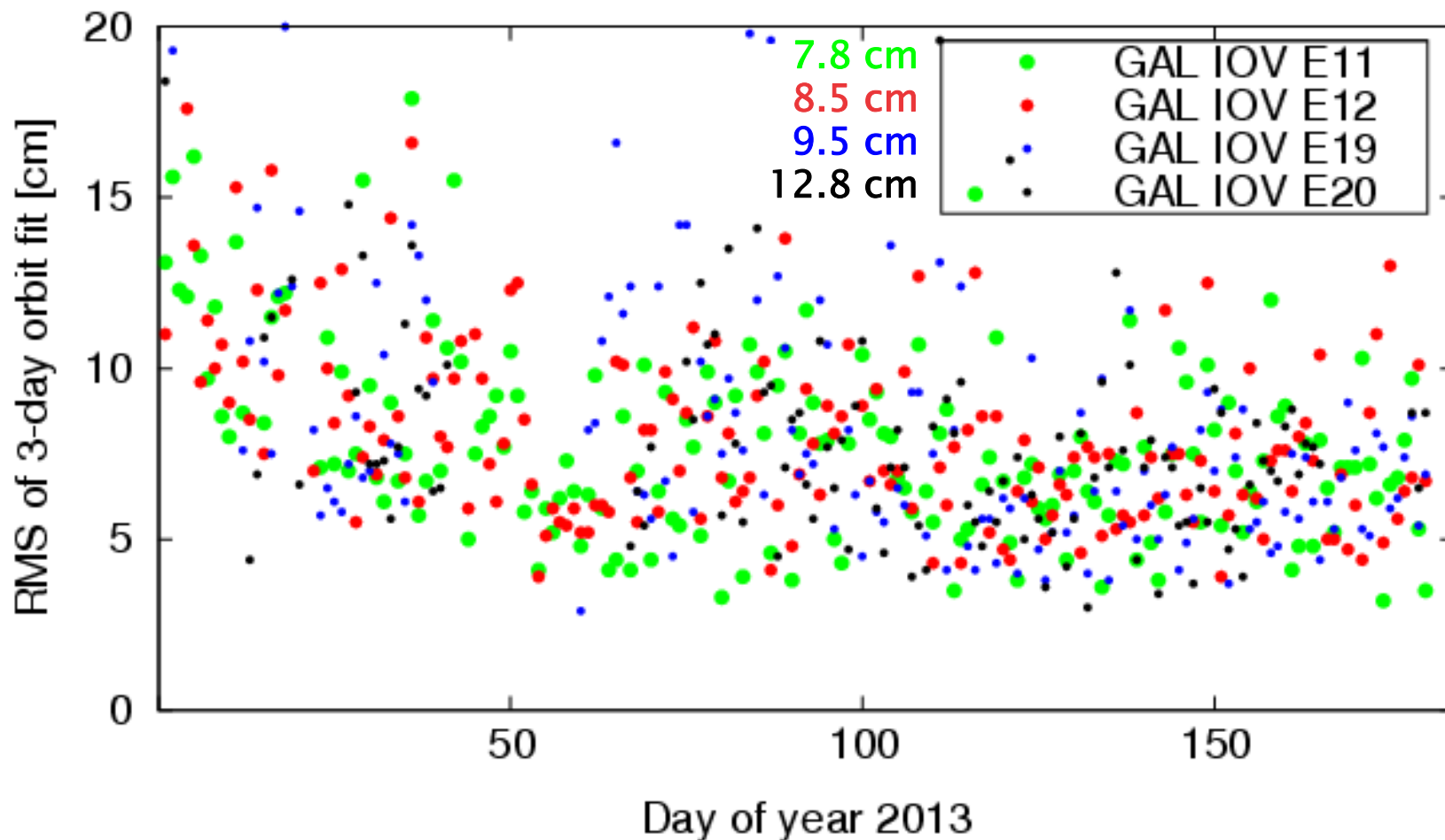
• *Remark on multi-day arc solution:*

Extracted orbit for day n-1 Extracted orbit for day n Extracted orbit for day n+1



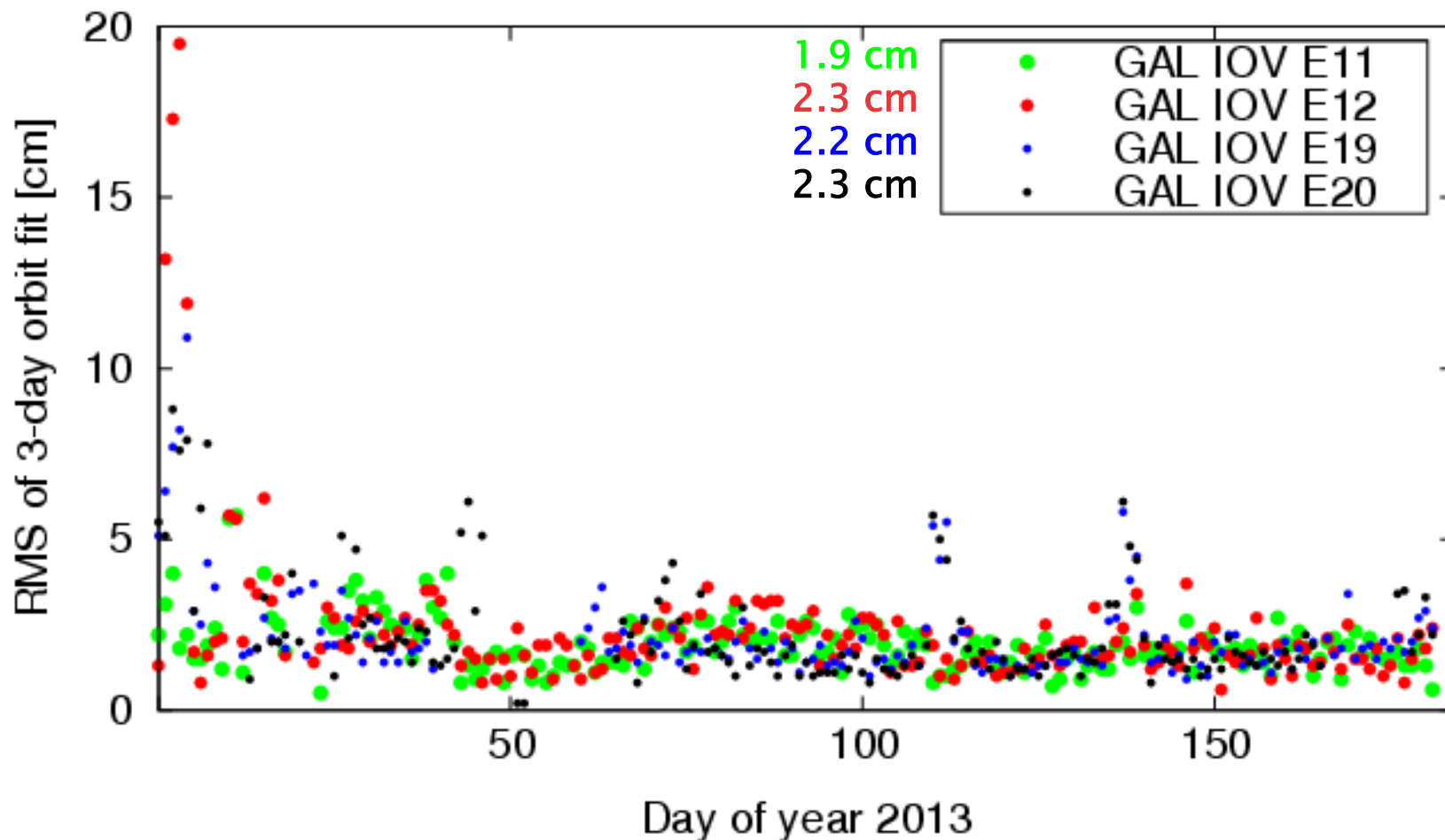
Orbit validation: three-day orbit fit

Arc length: 1 day



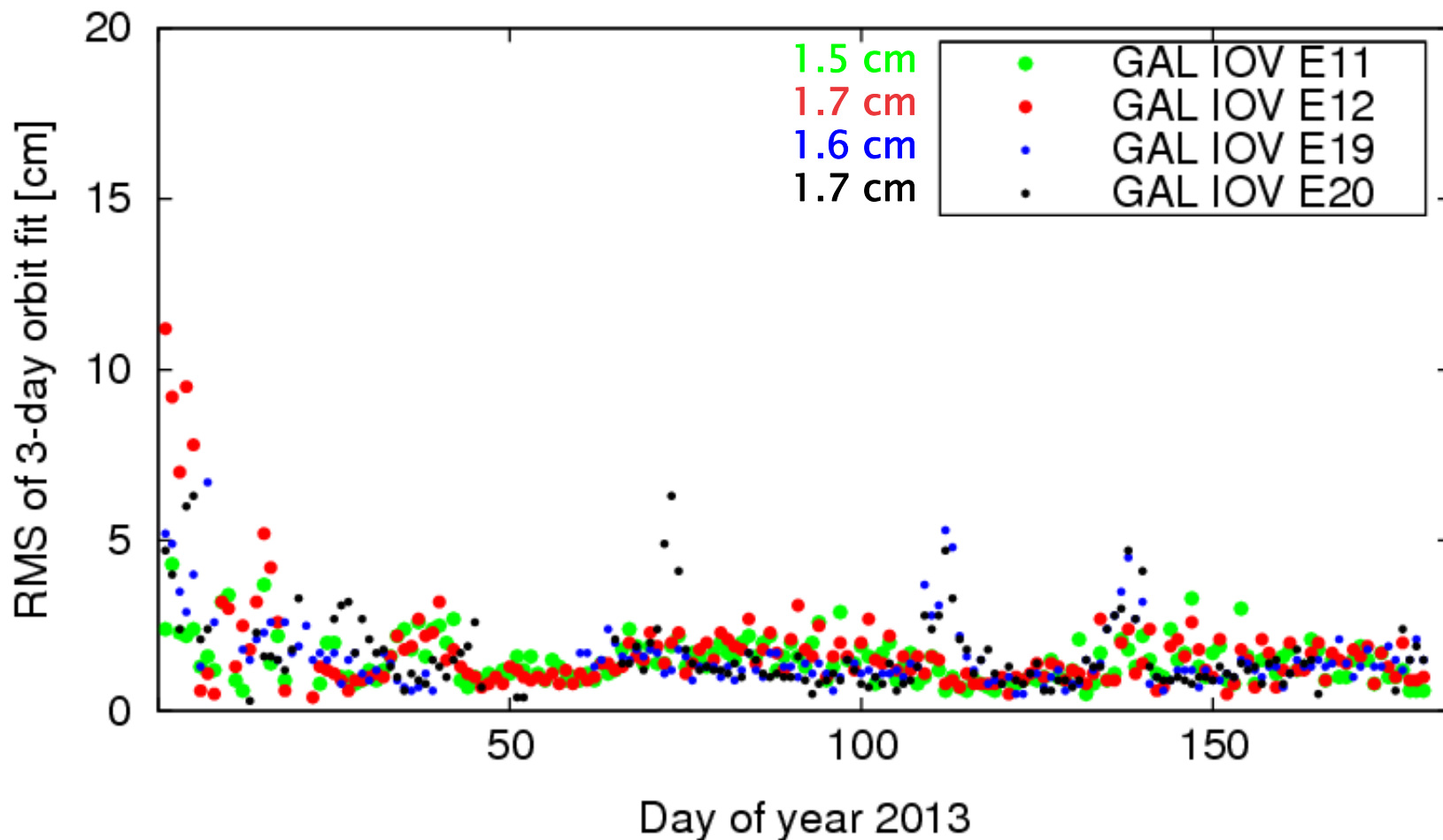
Orbit validation: three-day orbit fit

Arc length: 3 days



Orbit validation: three-day orbit fit

Arc length: 5 days



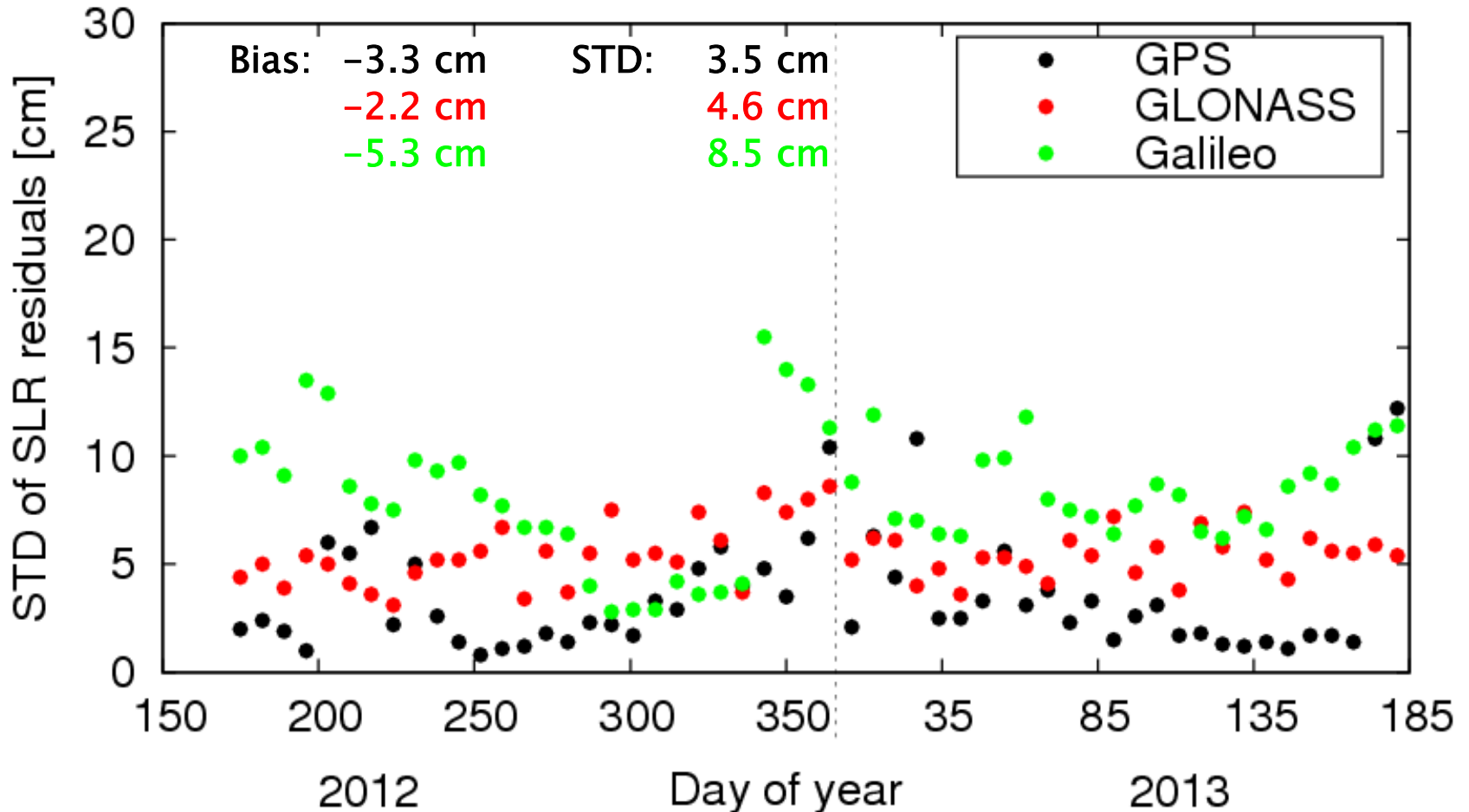
Orbit validation: SLR residuals

STD of SLR residuals per week and GNSS

Arc length	GPS	GLONASS	Galileo
1 day	3.5 cm	4.8 cm	9.6 cm
3 days	3.5 cm	4.6 cm	8.5 cm
5 days	3.6 cm	4.6 cm	9.4 cm

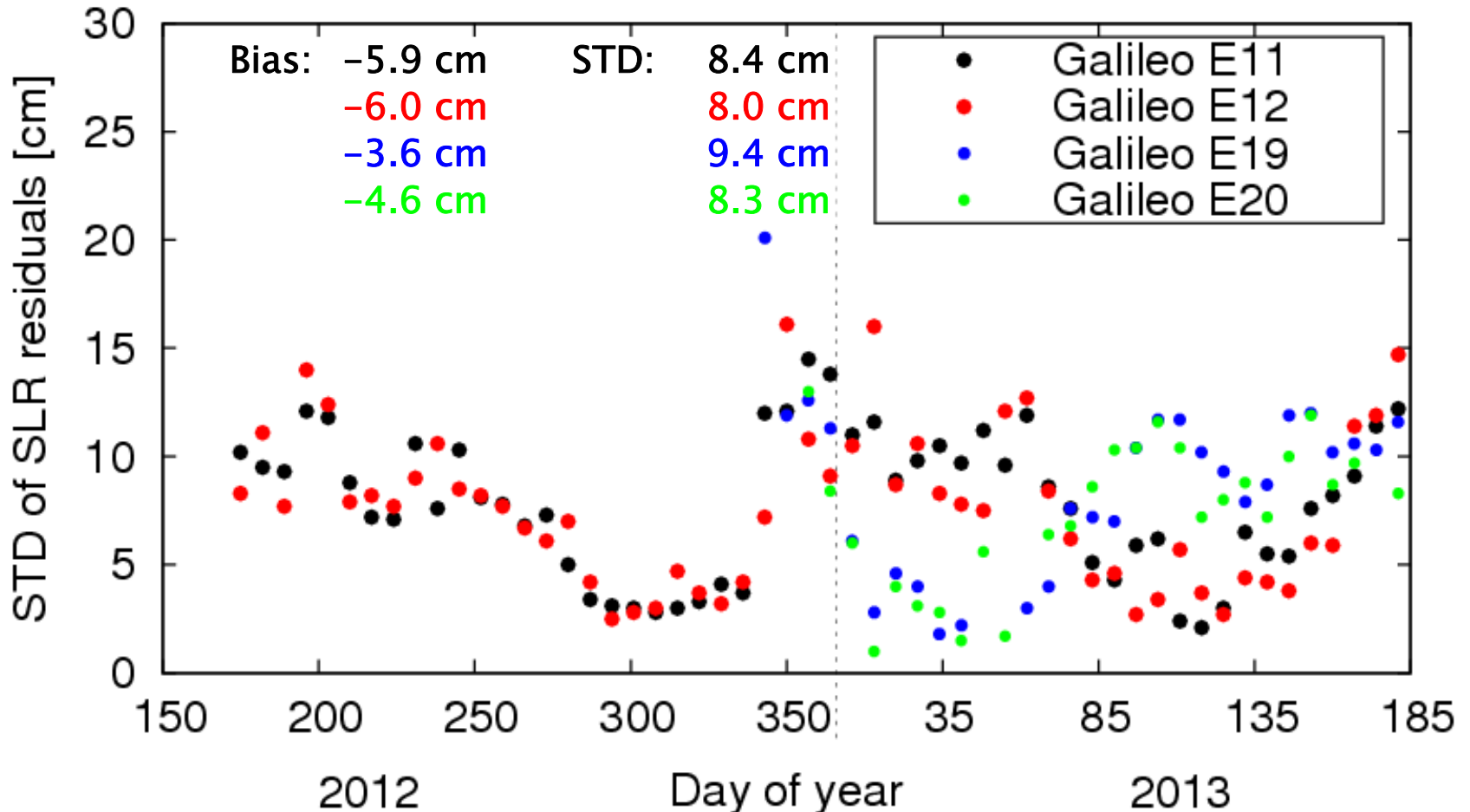
Orbit validation: SLR residuals

STD of SLR residuals per week: GNSS-wise



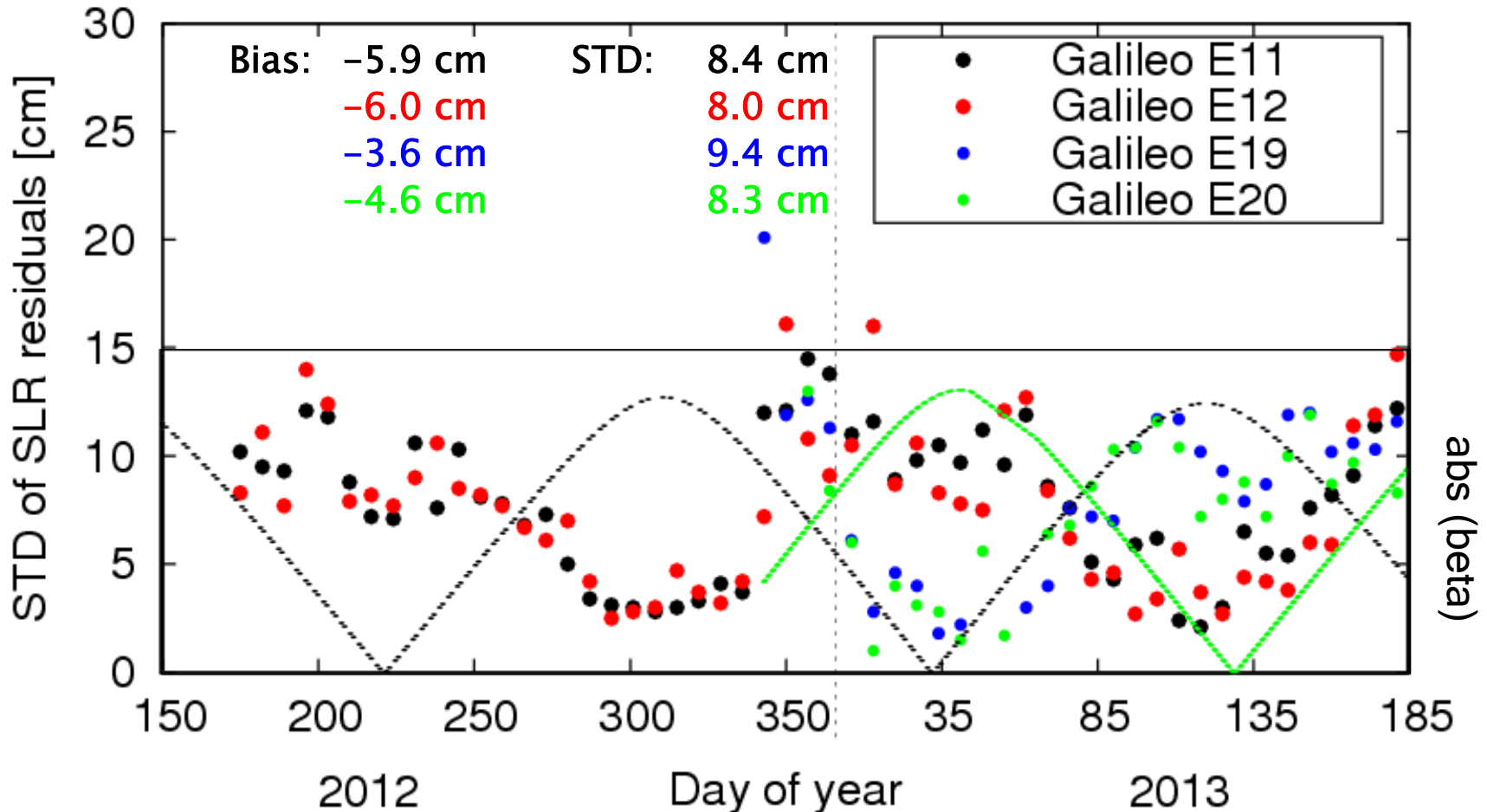
Orbit validation: SLR residuals

STD of SLR residuals per week: satellite-wise



Orbit validation: SLR residuals

STD of SLR residuals per week: satellite-wise

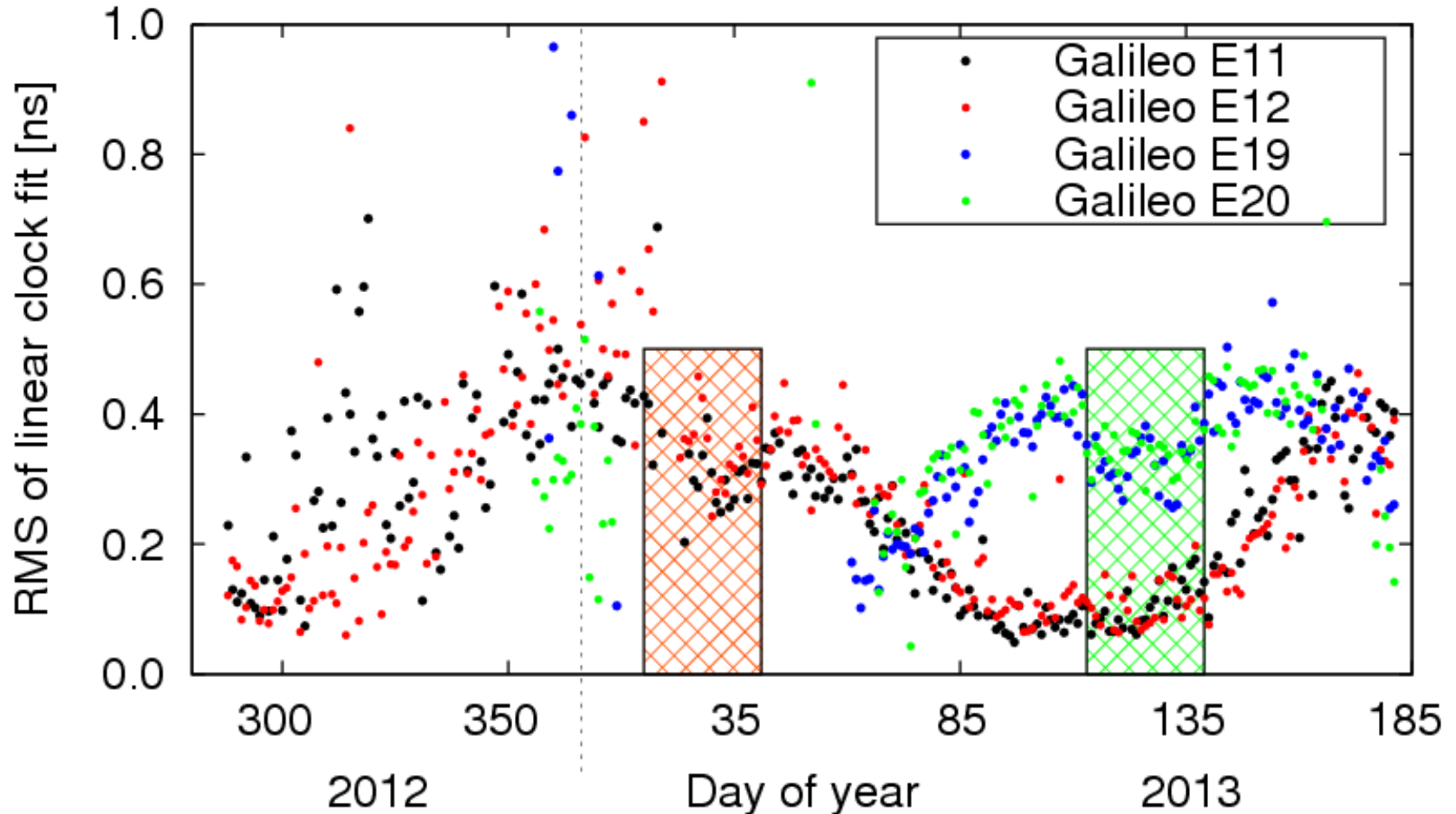


CODE MGEX clock solution: overview

GNSS considered:	GPS + Galileo (up to 36 satellites)
Timespan covered:	GPS-weeks 1710–1746 (DOY 12/288–13/180)
Number of stations:	150 (GPS), 30 –40 (Galileo)
Processing scheme:	zero-difference network processing (code+phase)
Signal frequencies:	L1 +L2 (GPS); E1(L1)+E5a (L5) (Galileo)
A priori information:	orbits, ERPs, coordinates, and troposphere from CODE MGEX orbit solution introduced as known
Reference frame:	IGb08
IERS conventions:	IERS2010
Product list:	epoch-wise (300s) satellite and station clock corrections in daily clock RINEX files; daily GPS–Galileo inter-system biases for mixed stations in Bernese DCB and BIAS–SINEX (BIA) format
Distribution:	ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/
Designator:	comwwwwd.???.Z

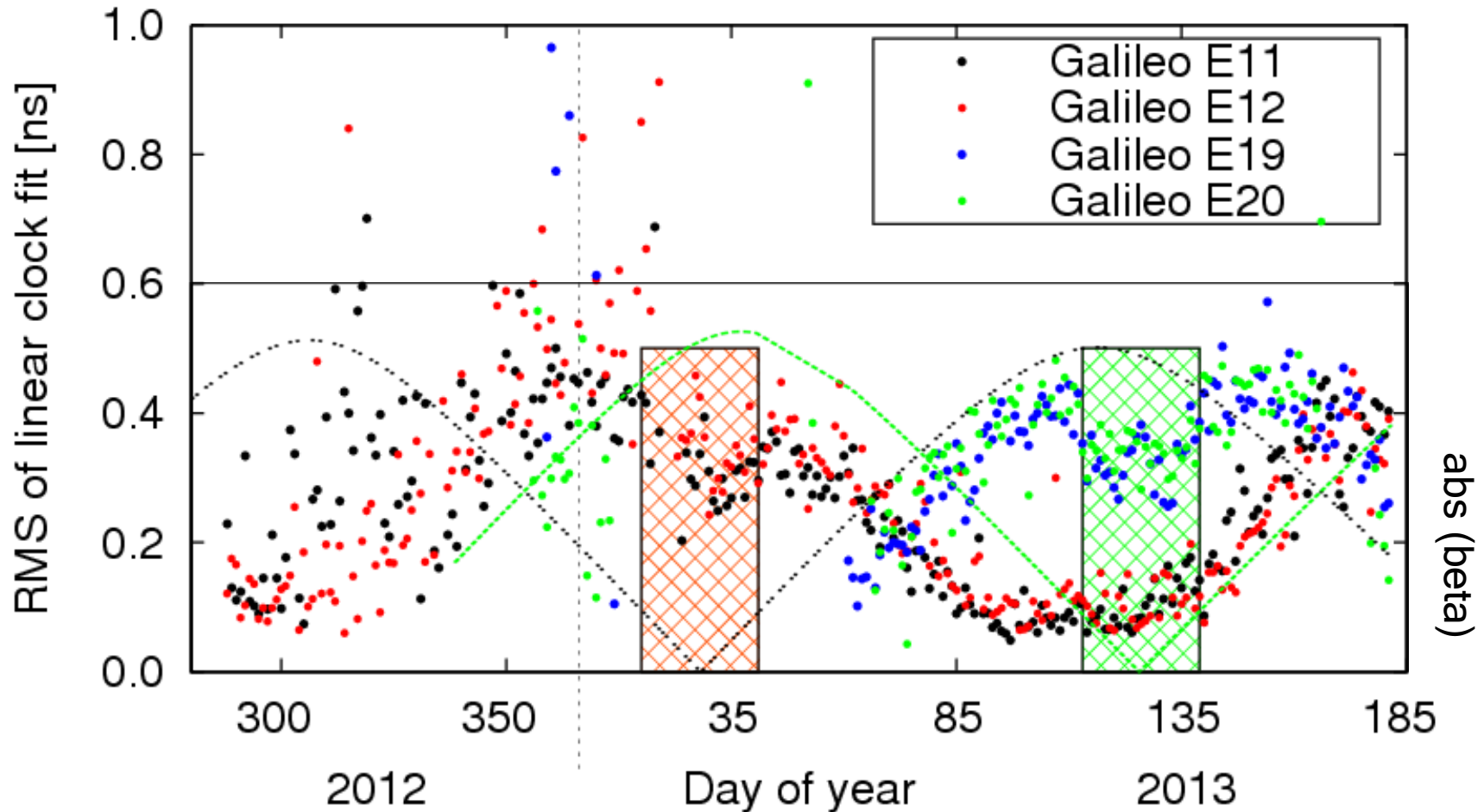
CODE MGEX clock solution

Galileo IOV: impact of sun eclipse



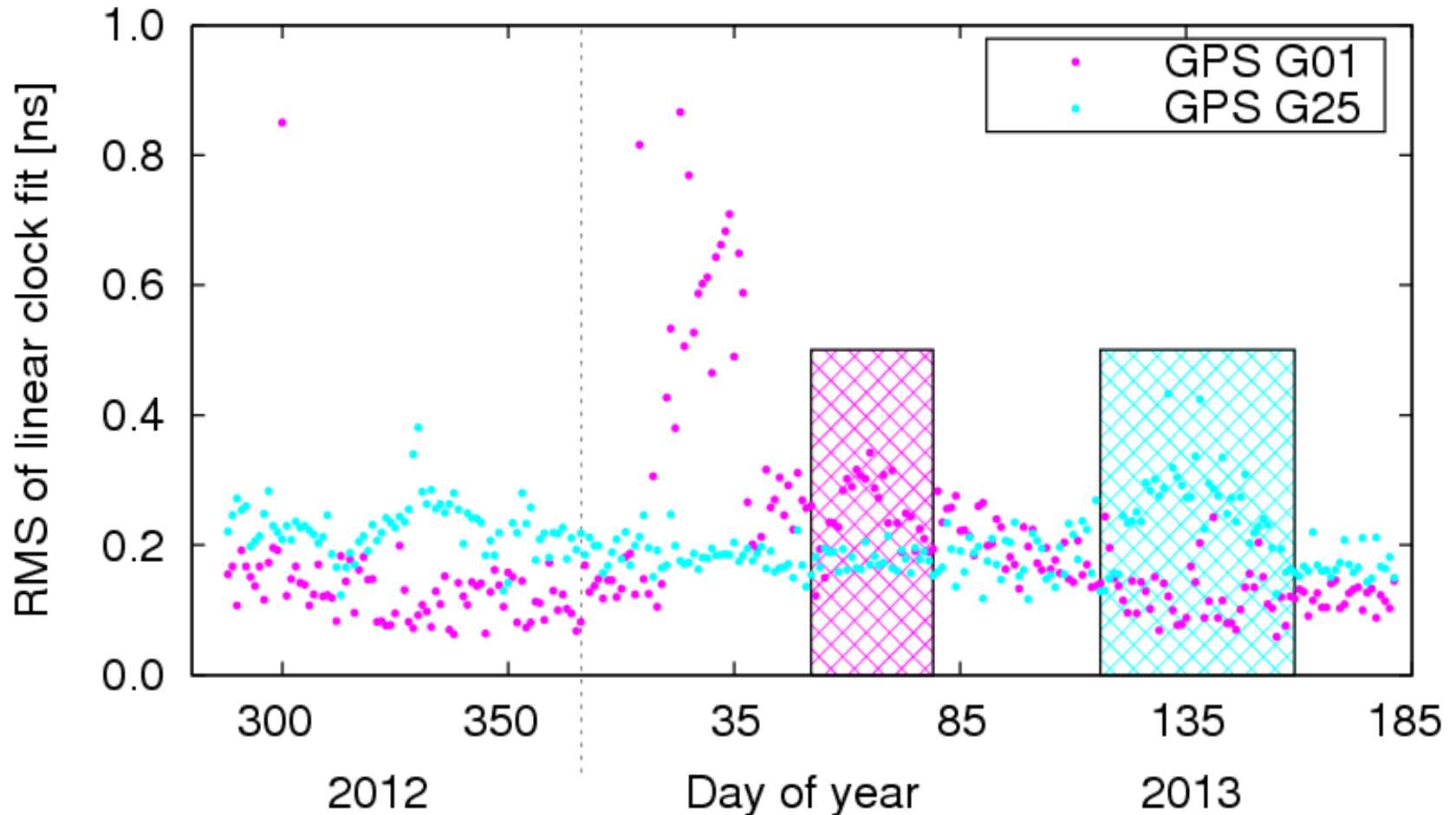
CODE MGEX clock solution

Galileo IOV: impact of sun eclipse



CODE MGEX clock solution

GPS-IIF: impact of sun eclipse



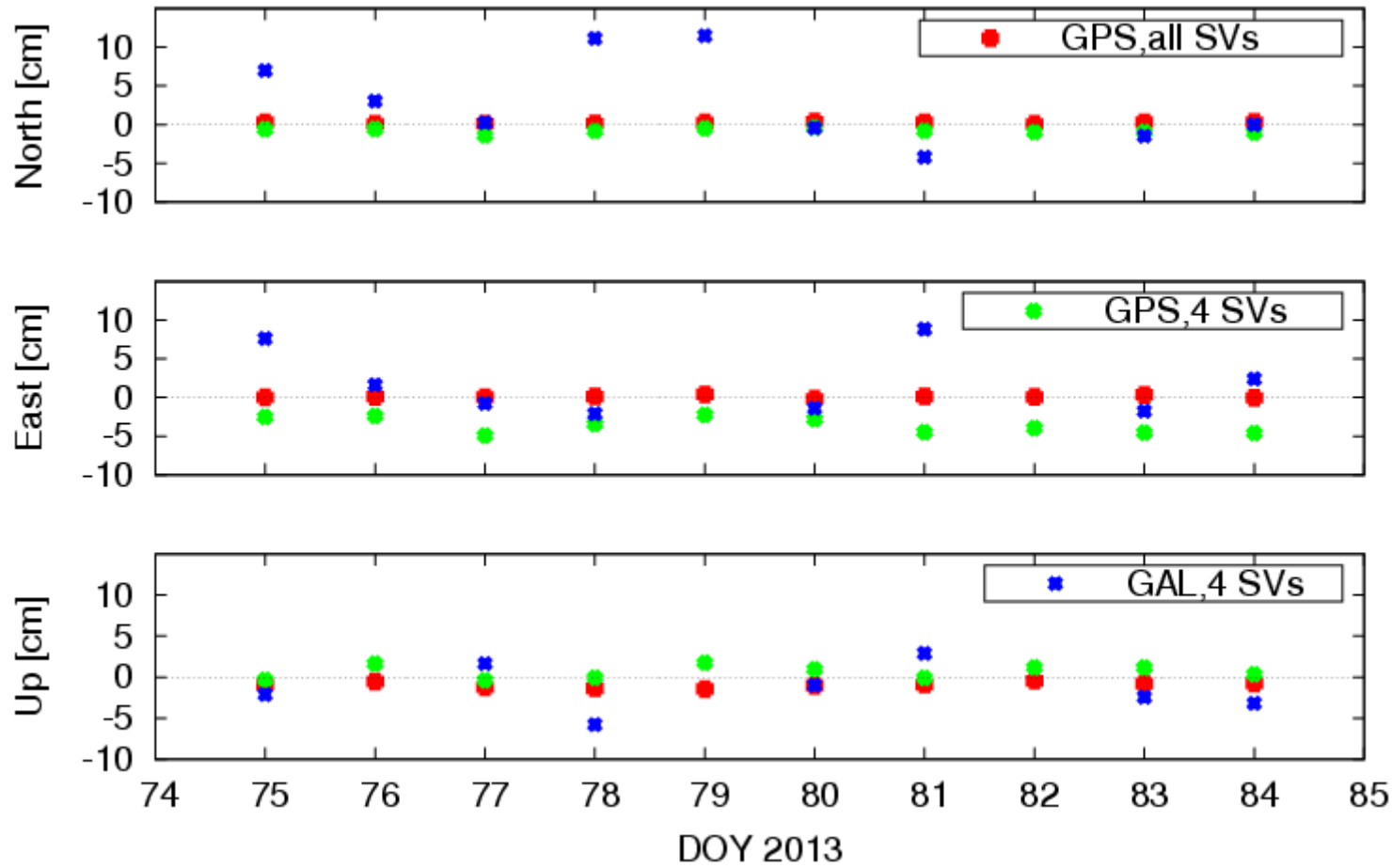
PPP, static mode (DOY 2013: 075 – 084)

Difference to CODE MGEX network solution (threshold 3 dm):
GPS+Galileo, **GPS**, **GPS (4 SVs)**, **Galileo**

Station	North [mm]		East [mm]		Up [mm]	
	mean	STD	mean	STD	mean	STD
OUS2	3.7	1.7	-2.8	2.1	-8.6	6.0
	3.2	1.3	-1.1	2.0	9.3	6.0
	-11.9	24.0	-19.1	22.3	13.6	27.7
	37.9	135.6	33.8	34.4	-0.3	106.9
RIO2	1.7	1.2	-1.0	2.1	2.8	4.3
	1.9	1.2	1.6	2.0	3.2	3.7
	1.9	3.2	-30.4	21.0	18.2	19.4
	-27.2	62.7	-59.0	86.2	-9.7	50.8
TASH	0.3	1.1	2.8	2.4	1.9	4.1
	-0.4	0.8	1.2	2.0	3.4	4.4
	-3.6	13.1	-6.1	13.6	33.2	18.2
	-17.4	92.1	57.0	77.8	-43.3	101.3
ZIM3	2.4	1.3	2.9	1.9	-9.9	2.8
	2.5	1.0	1.0	1.7	-9.5	3.4
	-8.0	3.1	-36.0	10.4	6.1	8.2
	50.2	83.7	47.4	96.9	-65.9	91.9

PPP, static mode (DOY 2013: 075 - 084)

Difference to CODE MGEX network solution for station ZIM3:
GPS+Galileo, **GPS**, **GPS (4 SVs)**, **Galileo**



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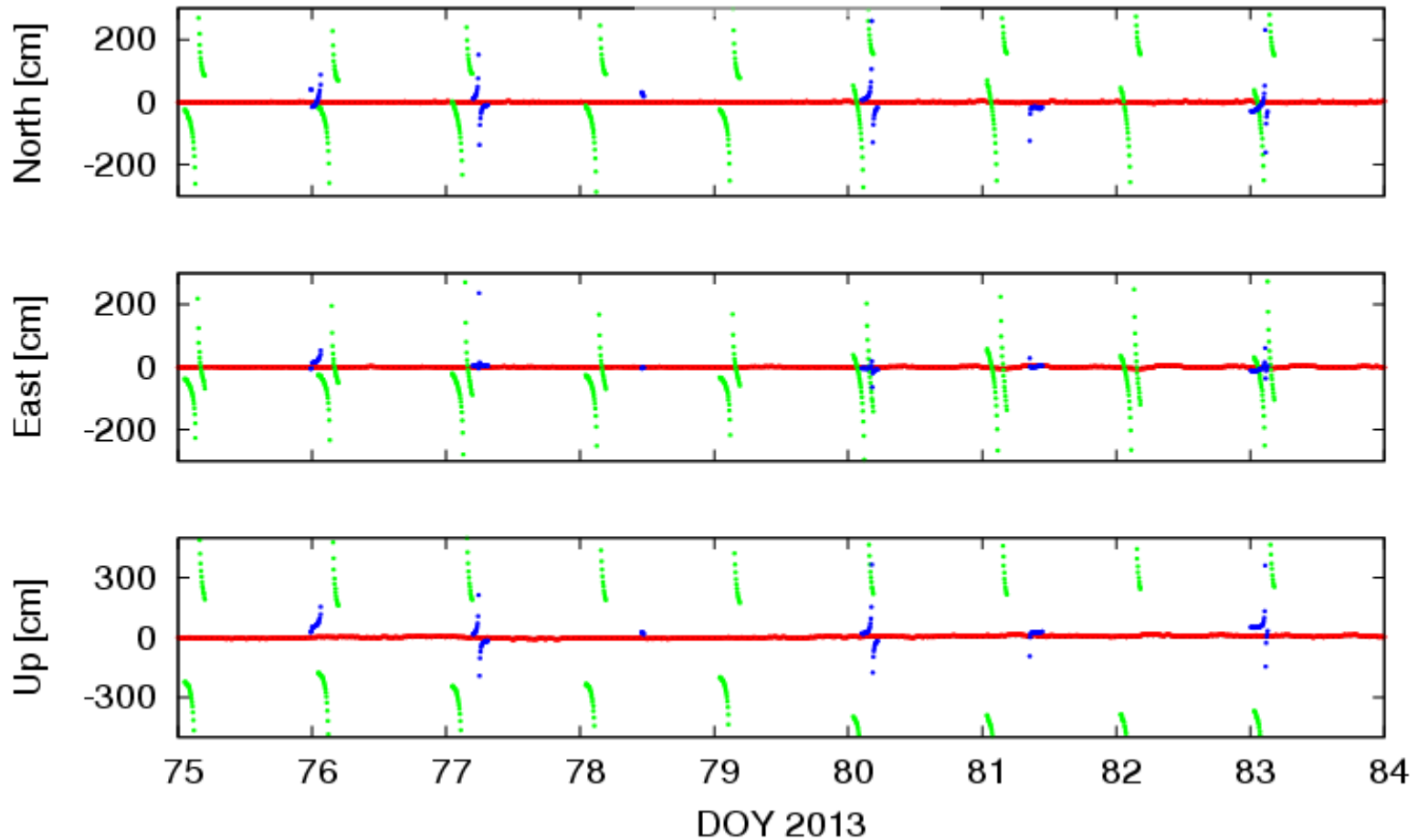
PPP, kinematic mode (DOY 2013: 075 – 084)

Difference to CODE MGEX network solution (threshold 1 m):
GPS+Galileo, **GPS**, **GPS (4 SVs)**, **Galileo**

Station	North [mm]		East [mm]		Up [mm]	
	mean	STD	mean	STD	mean	STD
OUS2	3.0	33.0	-7.8	38.1	210.1	112.1
	2.5	38.6	-7.2	47.7	216.8	119.9
	-3132.4	2907.3	-3959.6	3819.2	5066.5	3375.5
	-104.6	1756.6	572.3	1036.7	-191.3	2251.3
RIO2	8.0	36.8	8.2	39.4	181.5	141.6
	7.8	43.9	12.2	47.5	185.7	149.0
	357.8	2034.4	63.0	901.1	557.2	4917.5
	-223.0	1283.7	-18.9	516.1	-549.8	1539.8
TASH	1.5	19.4	0.9	26.6	112.1	92.8
	1.1	21.6	-2.2	29.6	114.2	95.0
	2225.0	2677.2	-2679.8	3040.4	5133.4	3545.8
	-326.2	1229.5	270.9	741.1	-7.2	1393.7
ZIM3	3.0	12.5	3.5	16.5	30.0	54.2
	3.3	13.2	1.0	17.0	30.3	55.1
	265.0	2331.1	-360.0	1634.5	-1129.9	4364.2
	-112.2	690.3	13.8	369.2	246.7	944.6

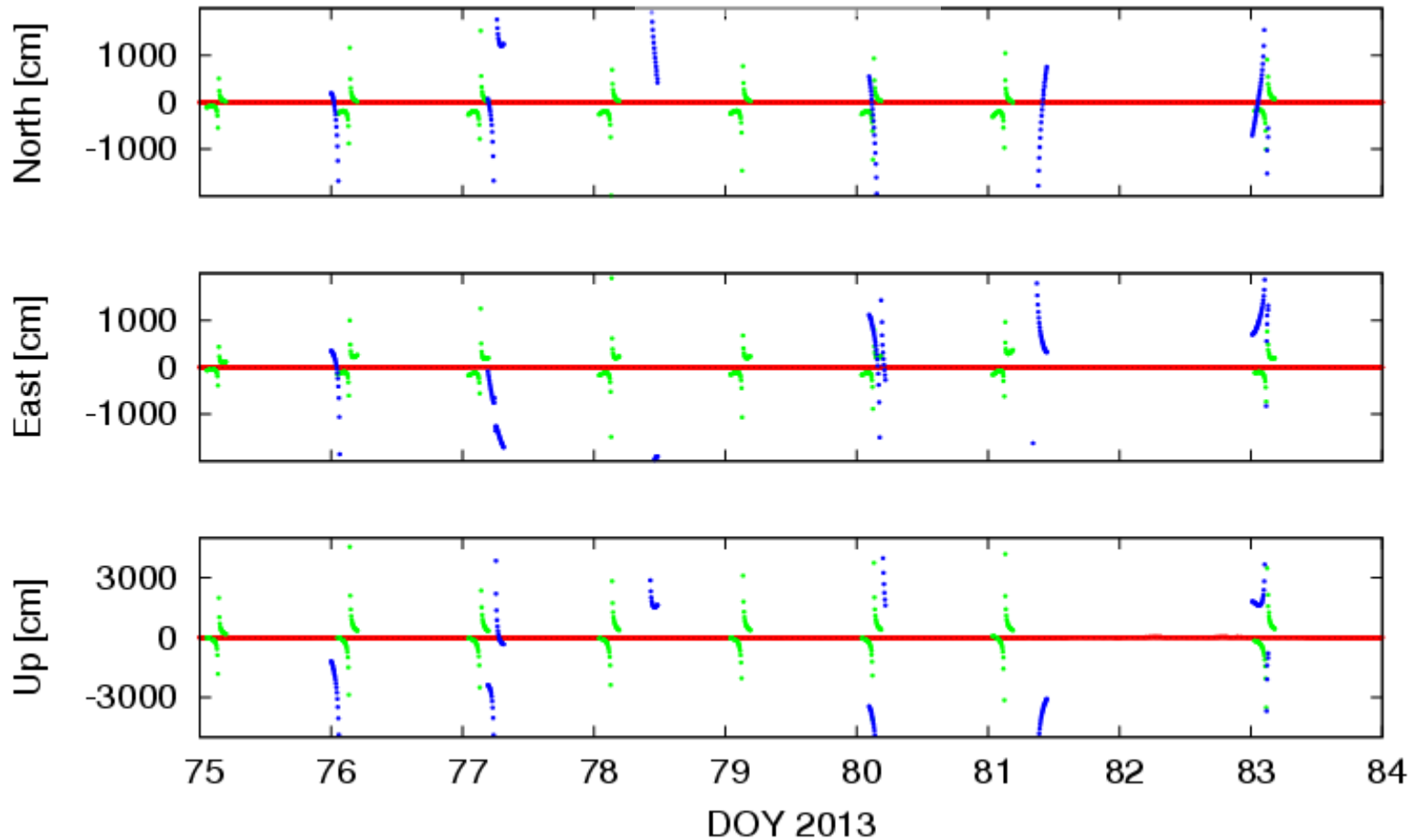
PPP, kinematic mode (DOY 2013: 075 – 084)

Difference to network solution: **GPS**, **GPS (4 SVs)**, **Galileo**
Station ZIM3

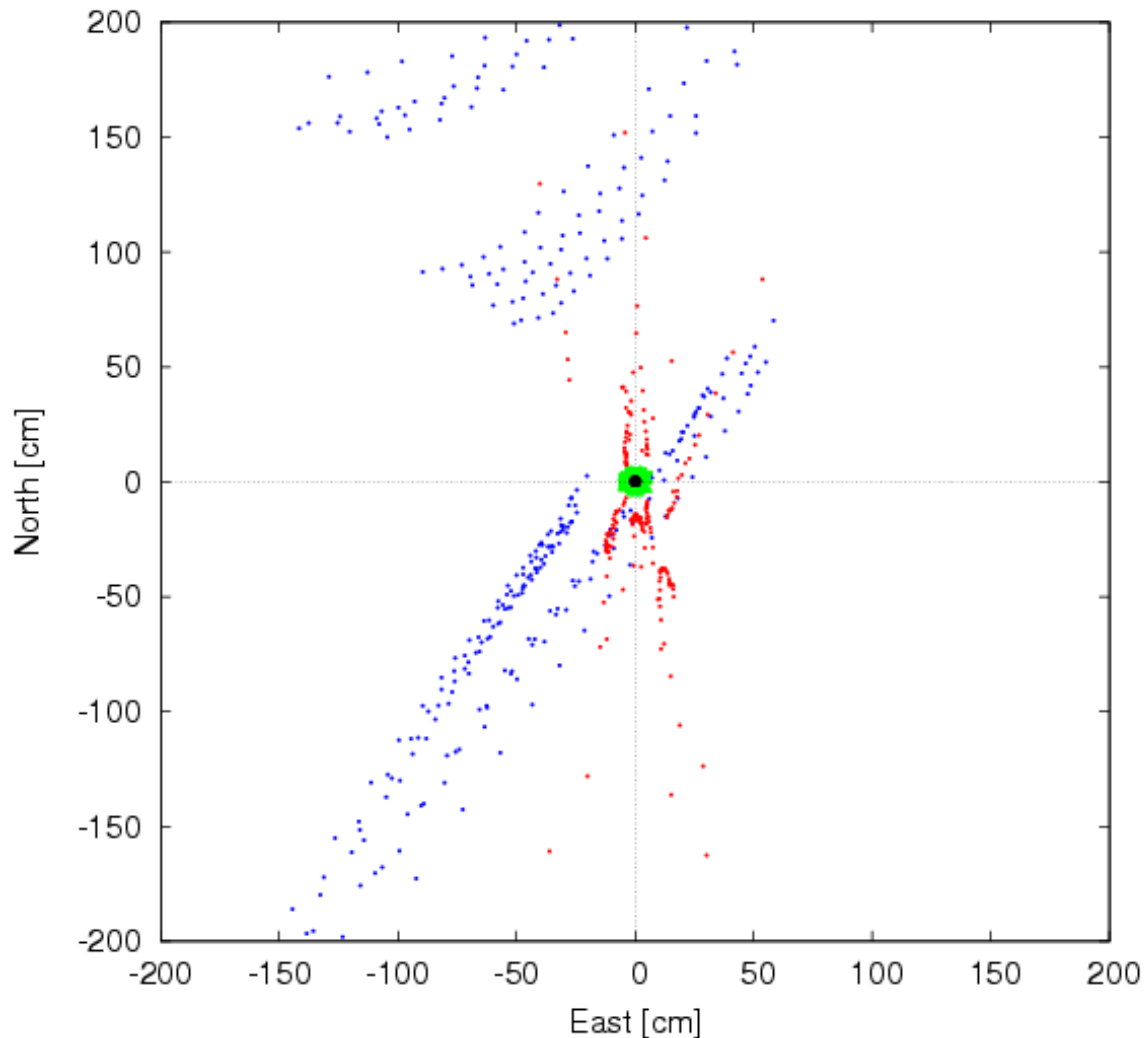


PPP, kinematic mode (DOY 2013: 075 – 084)

Difference to network solution: **GPS**, **GPS (4 SVs)**, **Galileo**
Station BRUX

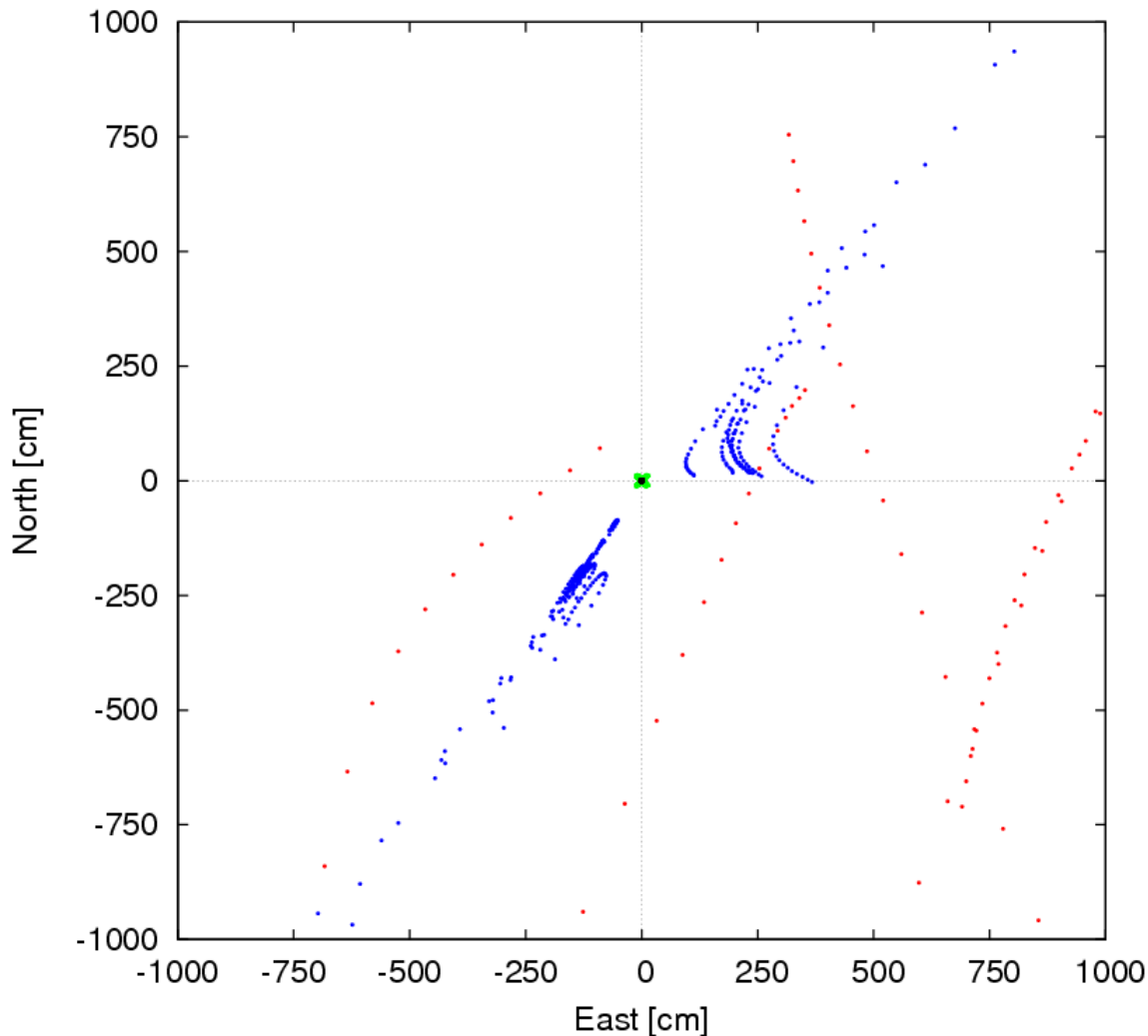


PPP, kinematic mode (DOY 2013: 075 – 084)



- Static
- Kinematic GPS
- Kinematic Galileo-only
- Kinematic GPS (4 SVs)

PPP, kinematic mode (DOY 2013: 075 – 084)



- Static
- Kinematic GPS
- Kinematic Galileo-only
- Kinematic GPS (4 SVs)

Summary

- The analysis of IGS MGEX data is very useful for understanding, integration, and exploitation of the new GNSS signals and systems.
- CODE provides a MGEX-based, fully integrated, triple-system orbit solution: **GPS+GLONASS+Galileo**
- Galileo orbits dramatically benefit from long arcs:
 - the inhomogeneous station distribution and
 - its long orbit revolution time ($\gg 12\text{h}$)
- CODE MGEX clock solutions are available and can be used **even for a Galileo-only PPP**.

Outlook

- **Preparing the next batch for publication including GPS+GLONASS+Galileo+BeiDou+QZSS**
- **Preparation of an operational MGEX processing chain (at least for Galileo)**
- **Understanding of the orbit models for the new satellites (SNF–project just started)**