Localisation précise par moyens spatiaux

Global GNSS Processing at CODE

Rolf Dach

rolf.dach@aiub.unibe.ch
Astronomical Institute, University of Bern

Outline

- **Introduction**
  - IGS: International GNSS Service
  - CODE – one of the global IGS analysis centers
  - Introducing some formats: RINEX, SP3, SINEX
- **Orbit Determination (at CODE)**
- **Code Biases: DCB, ISB, IFB**

Outline

- **Introduction**
- **Orbit Determination (at CODE)**
  - Development of the IGS tracking station network
  - Orbit quality as a function of the tracking network and observation modeling (reprocessing)
  - Length of an orbital arc in the GNSS processing
  - Methods for orbit validation
  - Handling of GPS repositioning events
- **Code Biases: DCB, ISB, IFB**

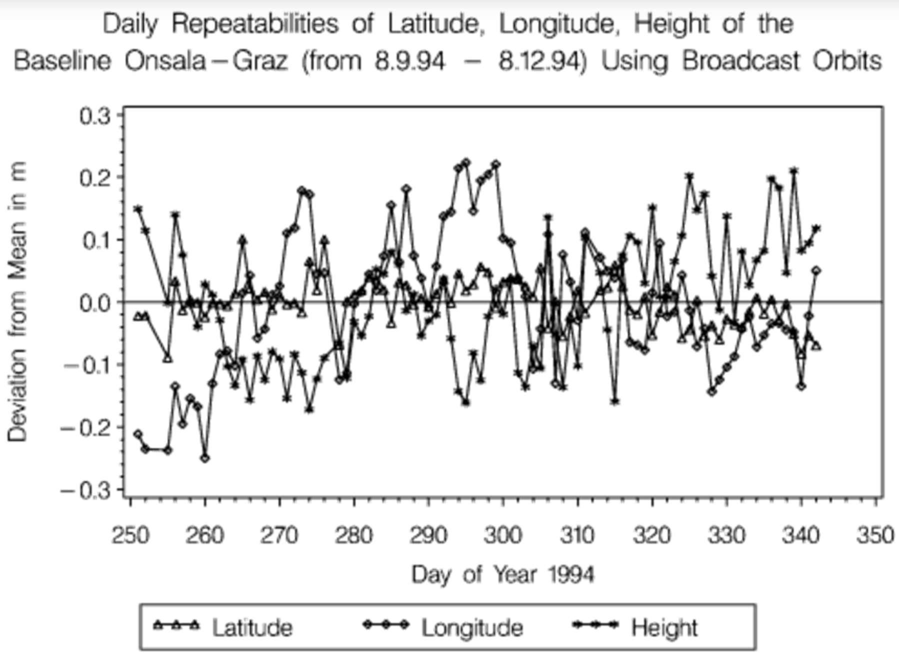
Outline

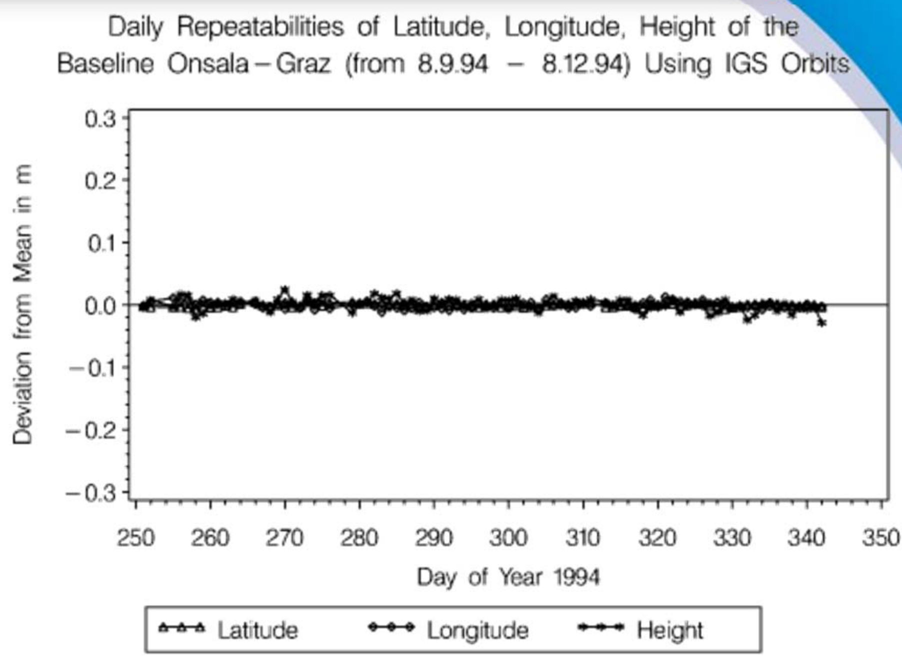
- **Introduction**

- **Orbit Determination (at CODE)**

- **Code Biases: DCB, ISB, IFB**
  - GNSS observation equation as starting point
  - Dependencies of components in the observation equation from GNSS, frequency and observation type and resulting biases
  - DCBs in a GPS, GLONASS, GPS/GLONASS network solution
  - How DCBs can be computed?
  - Bonus: GLONASS-GPS translation bias

IGS: Motivation





- Repeatability (north, east, up) when processing 90 days of GPS observations at Graz (Austria) and Onsala (Sweden) (1200 km baseline) with broadcast orbits
- Towards the end of the 1980ties it was recognized that the error of the broadcast orbit was the accuracy limiting factor.
- As orbit determination for a satellite system is not a trivial business which can be done on a case-by-case basis, this was the motivation for the creation of a scientific orbit determination service.

Rule of thumb by Baueršíma

$$\frac{\Delta_{Baseline}}{\Delta_{Orbit}} \approx \frac{Length\ of\ the\ baseline}{Height\ of\ the\ orbit} \qquad \text{with} \qquad Height\ of\ the\ orbit \approx 25000km$$

Errors in baseline components due to orbit errors (Baueršíma, 1982)

Orbit error	Baseline length	Baseline error	
2.50 m	1 km	0.1 ppm	0.1 mm
2.50 m	10 km	0.1 ppm	1 mm
2.50 m	100 km	0.1 ppm	10 mm
2.50 m	1000 km	0.1 ppm	100 mm
0.05 m	1 km	0.002 ppm	≈0 mm
0.05 m	10 km	0.002 ppm	<0.1 mm
0.05 m	100 km	0.002 ppm	0.2 mm
0.05 m	1000 km	0.002 ppm	2.0 mm

IGS: History and first steps

August 1989, IAG Scientific Assembly in Edinburgh
first ideas to establish a service to support users with highest requirements in the GPS data processing

February 1991 Call for Participation with more than 100 responses

August 1991–March 1992 IGS Campaign Oversight Committee
planned a two weeks test campaign in Summer 1992

21. June 1992 test campaign started activities never stopped again

November 1992 activities named now “IGS Pilot Service”

01. January 1994 IGS starts as an official service of the IAG

IGS: What does it mean?

- International GPS Service for Geodesy and Geodynamics
  January 1994

- International GPS Service
  May 1998

- International GNSS Service
  March 2005

IGS: Main components

- **GNSS–Stations of the IGS–Tracking Network**
  basis for IGS activities; contributions from many different organizations
- **Regional and Global Data Centers**
  provide the data to the users and analysis centers
- **Analysis Centers**
  compute the products from the data of the IGS–stations
- **Analysis Center Coordinator**
  combines the contributions from the analysis centers to IGS–products
- **Product Databases**
  provide the IGS products to the users
- **IGS Central Bureau**
  day-to-day management of the IGS
- **IGS Governing Board**
  policy guidance of the IGS
- **IGS Working groups**
  for many different topics

IGS: Product lines

Final series – ORB, ERP, CLK (300/30 sec. sampling), CRD

- available about two weeks after the end of the week
- GPS and GLONASS in compatible but independent series

Rapid series – ORB, ERP, CLK

- available at the day after the measurements, 17:00 UTC
- quality very close to the final products

Ultra–rapid series – ORB, ERP, (CLK, 300 sec. sampling)

- four updates per day, latency 3 hours
- contains 24 hours estimated and 24 hours predicted orbits
- GLONASS series on an experimental stage

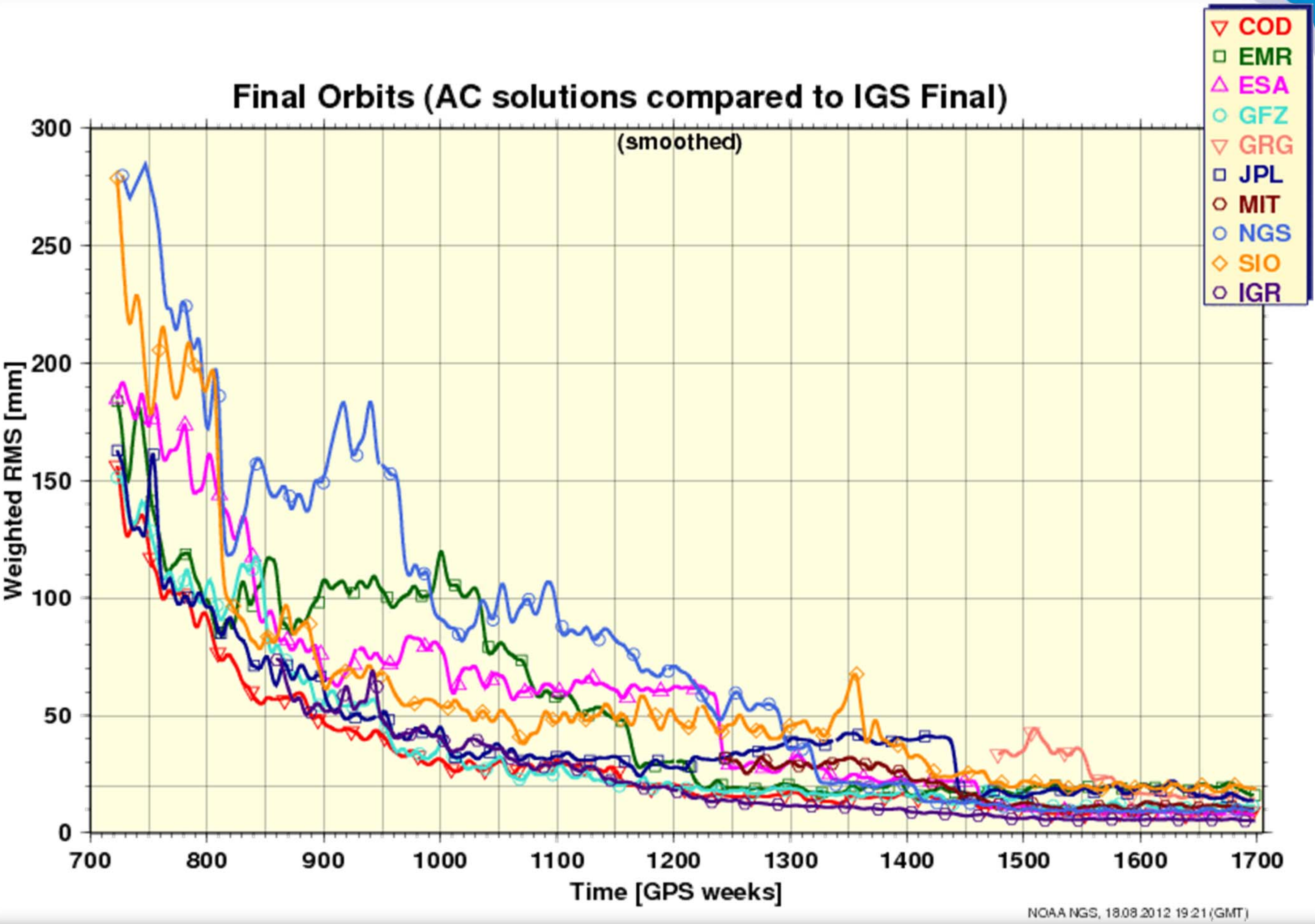
IGS: Orbit combination

Analysis Center 1 | Analysis Center 2 | Analysis Center 3 | ... | Analysis Center n

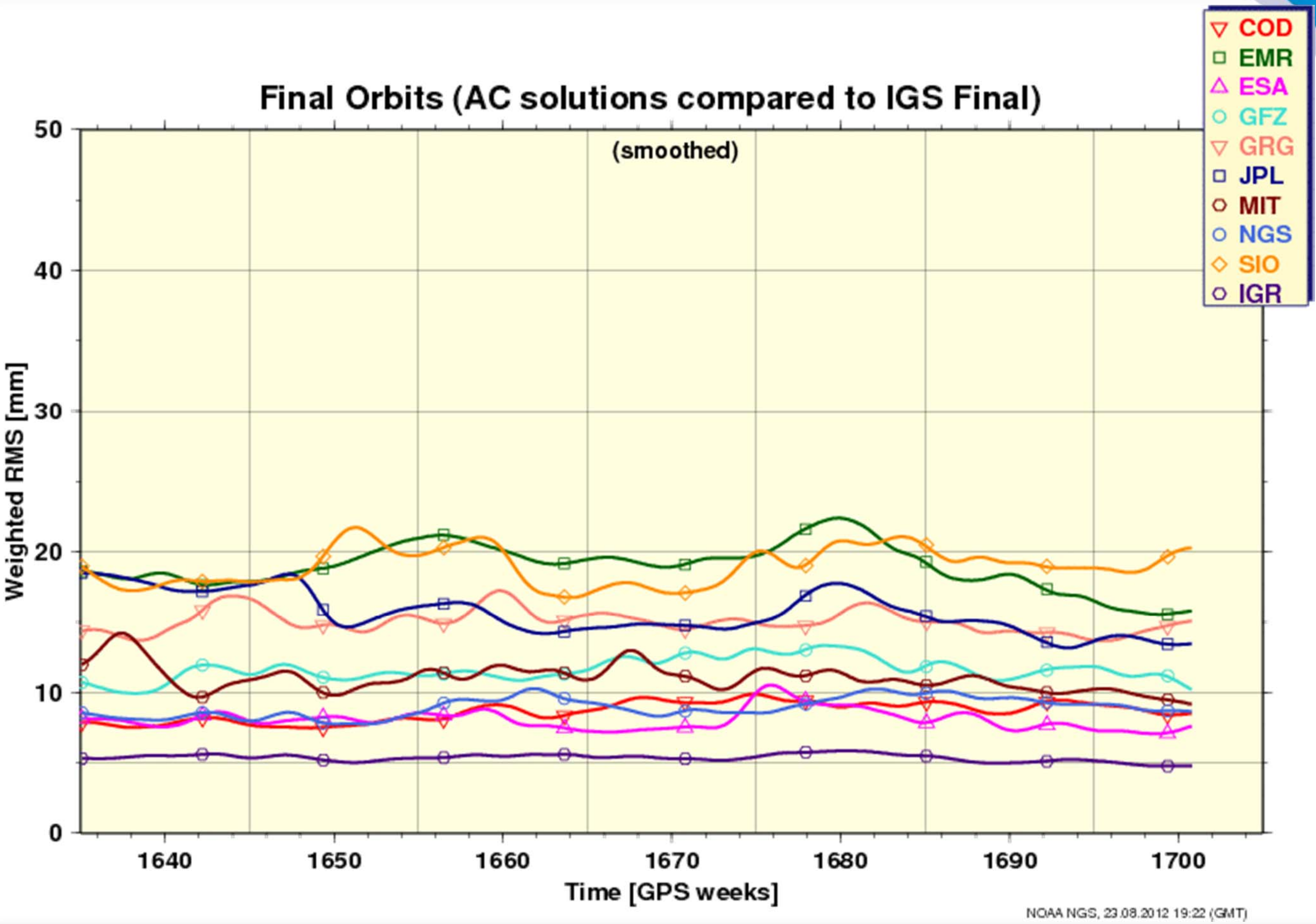
1. An unweighted mean orbit between the Analysis Centers is computed.
2. The standard deviation of each contribution to this mean orbit is computed to assign a weight to each Analysis Center.
3. The combined IGS orbit consists of the satellite positions computed as the weighted mean of the positions contributed by the Analysis Centers.
4. The mean errors and the transformation parameters of the individual solutions with respect to the IGS orbit are made available every week for each day of the (preceding) week.

Combined IGS orbit

IGS: Consistency of the final GPS orbits



IGS: Consistency of the final GPS orbits



IGS: Product quality

Quality of the IGS core products at end of 2011
(see http://acc.igs.org/erp/egu12-igu-erps.pdf)

Series	Product Type	Accuracy	
Ultra-Rapid (predicted)	GNSS Orbits GPS satellite clocks EOPs	GPS: 5 cm (1D) RMS: 3 ns PM: 250 µas	GLONASS: 10 cm (1D) SDev: 1.5 ns dLOD: 50 µs
Ultra-Rapid (observed)	GNSS Orbits GPS satellite clocks EOPs	GPS: 3 cm (1D) RMS: 150 ps PM: <150 µas	GLONASS: 10 cm (1D) SDev: 50 ps dLOD: 10 µs
Rapid	GNSS Orbits GPS sat. & rec. clocks EOPs	GPS: 2.5 cm (1D) RMS: 75 ps PM: <40 µas	SDev: 25 ps dLOD: 10 µs
Final	GNSS Orbits GPS sat. & rec. clocks EOPs Terrestrial Frame	GPS: 2.5 cm (1D) RMS: 75 ps PM: <30 µas N&E: 2 mm	GLONASS: <5 cm (1D) SDev: 20 ps dLOD: 10 µs U: 5 mm

CODE: What does it mean?

CODE, Center for Orbit Determination in Europe, is one of at present ten Analysis Centers of the IGS.

CODE is formed as a joint venture of

- the Astronomical Institute of the University of Bern (AIUB),
- the Swiss Federal Office of Topography (swisstopo),
- the Institut für Kartographie und Geodäsie (BKG), and
- the Institut für Astronomische und Physikalische Geodäsie of TU München (IAPG, TUM).

AIUB

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Bundesamt für
Kartographie und Geodäsie

Technische Universität München

CODE: Analysis Center of the IGS

- CODE is located at the AIUB in Bern.
- CODE started operating on 21 June 1992.
- Initially about 20, today about 250 stations are processed daily.
- All results are generated using the Bernese GNSS Software.
- CODE provides products for the final, rapid, and ultra-rapid IGS products.
  All of them (except clocks) are based on a fully combined GPS/GLONASS data analysis.
- CODE started with this approach in May 2003.
  Meanwhile also other analysis centers join this a strategy.

International exchange formats

Within the IGS lots of data, products and meta information need to be exchange:

	Format
▪ Meta data (equipment at the stations)	
▪ Observations data and navigation data from the stations	**RINEX**
▪ Orbit products	**SP3c**
▪ Solutions with full covariance information	**SINEX**
▪ Clock products	**Clock RINEX**
▪ Miscellaneous information: e.g., antenna phase center corrections	**ANTEX**

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Clock products	**Clock RINEX**
Miscellaneous information: e.g., antenna phase center corrections	**ANTEX**

RINEX: observations

RINEX = Receiver INdependent EXchange format

GNSS observation data in text format,
independent from any internal receiver/manufacturer format

Contains (among others):

- Meta information (GNSS: equipment, antenna phase center offsets)
- List of observation types

Maintained by RINEX working group of IGS and RTCM-SC 104
(Chair: K. MacLeod, NRCan)

RINEX: observations

```
     2.11           OBSERVATION DATA    M (MIXED)           RINEX VERSION / TYPE
GPSBase 2.73 3713                       31-Aug-12 23:59:44  PGM / RUN BY / DATE
ZIM2                                                        MARKER NAME
14001M008                                                   MARKER NUMBER
GPSBASE             SWISSTOPO                               OBSERVER / AGENCY
4646K03180          TRIMBLE NETR5       4.48                REC # / TYPE / VERS
     0                                                      RCV CLOCK OFFS APPL
60369               TRM59800.00     NONE                    ANT # / TYPE
        0.0000        0.0000        0.0000                  ANTENNA: DELTA H/E/N
  4331300.1490   567537.0850  4633133.5110                  APPROX POSITION XYZ
     1     1     0                                          WAVELENGTH FACT L1/2
    10    C1    P1    P2    C2    L1    L2    S1    S2    D1# / TYPES OF OBSERV
          D2                                                # / TYPES OF OBSERV
    30.000                                                  INTERVAL
  2012     9     1     0     0    0.0000000     GPS         TIME OF FIRST OBS
                                                            END OF HEADER
 12  9  1  0  0  0.0000000  0 21G16G08G20G32G23G13G10G04G07R10R12R19
                                R17R13R11R01G30R18R02G02R03
  24765656.063                    24765661.480                  130144380.32603
 101411252.65546       37.000          21.000        1872.578        1459.152
  25309764.430                    25309774.457                  133003675.58304
 103639299.76746       39.000          21.000        3726.313        2903.620
...
  22260626.523                    22260632.324                  116980423.31206
  91153636.17647       47.000          40.000        3056.719        2381.859
 24153130.023    24153128.371    24153137.082                  128749703.74306
 100138756.39447       43.000          36.000       -4041.707       -3149.382
  20868394.672    20868393.488    20868400.883                  111475539.59707
  86703023.00948       51.000          48.000        3137.008        2444.422
...
12  9  1  0  0 30.0000000  0 21G16G08G20G32G23G13G10G04G07R10R12R19
                                R17R13R11R01G30R18R02G02R03
  24755002.898                    24755008.742                  130088397.67704
 101367629.86146       38.000          21.000        1859.422        1448.900
...
```

Header part

Data part

RINEX: observations

```
     2.11           OBSERVATION DATA    M (MIXED)           RINEX VERSION / TYPE
GPSBase 2.73 3713                       31-Aug-12 23:59:44  PGM / RUN BY / DATE
ZIM2                                                        MARKER NAME
14001M008                                                   MARKER NUMBER
GPSBASE             SWISSTOPO                               OBSERVER / AGENCY
4646K03180          TRIMBLE NETR5       4.48                REC # / TYPE / VERS
     0                                                      RCV CLOCK OFFS APPL
60369               TRM59800.00     NONE                    ANT # / TYPE
        0.0000        0.0000        0.0000                  ANTENNA: DELTA H/E/N
   331300.1490   567537.0850  4633133.5110                  APPROX POSITION XYZ
     1     1     0                                          WAVELENGTH FACT L1/2
    10    C1    P1    P2    C2    L1    L2    S1    S2    D1# / TYPES OF OBSERV
          D2                                                # / TYPES OF OBSERV
    30.000                                                  INTERVAL
  2012     9     1     0     0    0.0000000     GPS         TIME OF FIRST OBS
                                                            END OF HEADER
 12  9  1  0  0  0.0000000  0 21G16G08G20G32G23G13G10G04G07R10R12R19
                                R17R13R11R01G30R18R02G02R03
  24765656.063                    24765661.480                  130144380.32603
 101411252.65546       37.000          21.000        1872.578        1459.152
  25309764.430                    25309774.457                  133003675.58304
 103639299.76746       39.000          21.000        3726.313        2903.620
...
  22260626.523                    22260632.324                  116980423.31206
  91153636.17647       47.000          40.000        3056.719        2381.859
 24153130.023    24153128.371    24153137.082                  128749703.74306
 100138756.39447       43.000          36.000       -4041.707       -3149.382
  20868394.672    20868393.488    20868400.883                  111475539.59707
  86703023.00948       51.000          48.000        3137.008        2444.422
...
12  9  1  0  0 30.0000000  0 21G16G08G20G32G23G13G10G04G07R10R12R19
                                R17R13R11R01G30R18R02G02R03
  24755002.898                    24755008.742                  130088397.67704
 101367629.86146       38.000          21.000        1859.422        1448.900
...
```

Meta information
- station
- receiver
- antenna
- position
- observation types

Epoch

List of satellites

G: GPS / R: GLONASS

Observation record per satellite

(empty field: no obs.)

RINEX: observations

RINEX = Receiver INdependent EXchange format

Deficiencies of the currently used RINEX 2 format:

- For all satellites of all GNSS the full list of observations is expected.
  (if, e.g., Galileo is added much more empty fields in GPS and GLONASS fill appear)
- Not all necessary tracking information can be provided.
  (How the code on the 2nd frequency for GPS has really been constructed?)

A new format for multi-GNSS purposes has been developed: RINEX 3.

RINEX: observations

```
     3.00           OBSERVATION DATA    Mixed(MIXED)        RINEX VERSION / TYPE
cnvtToRINEX 2.11.0  PNAC                02-Sep-12 00:04 UTC PGM / RUN BY / DATE
ZIM2                                                        MARKER NAME
14001M008                                                   MARKER NUMBER
GEODETIC                                                    MARKER TYPE
AGNES               SWISSTOPO                               OBSERVER / AGENCY
4646K03180          TRIMBLE NETR5       4.48                REC # / TYPE / VERS
60369               TRM59800.00     NONE                    ANT # / TYPE
        0.0000        0.0000        0.0000                  ANTENNA: DELTA H/E/N
  4331300.1490   567537.0850  4633133.5110                  APPROX POSITION XYZ
G   12 C1C C2W C5X L1C L2W L5X D1C D2W D5X S1C S2W S5X      SYS / # / OBS TYPES
R   12 C1C C1P C2P L1P L2P D1C D1P D2P L1C S1C S1P S2P      SYS / # / OBS TYPES
  2012     9     1     0     0    0.0000000     GPS         TIME OF FIRST OBS
                                                            END OF HEADER
> 2012  9  1  0  0  0.0000000  0 21
G02  22589950.273 8  22589954.789 6                   118711006.383 8  92502128.899 6                    ...
G04  20794711.078 9  20794716.625 7                   109276975.064 9  85150980.972 7                    ...
...
G32  25935591.992 6  25935599.738 3                   136292508.49916 106202065.95713                    ...
R01  21052556.016 8  21052555.535 8  21052562.563 7 112537843.451 8 112538056.461 8  87529675.075 7 ...
R02  19716255.945 9  19716254.879 9  19716260.273 8 105210168.624 9 105209910.632 9  81829916.303 8 ...
...
> 2012  9  1  0  0 30.0000000  0 21
G02  22575960.852 8  22575964.965 6                   118637493.230 8  92444845.965 6                    ...
...

> 2012  9  1  7  1 30.0000000  0 19
G09  19965745.773 9  19965751.992 8                   104920706.722 9  81756429.961 8                    ...
...
G22  24240409.445 7  24240415.559 4                   127384301.240 7  99260425.976 4                    ...
G25  25663278.844 6                  25663288.879 7 134861381.18616                  100708253.85317 ...
G26  23574927.578 7  23574937.262 5                   123887081.627 7  96535400.917 5                    ...
G27  20694508.273 8  20694515.051 7                   108750288.713 8  84740590.529 7                    ...
R05  22466635.914 8  22466634.613 7  22466645.121 7 120096860.310 8 120096999.316 7  93408779.111 7 ...
...
```

Header part

Data part

RINEX: observations

```
 3.00           OBSERVATION DATA    Mixed(MIXED)        RINEX VERSION / TYPE
cnvtToRINEX 2.11.0  PNAC              02-Sep-12 00:04 UTC PGM / RUN
ZIM2                                                    MARKER NA
14001M008                                               MARKER NU
GEODETIC                                                MARKER TY
AGNES               SWISSTOPO                           OBSERVER
4646K03180          TRIMBLE NETR5       4.48            REC # / T
60369               TRM59800.00     NONE                ANT # / T
        0.0000        0.0000        0.0000              ANTENNA:
  4331300.1490   567537.0850  4633133.5110              APPROX PO
G   12 C1C C2W C5X L1C L2W L5X D1C D2W D5X S1C S2W S5X  SYS / # /
R   12 C1C C1P C2P L1P L2P D1C D1P D2P L1C S1C S1P S2P  SYS / # /
  2012     9     1     0     0    0.0000000     GPS     TIME OF F
                                                        END OF HEADER
> 2012  9  1  0  0  0.0000000  0 21
G02  22589950.273 8  22589954.789 6                 118711006.383 8  92502128.899 6                ...
G04  20794711.078 9  20794716.625 7                 109276975.064 9  85150980.972 7                ...
...
G32  25935591.992 6  25935599.738 3                 136292508.49916 106202065.95713                ...
R01  21052556.016 8  21052555.535 8  21052562.563 7 112537843.451 8 112538056.461 8  87529675.075 7 ...
R02  19716255.945 9  19716254.879 9  19716260.273 8 105210168.624 9 105209910.632 9  81829916.303 8 ...
...
> 2012  9  1  0  0 30.0000000  0 21
G02  22575960.852 8  22575964.965 6
...
> 2012  9  1  7  1 30.0000000  0 19
G09  19965745.773 9  19965751.992 8                 104920706.722 9  81756429.961 8                ...
...
G22  24240409.445 7  24240415.559 4                 127384301.240 7  99260425.976 4                ...
G25  25663278.844 6                  25663288.879 7 134861381.18616                 100708253.85317 ...
G26  23574927.578 7  23574937.262 5                 123887081.627 7  96535400.917 5                ...
G27  20694508.273 8  20694515.051 7                 108750288.713 8  84740590.529 7                ...
R05  22466635.914 8  22466634.613 7  22466645.121 7 120096860.310 8 120096999.316 7  93408779.111 7 ...
...
```

RINEX 3		RINEX 2	
C1C	C1P	C1	P1
C2C	C2P	C2	P2
L1P	L1C	L1	
L2P	L2C	L2	
...		...	

Observation records

- one line per satellite
- observation types are GNSS-specific

RINEX: navigations

RINEX = Receiver INdependent EXchange format

GNSS navigation data in text format,
independent from any internal receiver/manufacturer format

Contains:

- GPS broadcast ephemerides
- GLONASS broadcast records

Maintained by RINEX working group of IGS and RTCM-SC 104
(Chair: K. MacLeod, NRCan)

SP3c: orbit products

- Positions (and velocities) for a list of satellites in a given sampling
- Given in the Earth fixed frame
- IGS provides positions of the GNSS satellites every 15 minutes
- Additional information:
  - Satellite clock corrections
  - Accuracy information
- Maintained by S. Hilla, NGS in cooperation with the services

SP3c: orbit products

```
#cP2012  9  1  0  0  0.00000000      96 d     IGS08 FIT AIUB
## 1703 518400.00000000   900.00000000 56171 0.0000000000000
+   55   G01G02G03G04G05G06G07G08G09G10G11G12G13G14G15G16G17
+        G18G19G20G21G22G23G25G26G27G28G29G30G31G32R01R02R03
+        R04R05R06R07R08R09R10R11R12R13R14R15R16R17R18R19R20
+        R21R22R23R24  0  0  0  0  0  0  0  0  0  0  0  0  0
+          0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
...

/* CENTER FOR ORBIT DETERMINATION IN EUROPE (CODE)
/* THIS IS THE OFFICIAL CODE RAPID 3-DAY SOLUTION
/* SOLUTION RA_12245, BROADCAST CLOCKS INCLUDED
/* PCV:IGS08      OL/AL:FES2004  NONE     YN ORB:CoN CLK:BRD
*  2012  9  1  0  0  0.00000000
PG01  16921.819384  13762.982632 -15202.395305    271.857250
PG02   6208.829840 -14772.286352  21274.094077    401.527621
PG03  -7224.820983  23955.152521  -9009.156949     95.599331
PG04  20531.101557  -7550.693238  15011.814108    291.056000
PG05     20.922404 -23887.653372  11452.131597   -348.304864
...
PG32   7182.271388  25850.246047    411.196956   -482.934993
PR01   9731.130403  17494.038662  15827.805141 999999.999999
PR02  11052.323721  -1421.381696  22956.219651 999999.999999
PR03   5933.793449 -18146.407263  16971.112864 999999.999999
PR04  -2659.650571 -25358.097929    880.122287 999999.999999
PR05  -9706.254994 -17595.301374 -15711.481816 999999.999999
...
PR23  10611.600018   5347.134862 -22580.924142 999999.999999
PR24  20600.231106  -7703.540430 -12945.789422 999999.999999
*  2012  9  1  0 15  0.00000000
PG01  15071.494033  13670.235123 -17110.203126    271.858580
PG02   8563.990796 -14388.582237  20661.659093    401.528644
PG03  -7926.802370  24508.671306  -6386.290163     95.603833
PG04  22113.397104  -7092.797771  12902.234432    291.066129
PG05    785.658449 -22630.418015  13756.073853   -348.307627
```

Header part

Data part

SP3c: orbit products

```
#cP2012  9  1  0  0  0.00000000      96 d      IGS08 FIT AIUB
## 1703 518400.00000000   900.00000000 56171 0.0000000000000
+   55   G01G02G03G04G05G06G07G08G09G10G11G12G13G14G15G16G17
+        G18G19G20G21G22G23G25G26G27G28G29G30G31G32R01R02R03
+        R04R05R06R07R08R09R10R11R12R13R14R15R16R17R18R19R20
+        R21R22R23R24  0  0  0  0  0  0  0  0  0  0  0  0  0
+          0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
...

/* CENTER FOR ORBIT DETERMINATION IN EUROPE (CODE)
/* THIS IS THE OFFICIAL CODE RAPID 3-DAY SOLUTION
/* SOLUTION RA_12245, BROADCAST CLOCKS INCLUDED
/* PCV:IGS08      OL/AL:FES2004  NONE     YN ORB:CoN CLK:BRD
*  2012  9  1  0  0  0.00000000
PG01  16921.819384  13762.982632 -15202.395305    271.857250
PG02   6208.829840 -14772.286352  21274.094077    401.527621
PG03  -7224.820983  23955.152521  -9009.156949     95.599331
PG04  20531.101557  -7550.693238  15011.814108    291.056000
PG05     20.922404 -23887.653372  11452.131597   -348.304864
...
PG32   7182.271388  25850.246047    411.196956   -482.934993
PR01   9731.130403  17494.038662  15827.805141 999999.999999
PR02  11052.323721  -1421.381696  22956.219651 999999.999999
PR03   5933.793449 -18146.407263  16971.112864 999999.999999
PR04  -2659.650571 -25358.097929    880.122287 999999.999999
PR05  -9706.254994 -17595.301374 -15711.481816 999999.999999
...
PR23  10611.600018   5347.134862 -22580.924142 999999.999999
PR24  20600.231106  -7703.540430 -12945.789422 999999.999999
*  2012  9  1  0 15  0.00000000
PG01  15071.494033  13670.235123 -17110.203126    271.858580
PG02   8563.990796 -14388.582237  20661.659093    401.528644
PG03  -7926.802370  24508.671306  -6386.290163     95.603833
PG04  22113.397104  -7092.797771  12902.234432    291.066129
PG05    785.658449 -22630.418015  13756.073853   -348.307627
```

Defines interval and sampling

List of satellites

Four comment lines

Epoch

Satellites

G: GPS / R: GLONASS

Satellite positions (km)

Satellite clock corrections (µs)

SINEX: solutions

SINEX = Solution INdependent EXchange format

Software- and technique independent

Contains:

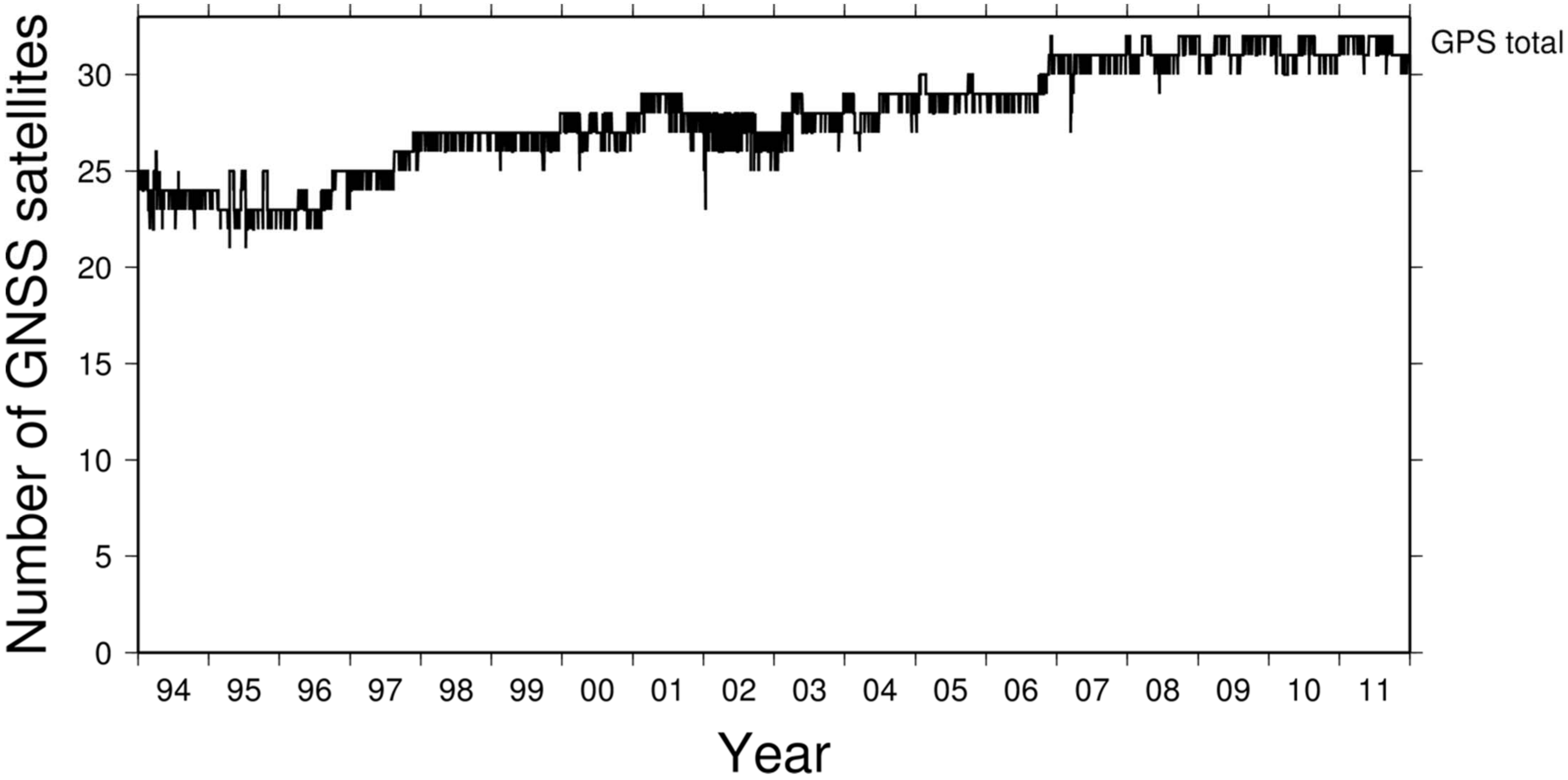
- List of stations (Abbreviation, full name, description)
- Meta information (GNSS: equipment, antenna phase center offsets)
- List of parameters (description, time interval)
- Different options to deliver the solution
  - normal equation, observation vector, apriori values
  - solution vector, solution covariance matrix, apriori constraints

Maintained by IERS working group (Chair: D. Thaller, AIUB)

Outline

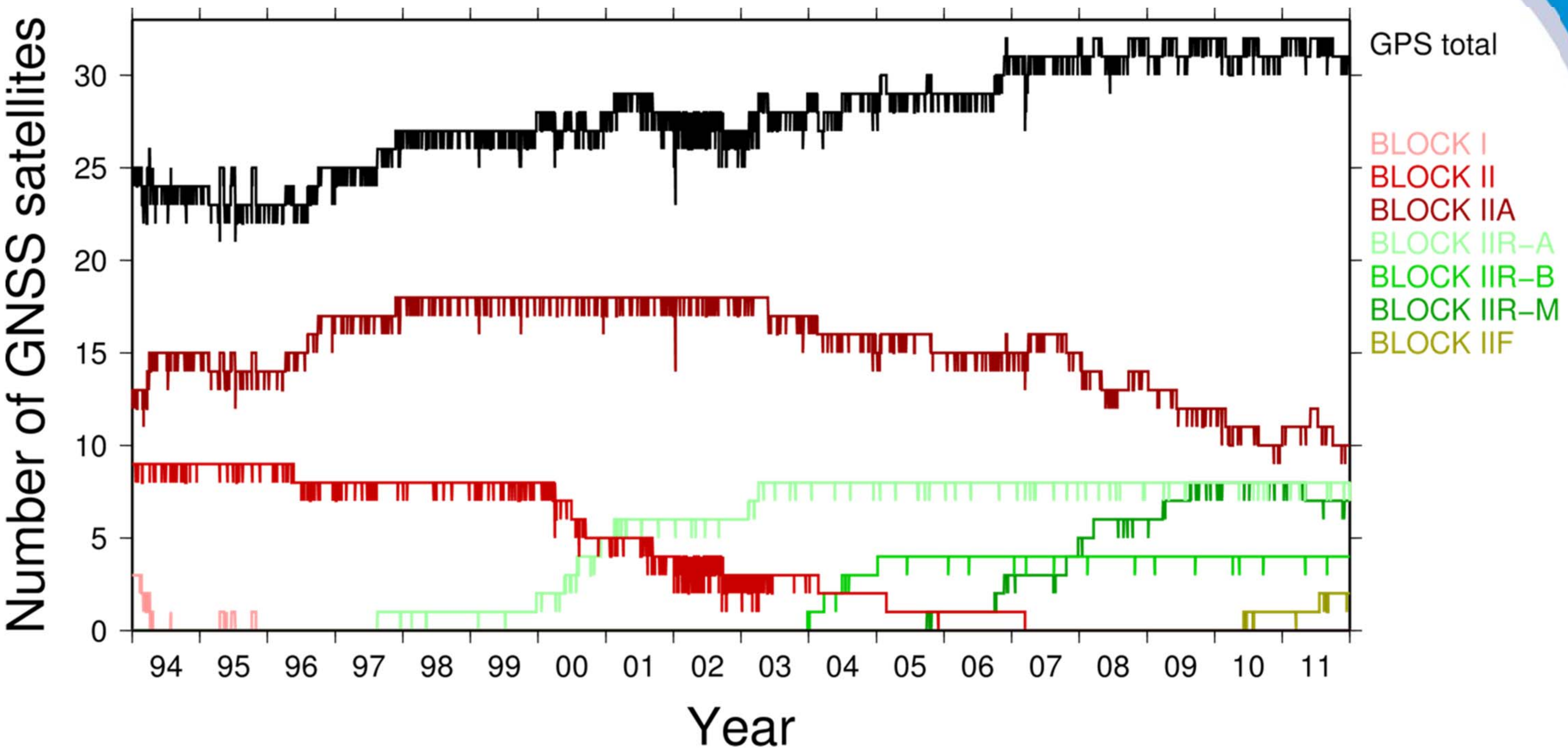
- **Introduction**
- **Orbit Determination (at CODE)**
  - Development of the IGS tracking station network
  - Orbit quality as a function of the tracking network and observation modeling (reprocessing)
  - Length of an orbital arc in the GNSS processing
  - Methods for orbit validation
  - Handling of GPS repositioning events
- **Code Biases: DCB, ISB, IFB**

Number of active GPS satellites



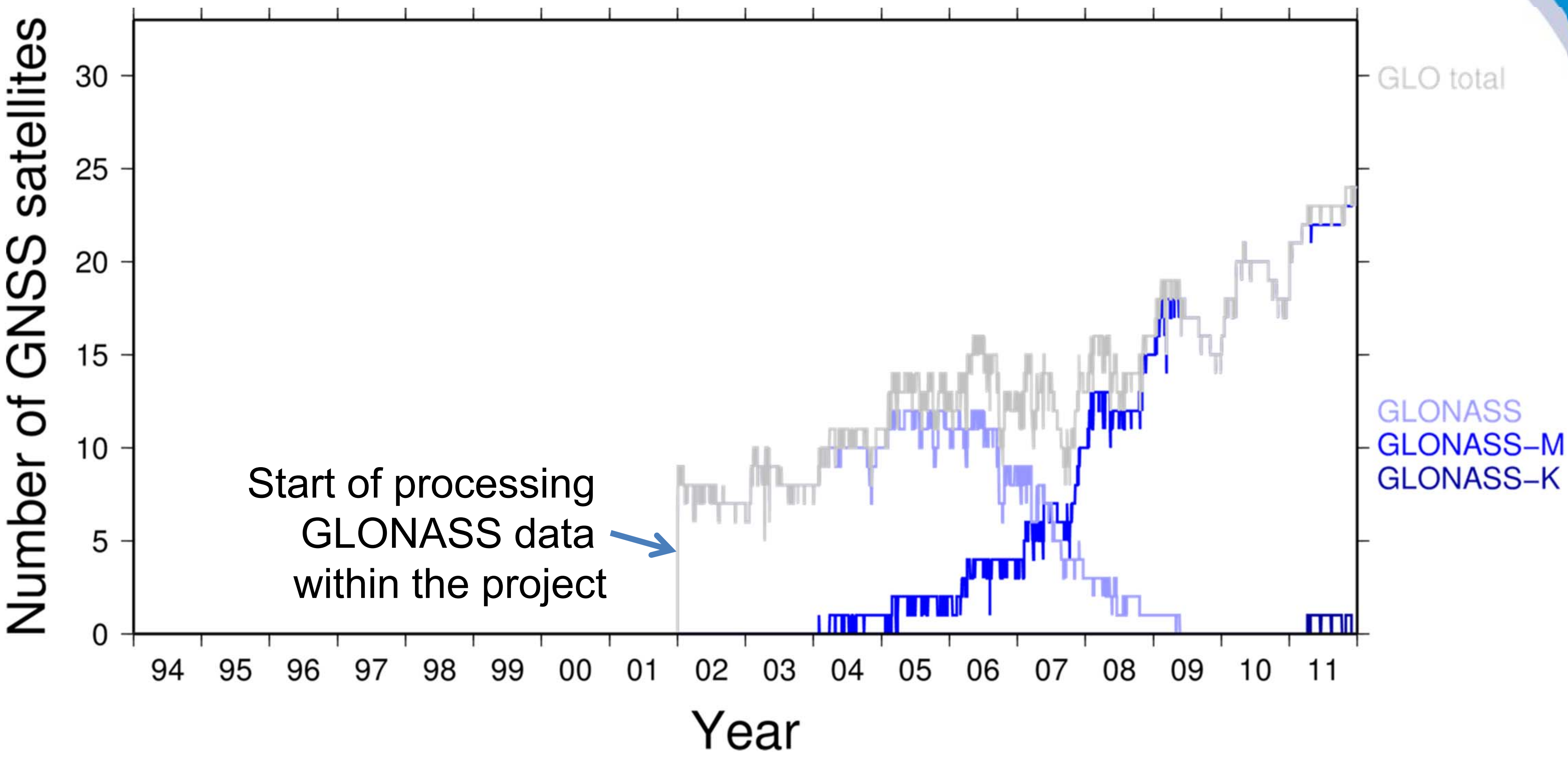
Statistics from Fritzsche et al. (2012)

Number of active GPS satellites



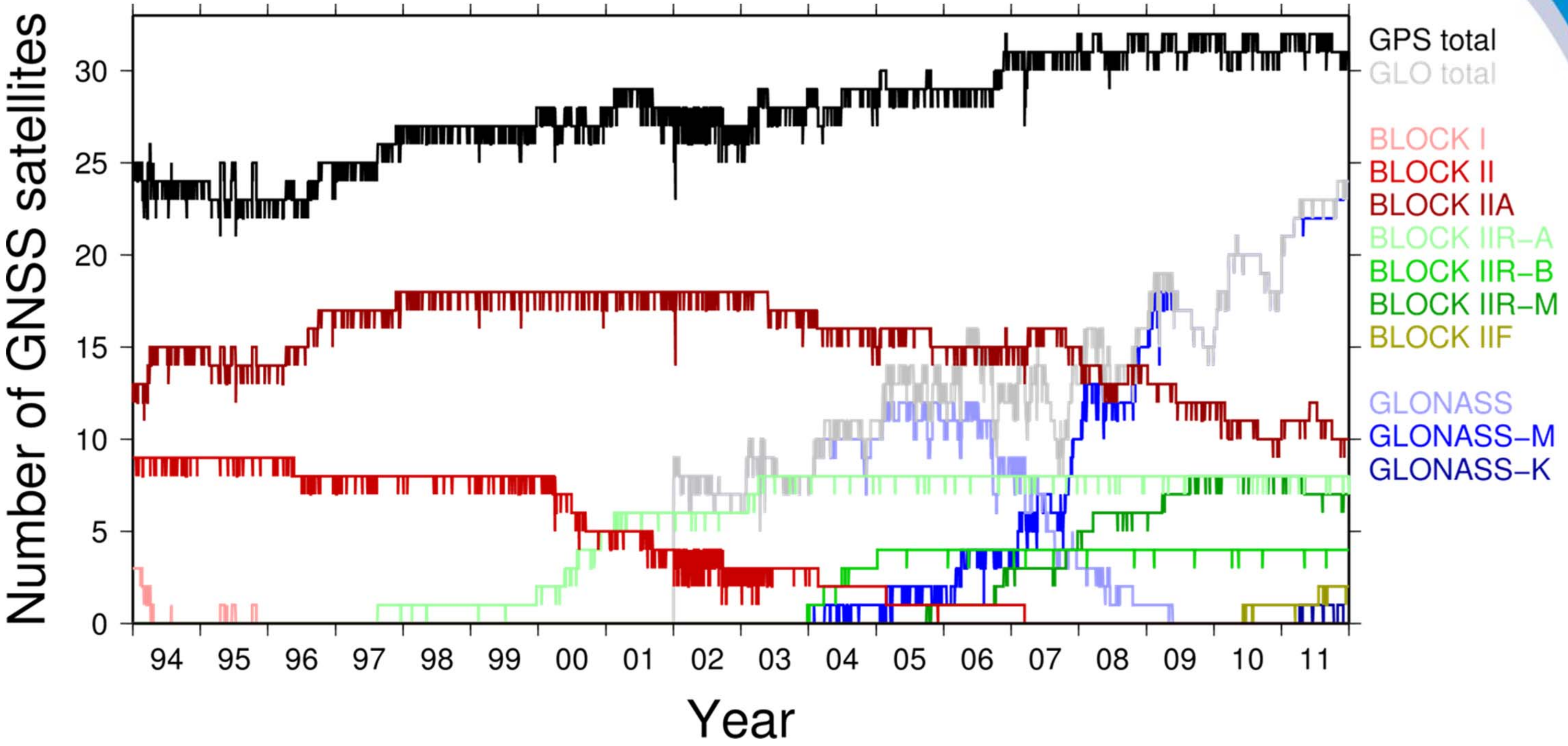
Statistics from Fritzsche et al. (2012)

Number of active GLONASS satellites



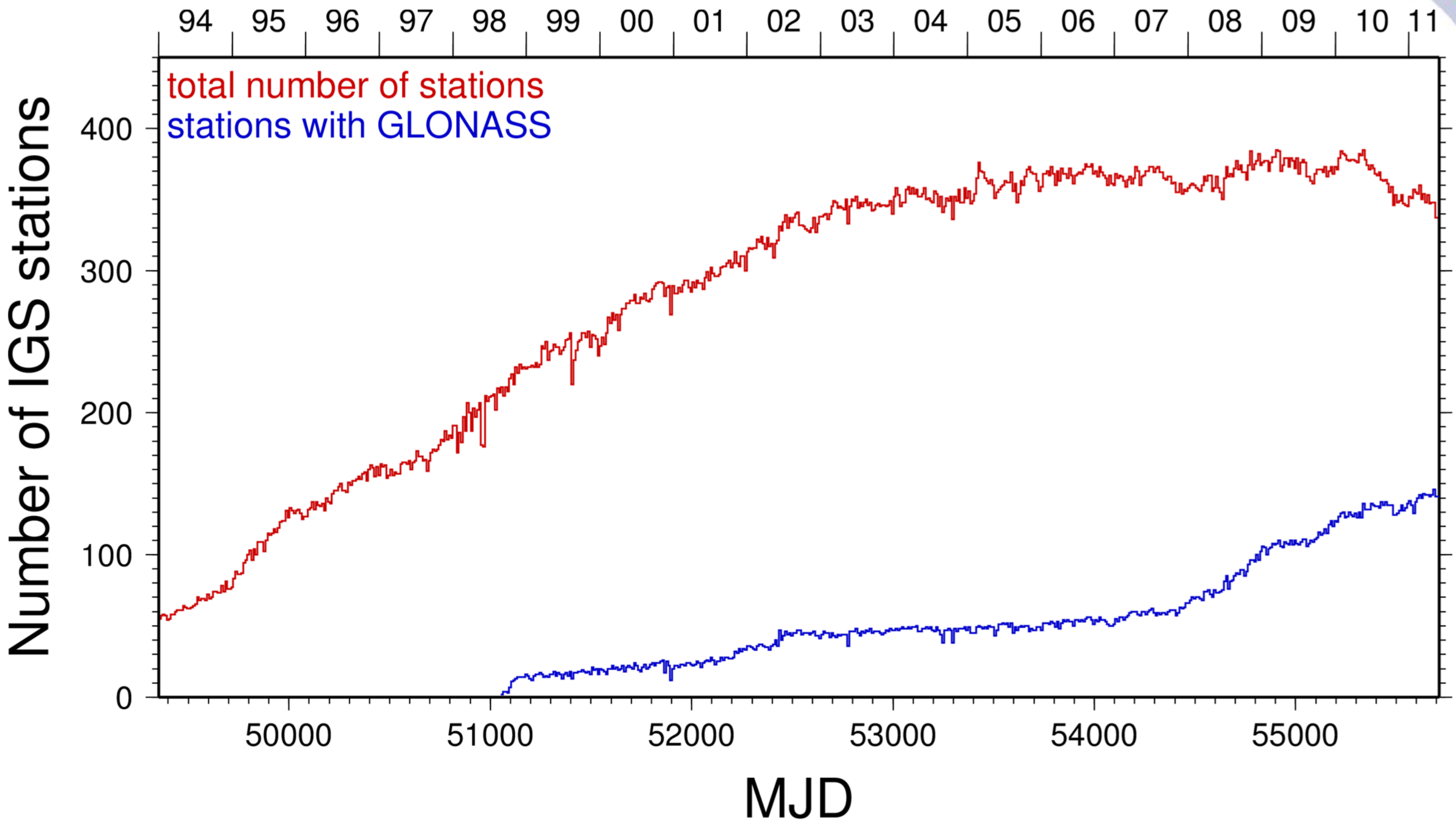
Statistics from Fritzsche et al. (2012)

Number of active GNSS satellites



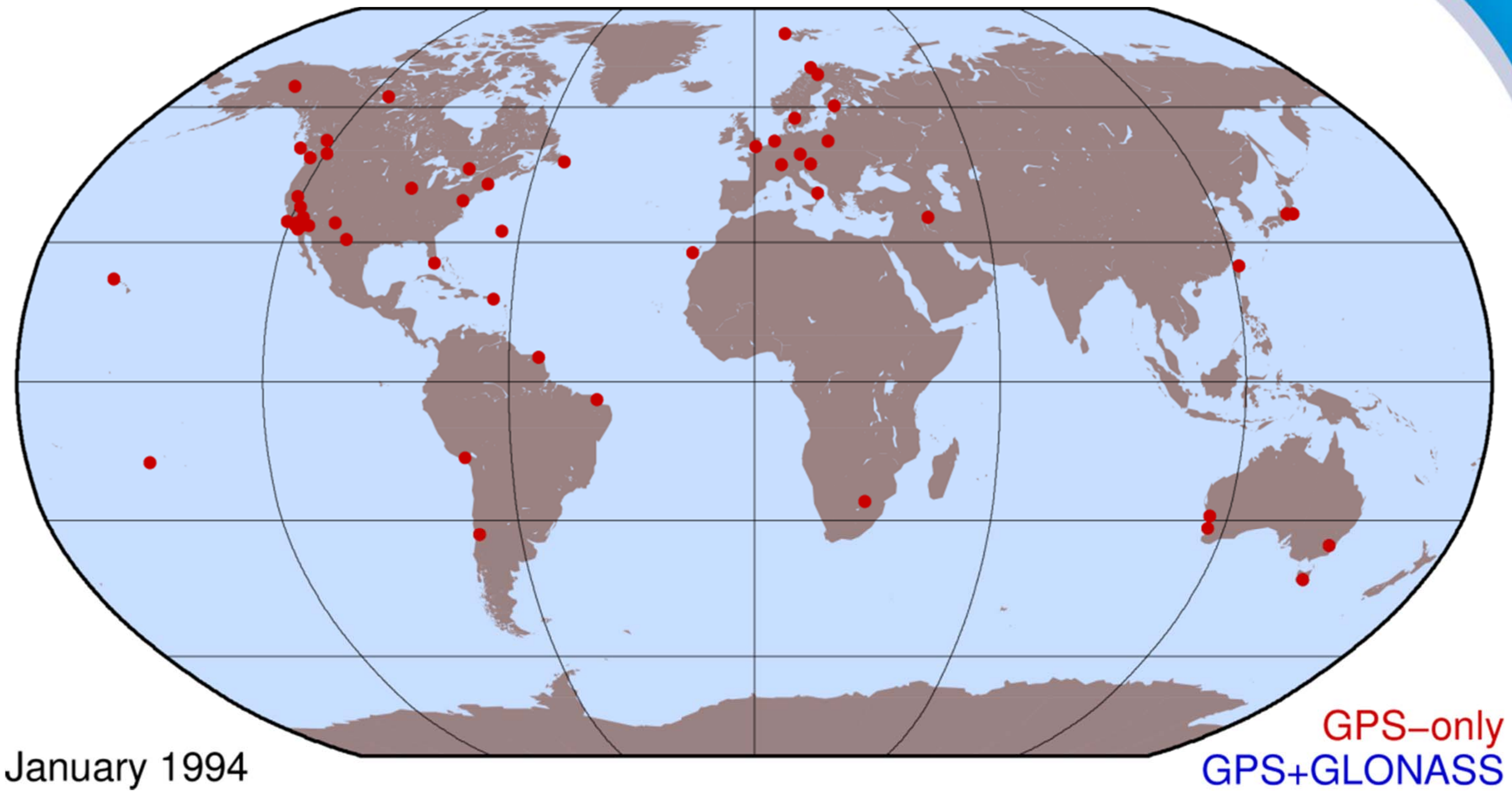
Statistics from Fritzsche et al. (2012)

Number of active IGS tracking stations



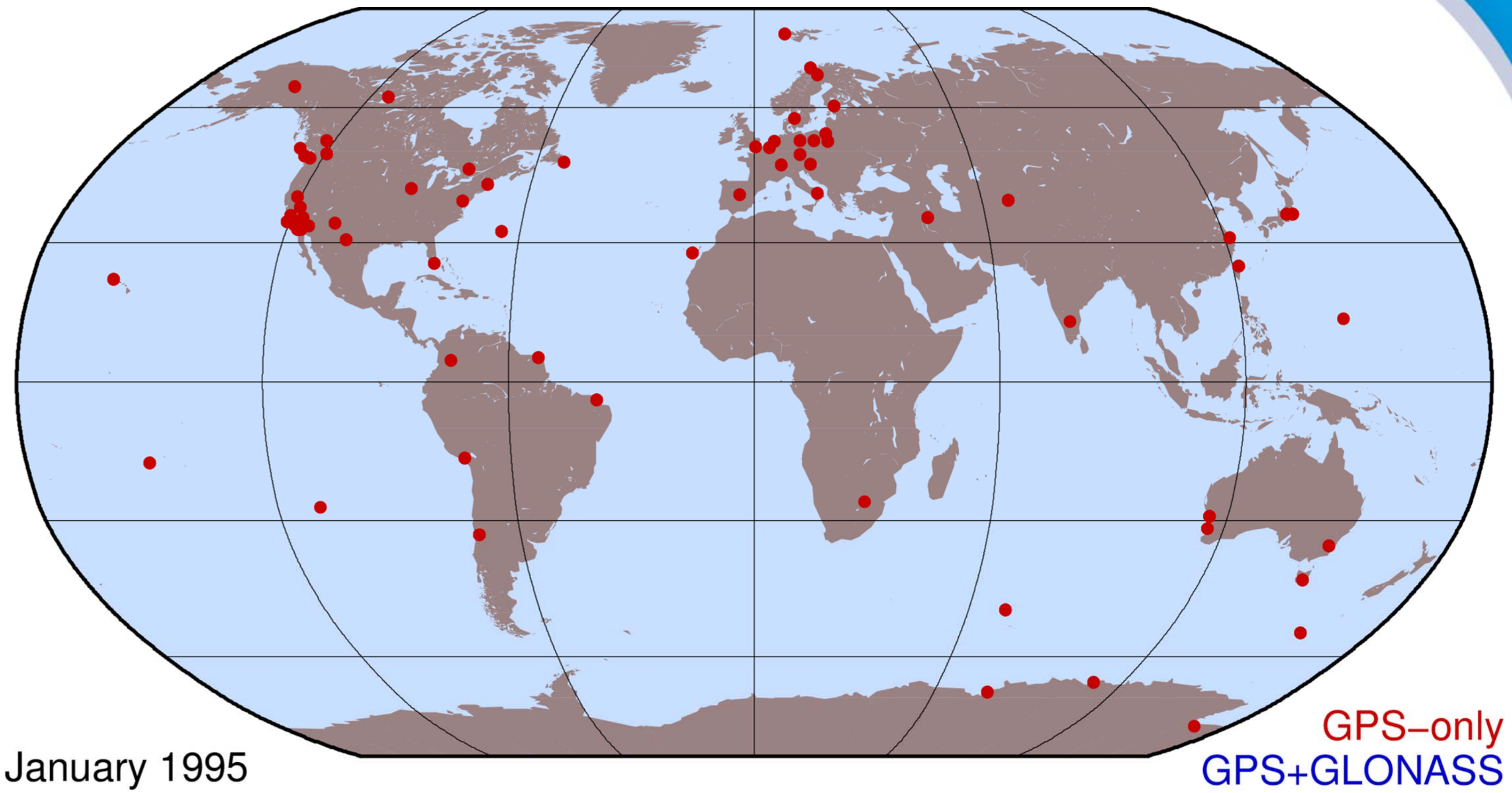
Statistics from May 2011

Distribution of active IGS tracking stations



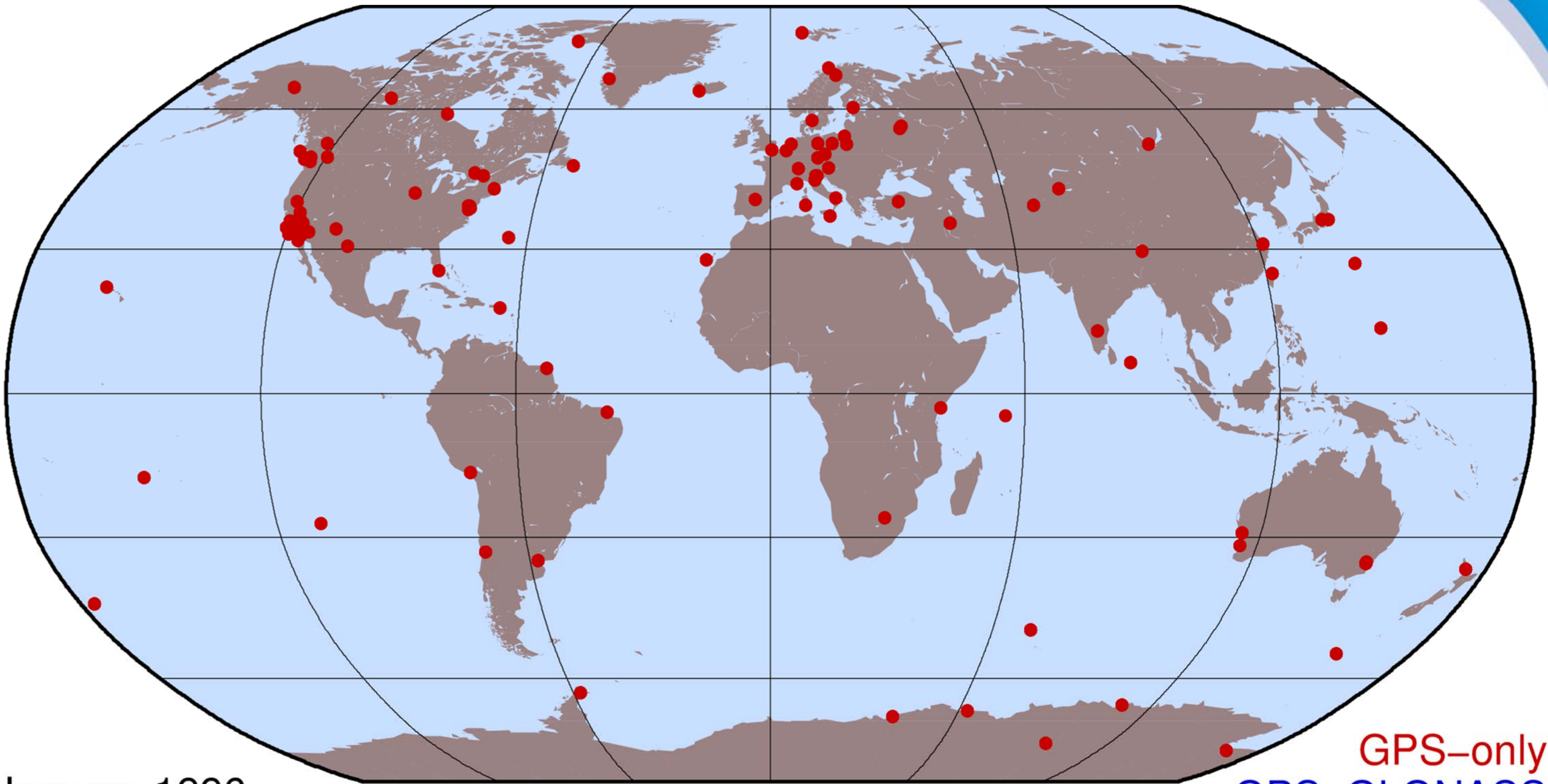
Statistics from May 2011

Distribution of active IGS tracking stations



Statistics from May 2011

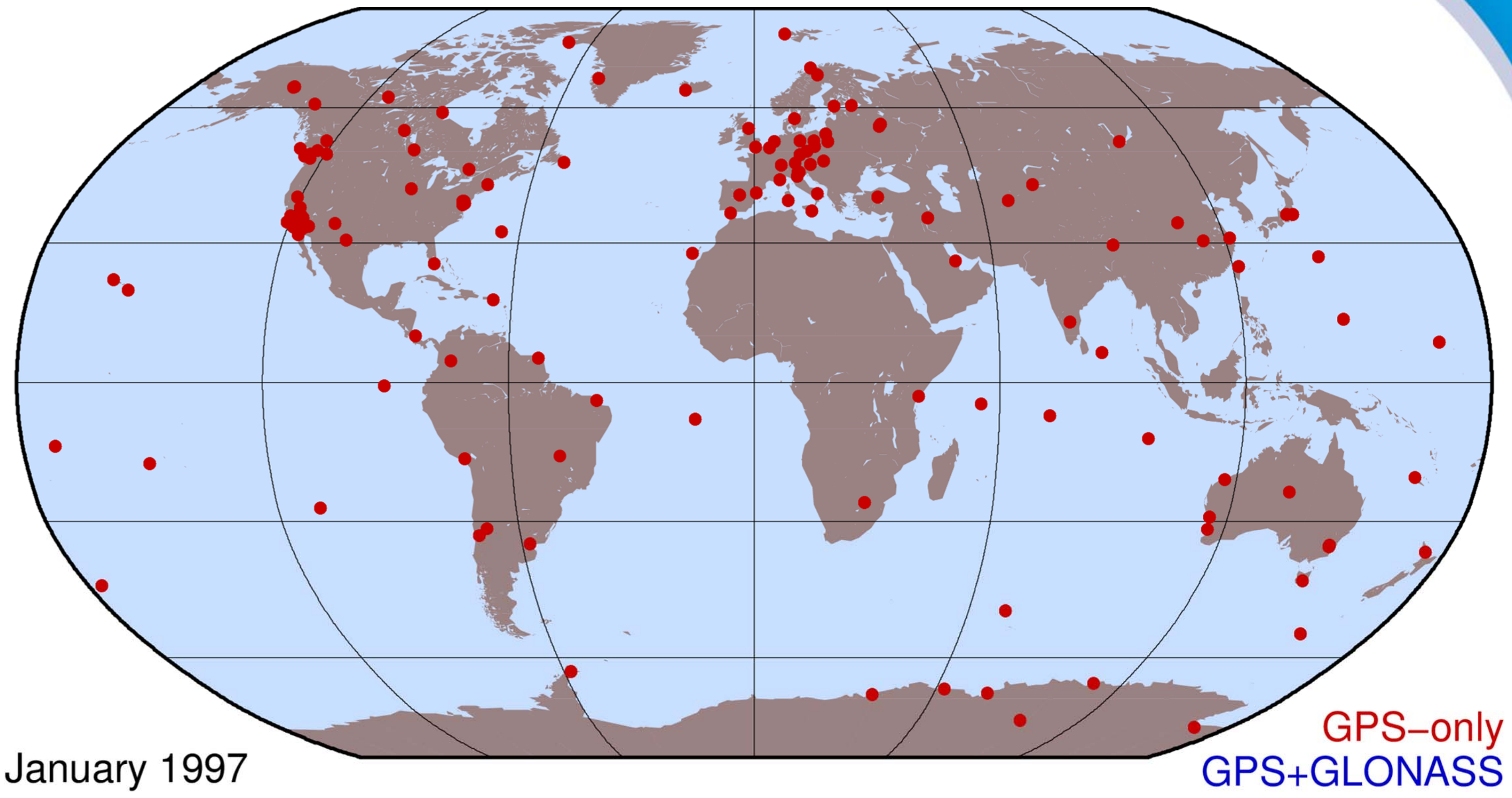
Distribution of active IGS tracking stations



January 1996

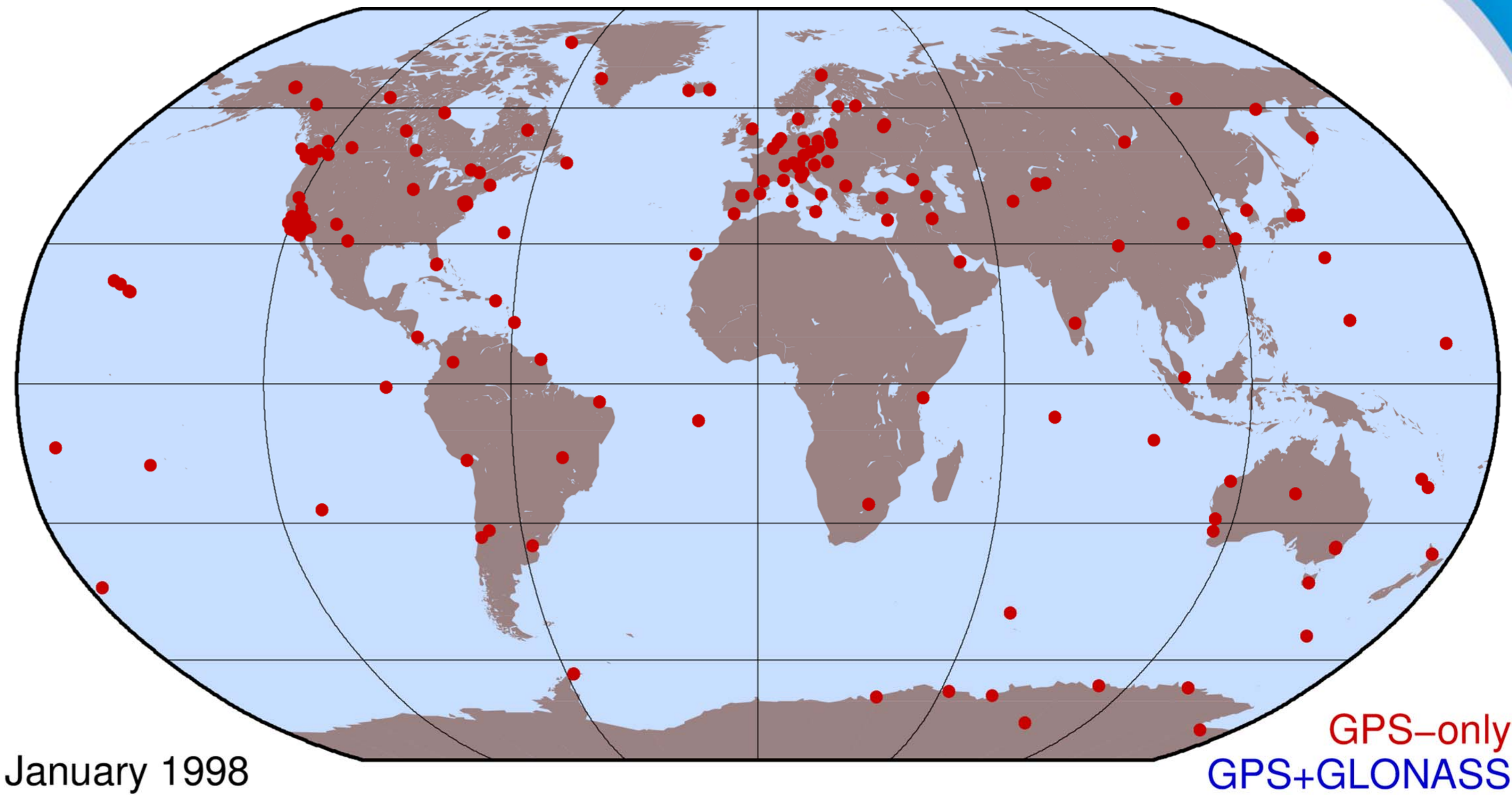
Statistics from May 2011

Distribution of active IGS tracking stations



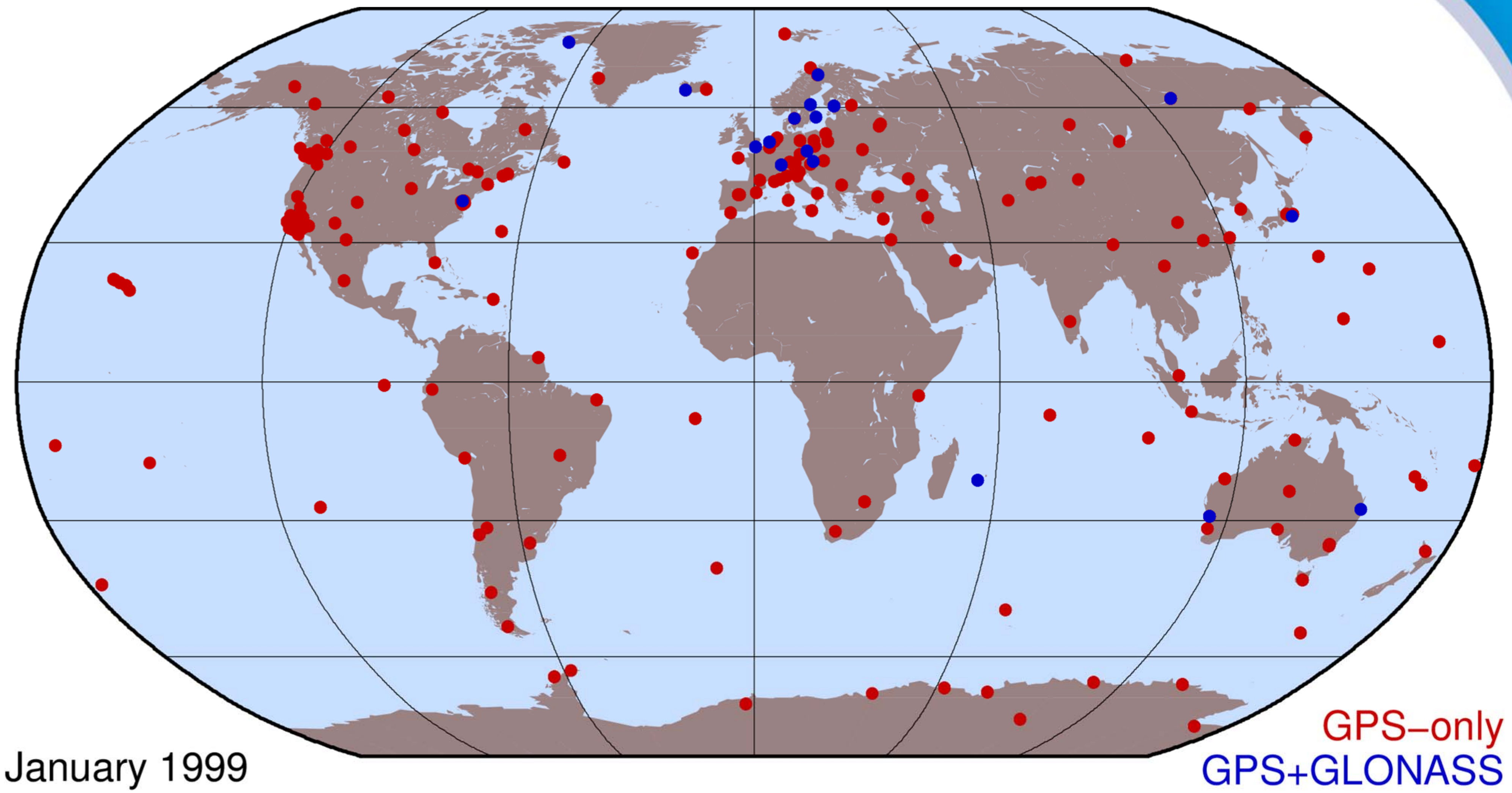
Statistics from May 2011

Distribution of active IGS tracking stations



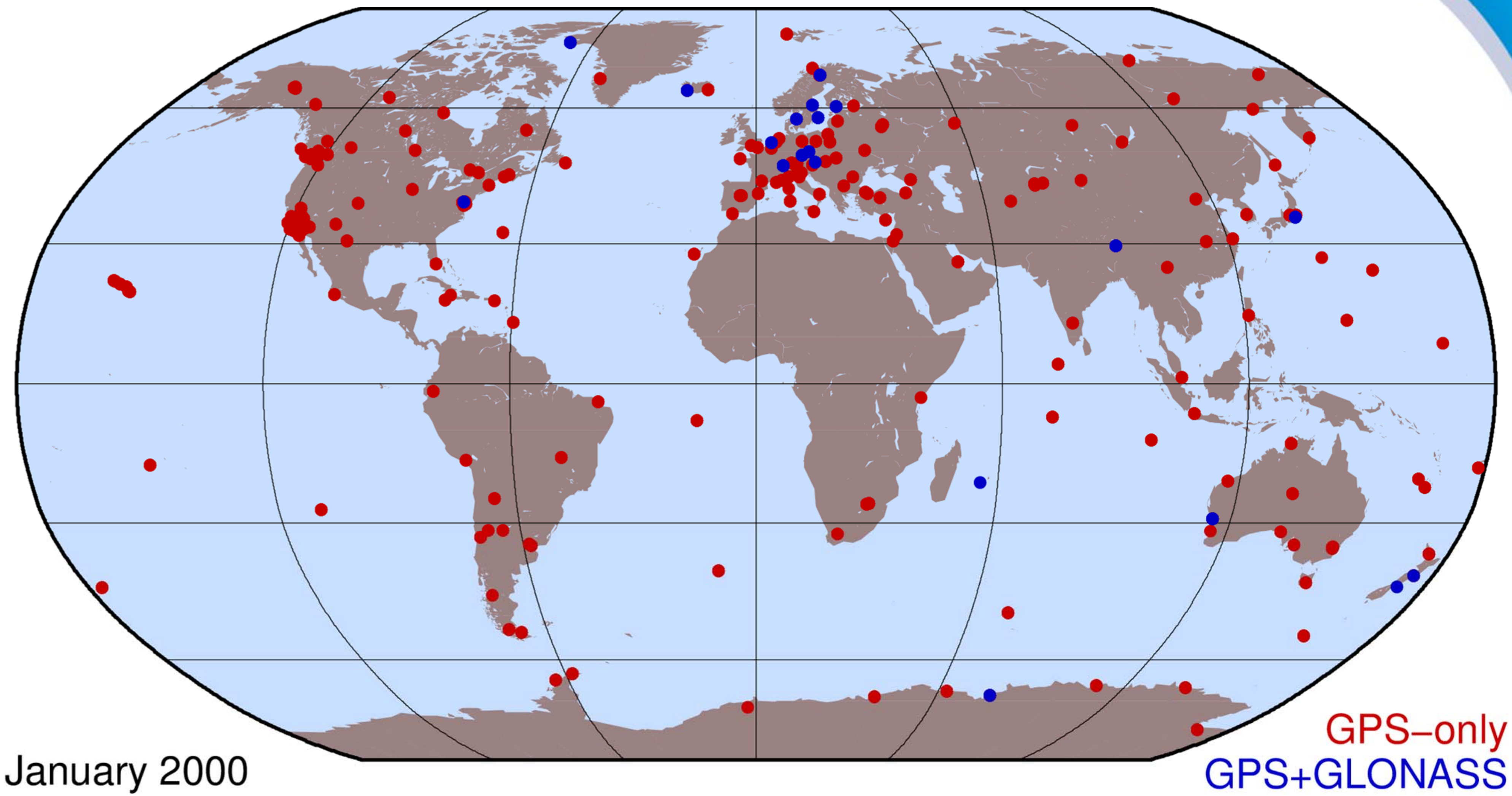
Statistics from May 2011

Distribution of active IGS tracking stations



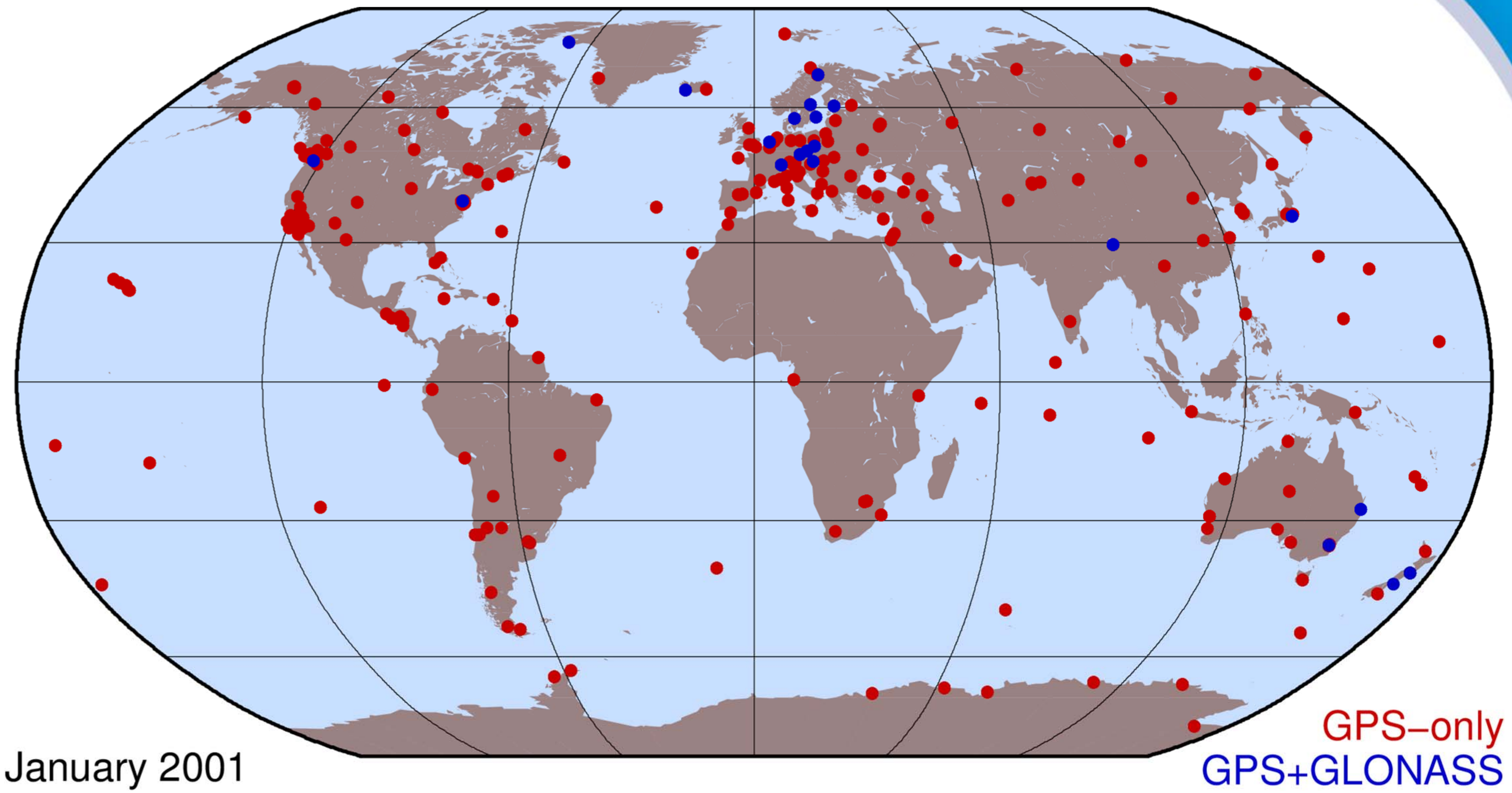
Statistics from May 2011

Distribution of active IGS tracking stations



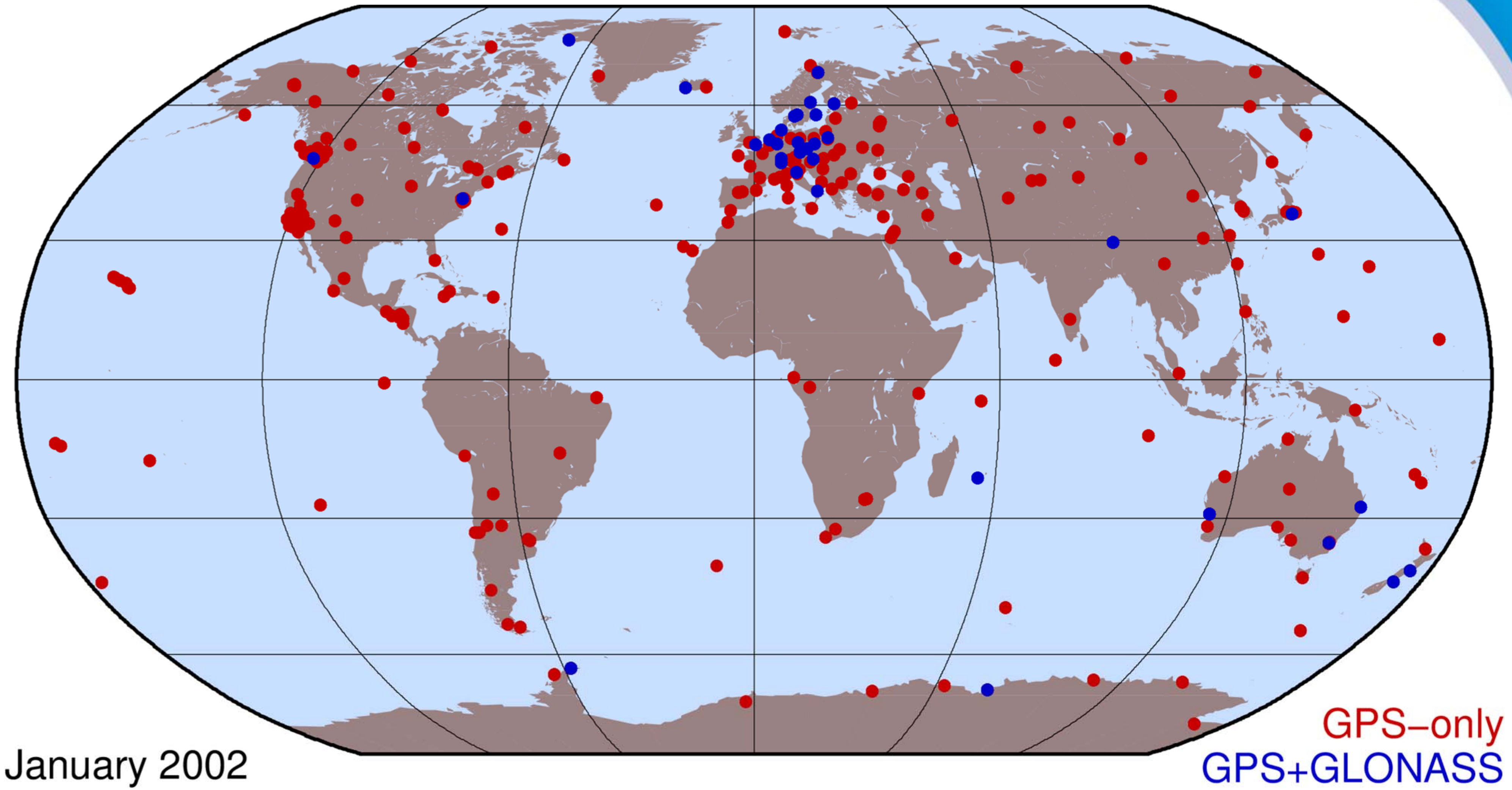
Statistics from May 2011

Distribution of active IGS tracking stations



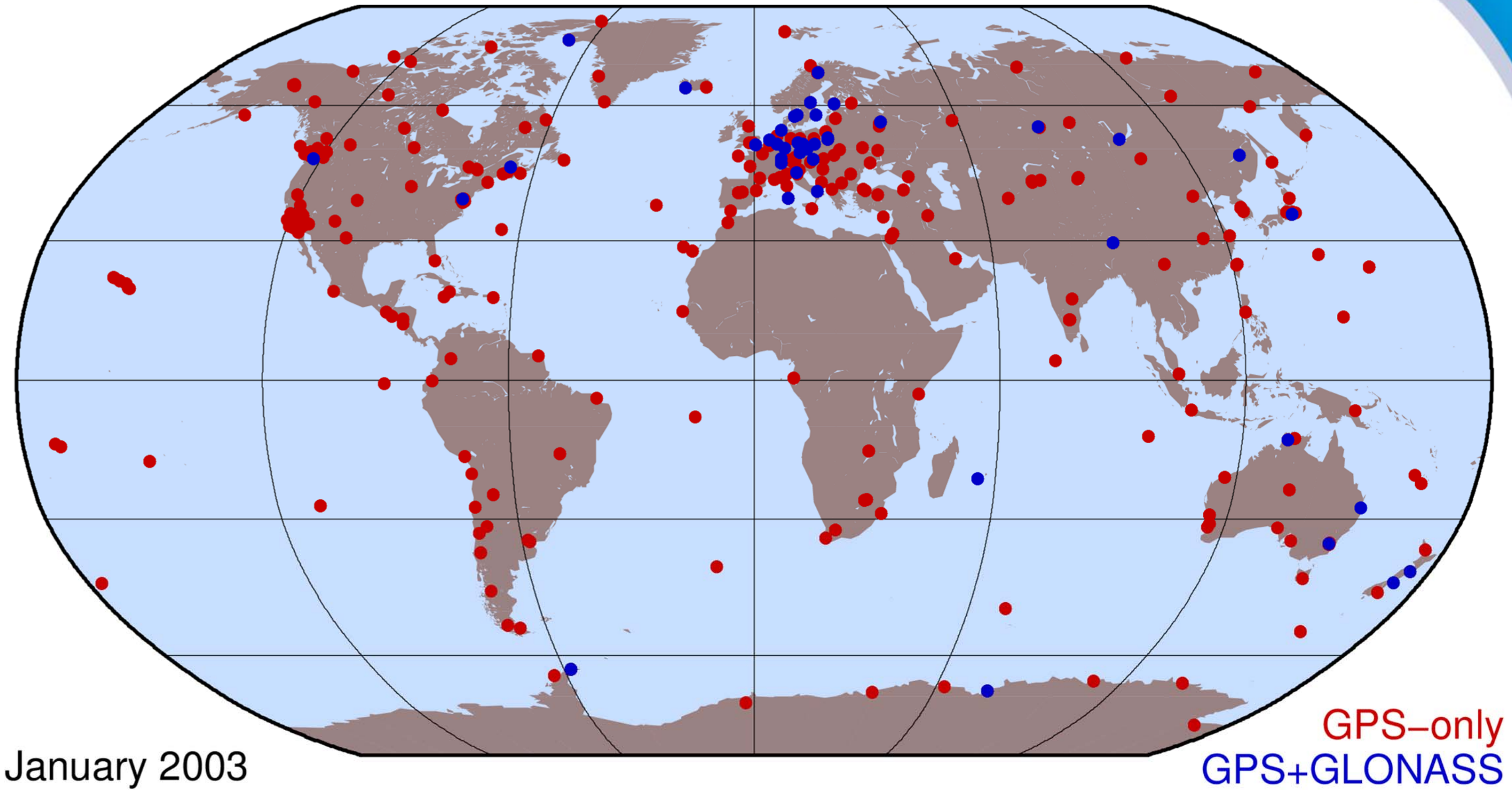
Statistics from May 2011

Distribution of active IGS tracking stations



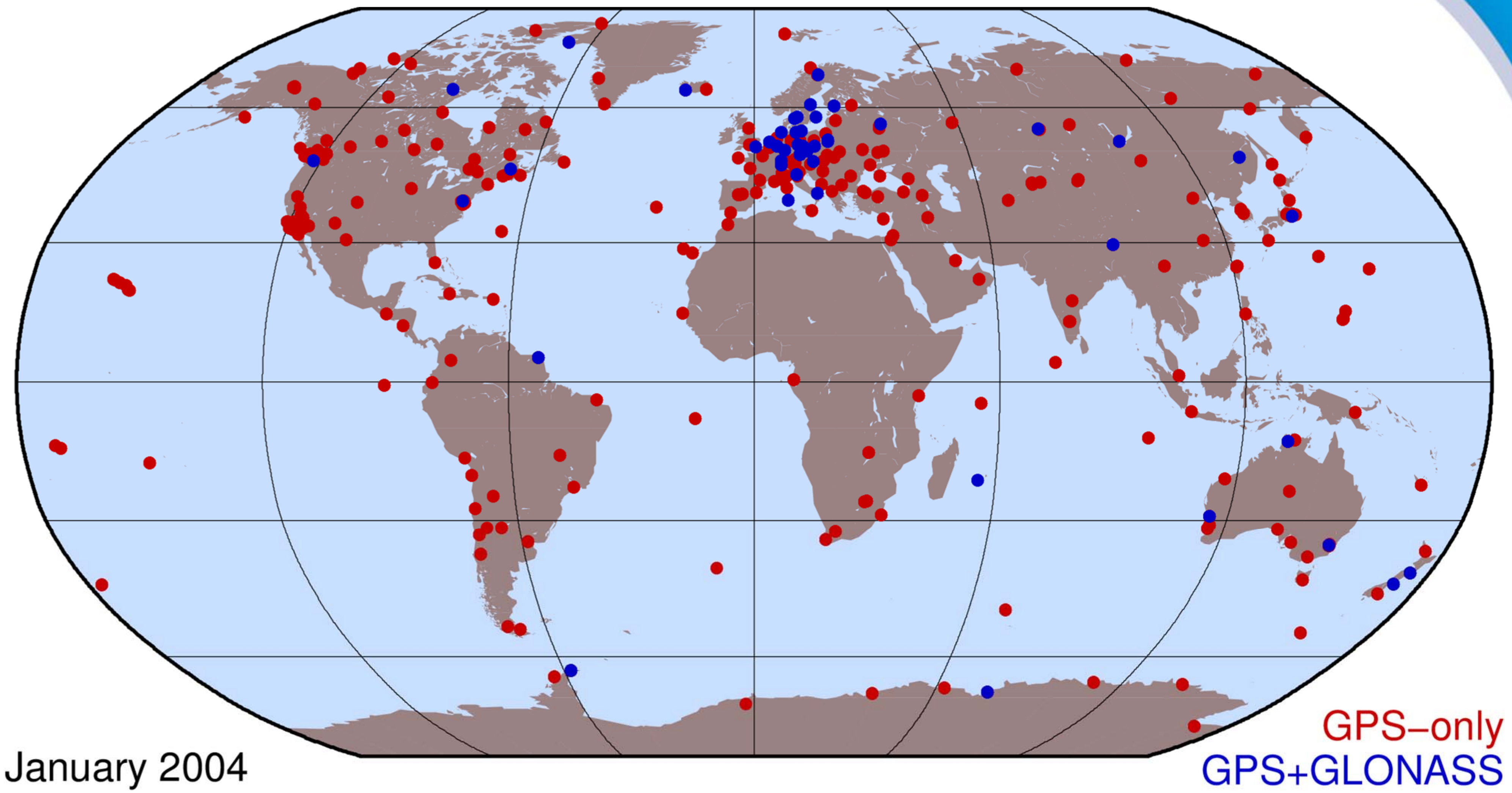
Statistics from May 2011

Distribution of active IGS tracking stations



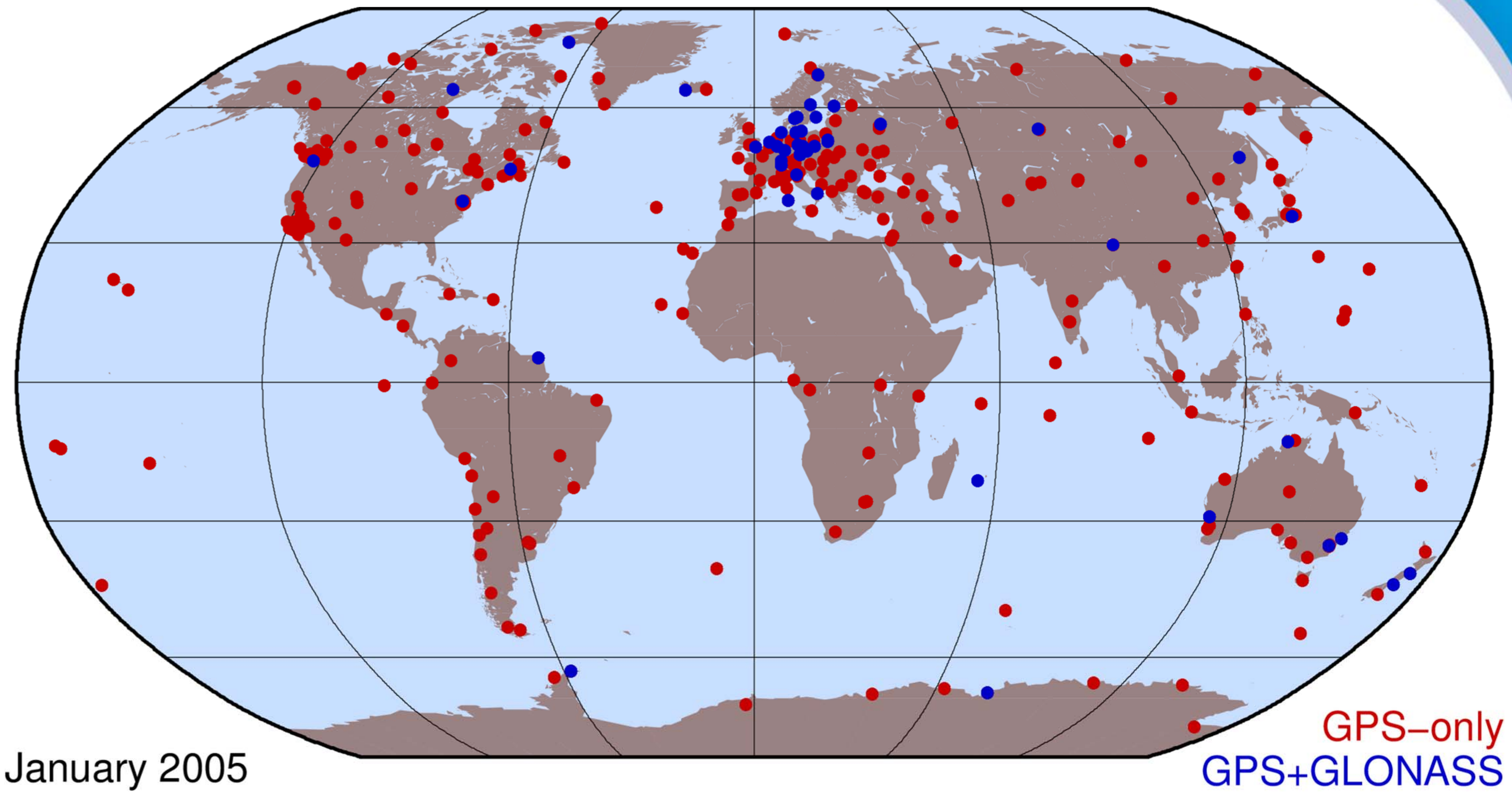
Statistics from May 2011

Distribution of active IGS tracking stations



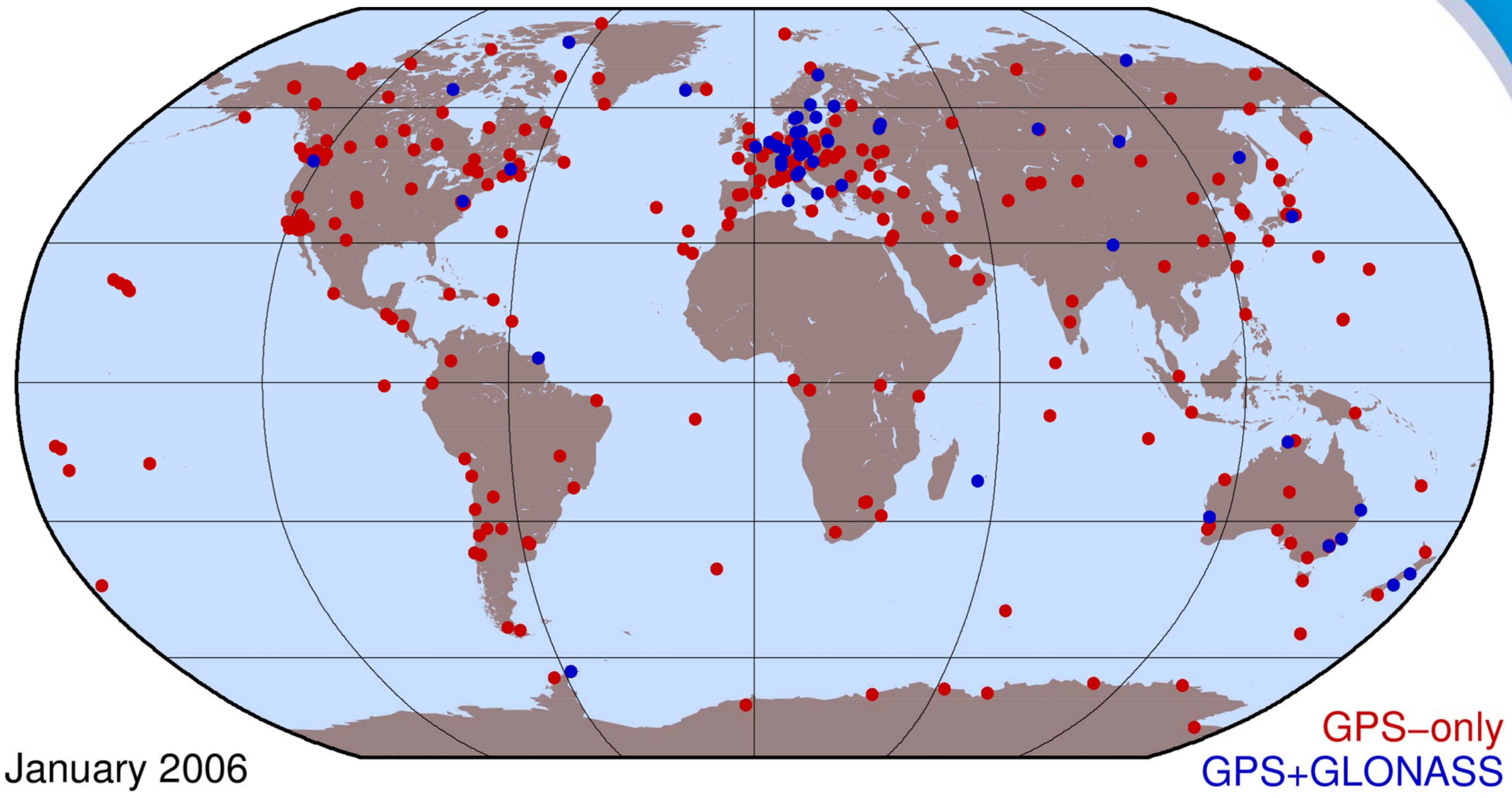
Statistics from May 2011

Distribution of active IGS tracking stations



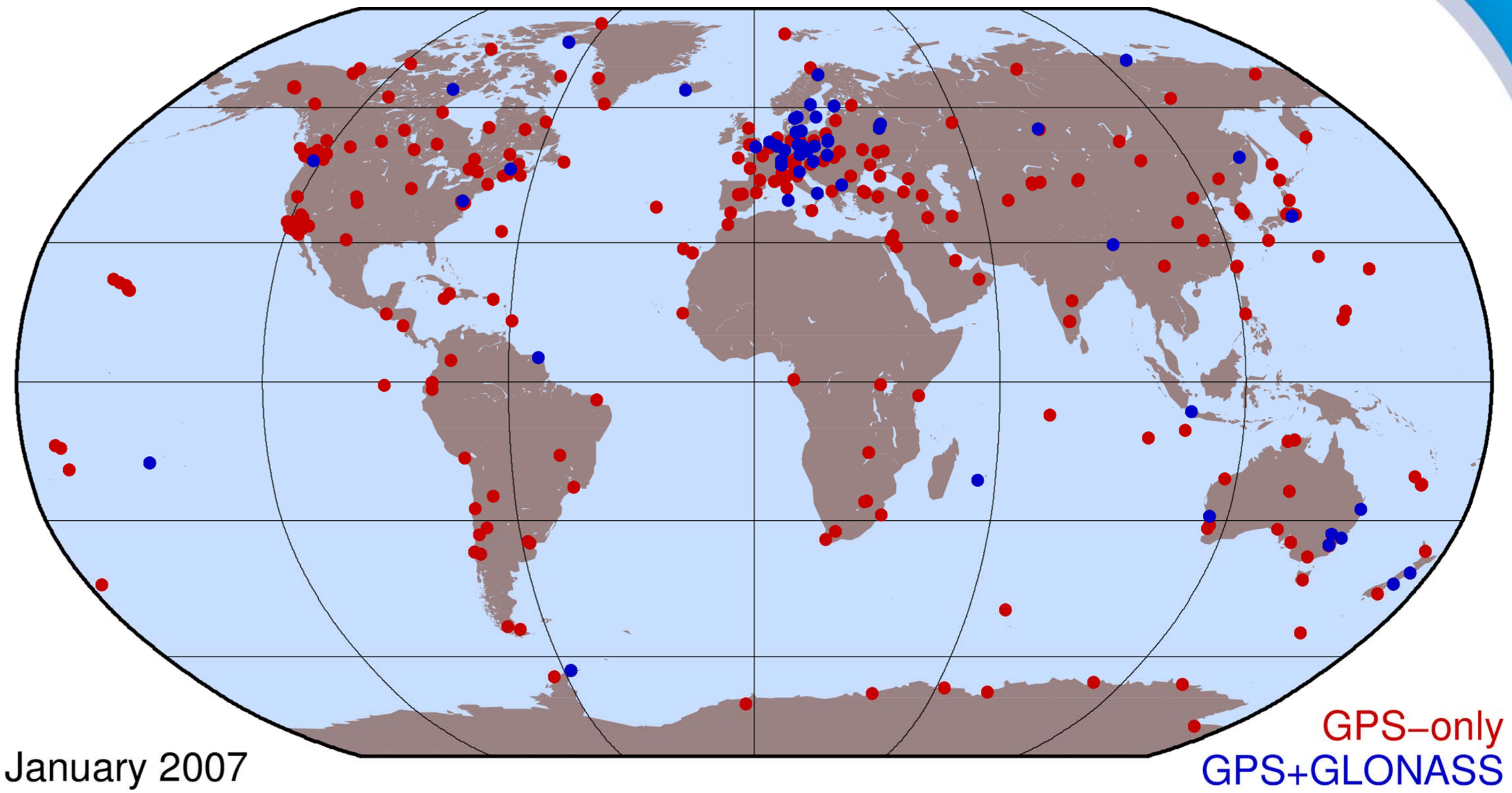
Statistics from May 2011

Distribution of active IGS tracking stations



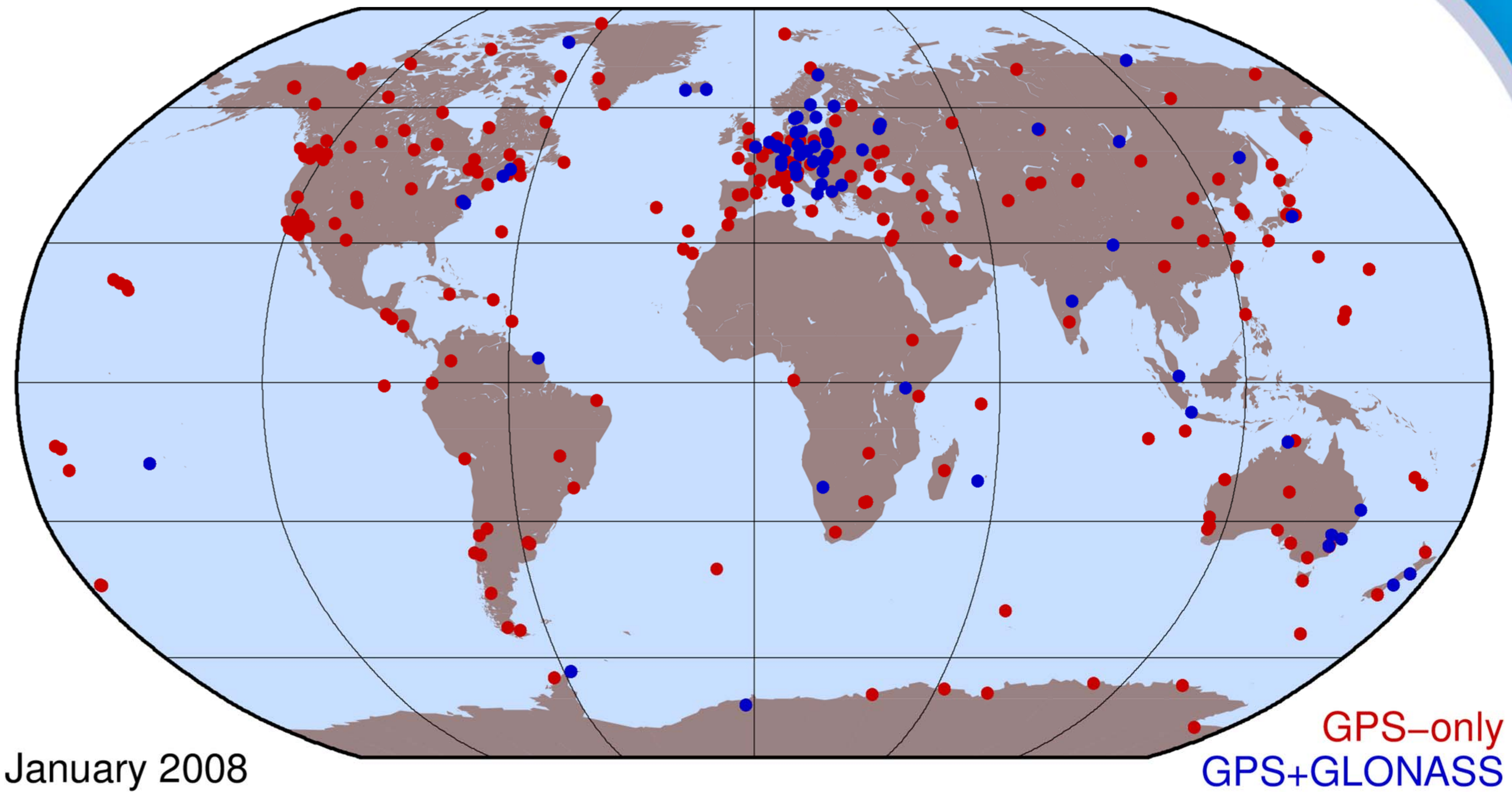
Statistics from May 2011

Distribution of active IGS tracking stations



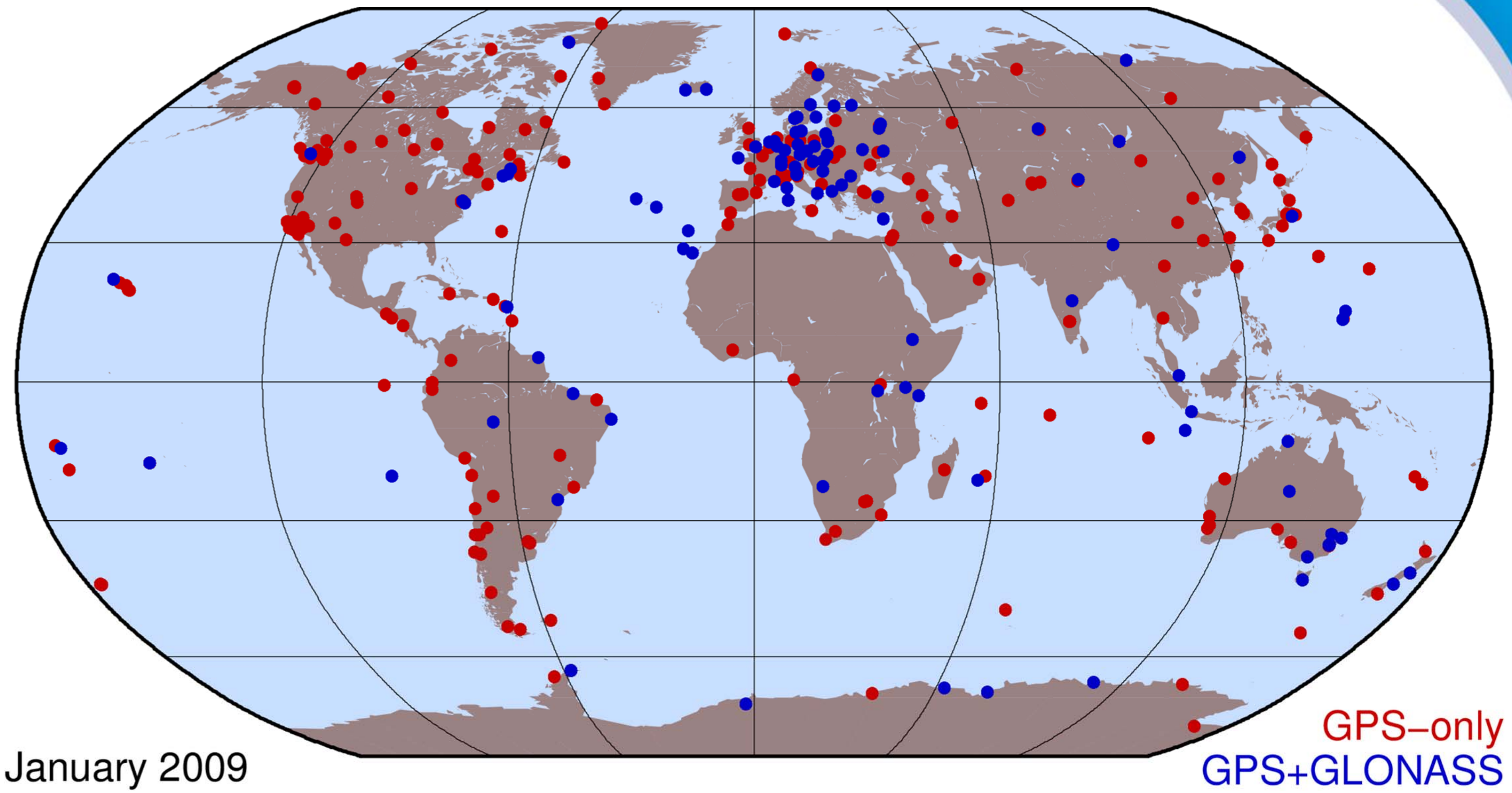
Statistics from May 2011

Distribution of active IGS tracking stations



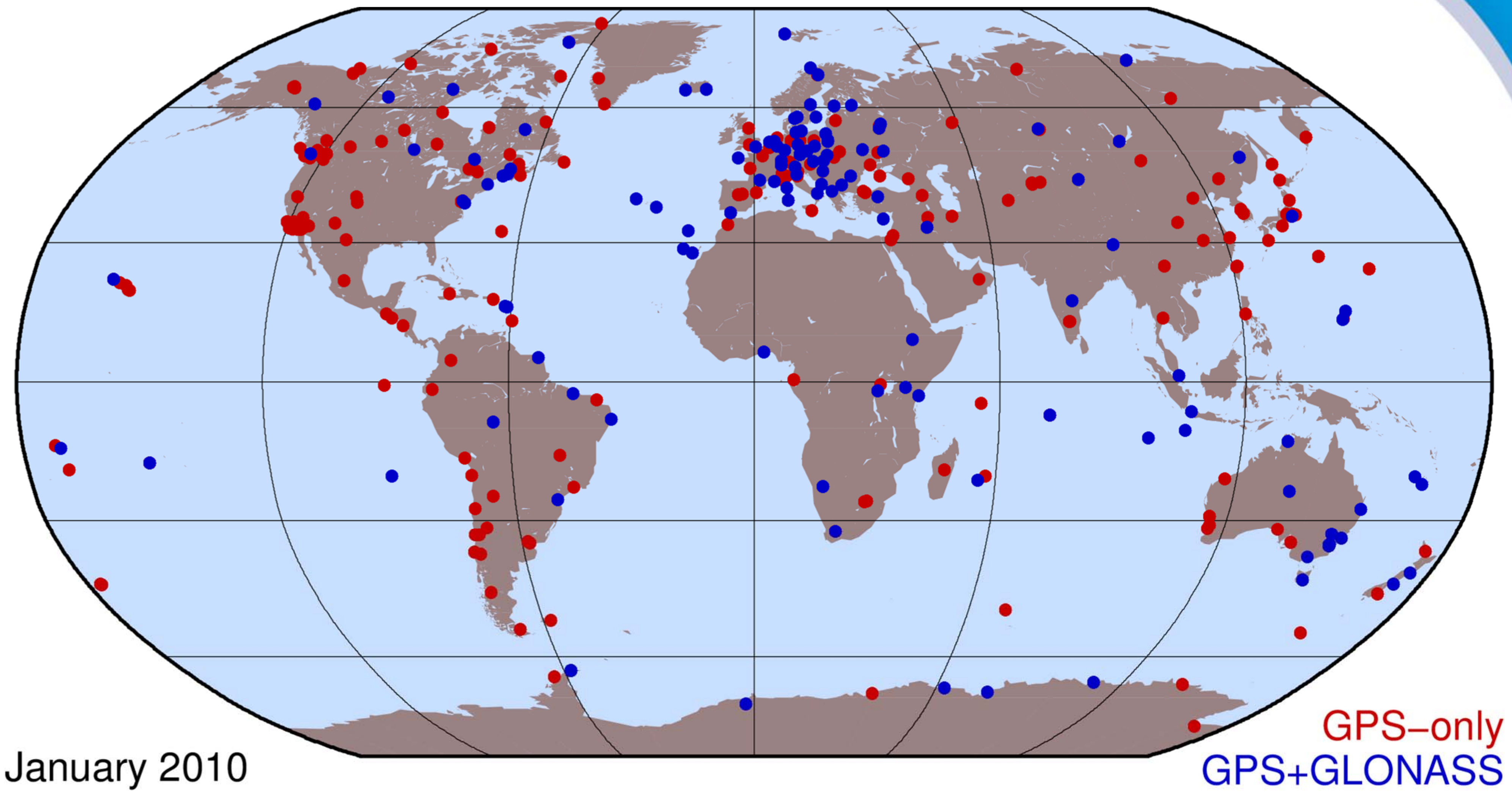
Statistics from May 2011

Distribution of active IGS tracking stations



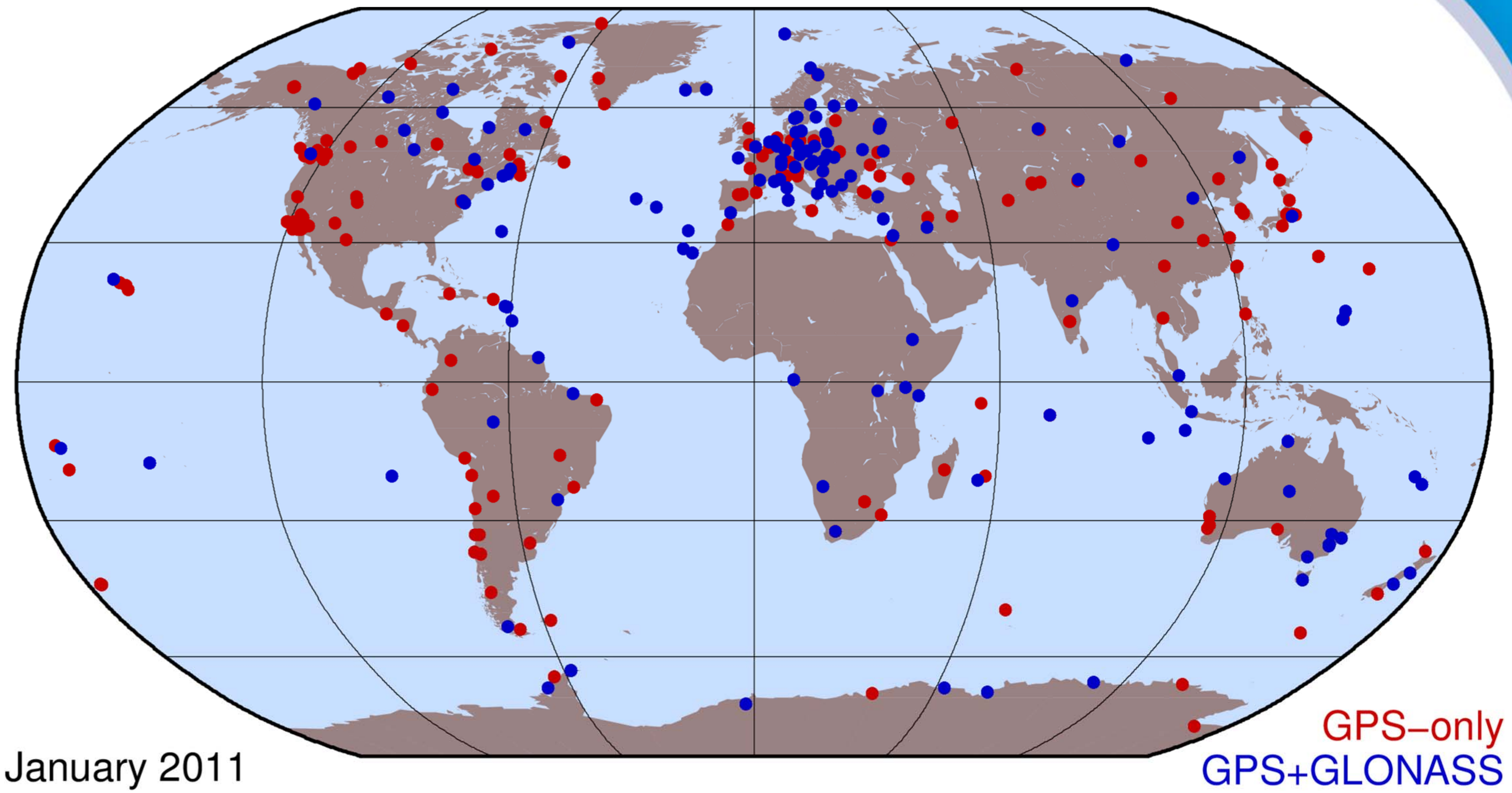
Statistics from May 2011

Distribution of active IGS tracking stations



Statistics from May 2011

Distribution of active IGS tracking stations



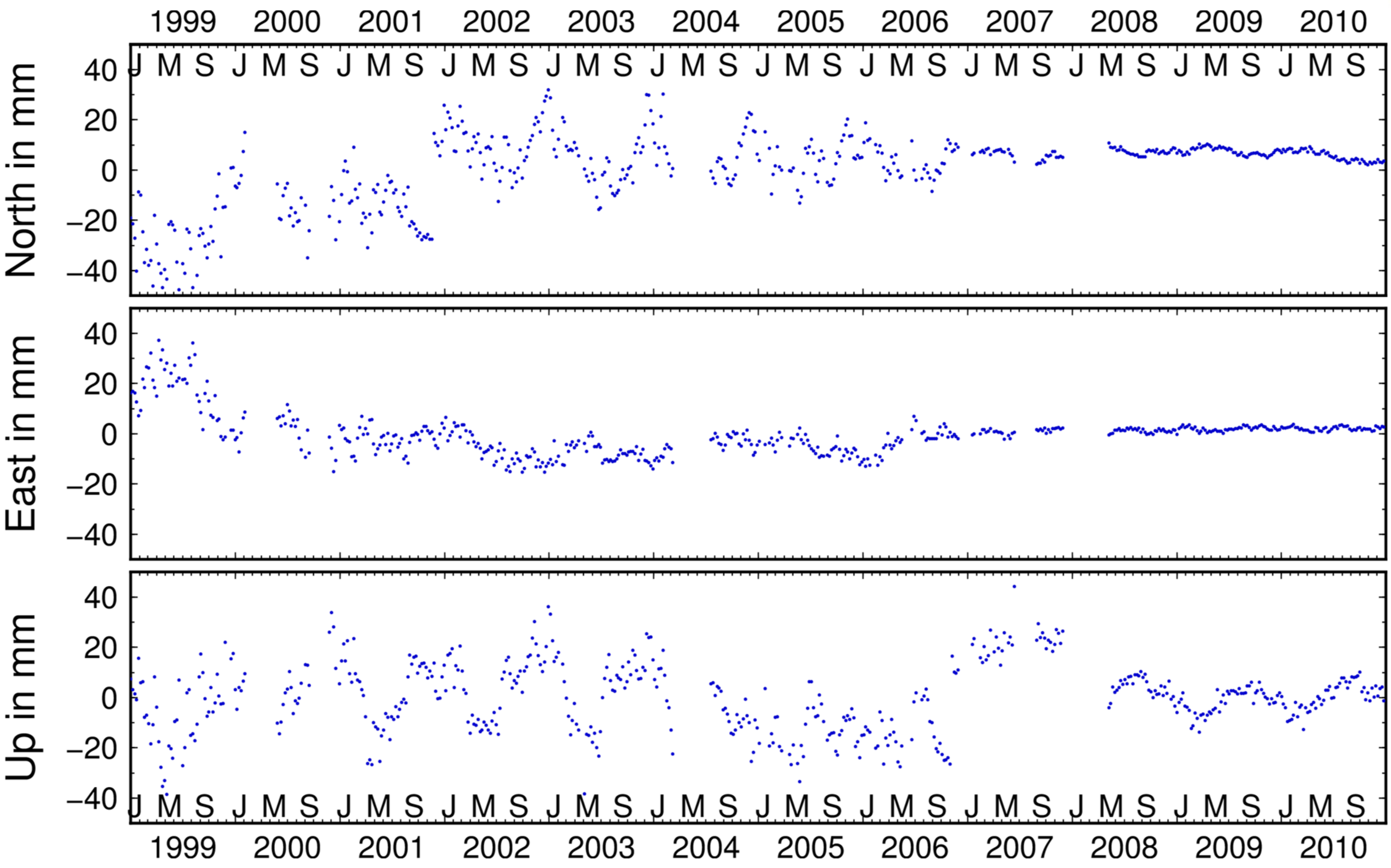
Statistics from May 2011

IGS tracking network

- The tracking network of the IGS consists of 370 (out of 440)[1] active stations contributed by many organizations on a voluntary basis.
- The continuous densification of the IGS network allowed an impressive improvement of the quality of the IGS orbits and other products.
- Currently the IGS network is in a transition phase from a GPS-only to a combined GPS/GLONASS(/Galileo/…) tracking network.
  In this context two contradictory requirements need to be balanced:
  - to have quickly as many new receivers/antennas in place as possible as
  - to keep an installed antenna as long as possible without any changes to support a good long-term stability for reference frame establishment
- Nevertheless, we have to notice that many of these stations primary serve other goals than been an IGS station.
  The maintenance of such a network is difficult and the data have to be used with care.

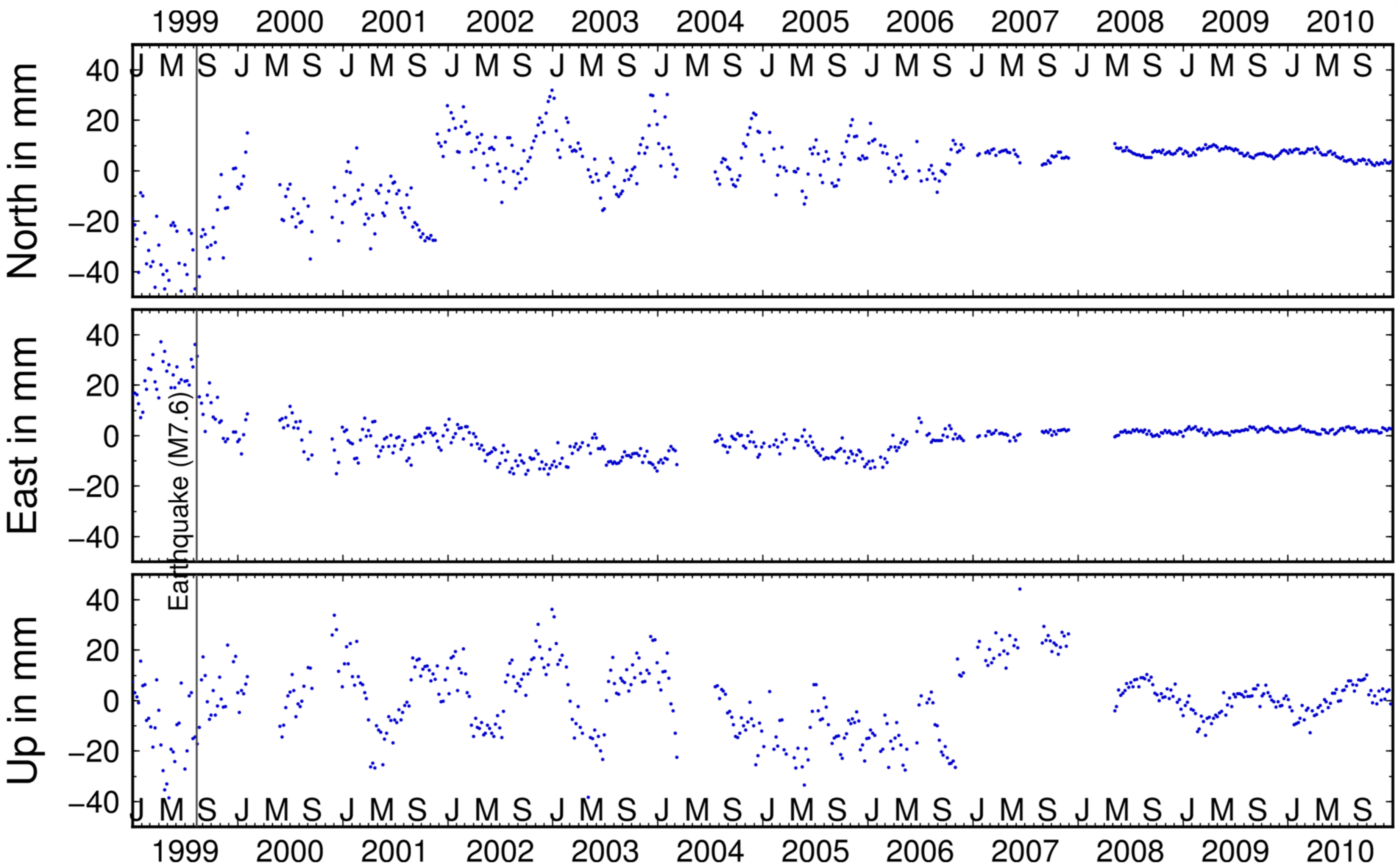
[1]Status: 27. August 2012

Coordinate time series for Ankara



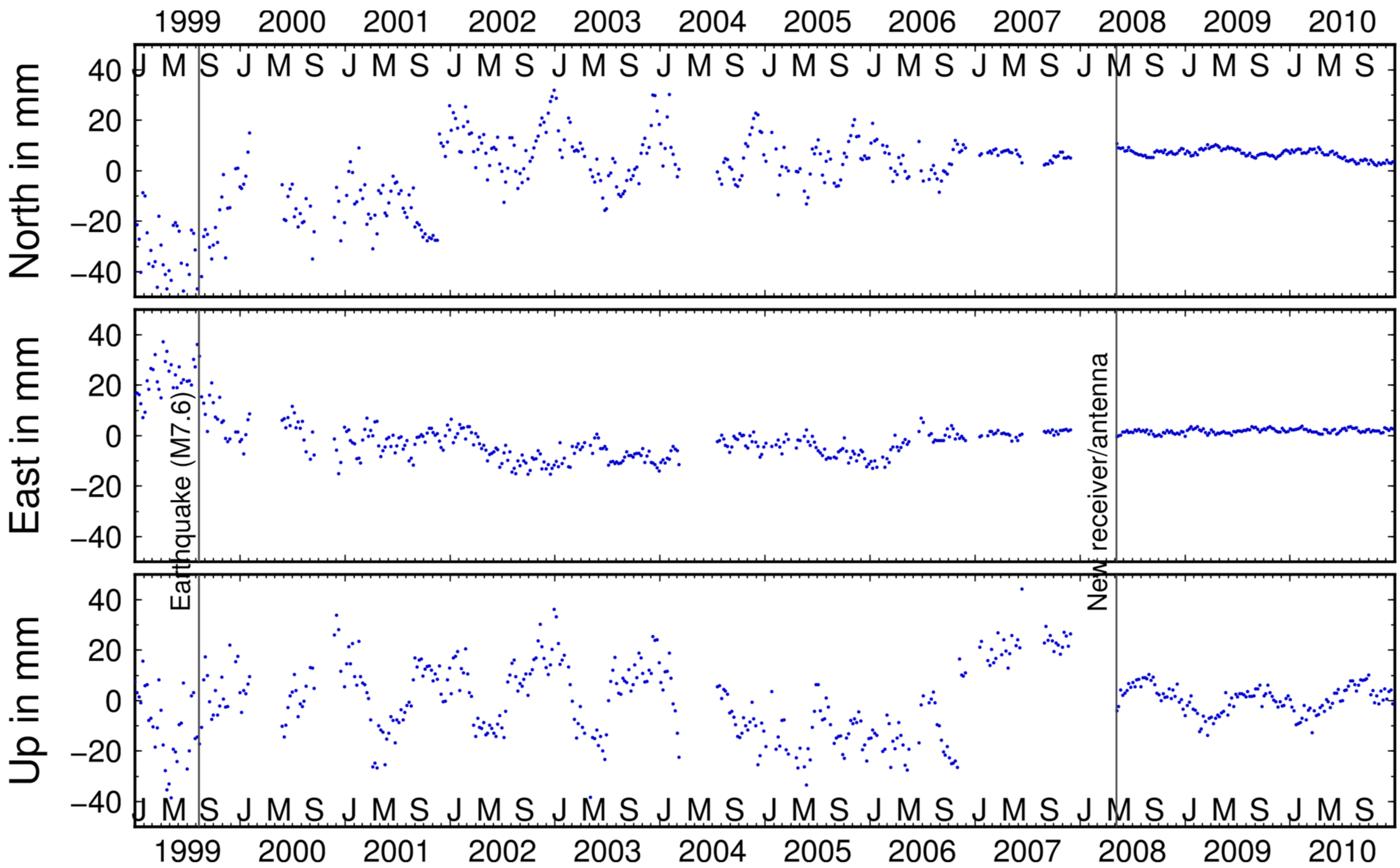
Operational series from CODE, weekly solutions

Coordinate time series for Ankara



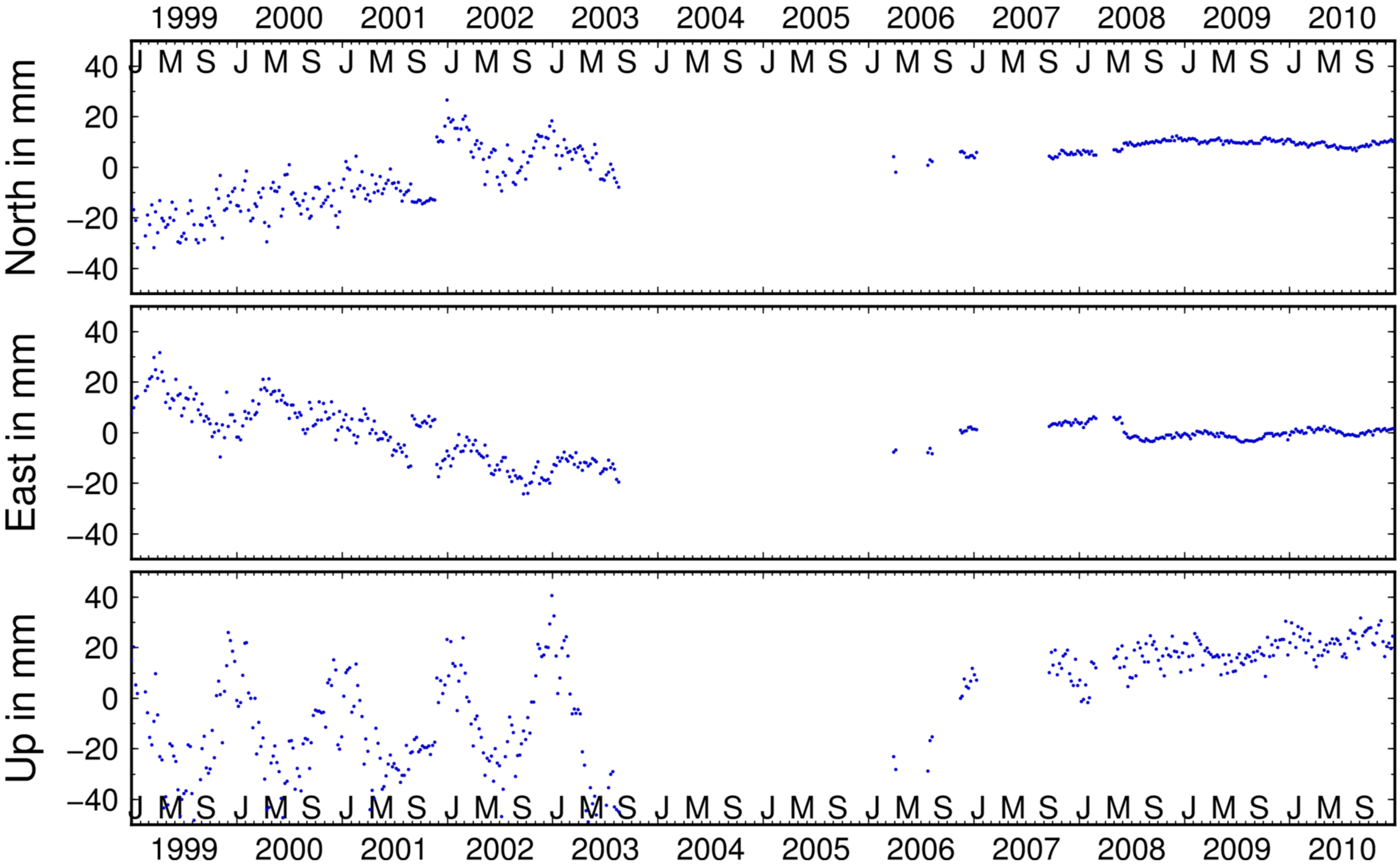
Operational series from CODE, weekly solutions

Coordinate time series for Ankara



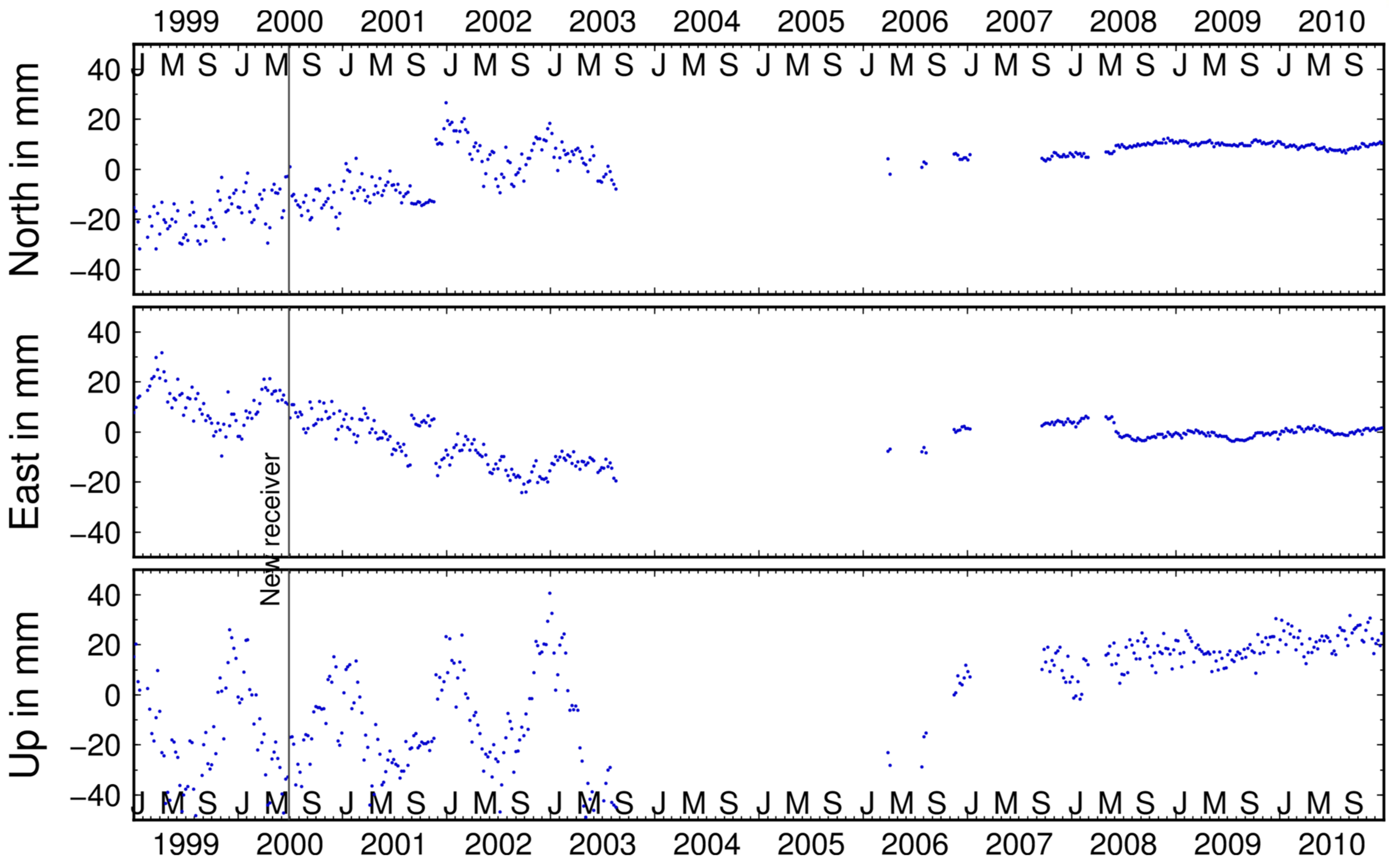
Operational series from CODE, weekly solutions

Coordinate time series for Reykjavik



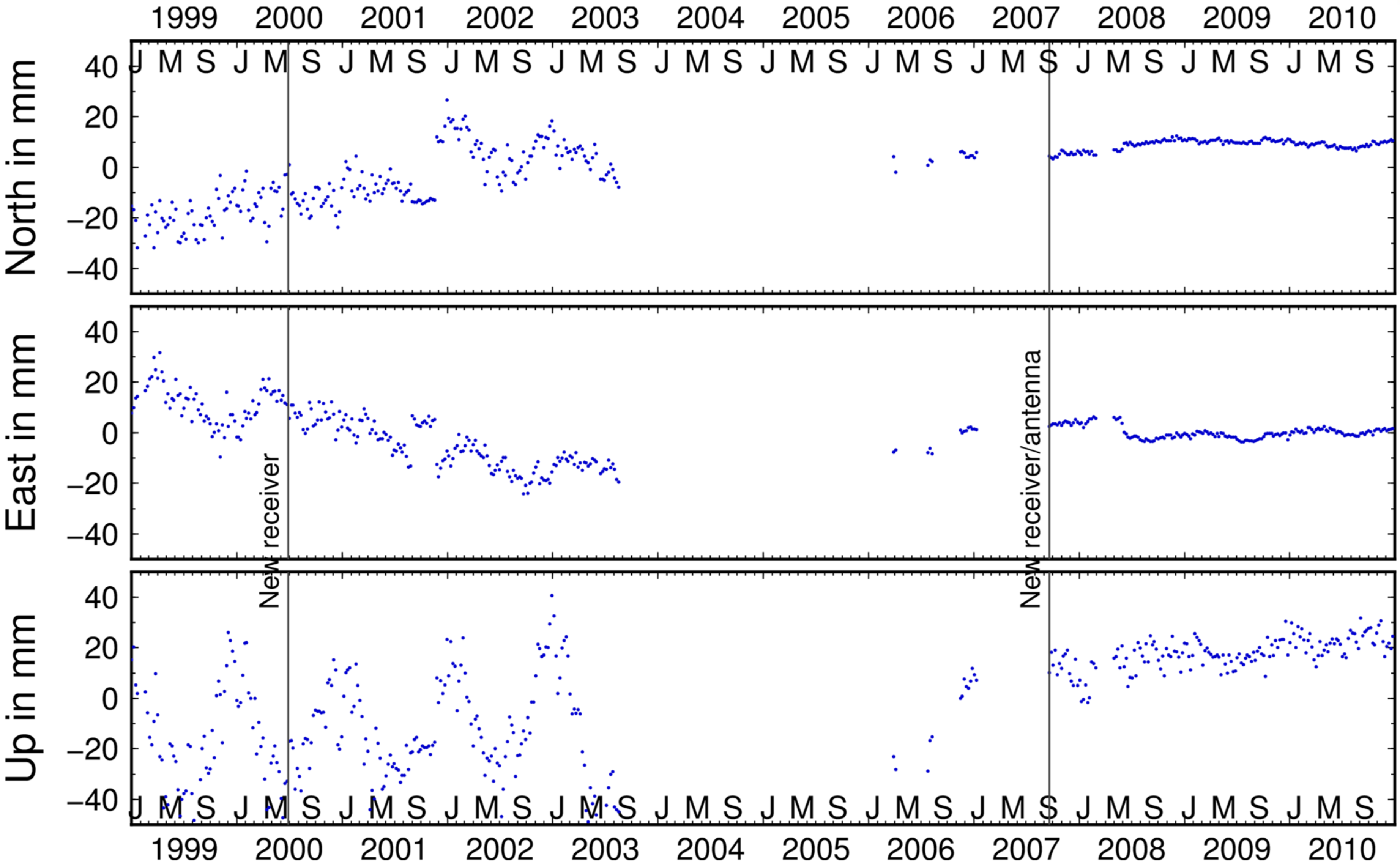
Operational series from CODE, weekly solutions

Coordinate time series for Reykjavik



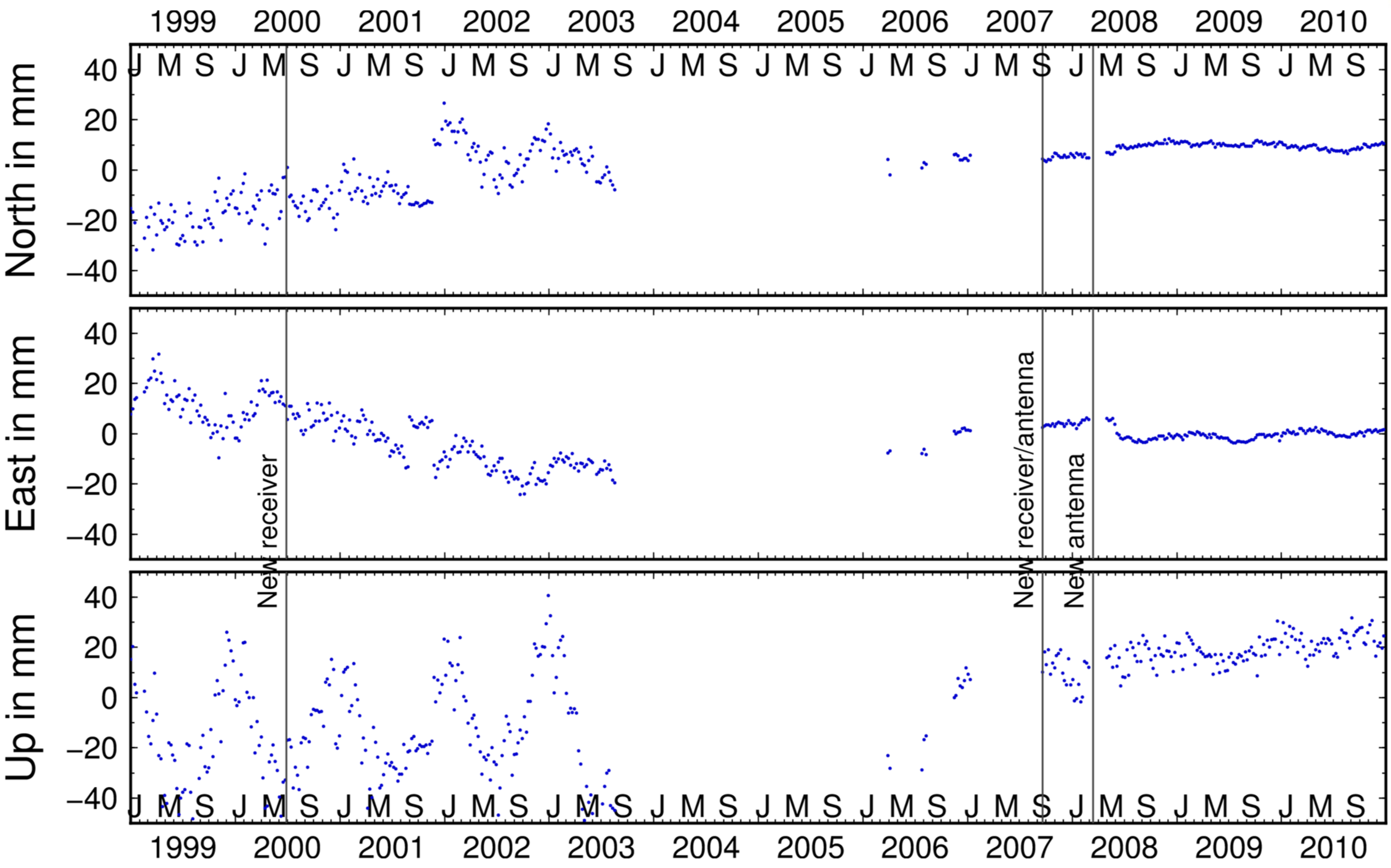
Operational series from CODE, weekly solutions

Coordinate time series for Reykjavik



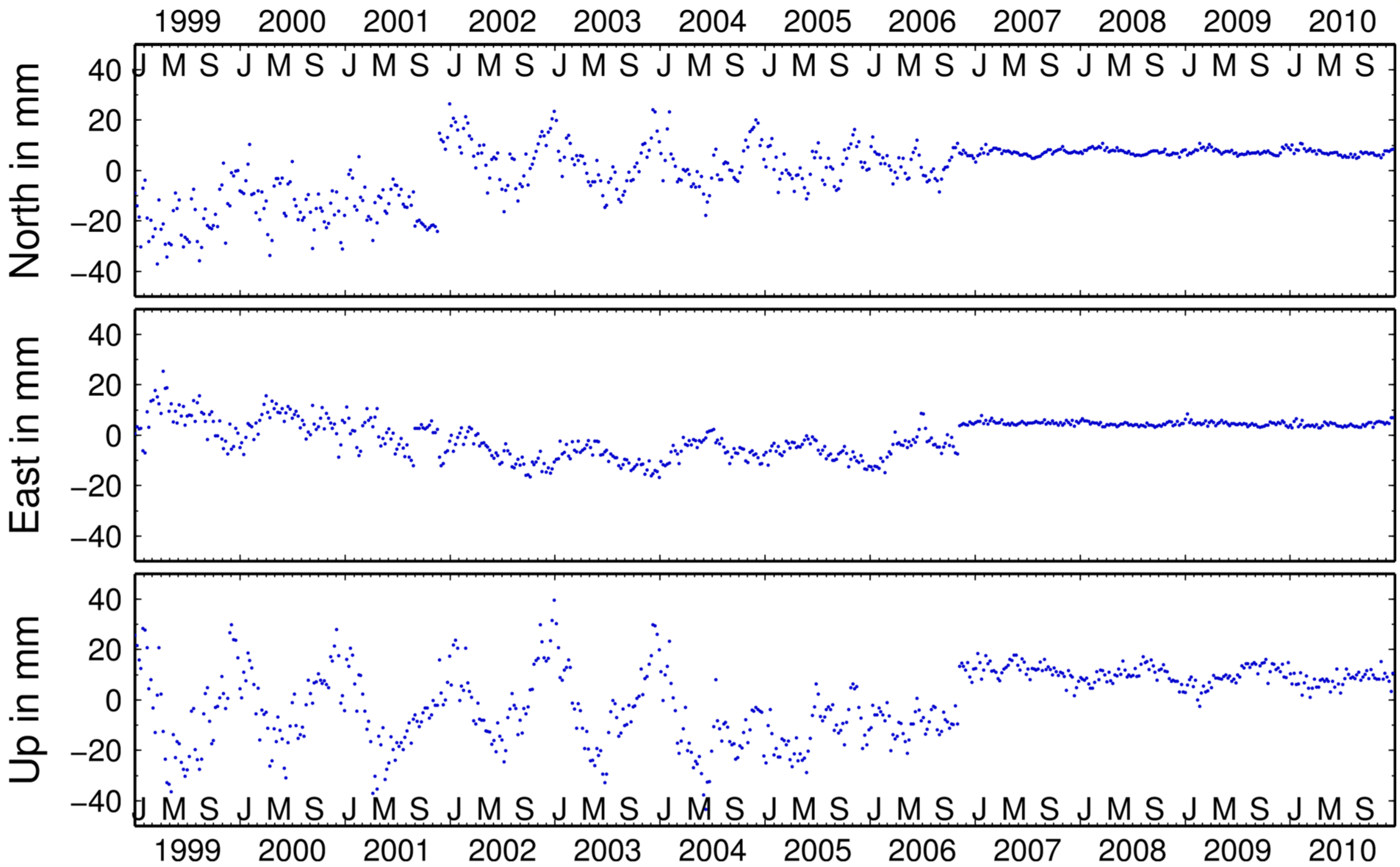
Operational series from CODE, weekly solutions

Coordinate time series for Reykjavik



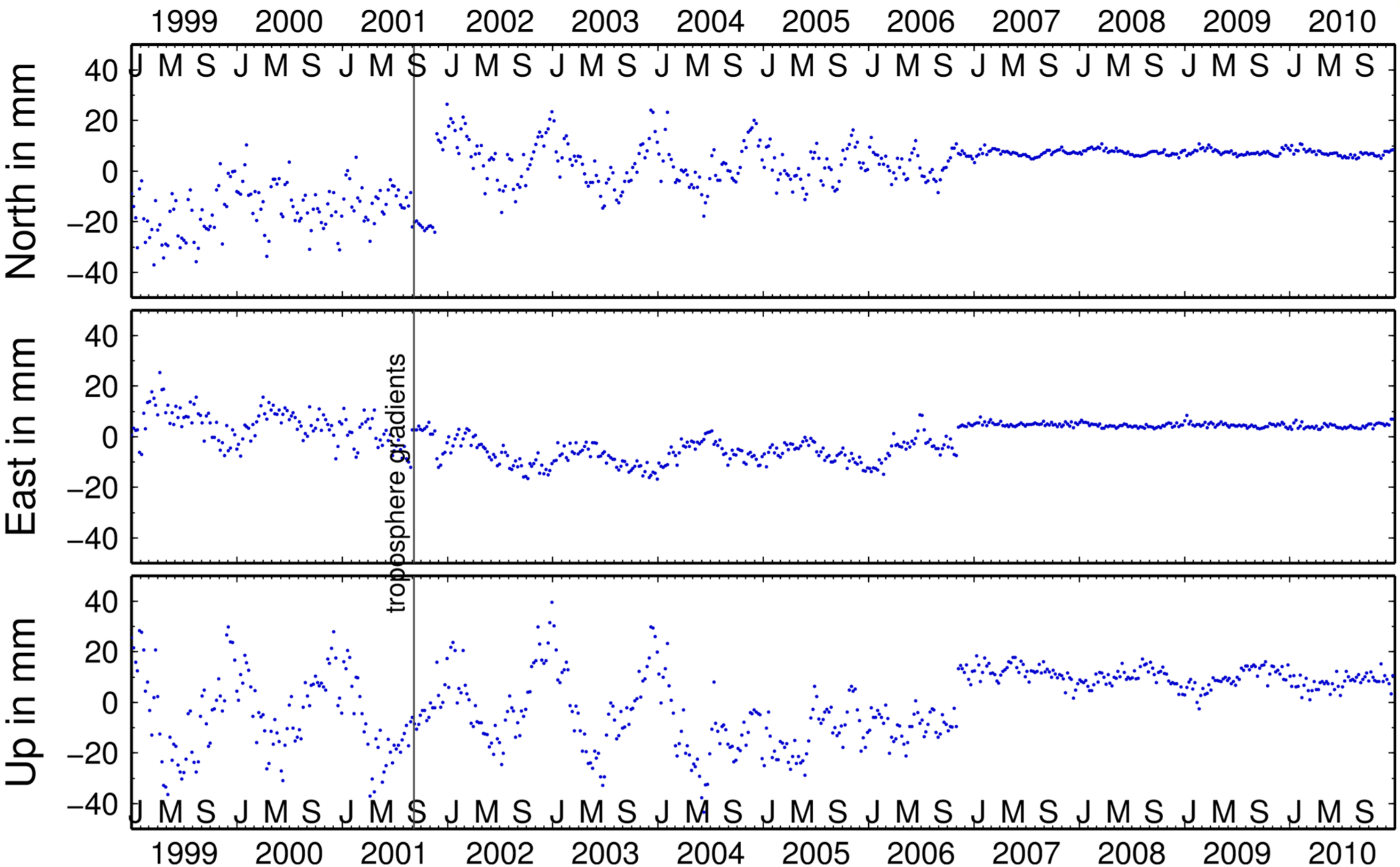
Operational series from CODE, weekly solutions

Coordinate time series for Zimmerwald



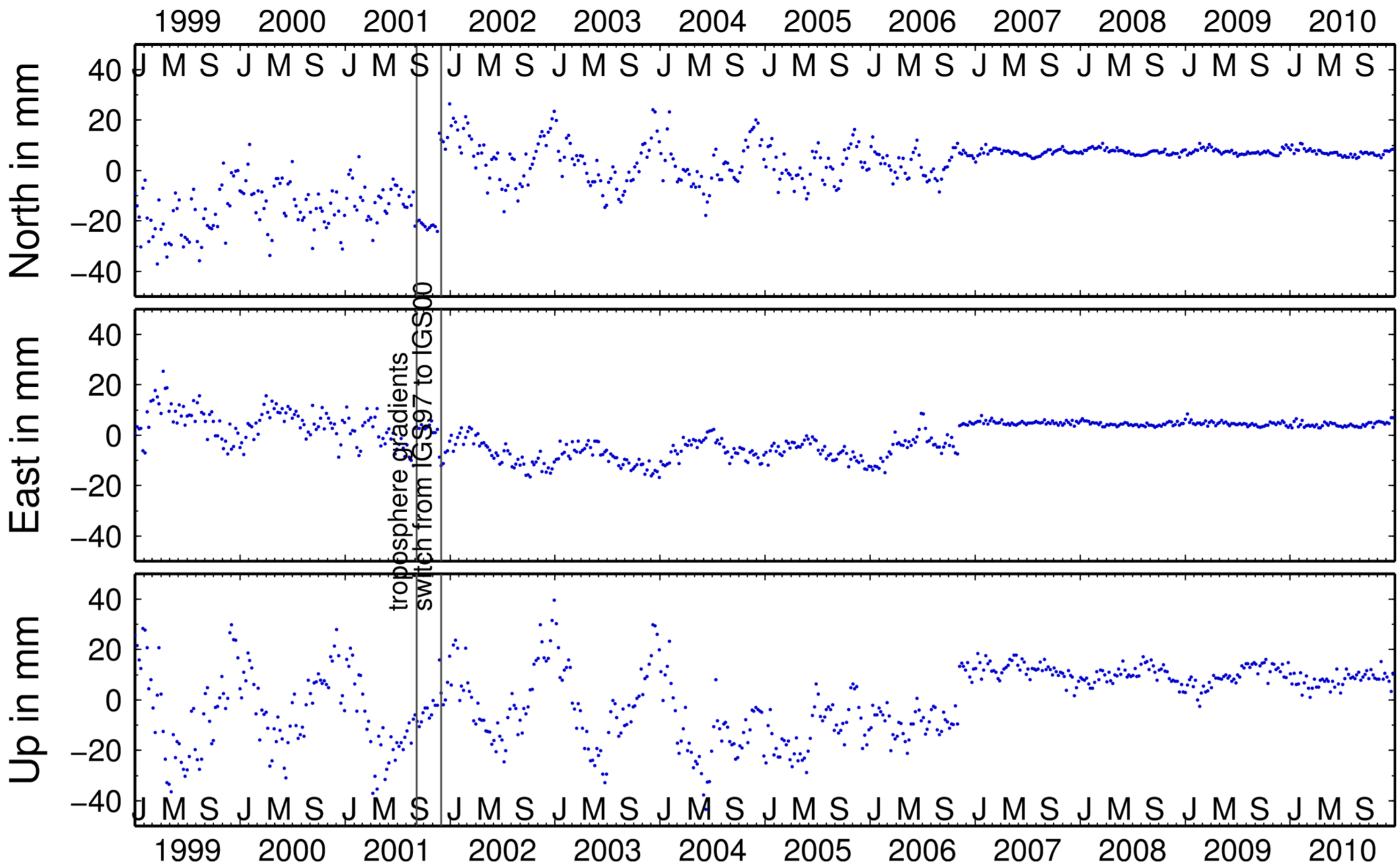
Operational series from CODE, weekly solutions

Coordinate time series for Zimmerwald



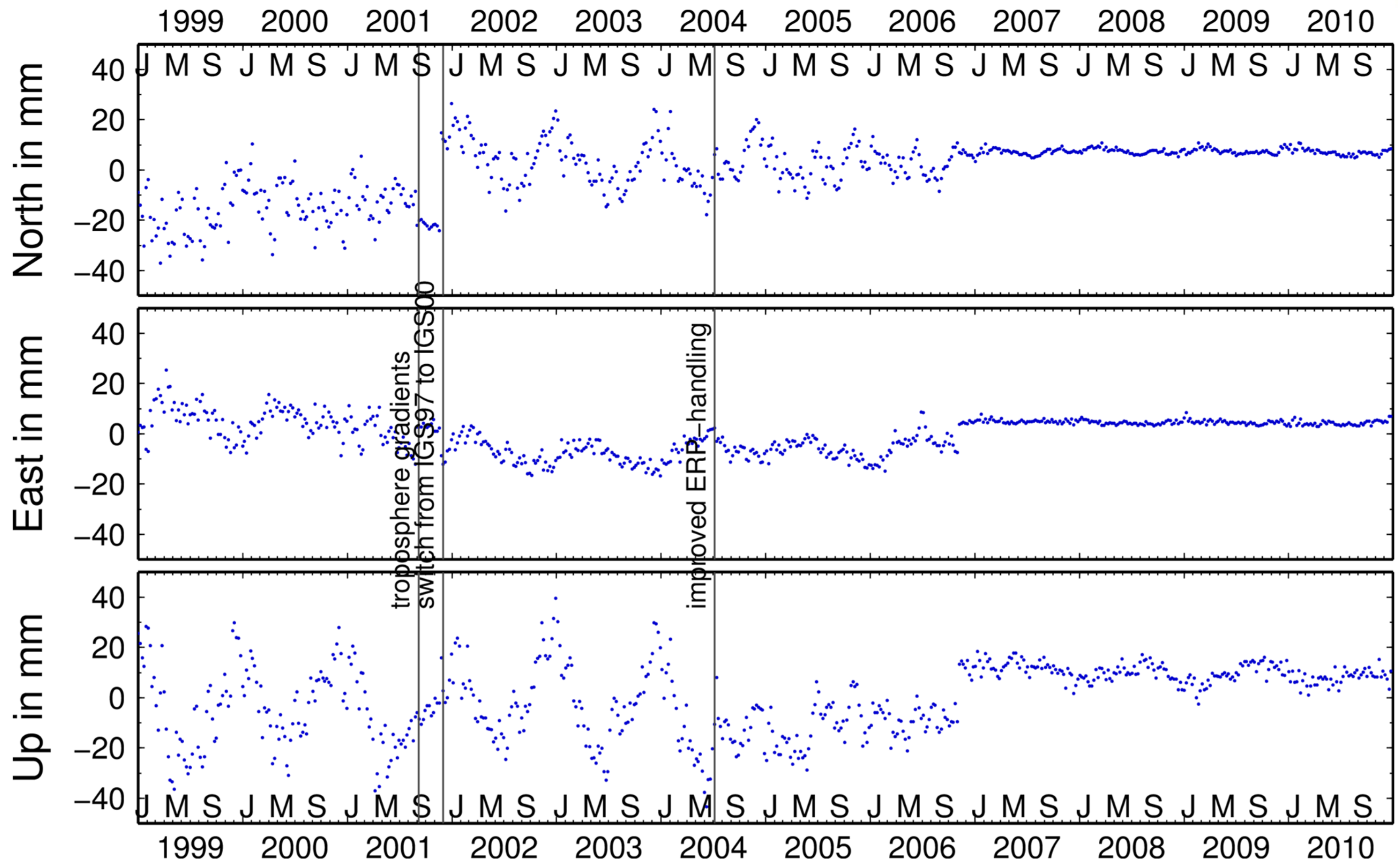
Operational series from CODE, weekly solutions

Coordinate time series for Zimmerwald



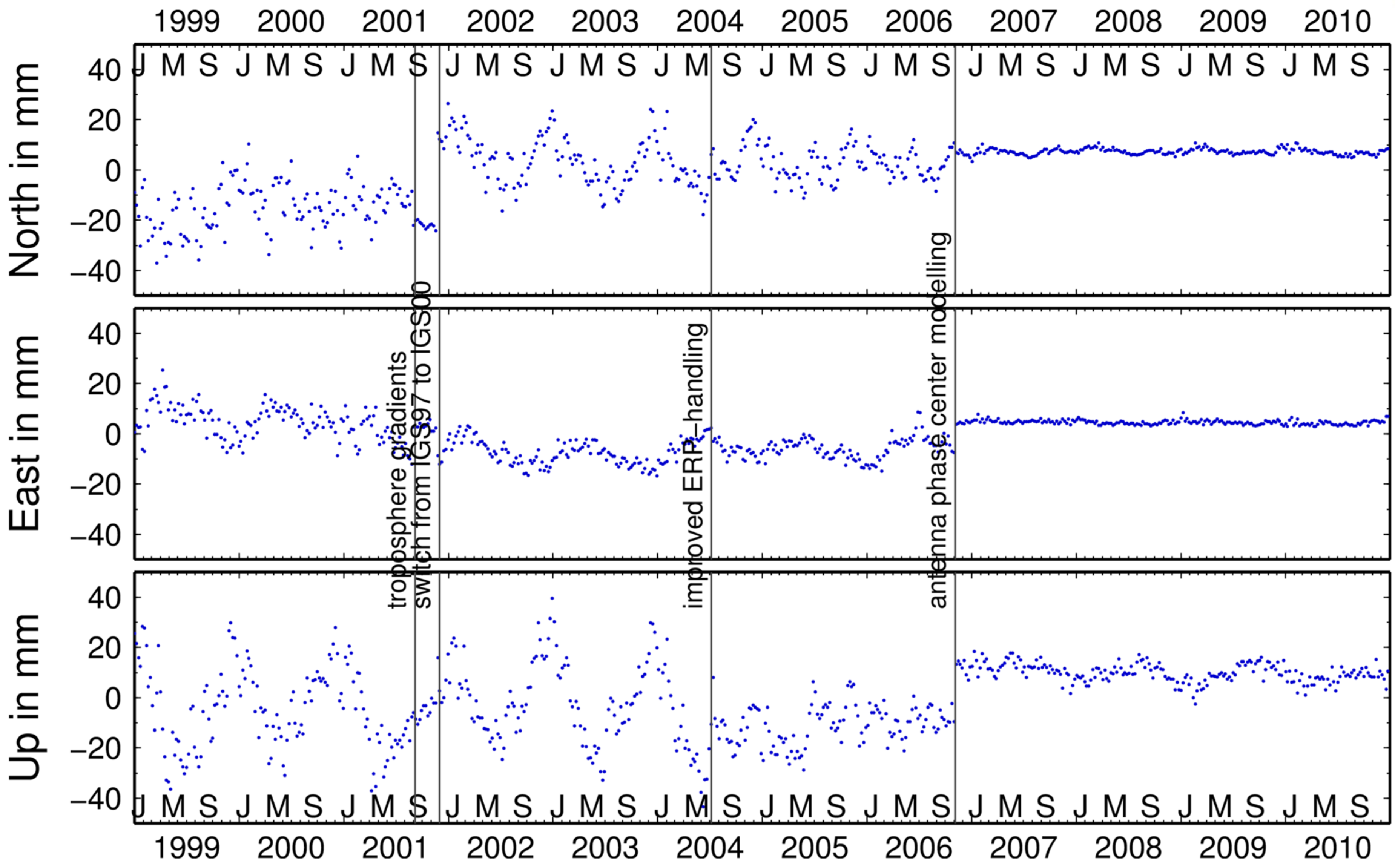
Operational series from CODE, weekly solutions

Coordinate time series for Zimmerwald



Operational series from CODE, weekly solutions

Coordinate time series for Zimmerwald



Operational series from CODE, weekly solutions

Reprocessing

Reprocessing of the IGS series by CODE was performed at
Institut für Astronomische und Physikalische Geodäsie
Technische Universität München

Time interval: 1996-2010

Includes GPS and GLONASS since May 2003

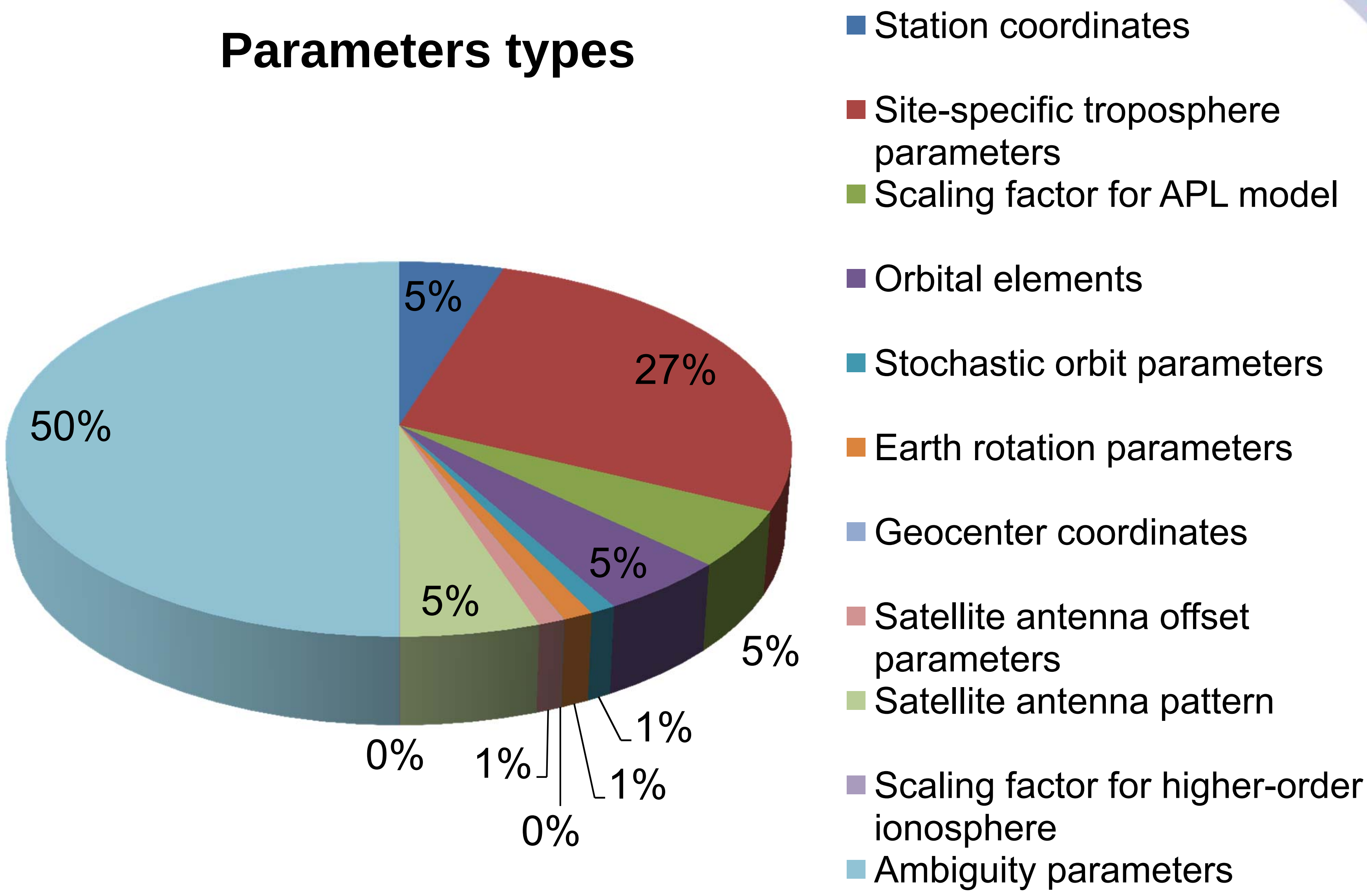
Statistics:

392	Stations
5,753	Daily solutions
1,278,571	Observation files
4,190,689,049	Original observations
63,066,190	Parameters
≈5 years	CPU-time

Reprocessing

Parameter Type	Number of parameters in daily solutions	
Station coordinates	3,064,737	
Site-specific troposphere parameters	17,268,978	
Scaling factor for APL model	3,064,737	
Orbital elements	3,001,095	
Stochastic orbit parameters	599,582	
Earth rotation parameters	698,875	
Geocenter coordinates	16,773	
Satellite antenna offset parameters	599,582	
Satellite antenna pattern	3,199,408	
Scaling factor for higher-order ionosphere	16,773	
Ambiguity parameters	31,535,650	
Total	**63,066,190**	

Reprocessing



Reprocessing

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Scaling factor for higher-order ionosphere	16,773	
Ambiguity parameters	31,535,650	
Total	**63,066,190**	

Reprocessing

Parameter Type	Number of parameters in daily solutions	Number of parameters in weekly solutions
Station coordinates	3,064,737	457,896
Site-specific troposphere parameters	17,268,978	14,656,864
Scaling factor for APL model	3,064,737	457,896
Orbital elements	3,001,095	3,001,095
Stochastic orbit parameters	599,582	599,582
Earth rotation parameters	698,875	652,795
Geocenter coordinates	16,773	2,391
Satellite antenna offset parameters	599,582	86,340
Satellite antenna pattern	3,199,408	457,058
Scaling factor for higher-order ionosphere	16,773	2,391
Ambiguity parameters	31,535,650	31,535,650
Total	**63,066,190**	**51,909,958**

Reprocessing

Parameter Type	Number of parameters in daily solutions	Number of parameters in weekly solutions
Station coordinates	3,064,737	457,896
Site-specific troposphere parameters	17,268,978	14,656,864
Scaling factor for AP[illegible]	[illegible],064,737	457,896
Orbital elements	[illegible]001,095	3,001,095
Stochastic orbit para[illegible]	599,582	599,582
Earth rotation parameters	698,875	652,795
Geocenter coordinates	16,773	2,391
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Reduction due to the different boundaries for the piece-wise linear representation

Reprocessing

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Site-specific troposphere parameters	17,268,978	14,656,864
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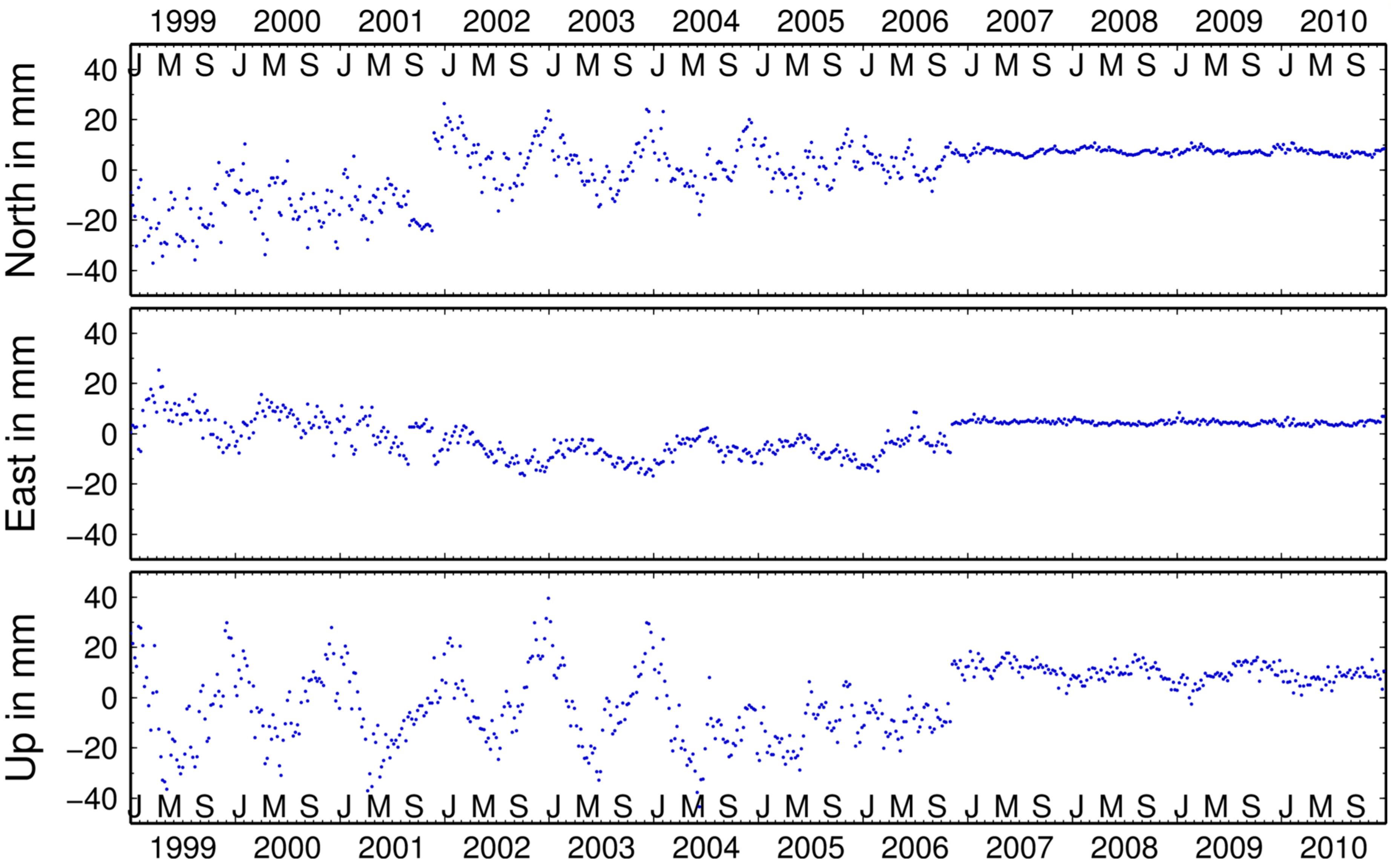
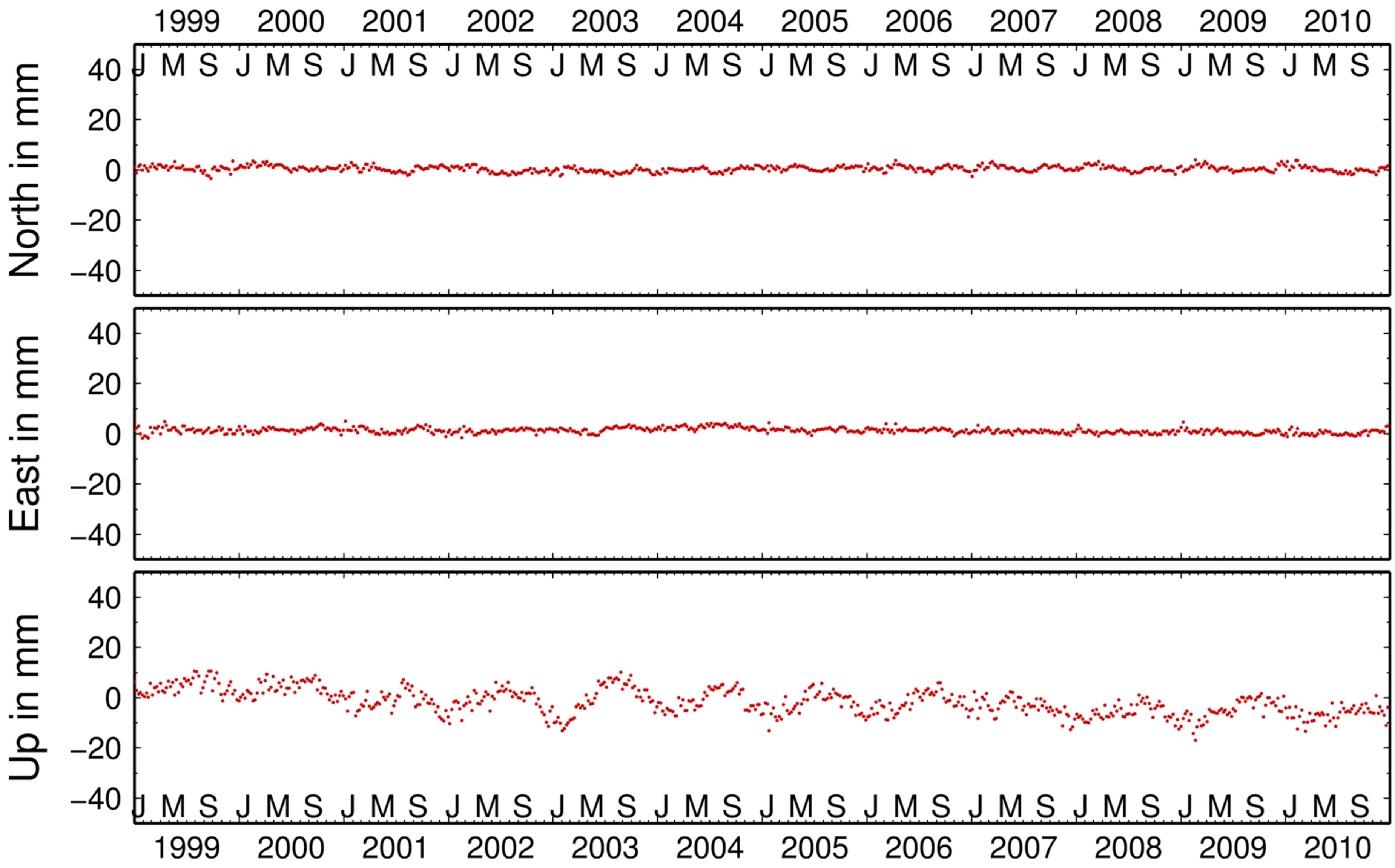
Coordinate time series for Zimmerwald



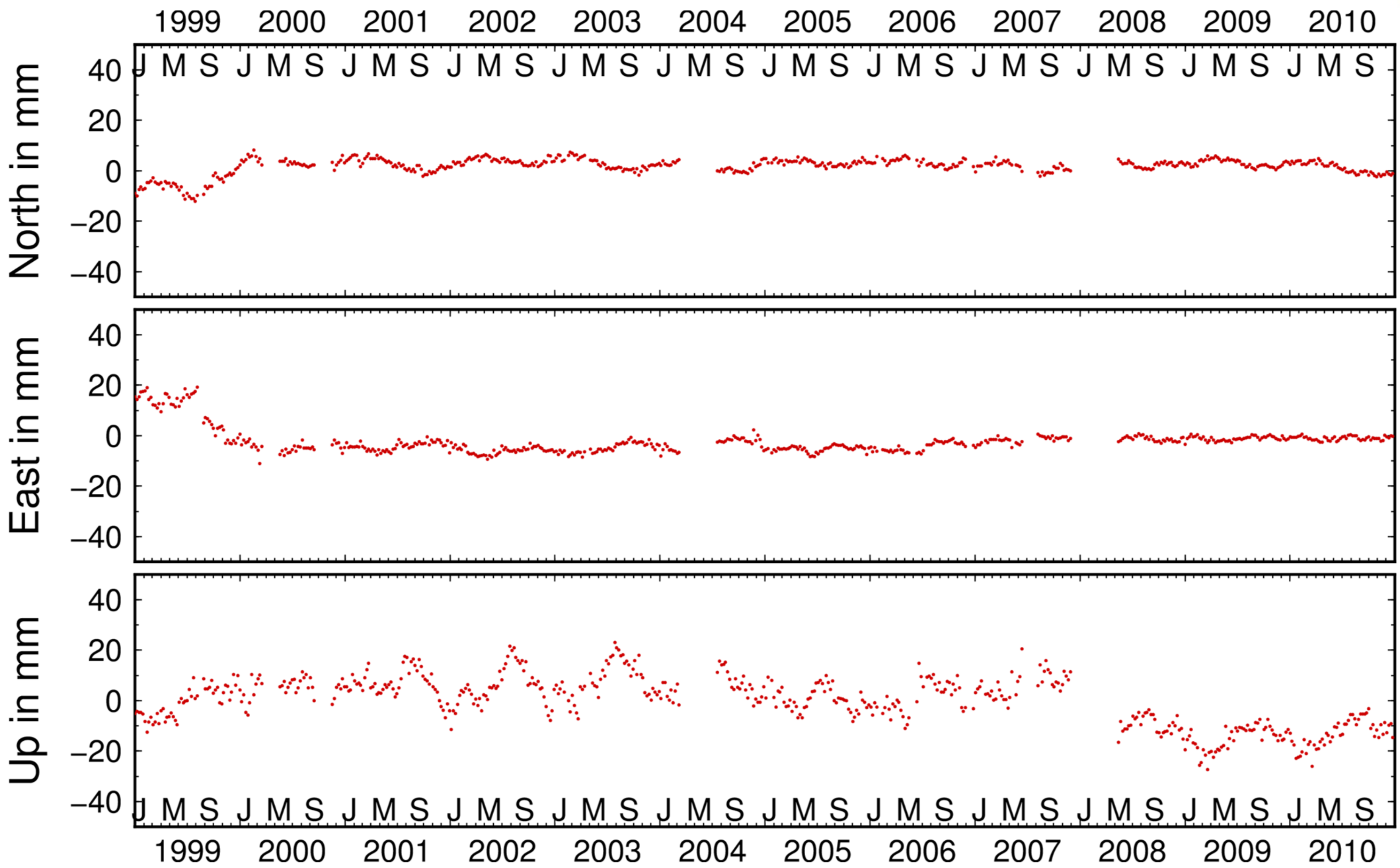
Operational series from CODE, weekly solutions

Coordinate time series for Zimmerwald



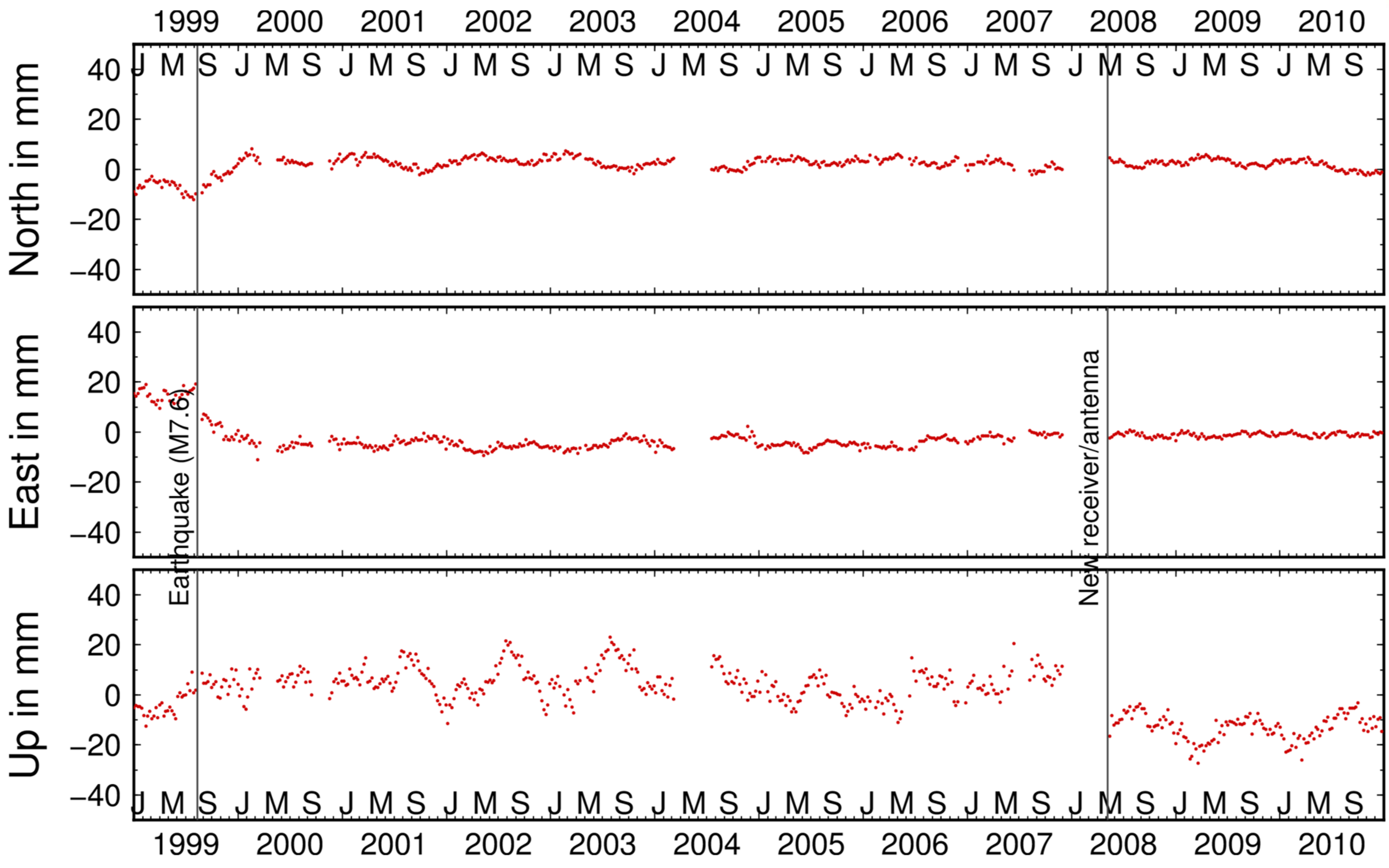
Reprocessed series from CODE, weekly solutions

Coordinate time series for Ankara



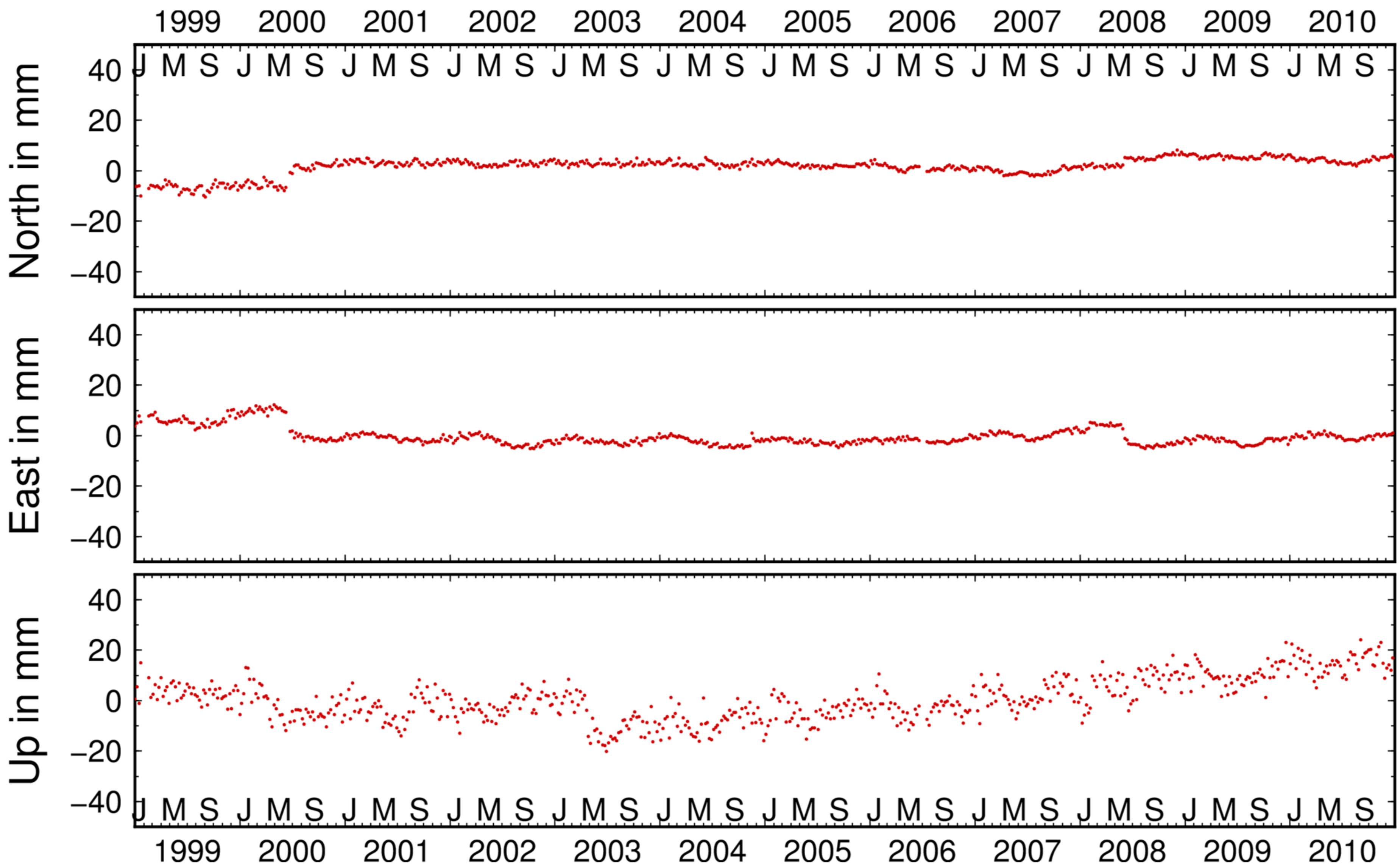
Reprocessed series from CODE, weekly solutions

Coordinate time series for Ankara



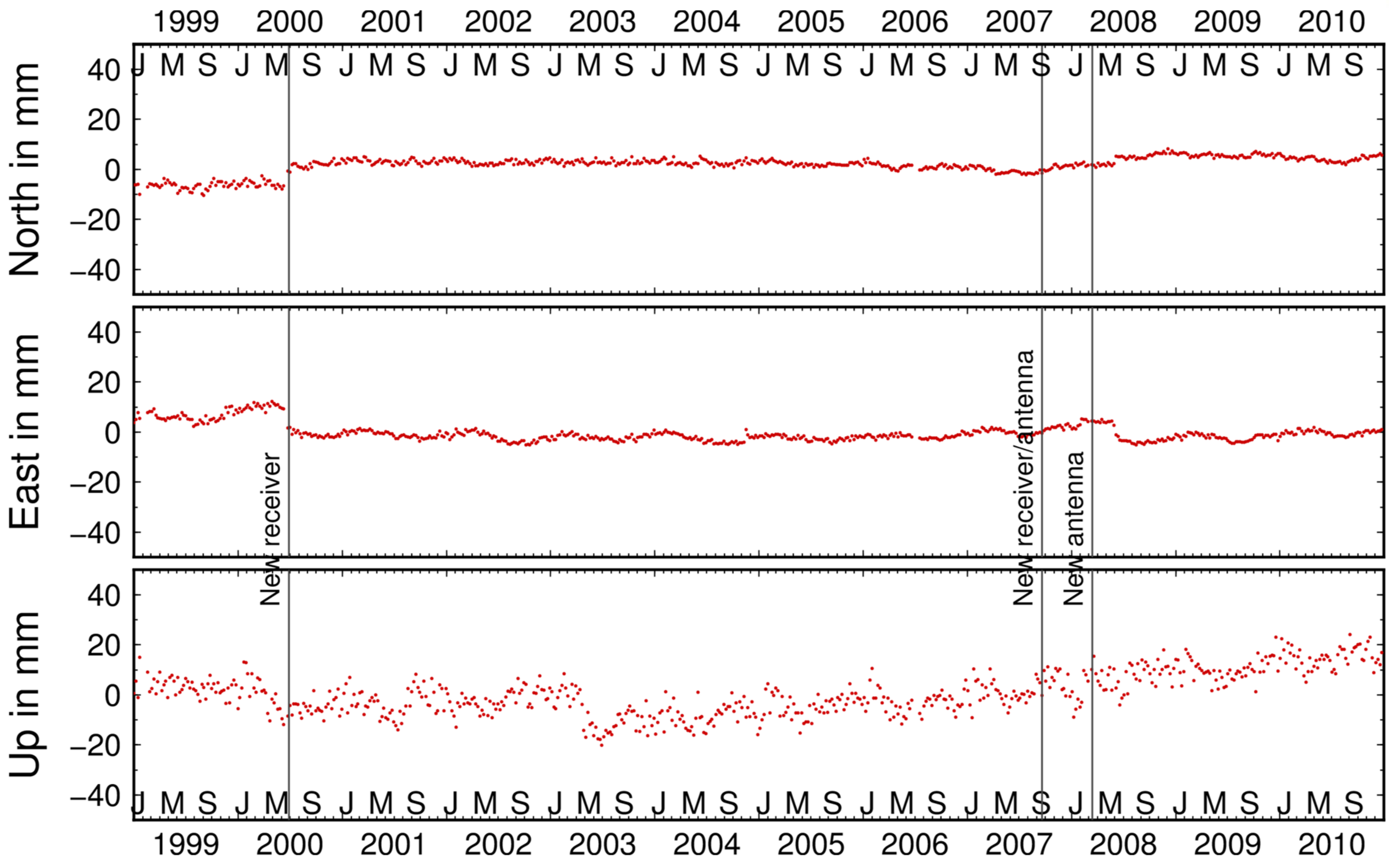
Reprocessed series from CODE, weekly solutions

Coordinate time series for Reykjavik



Reprocessed series from CODE, weekly solutions

Coordinate time series for Reykjavik

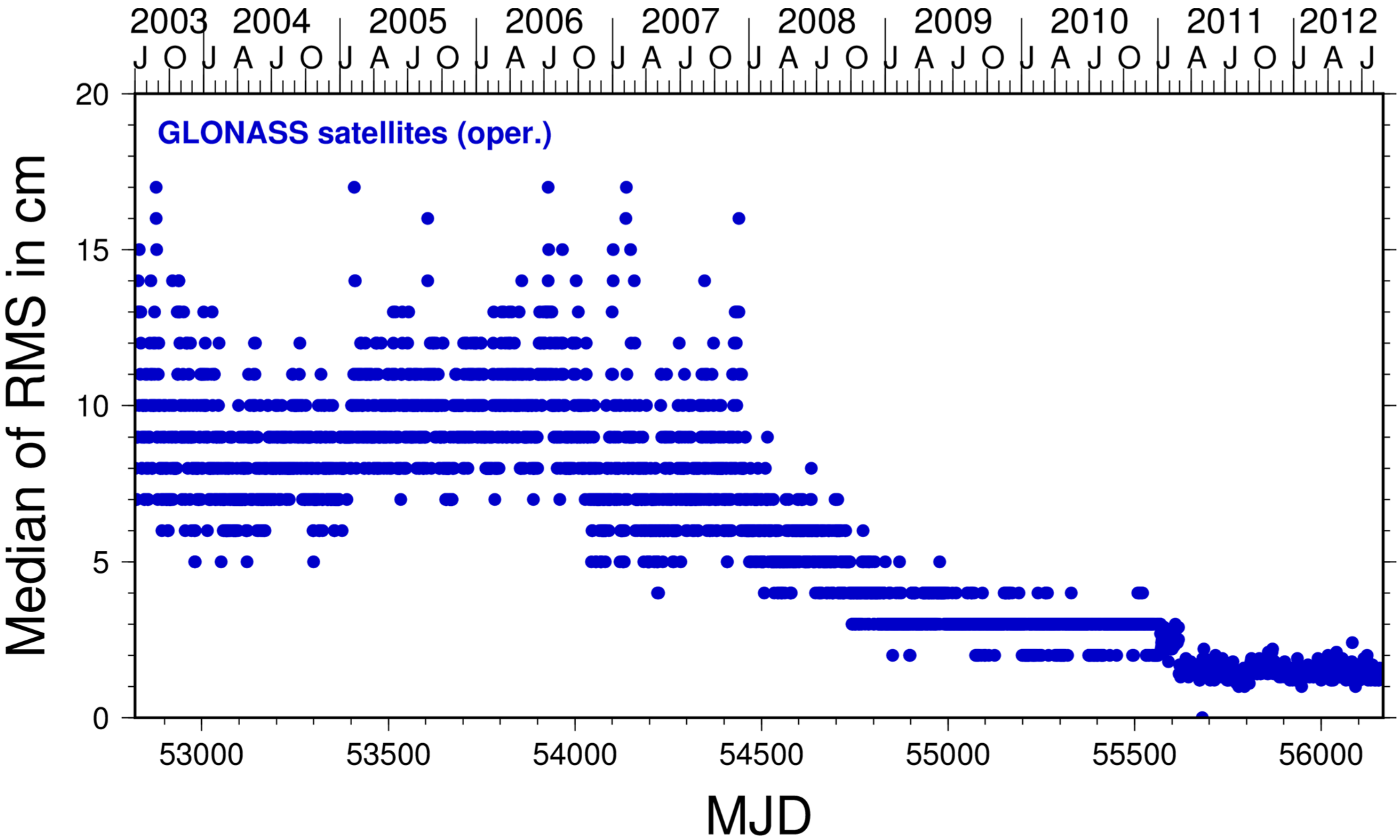


Reprocessed series from CODE, weekly solutions

GNSS data processing

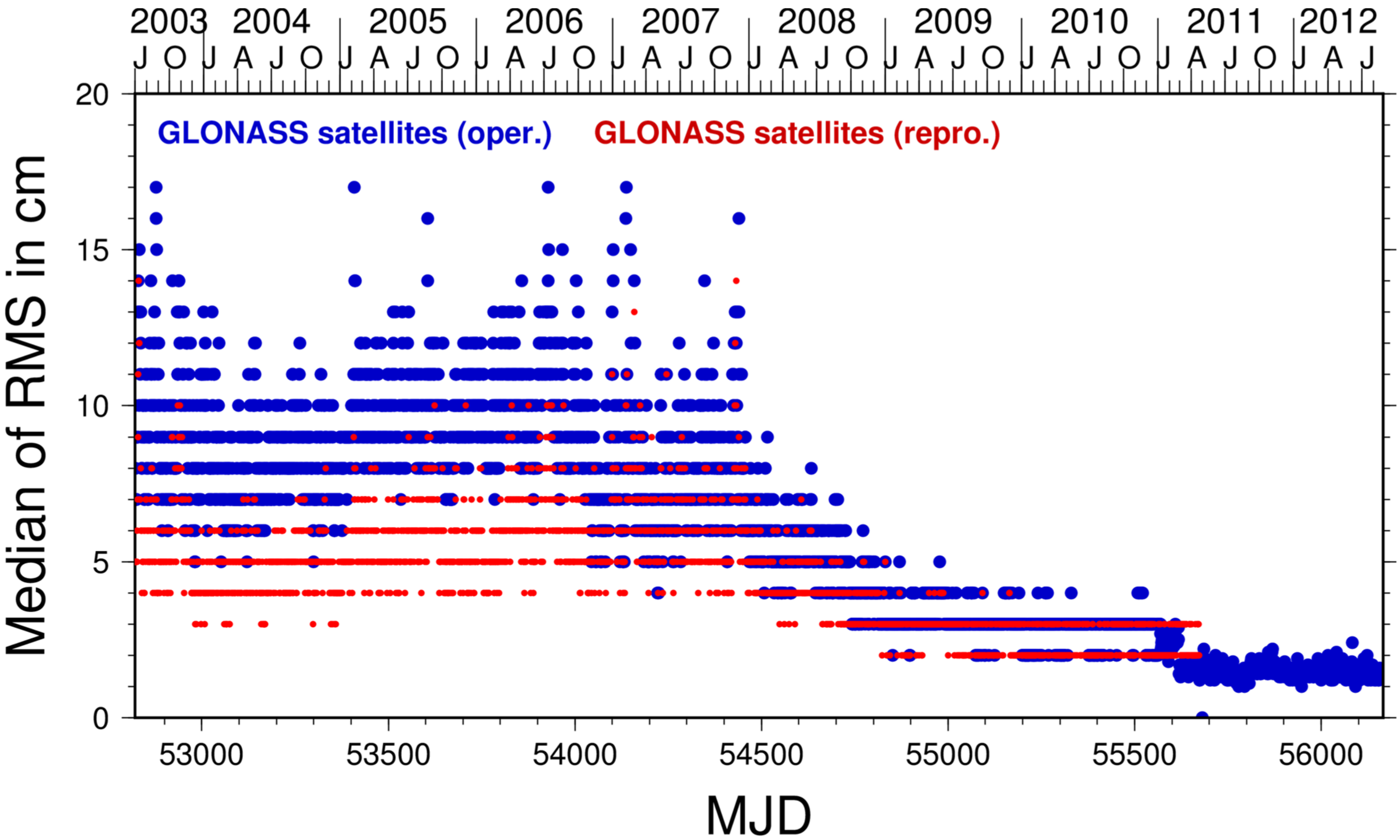
- A certain set of parameters need to be estimated in a GNSS-data analysis independent from the real purpose of the solution:
  - Mandatory:
    station coordinates, troposphere parameters (25%), ambiguities (50%)
  - Optional for GNSS orbit determination:
    GNSS orbit and Earth rotation parameters, geocenter coordinates
- GNSS-derived times series (e.g., station coordinates) reflect
  1. data analysis model and their changes, reference frame updates,
  2. equipment changes (antennas, receivers or even firmware), and
  3. real geophysical events or processes.
- A consistent reprocessing of the complete GNSS time series helps to eliminate (1st group) or reduce (2nd group) the influence from the GNSS data processing on the resulting time series.
- We have looked at station coordinate series so far.
  What about the orbits?

Better orbit due to reprocessing



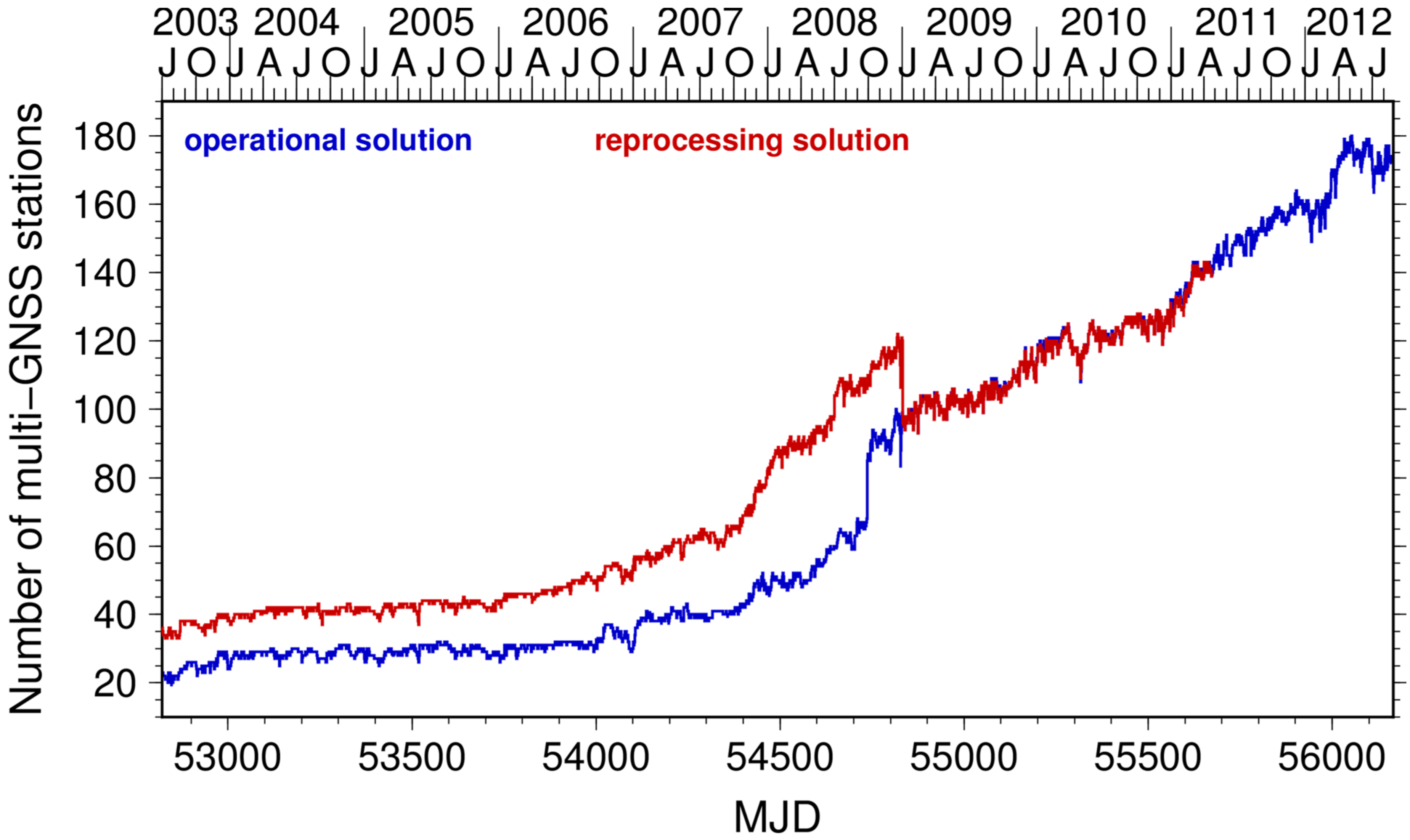
Operational/reprocessed series from CODE

Better orbit due to reprocessing



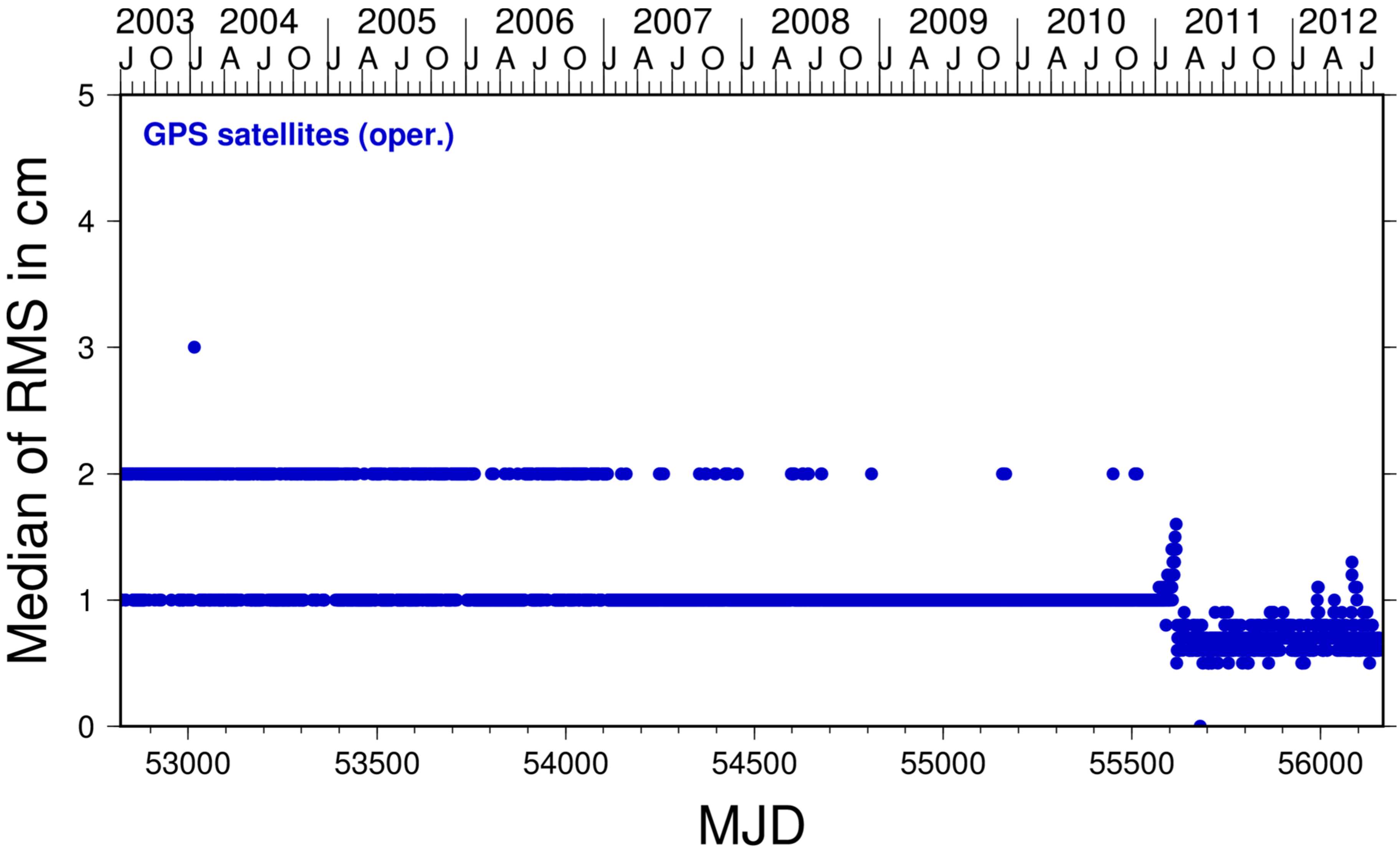
Operational/reprocessed series from CODE

Number of GLONASS tracking stations



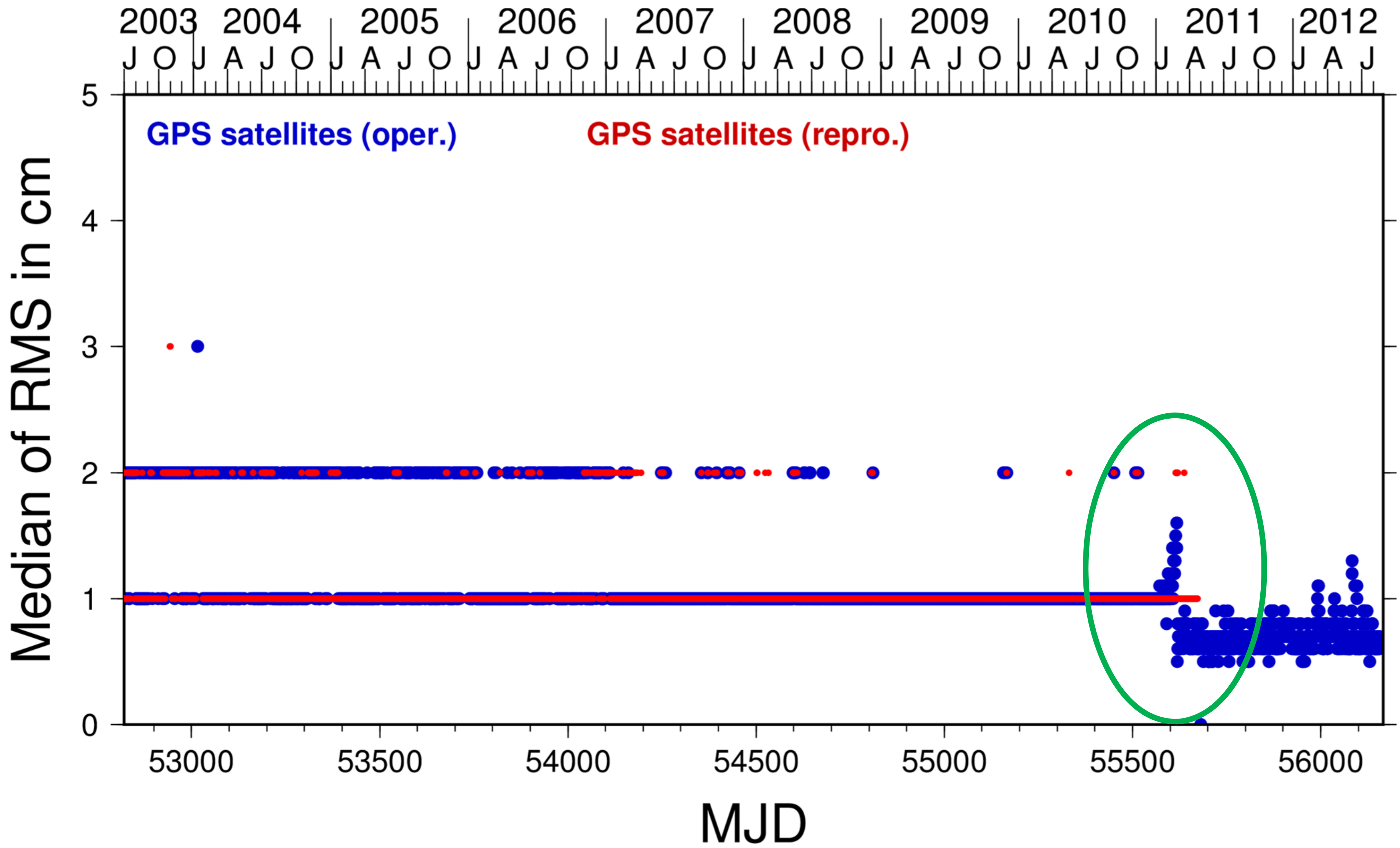
Operational/reprocessed series from CODE

Better orbit due to reprocessing



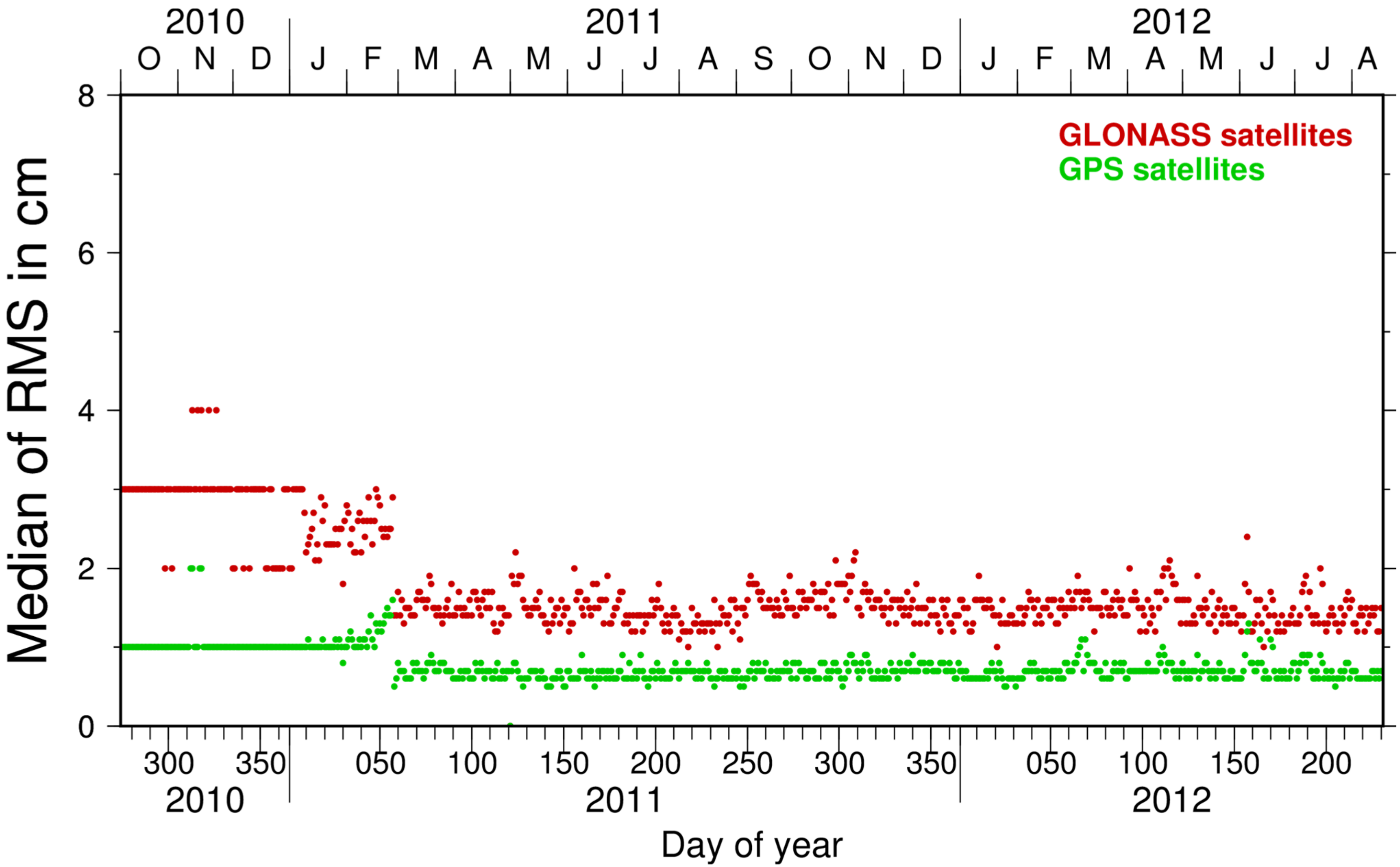
Operational/reprocessed series from CODE

Better orbit due to reprocessing



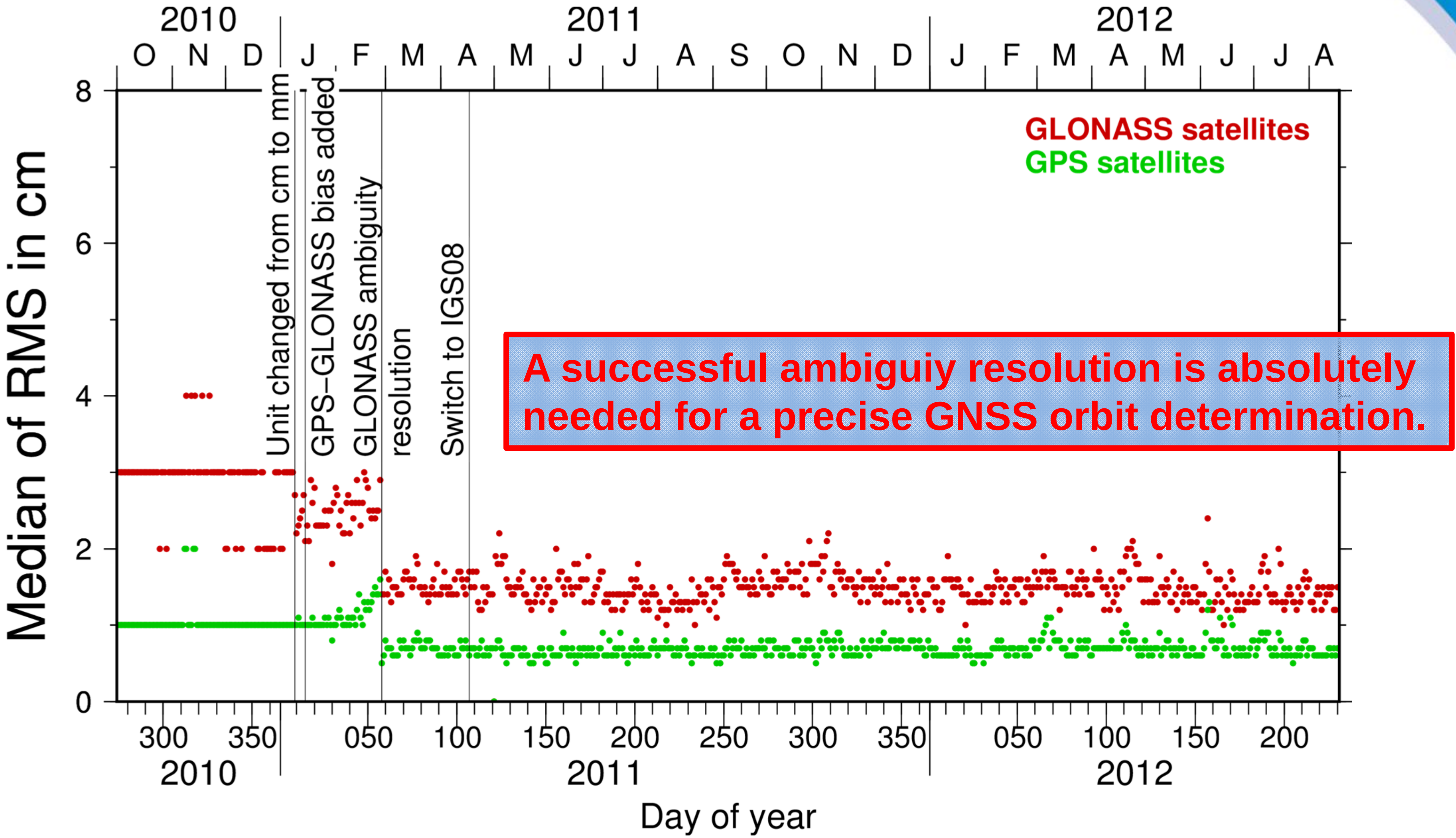
Operational/reprocessed series from CODE

CODE processing changes in 2011



Operational series from CODE

CODE processing changes in 2011



Operational series from CODE

IGS-MGEX campaign

IGS-MGEX: IGS Multi-GNSS Experiment

- **August 2011: Call for Participation:**

  This Call for Participation for the IGS Multi-GNSS Experiment – IGS-MGEX – recognizes the availability of new additional GNSS signals and new constellations on the horizon. The IGS is preparing for this next phase in the evolution of the IGS to eventually generate products for all GNSS available.
- **October 2011: Proposal deadline**
- **December 2011/January 2012:**
  Evaluation of the proposals by the IGS' GNSS working group
- **IGS-MGEX runs from 01-February until 31-August 2012 extended to the end of 2013**
- First results have been presented at the **IGS workshop in Olsztyn,** Poland (end of July 2012).

CODE contribution to IGS-MGEX

CODE has contributed a triple-GNSS solution (the only?):

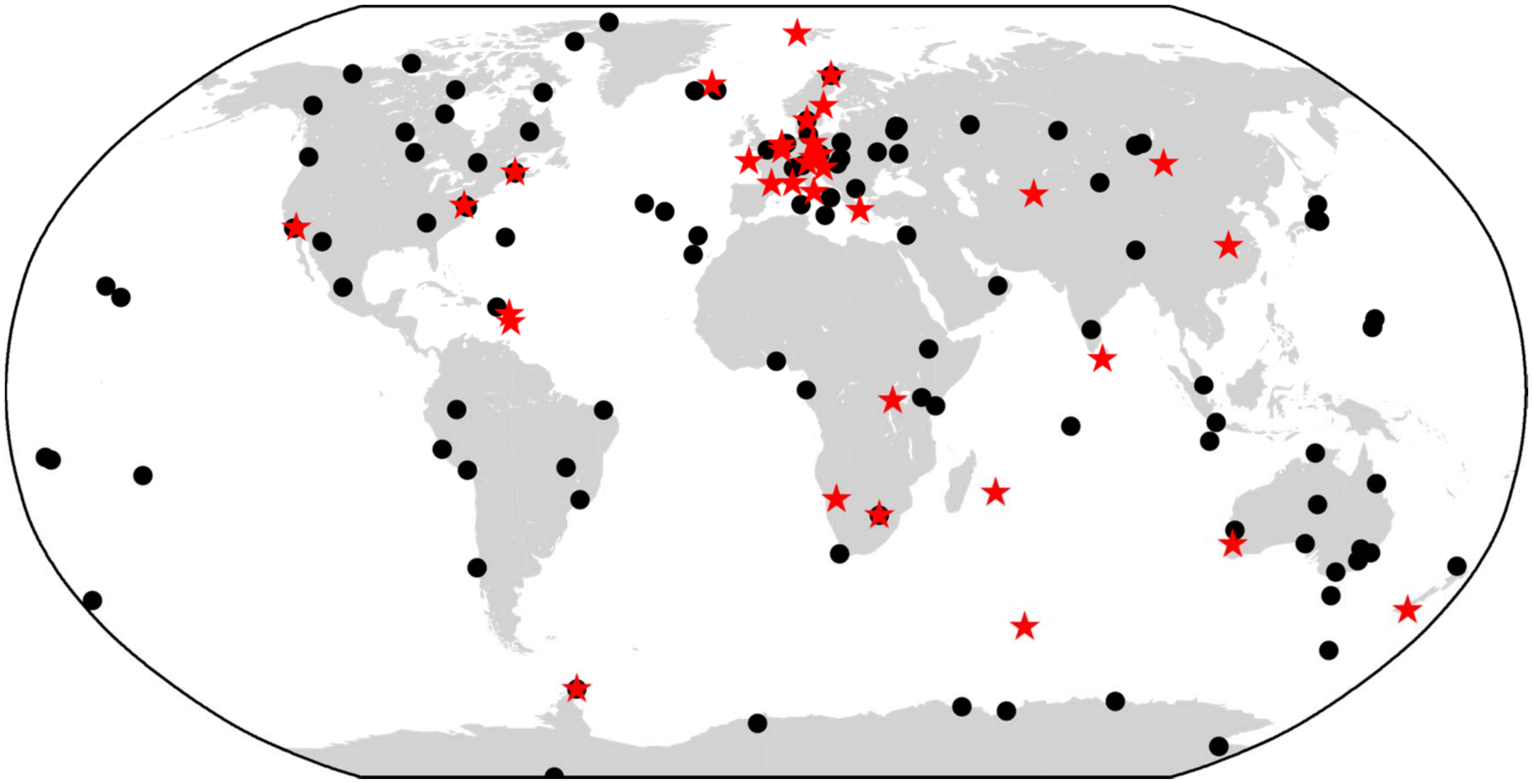
GPS+GLONASS+Galileo

(Presented at the IGS workshop by Dr. Lars Prange)

- The solution has been derived from the IGS rapid procedure at CODE considering in addition available Galileo-tracking data (insufficient COMPASS and QZSS tracking data in May 2012).
- Technical details (for completeness):
  - Specific cluster containing all Galileo data has been processed to consider all correlations for the Galileo measurements in a optimal way.
  - No ambiguity resolution for Galileo observations has been done so far.
  - Orbit solutions for four weeks have been presented at the IGS workshop.
- A lot of data format problems have been sorted out together with IGS database and station managers before the IGS MGEX data could be processed.

CODE-MGEX: station distribution

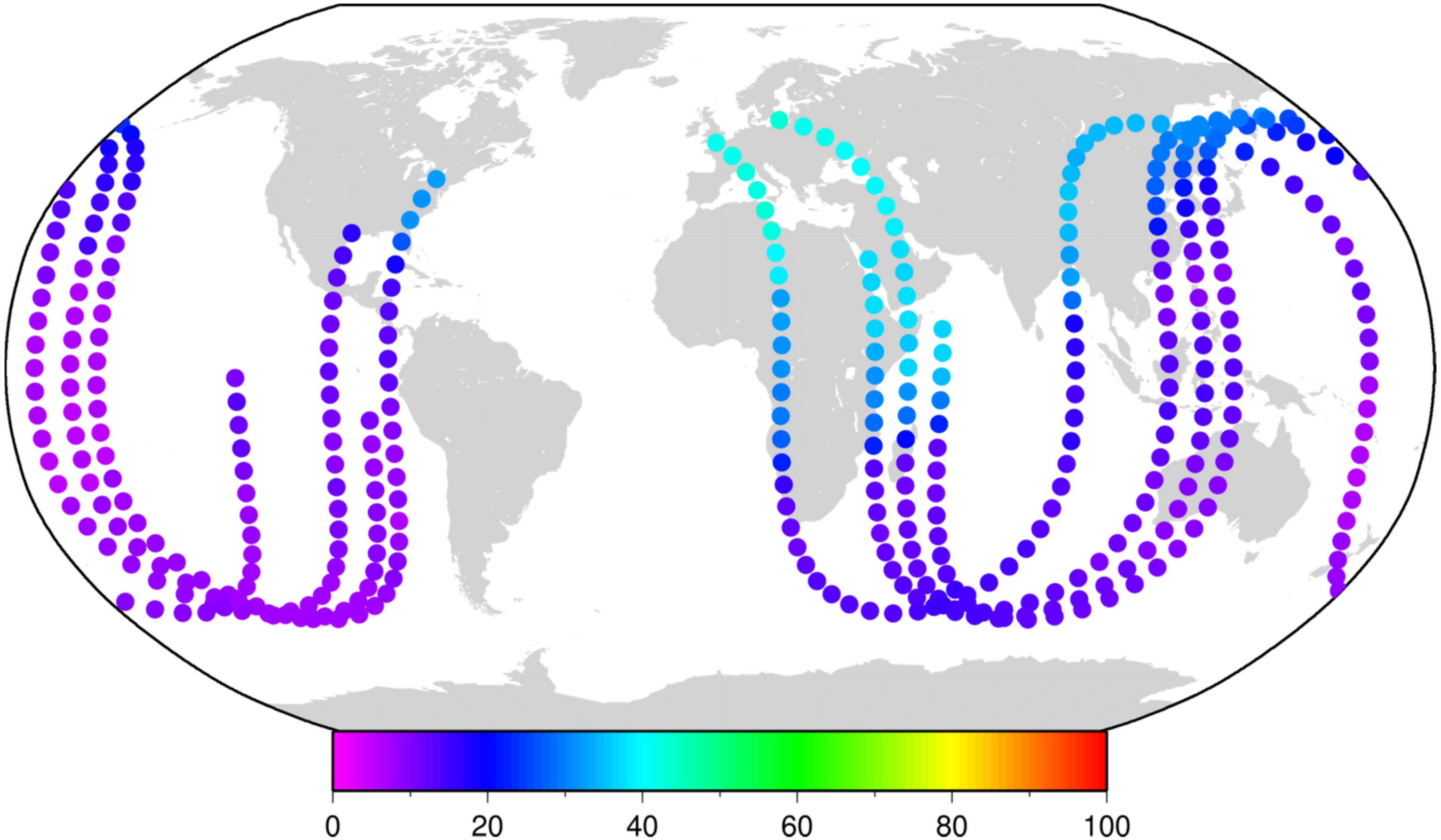
Number and distribution of tracking stations contributing to the CODE-MGEX solution



Number of				
stations	● GPS: 147	GLONASS: 120	★ Galileo: 35	
observations	20,000-24,000	16,000-19,000	1,000-3,500	per sat. and day

CODE-MGEX: „trackability“

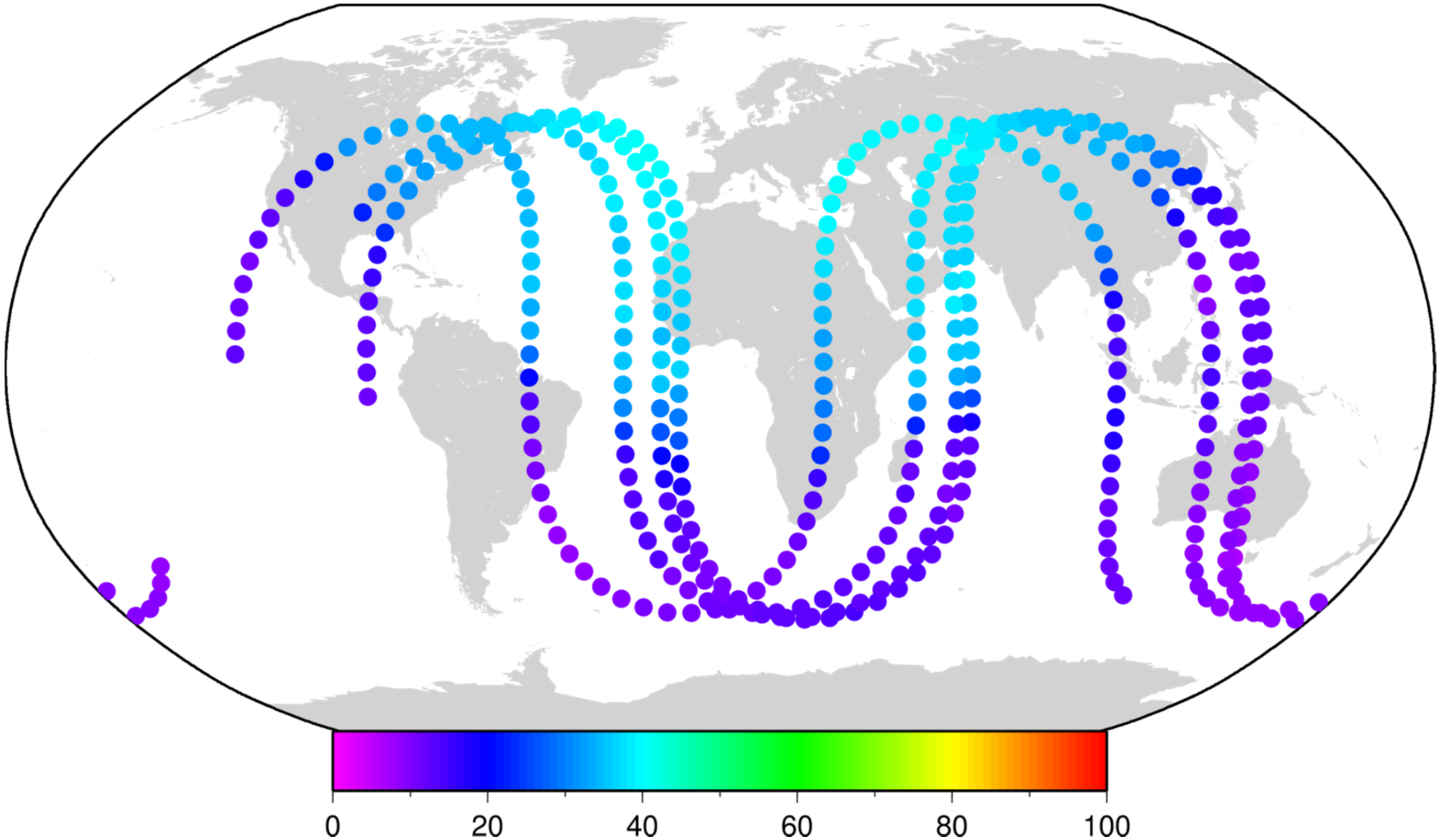
Number of stations that could theoretically track
the satellites of the **Galileo** constellation; sampling 15 min; **DOY 150**



=> only parts of a daily orbit arc are covered with observations

CODE-MGEX: „trackability“

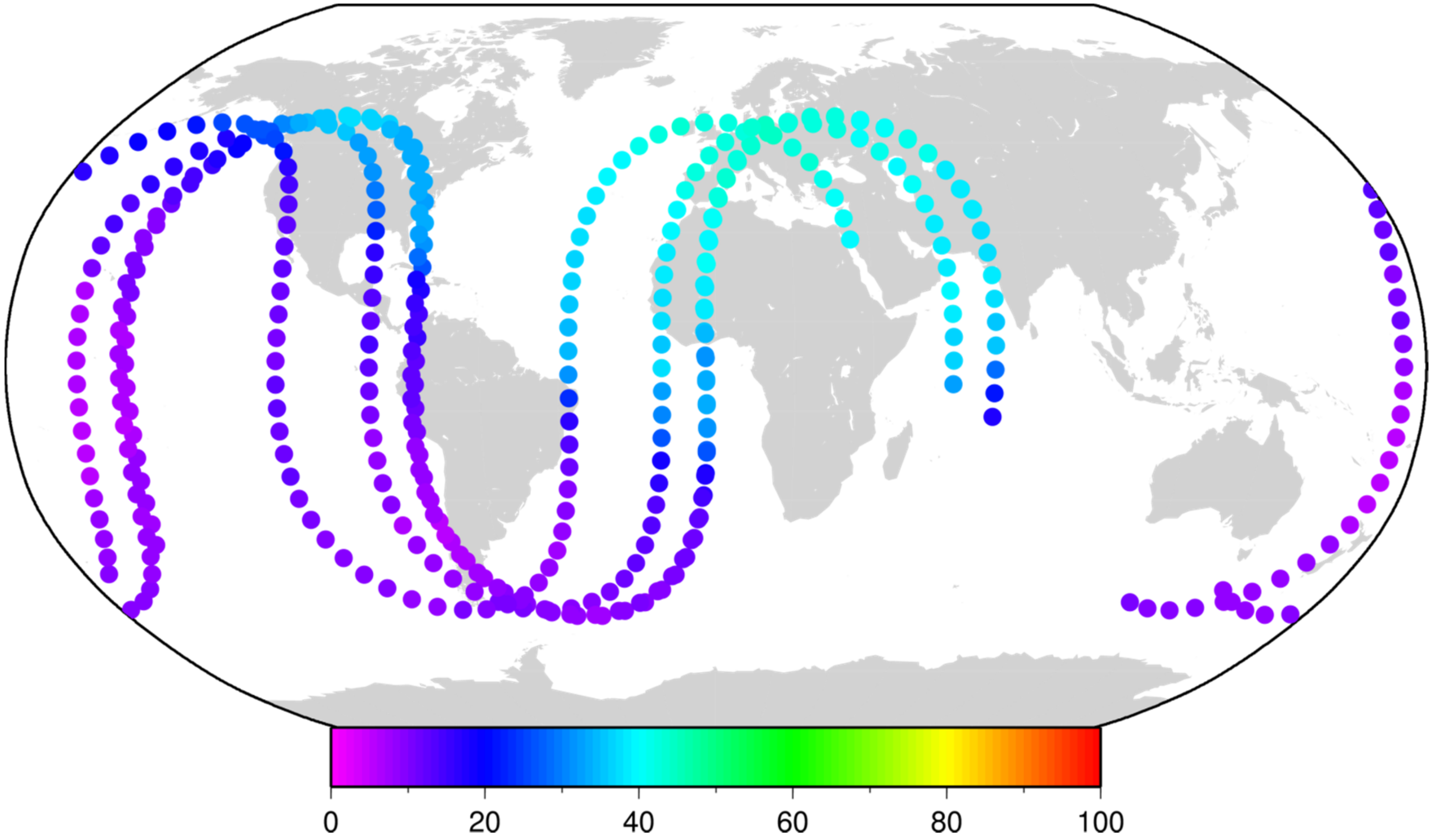
Number of stations that could theoretically track
the satellites of the **Galileo** constellation; sampling 15 min; **DOY 151**



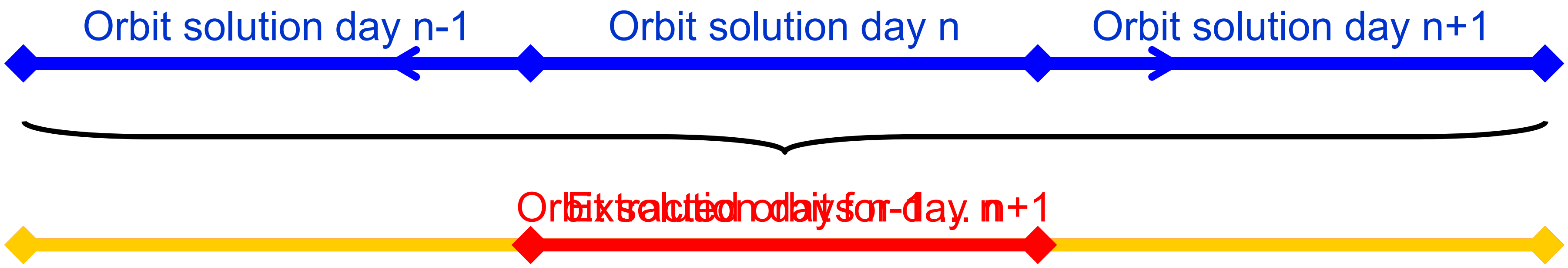
=> Optimal observation scenario (many European stations)

CODE-MGEX: „trackability“

Number of stations that could theoretically track
the satellites of the **Galileo** constellation; sampling 15 min; **DOY 152**



Multi-day arcs

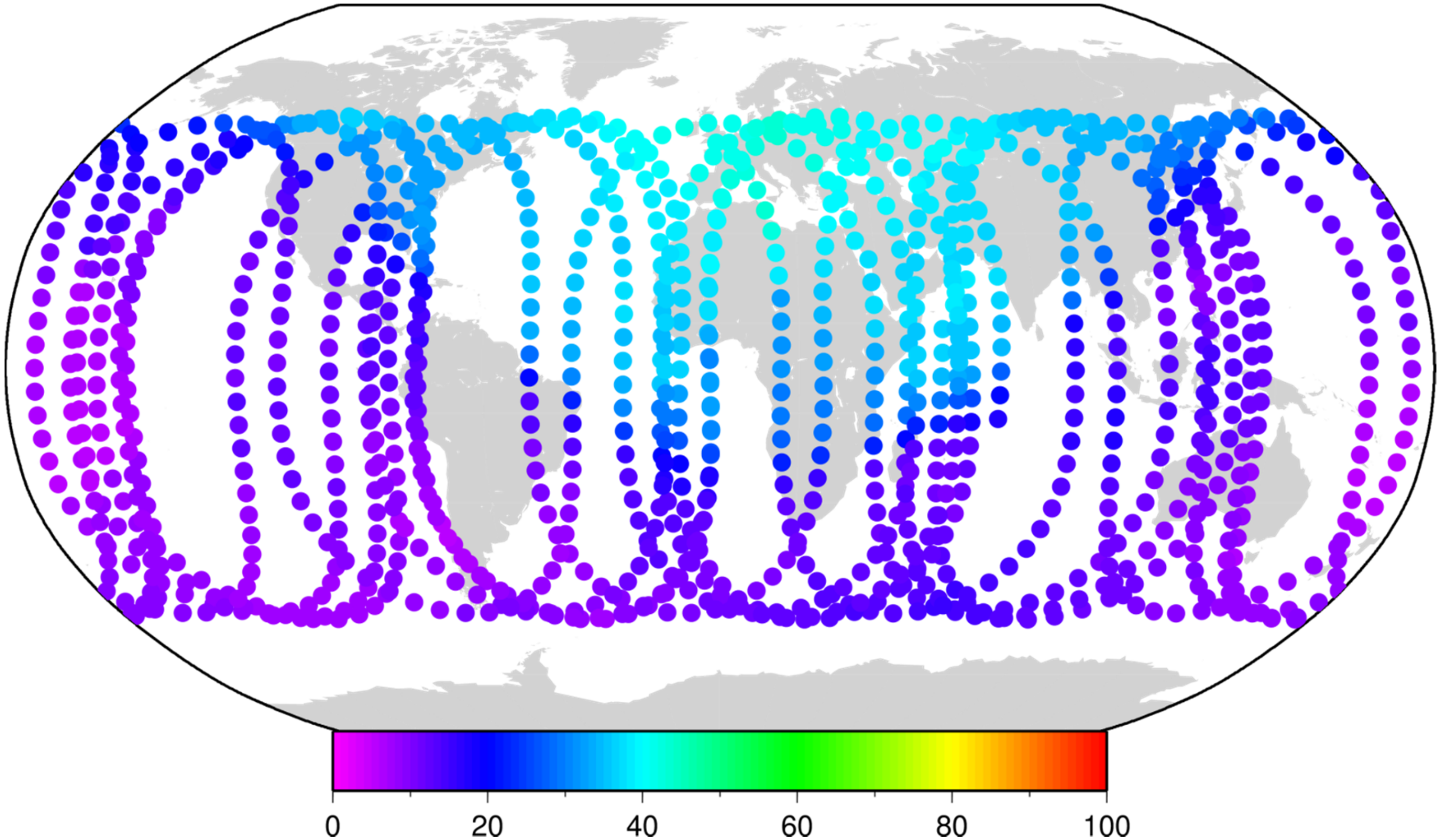


Advantage of the „Extracted orbit for day n" with respect to the direct „Orbit solution day n":

- no (or at least less) degradation of the orbit at the end of the boundary.
- smoothed day boundary discontinuities
(in particular if the satellite was only weakly observed)

CODE-MGEX: „trackability“

Number of stations that could theoretically track the satellites of the **Galileo** constellation; sampling 15 min; **DOYs 150-152**



=> long-arc: several passes over reasonable number of stations

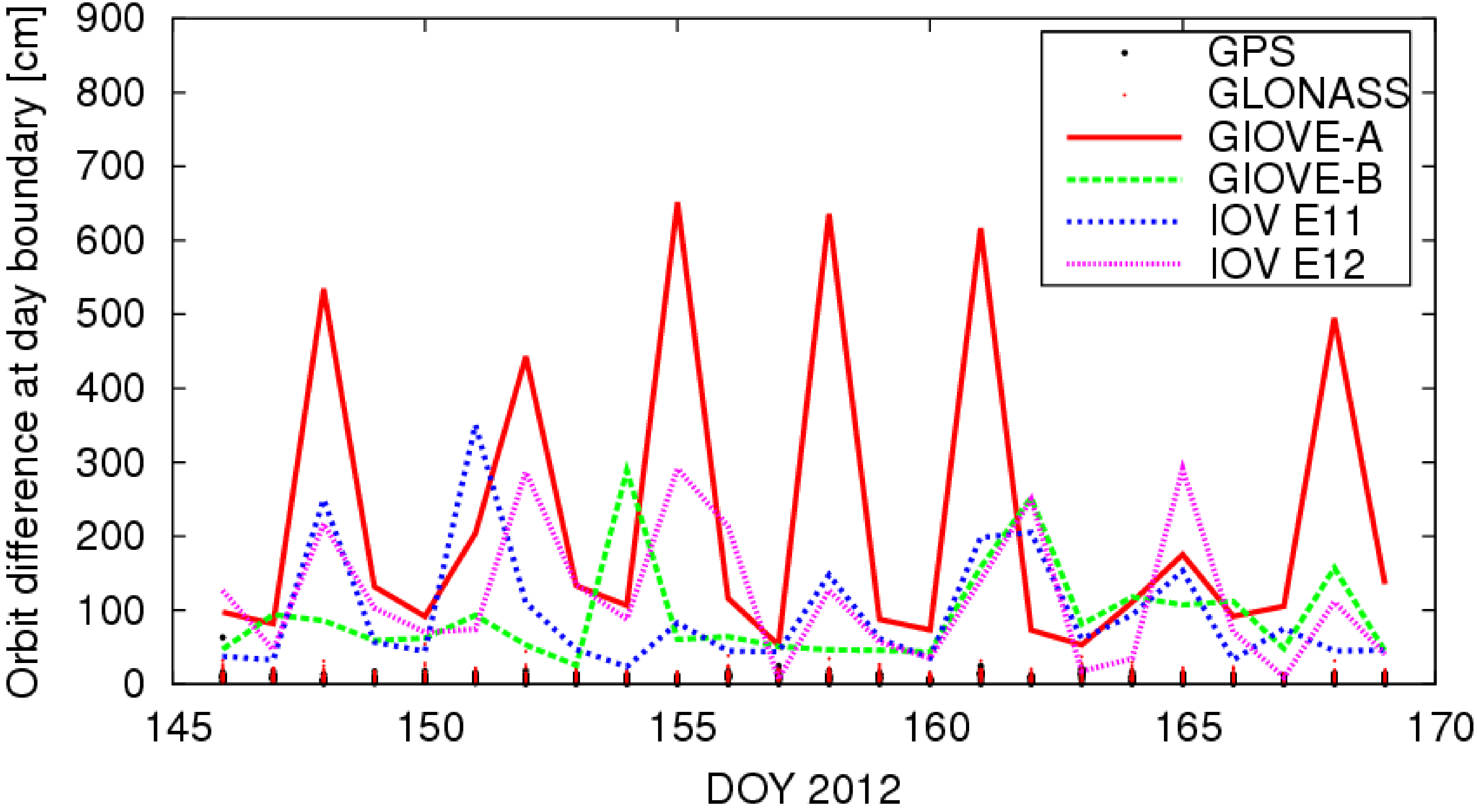
Methods for orbit validation

1. Orbit overlaps

CODE-MGEX solution: orbit overlaps

GPS, GLONASS, Galileo: 1 day arcs

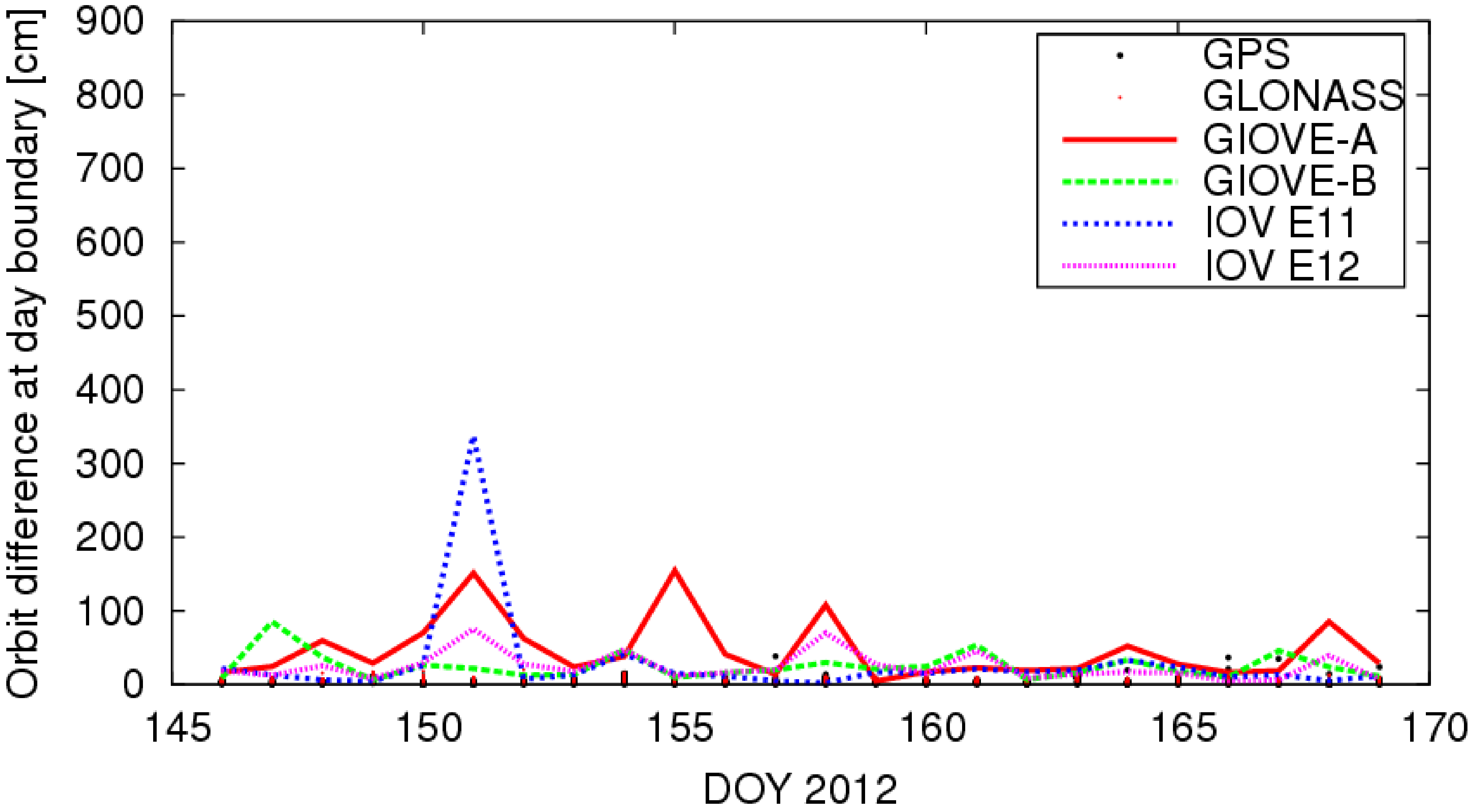
(mean: G01: 7.6 cm; R24: 10.1 cm; Galileo: 90 – 220 cm)



CODE-MGEX solution: orbit overlaps

GPS, GLONASS, Galileo: 3 day arcs (last; RAPID-mode)

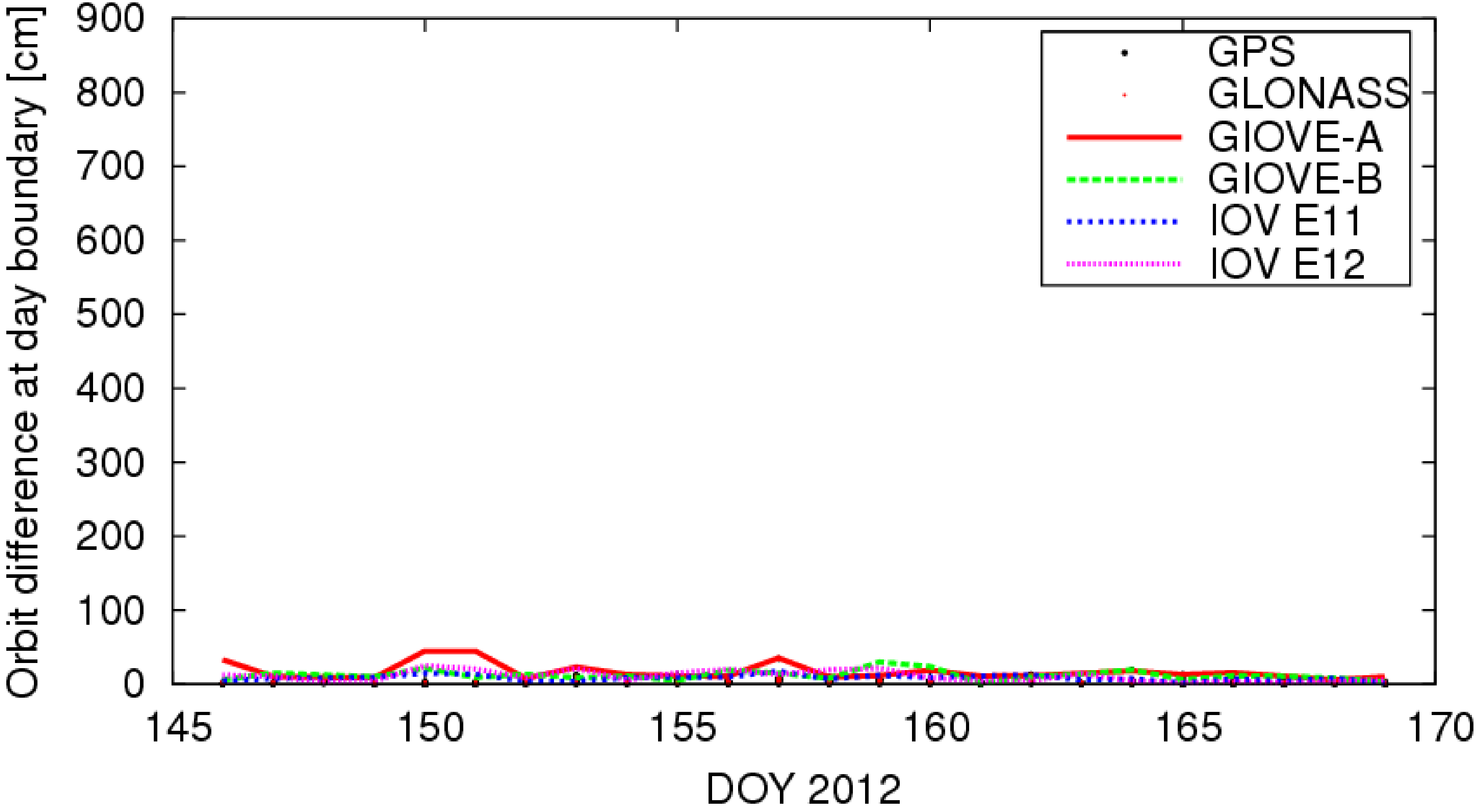
(mean: G01: 5.2 cm; R24: 5.3 cm; Galileo: 25 – 46 cm)



CODE-MGEX solution: orbit overlaps

GPS, GLONASS, Galileo: 3 day arcs (mid)

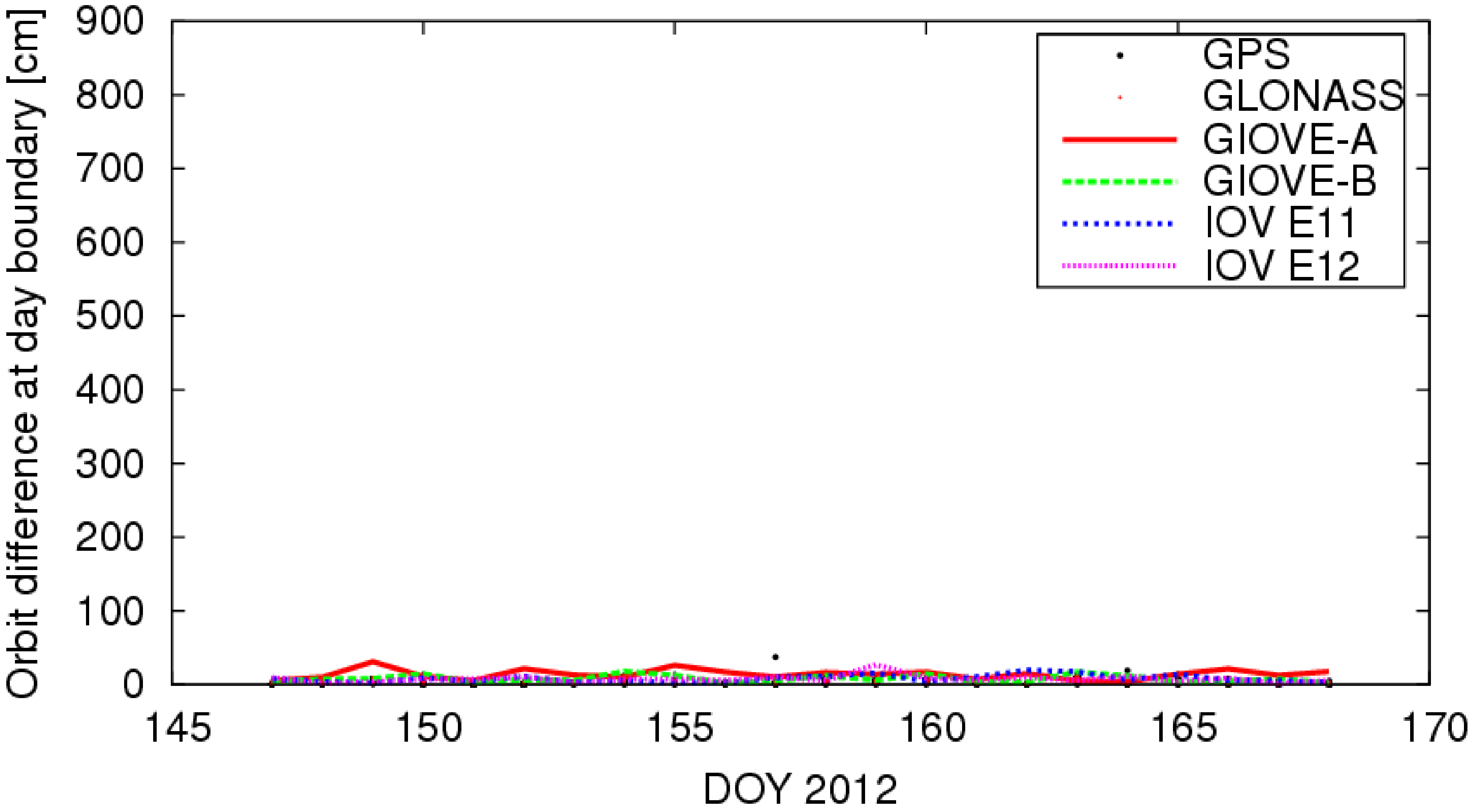
(mean: G01: 3.5 cm; R24: 3.5 cm; Galileo: 8.5 – 17 cm)



CODE-MGEX solution: orbit overlaps

GPS, GLONASS, Galileo: 5 day arcs (mid)

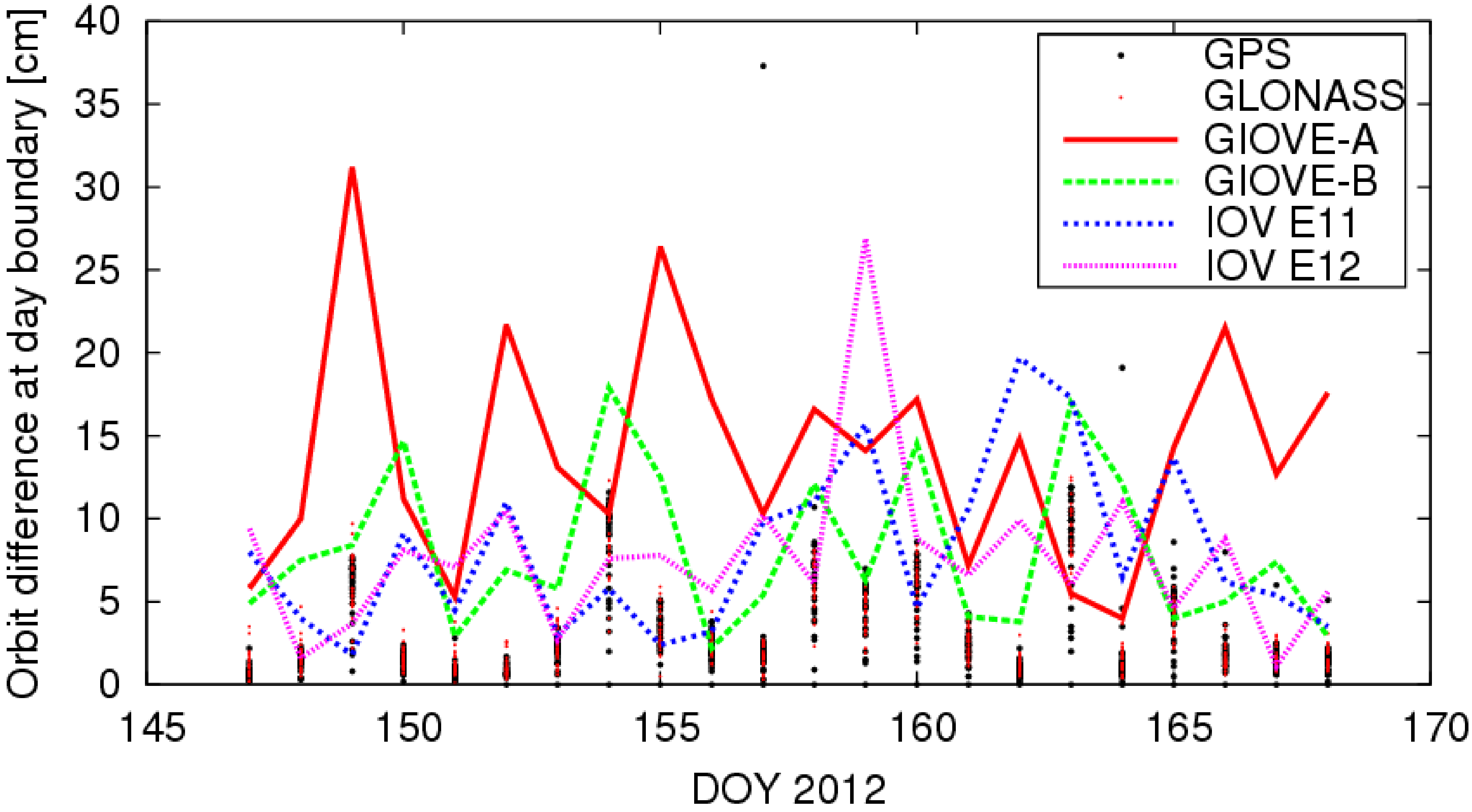
(mean: G01: 3.5 cm; R24: 3.5 cm; Galileo: 8 – 14 cm)



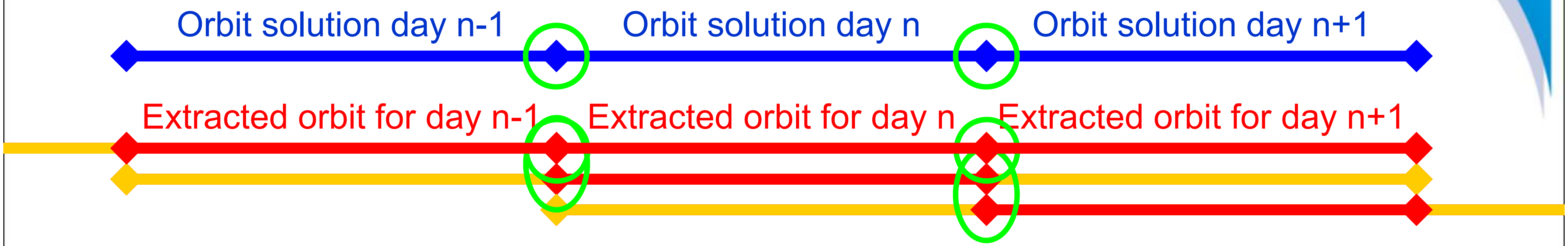
CODE-MGEX solution: orbit overlaps

GPS, GLONASS, Galileo: 5 day arcs (mid)

(mean: G01: 3.5 cm; R24: 3.5 cm; Galileo: 8 – 14 cm)



Orbit overlaps for multi-day arcs



Disadvantage of the „Extracted orbit for day n“ with respect to the direct „Orbit solution day n“:

- The orbits extracted from the three-day arc are not independent anymore.
- Day boundary discontinuities cannot be used as a real quality indicator anymore.

Methods for orbit validation

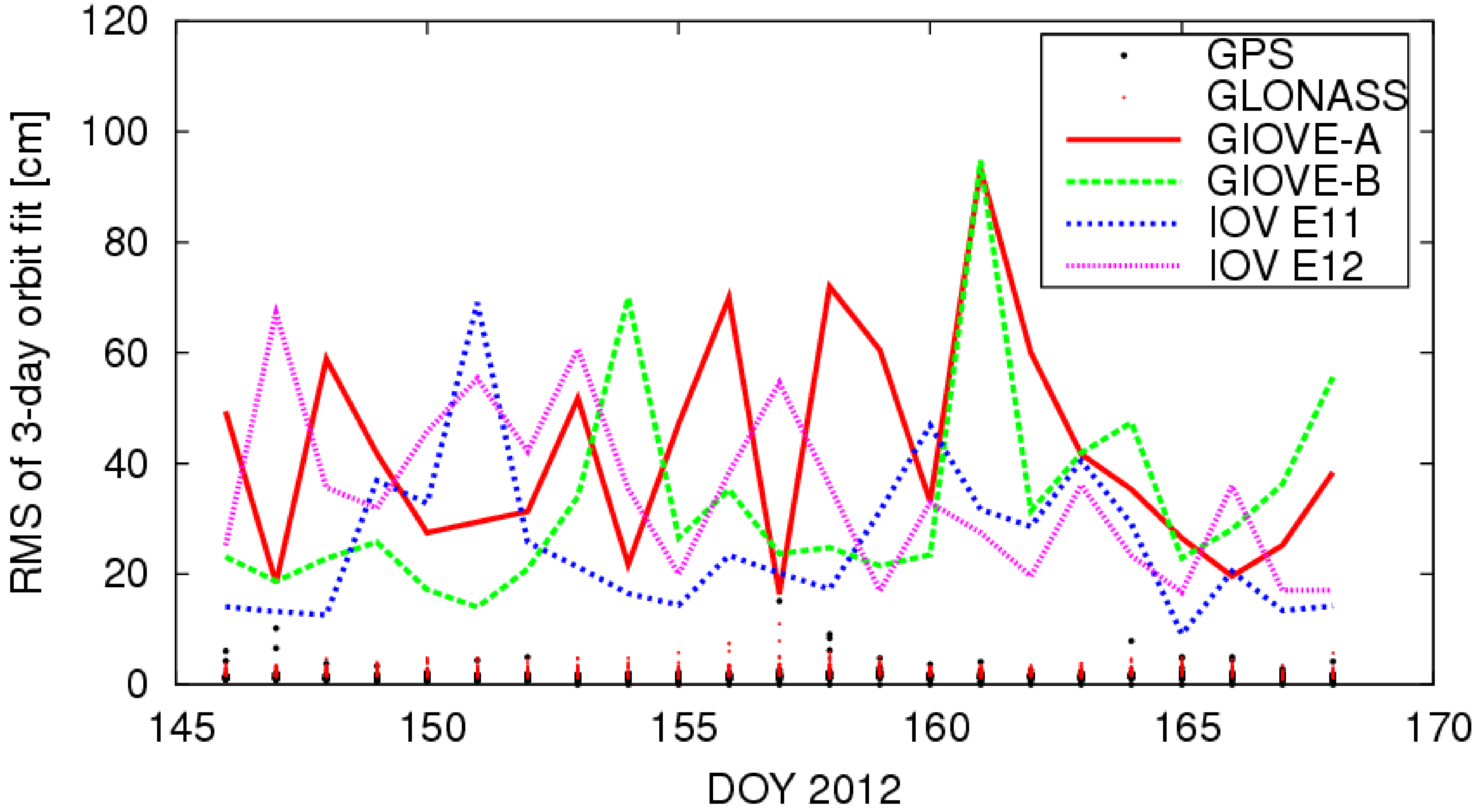
1. Orbit overlaps

2. Fitting long-arcs

CODE-MGEX solution: 3-day orbit fit

GPS, GLONASS, Galileo: 1 day arcs

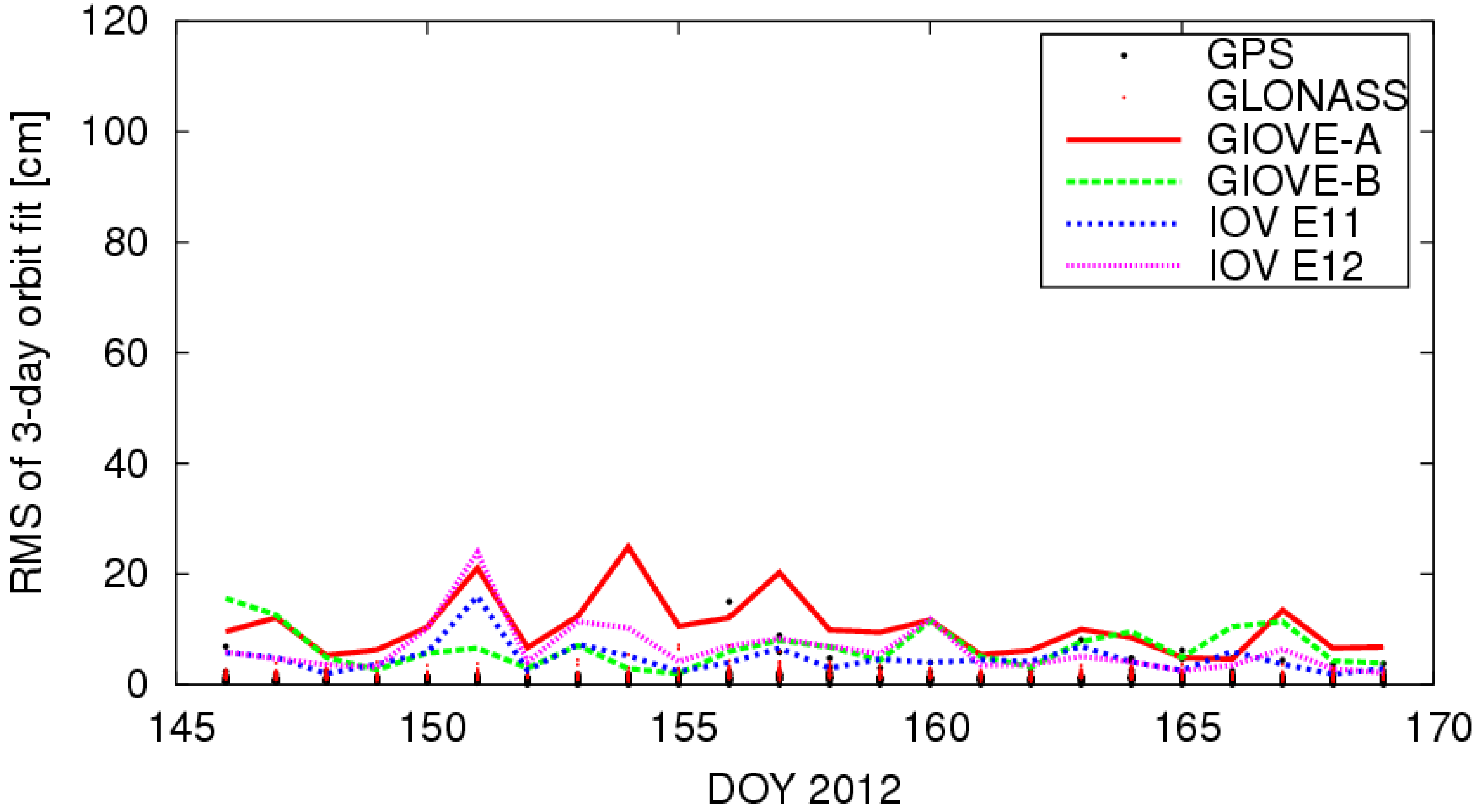
(mean: G01: 1.5 cm; R24: 2.4 cm; Galileo: 25 – 42 cm)



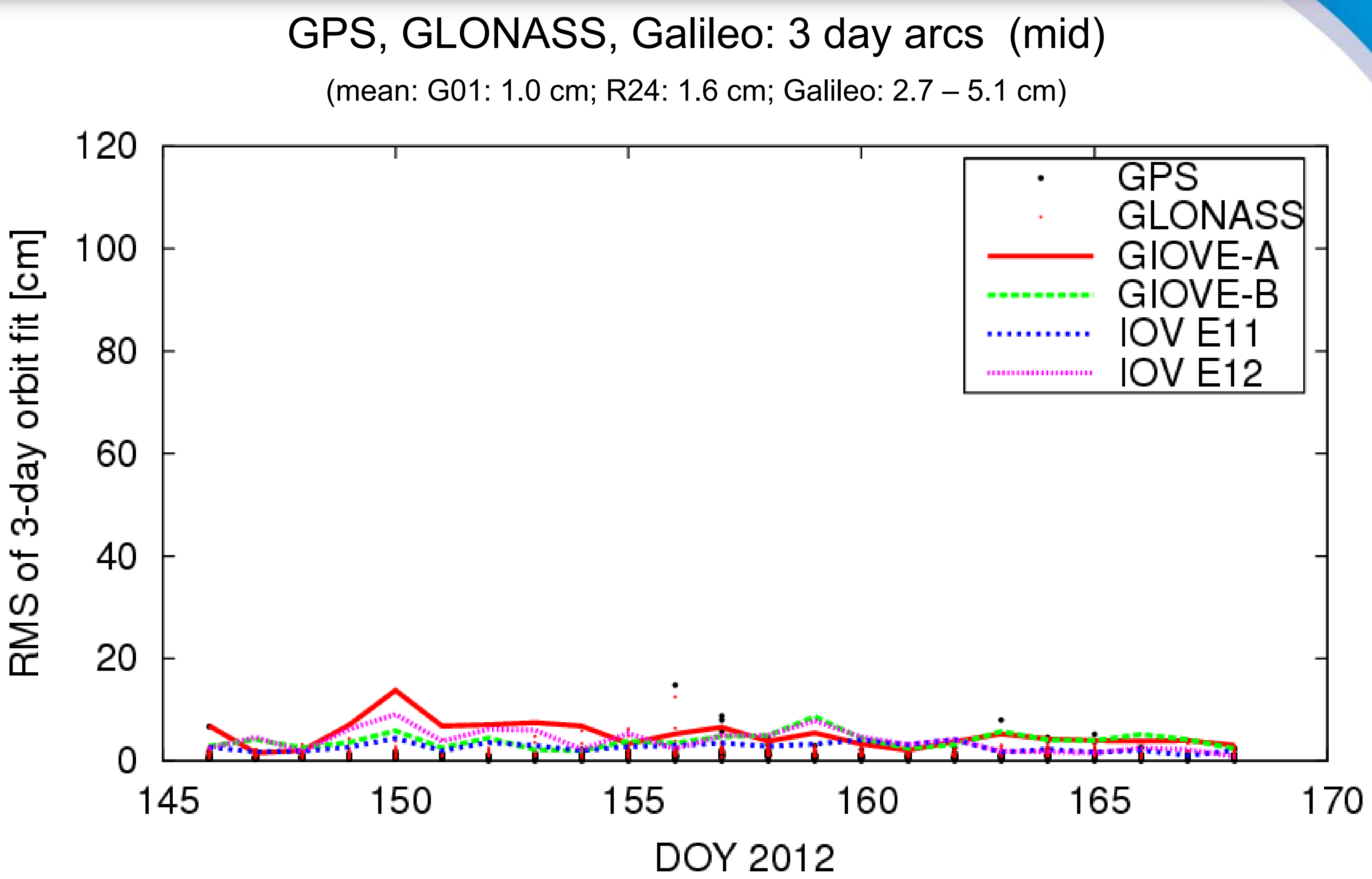
CODE-MGEX solution: 3-day orbit fit

GPS, GLONASS, Galileo: 3 day arcs (last; RAPID-mode)

(mean: G01: 1.2 cm; R24: 1.8 cm; Galileo: 4.8 – 10.4 cm)



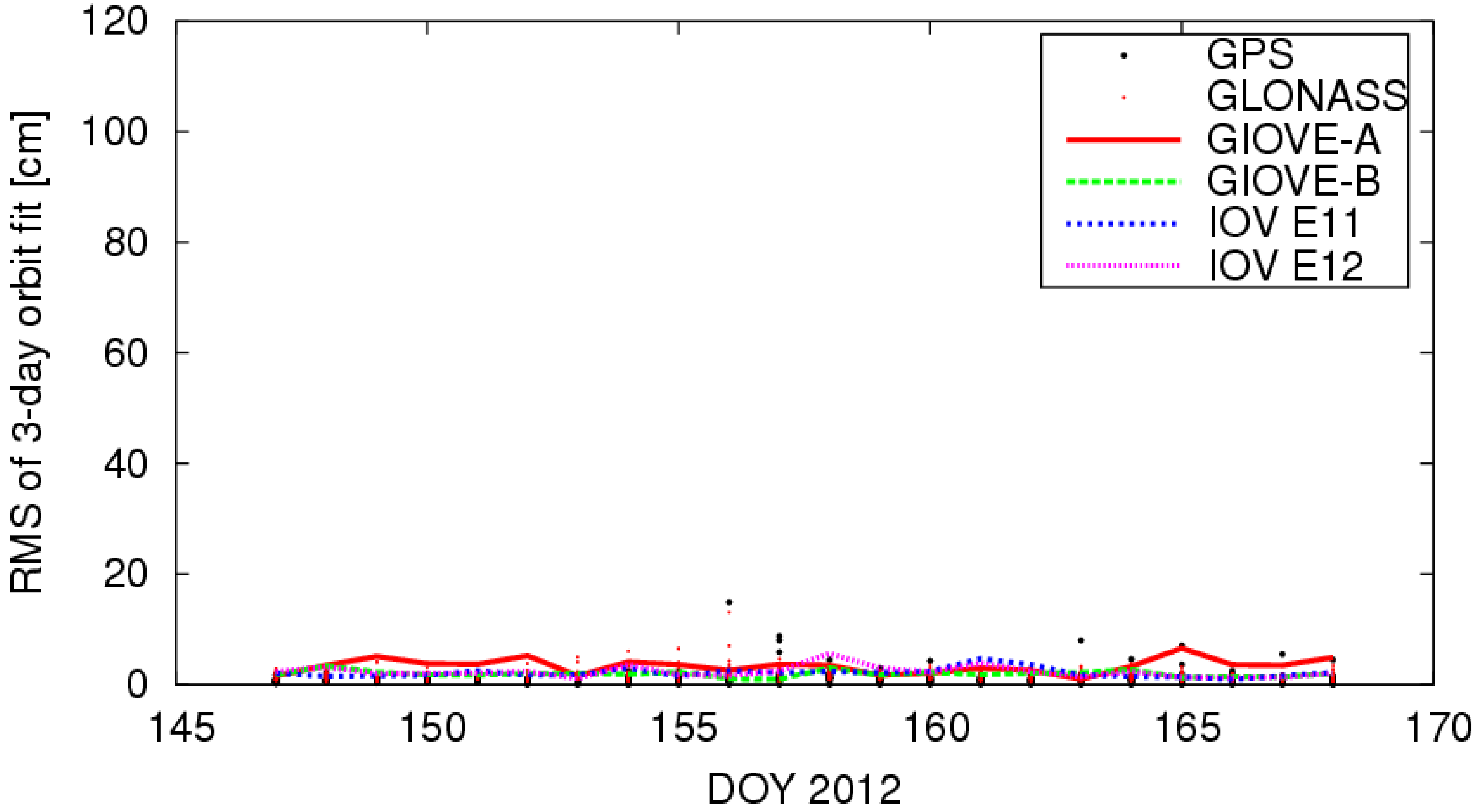
CODE-MGEX solution: 3-day orbit fit



CODE-MGEX solution: 3-day orbit fit

GPS, GLONASS, Galileo: 5 day arcs (mid)

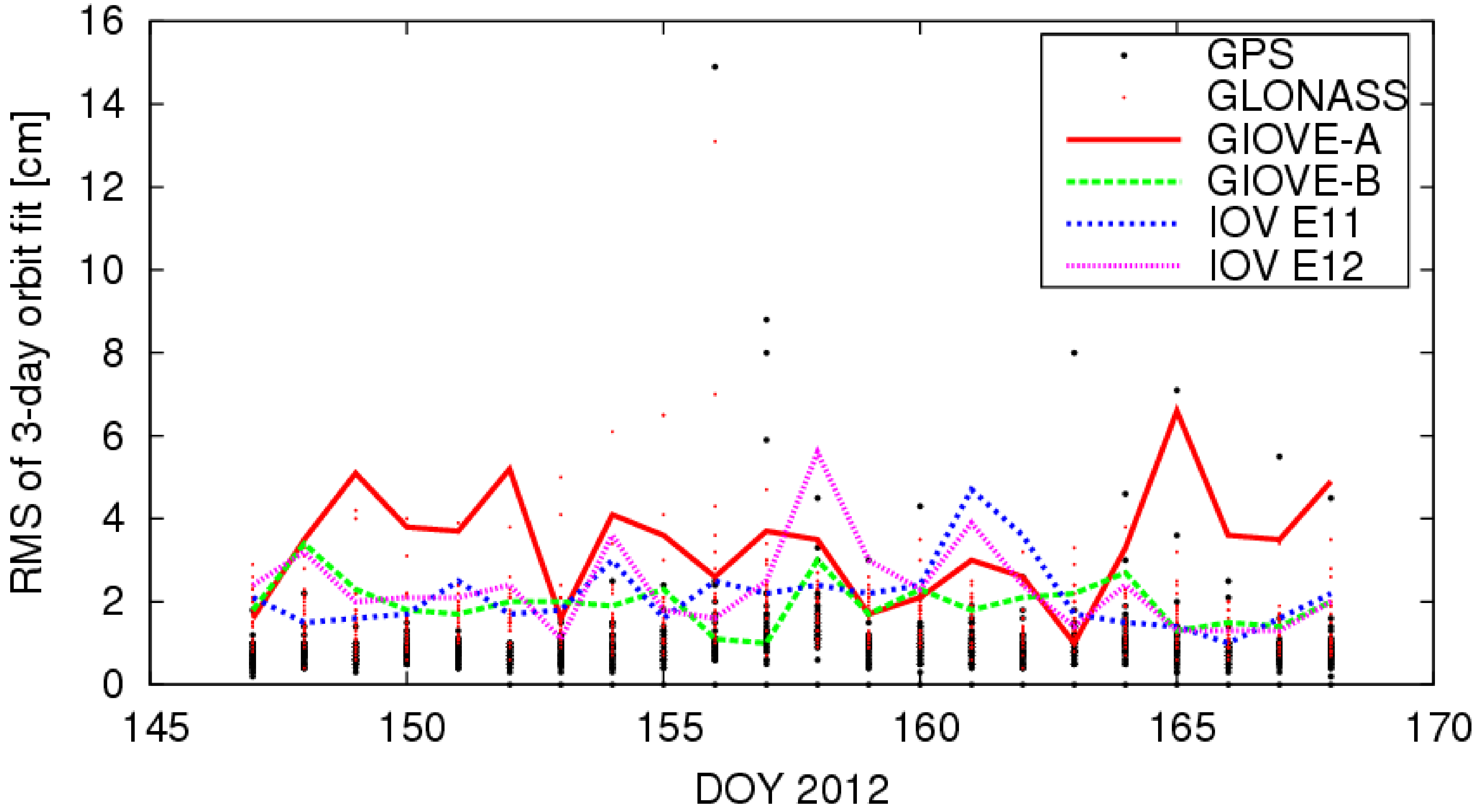
(mean: G01: 0.9 cm; R24: 1.5 cm; Galileo: 2.0 – 3.4 cm)



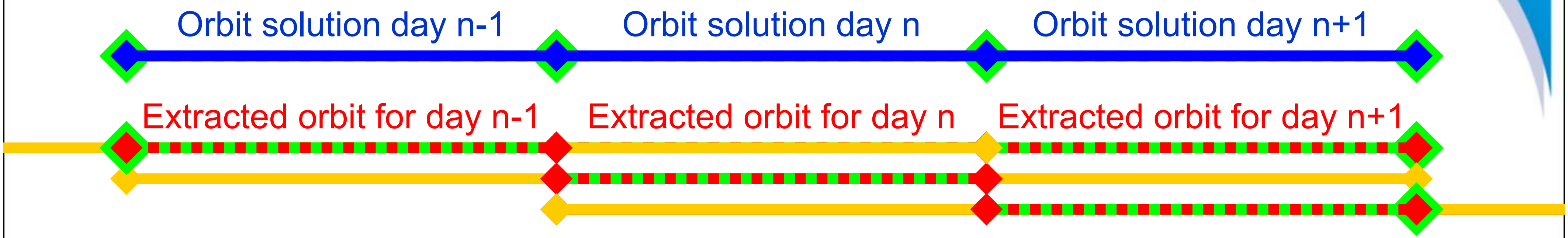
CODE-MGEX solution: 3-day orbit fit

GPS, GLONASS, Galileo: 5 day arcs (mid)

(mean: G01: 0.9 cm; R24: 1.5 cm; Galileo: 2.0 – 3.4 cm)



3-day orbit fit for multi-day arcs



Disadvantage of the „Extracted orbit for day n" with respect to the direct „Orbit solution day n":

- The orbits extracted from the three-day arc are not independent anymore.
- An orbit fit over several days cannot be used as a real quality indicator anymore.

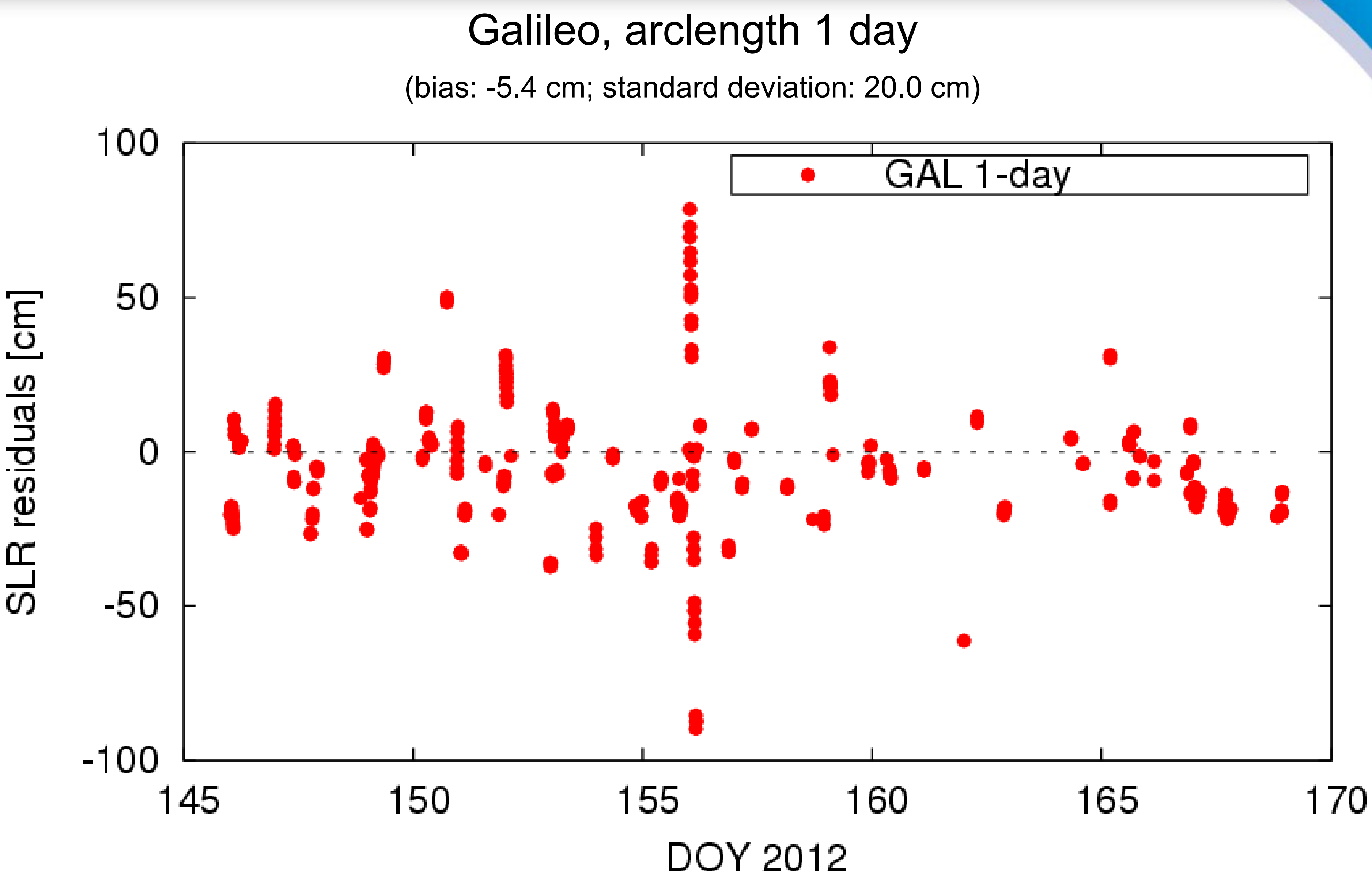
Methods for orbit validation

1. Orbit overlaps

2. Fitting long-arcs

3. Comparison with independent measurements (e.g., SLR)
   - Consistency of the station coordinates between GNSS and SLR is required.
   - Biases of both techniques need to be known.
   - In case of problems an identification must be implemented to define which technique has caused the problem.

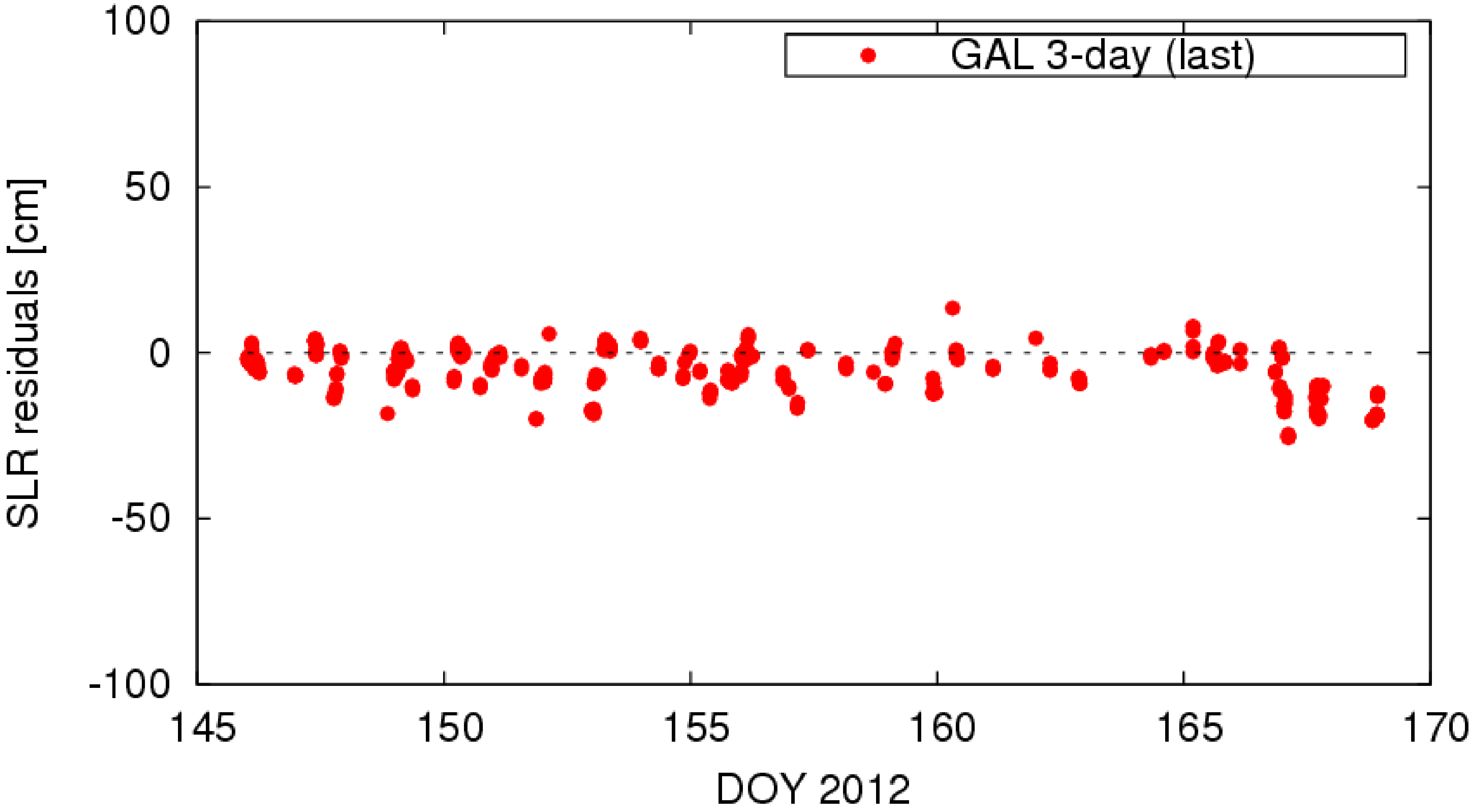
CODE-MGEX solution: SLR residuals



CODE-MGEX solution: SLR residuals

Galileo, last day of 3-day long-arc (RAPID-mode)

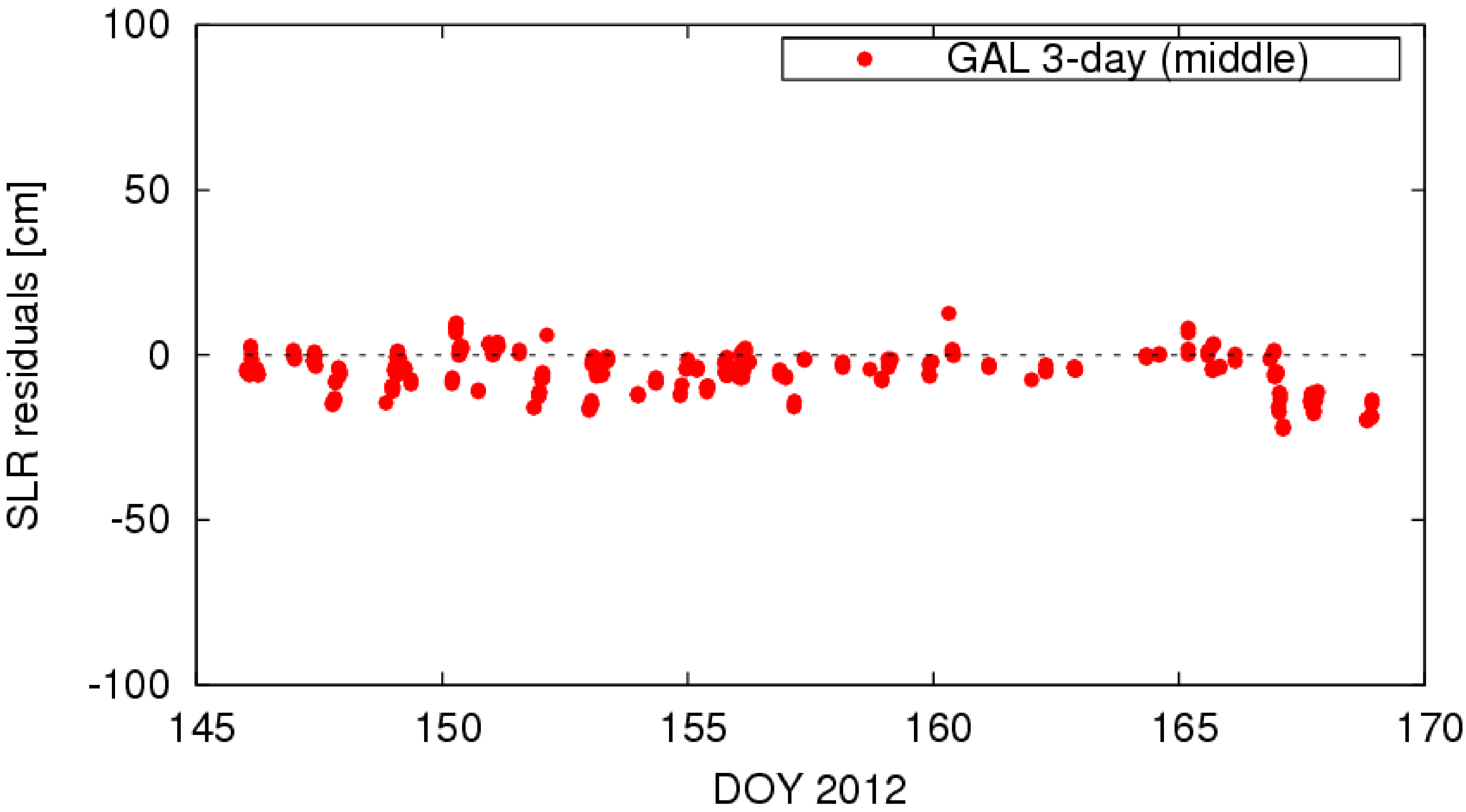
(bias: -5.0 cm; standard deviation: 6.4 cm)



CODE-MGEX solution: SLR residuals

Galileo, mid day of 3-day long-arc

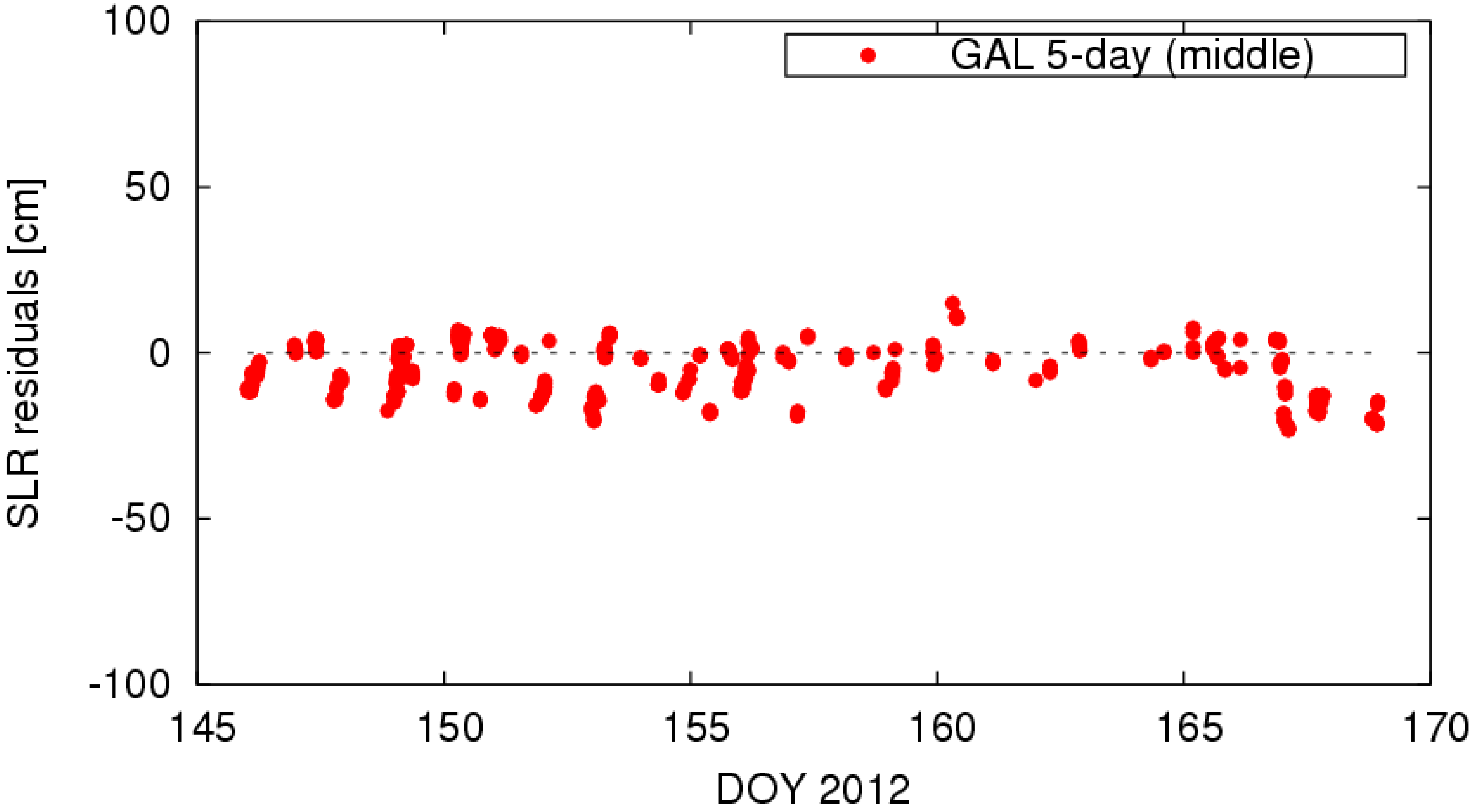
(bias: -5.0 cm; standard deviation: 5.8 cm)



CODE-MGEX solution: SLR residuals

Galileo, mid day of 5-day long-arc

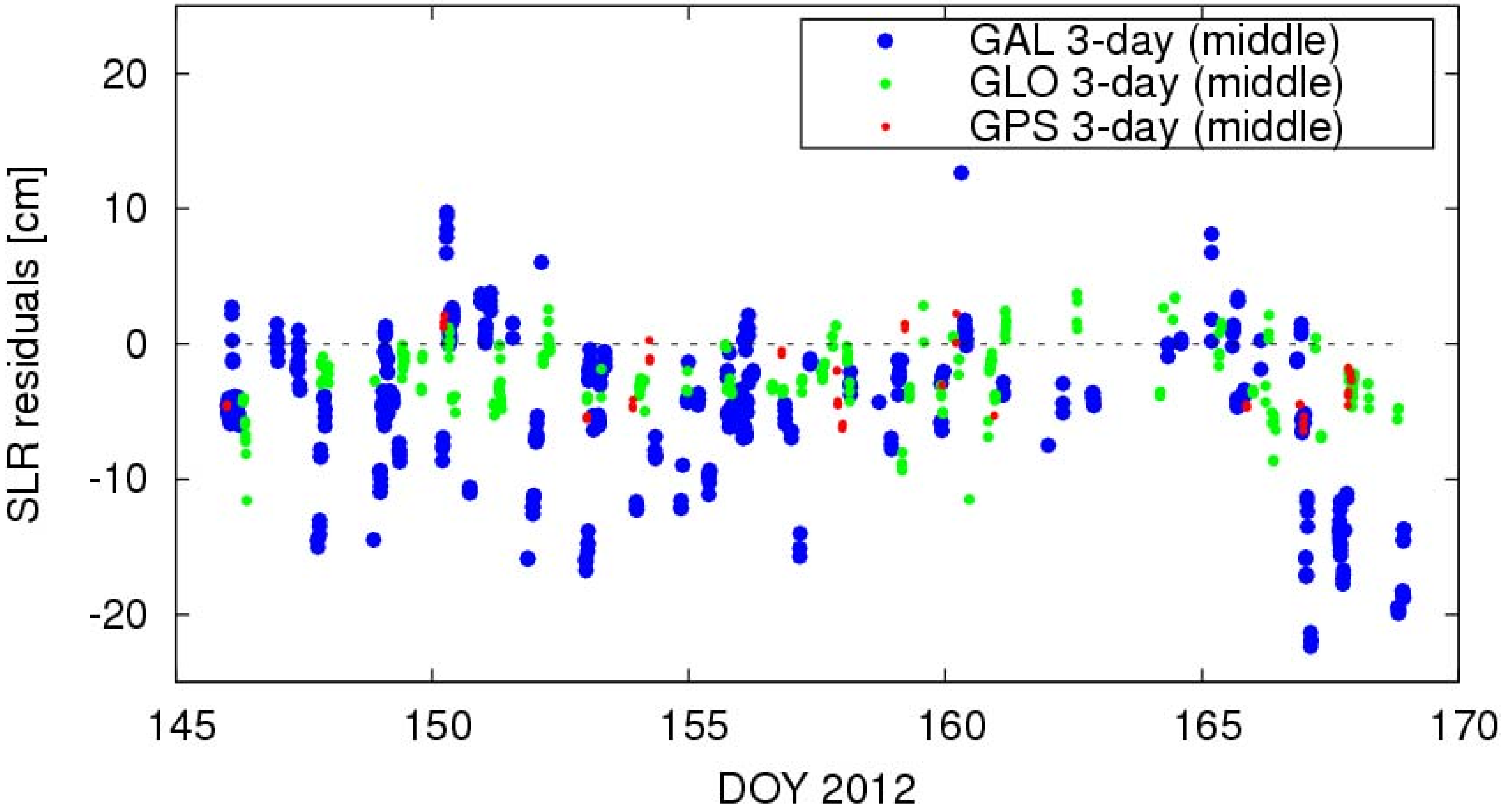
(bias: -5.4 cm; standard deviation: 7.9 cm)



CODE-MGEX solution: SLR residuals

Comparison of satellite systems

(GPS / GLO / GAL: bias: -3.1 / -2.5 / -5.0 cm; STD: 2.5 / 2.5 / 5.8 cm)



Length of orbital arcs

GNSS data are typically provided in observation files of one day.
A one-day orbit solution is, therefore, native.

Why longer orbital arcs?

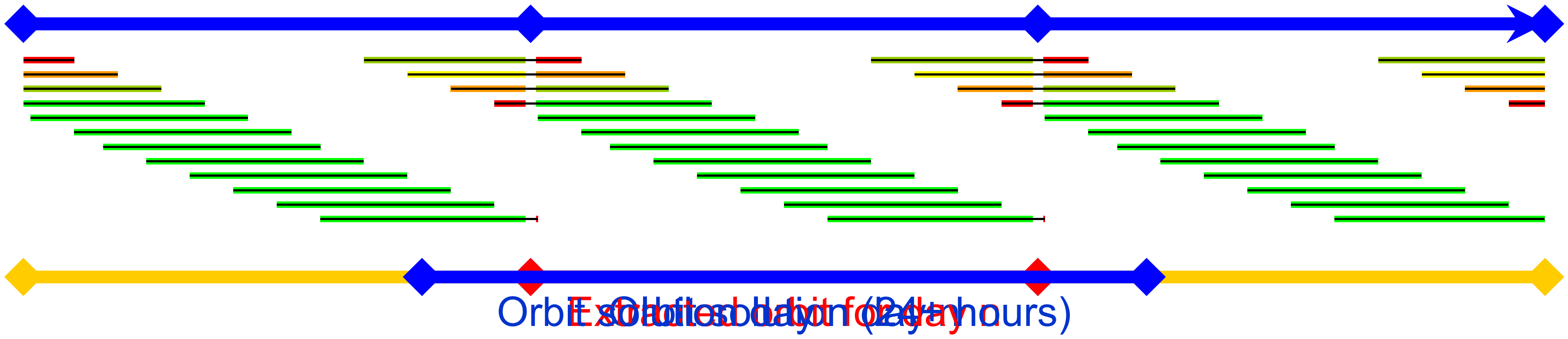
- With longer satellite arcs deficiencies in the tracking network can be compensated. The solution becomes more robust for poorly observed satellites.
- The orbit model must be good enough to represent the satellite trajectory during the longer satellite arc.

Why not longer orbital arcs?

- The consecutive days are not independent anymore.
  - need to be considered when validating the orbits
  - problems in the analysis from one day may degrade also the orbits from other days.
  - the measurements are used more than once.

Length of orbital arcs

The receiver are continuously measuring but the ambiguities from one satellite pass are artificially cut due to processing batches.



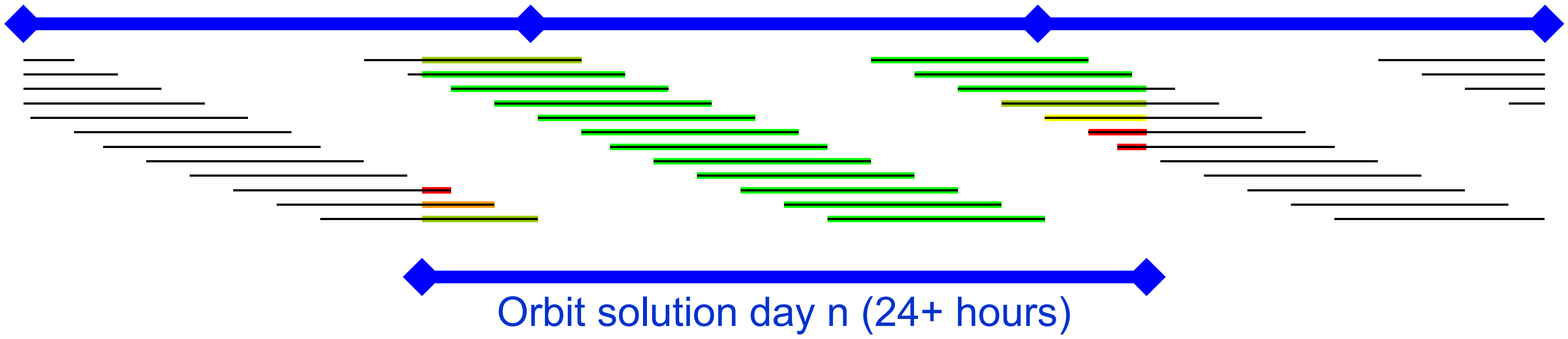
An orbit arc is affected by poorly determined ambiguities at its boundaries.

This can be compensated

- extracting the orbit for day *n* from a long arc over three (or more) days.
- increase the length of the processing batch.

Length of orbital arcs

The receiver are continuously measuring but the ambiguities from one satellite pass are artificially cut due to processing batches.



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- extracting the orbit for day *n* from a long arc over three (or more) days.
- increase the length of the processing batch.

Length of orbital arcs

The receiver are continuously measuring but the ambiguities from one satellite pass are artificially cut due to processing batches.

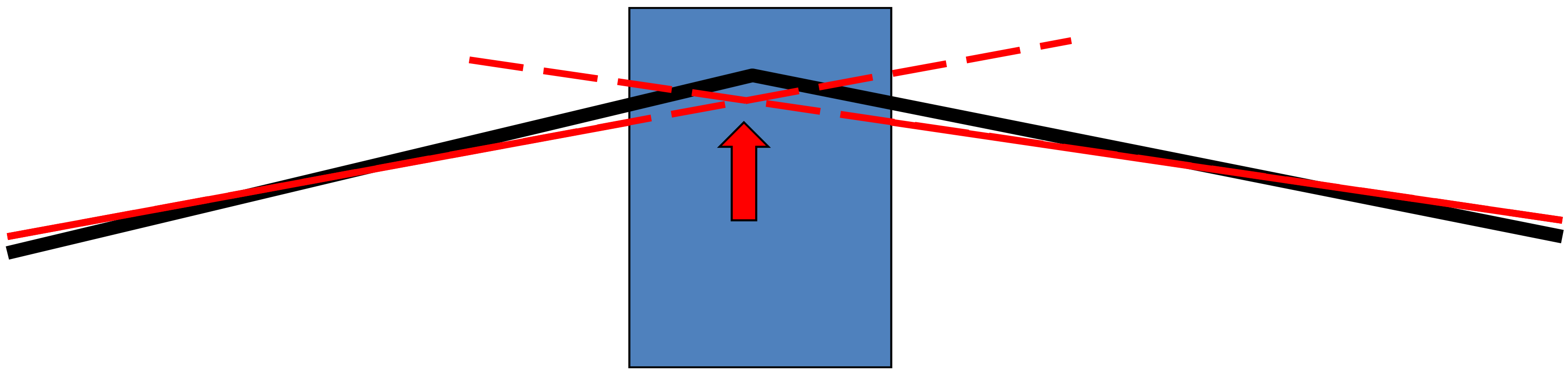
An orbit arc is affected by poorly determined ambiguities at its boundaries.

This can be compensated

- extracting the orbit for day *n* from a long arc over three (or more) days.
  - Each observation is used exact three times.
  - Can easily be generated on normal equation level.
    (each observation needs only be processed once)
- increase the length of the processing batch.
  - Orbital arcs are shorter – less smoothing.
  - Observation files need to be re-organized (from daily files).
  - The processing for each arc starts from the original observation what increases the processing load.

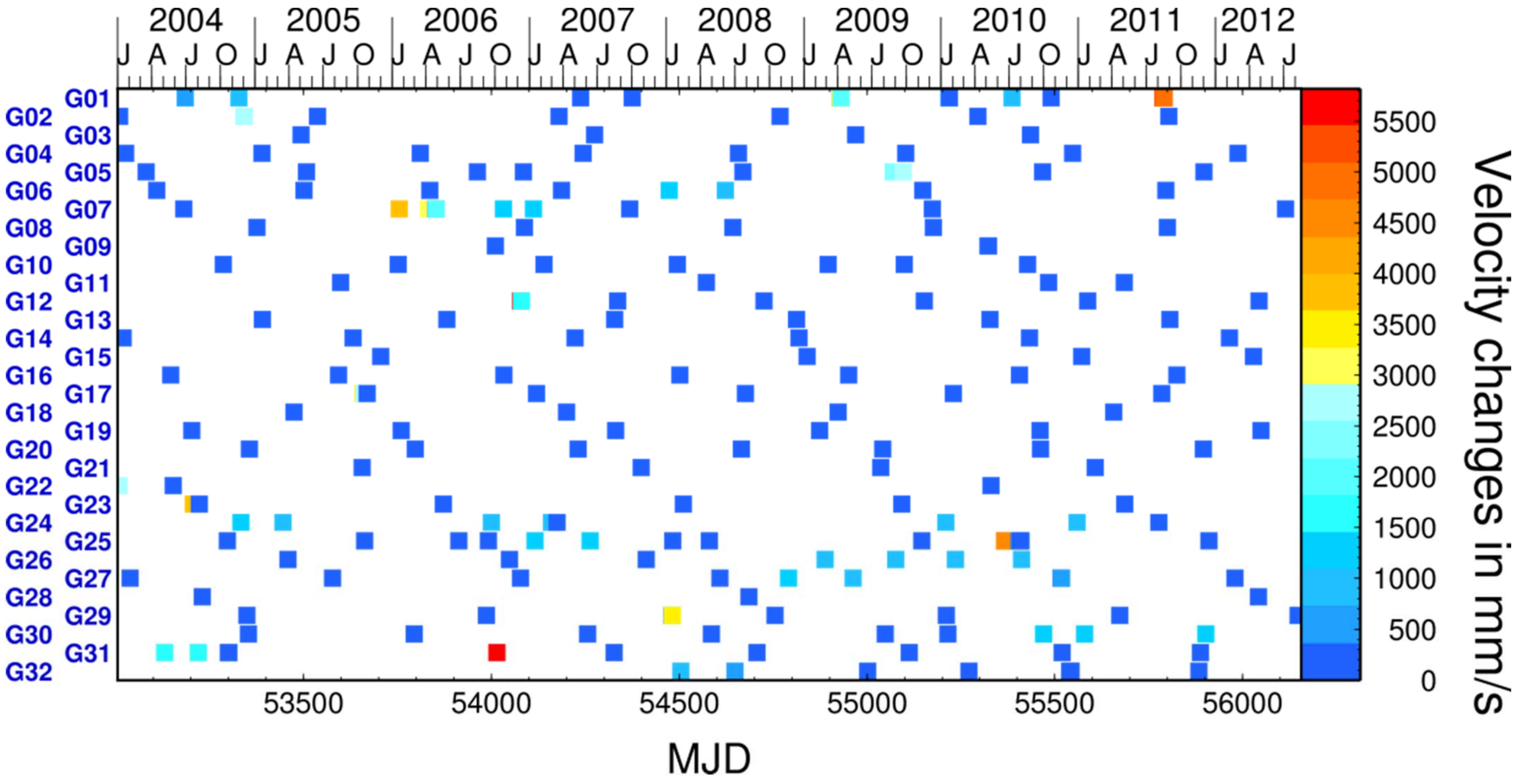
GPS satellite repositioning events

CODE determines the repositioning events for the GPS satellites.



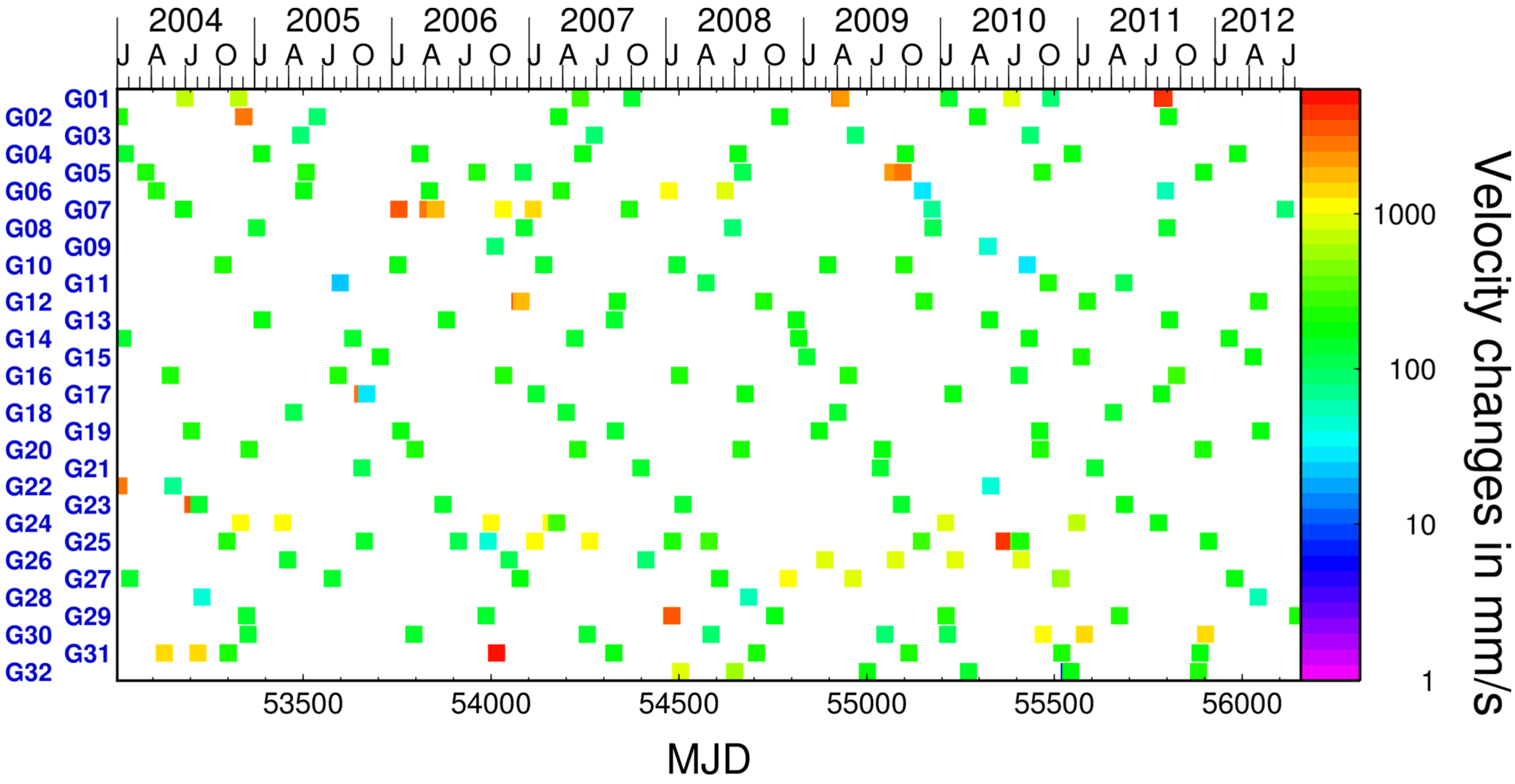
- Two independent satellite arcs are assumed (before and after the event)
- The smallest distance between both arcs gives the epoch and magnitude of the event.

GPS satellite repositioning events



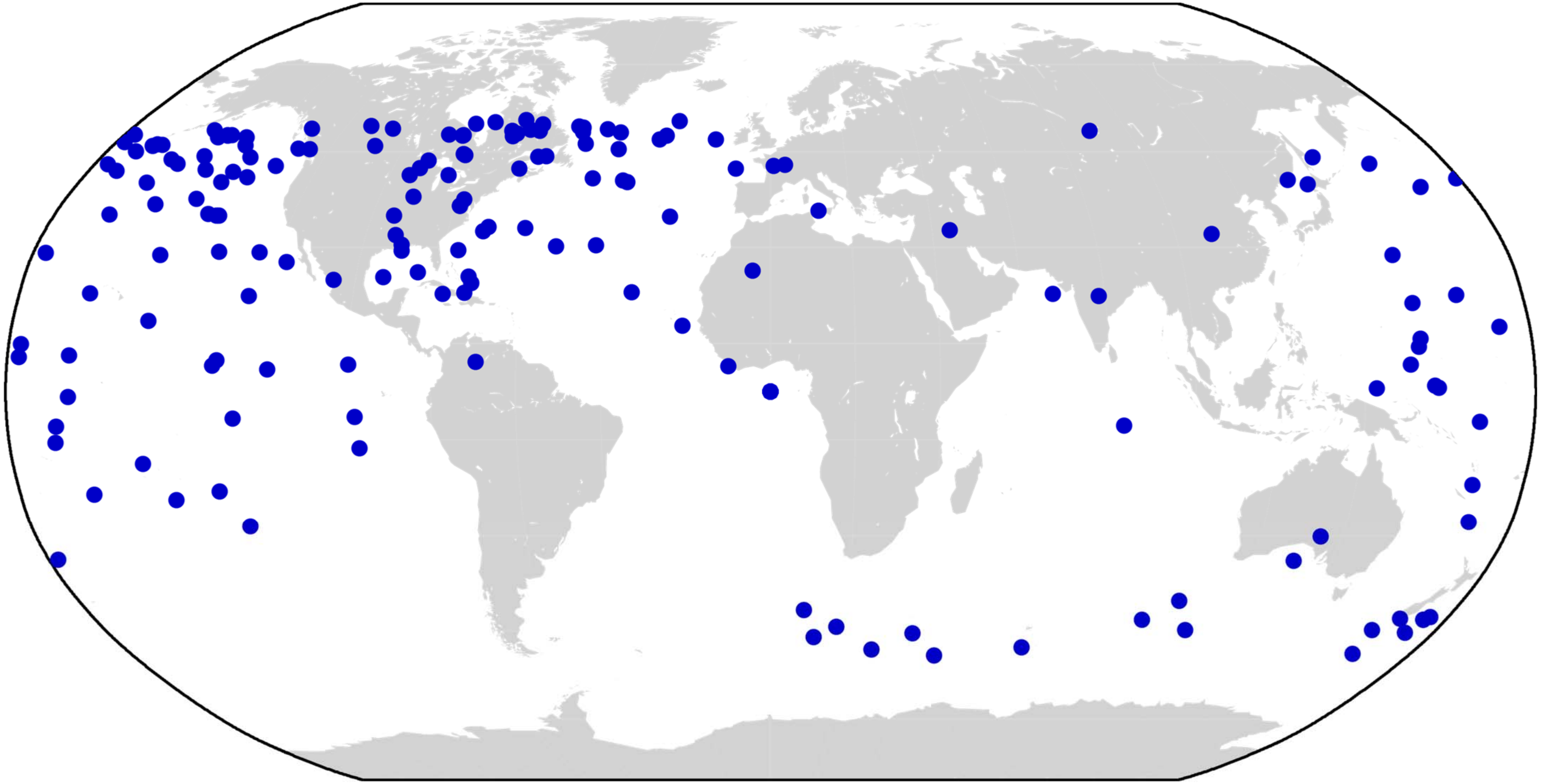
As computed by CODE

GPS satellite repositioning events



As computed by CODE

GPS satellite repositioning events



As computed by CODE

Outline

- **Introduction**
- **Orbit Determination (at CODE)**
- **Code Biases: DCB, ISB, IFB**
  - GNSS observation equation as starting point
  - Dependencies of components in the observation equation from GNSS, frequency and observation type and resulting biases
  - DCBs in a GPS, GLONASS, GPS/GLONASS network solution
  - How DCBs can be computed?
  - Bonus: GLONASS-GPS translation bias

GNSS observation equation

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

GNSS observation equation

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

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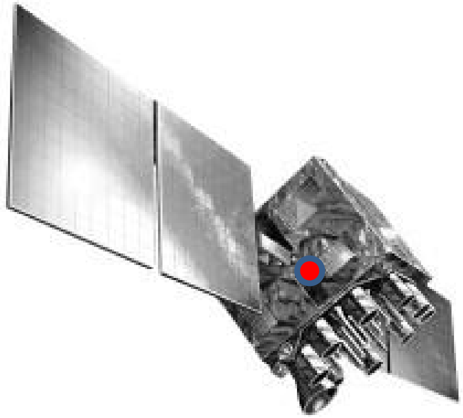
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

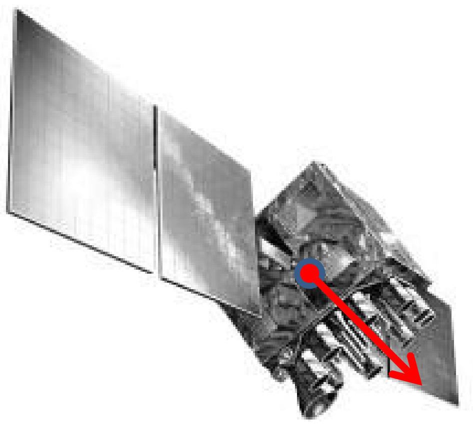


$\overrightarrow{x^k}$ position vector of satellite *k* related to its center of mass

GNSS observation equation

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$



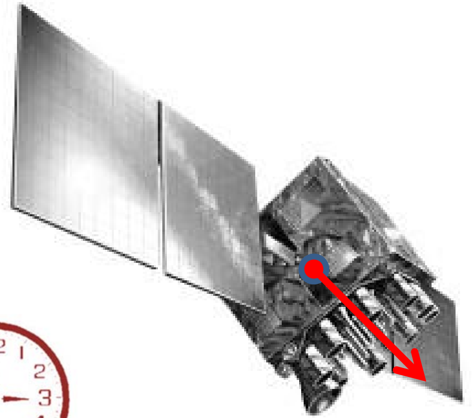
$\overrightarrow{x^k}$ position vector of satellite *k* related to its center of mass

$\overrightarrow{\Delta x^k}$, $\overrightarrow{\Delta \chi^k}$ vector from the center of mass of the satellite *k* to the antenna signal emission point for code and phase observations

GNSS observation equation

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c\cdot(\delta_i + a_i) - c\cdot\left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c\cdot(\delta_i + \alpha_i) - c\cdot\left(\delta^k + \alpha^k\right)$$
$$+\lambda^k\cdot N_i^k + \lambda^k\cdot\Delta\varphi_i^k$$



$\overrightarrow{x^k}$ — position vector of satellite *k* related to its center of mass

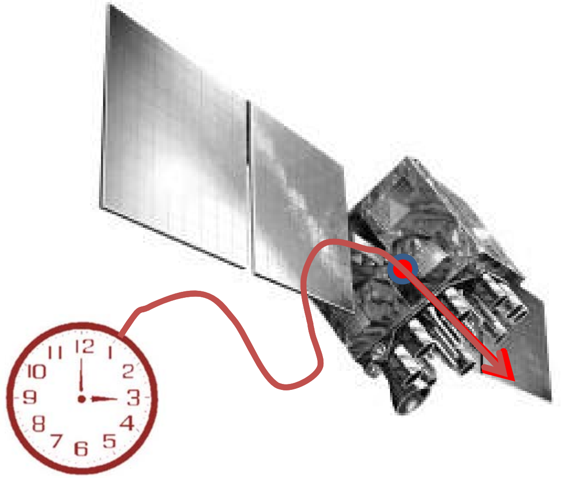
$\overrightarrow{\Delta x^k}$, $\overrightarrow{\Delta \chi^k}$ — vector from the center of mass of the satellite *k* to the antenna signal emission point for code and phase observations

δ^k — clock correction of the satellite *k* with respect to GPS time

GNSS observation equation

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + {\color{red}a^k}\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + {\color{red}\alpha^k}\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

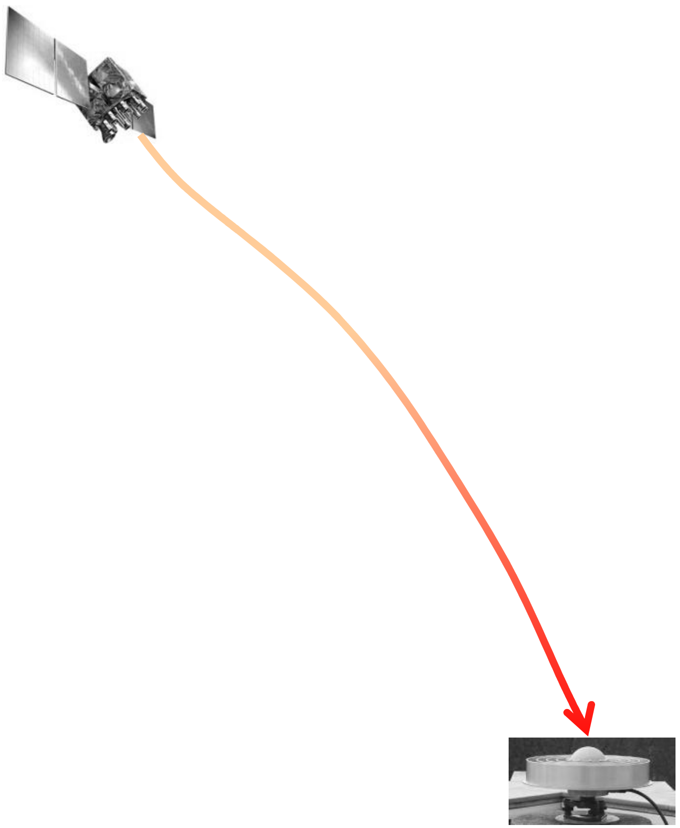


$\overrightarrow{x^k}$	position vector of satellite *k* related to its center of mass
$\overrightarrow{\Delta x^k}$, $\overrightarrow{\Delta \chi^k}$	vector from the center of mass of the satellite *k* to the antenna signal emission point for code and phase observations
δ^k	clock correction of the satellite *k* with respect to GPS time
a^k, α^k	hardware delay in the satellite *k* for code and phase measurements

GNSS observation equation

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$



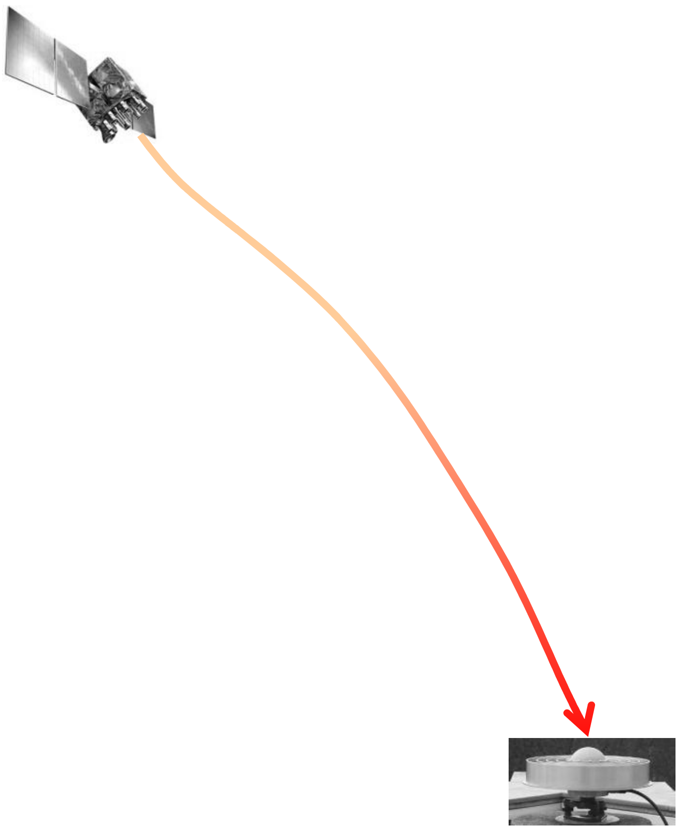
I_i^k signal delay in the ionosphere

T_i^k signal delay in the troposphere

GNSS observation equation

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$



I_i^k signal delay in the ionosphere

T_i^k signal delay in the troposphere

GNSS observation equation

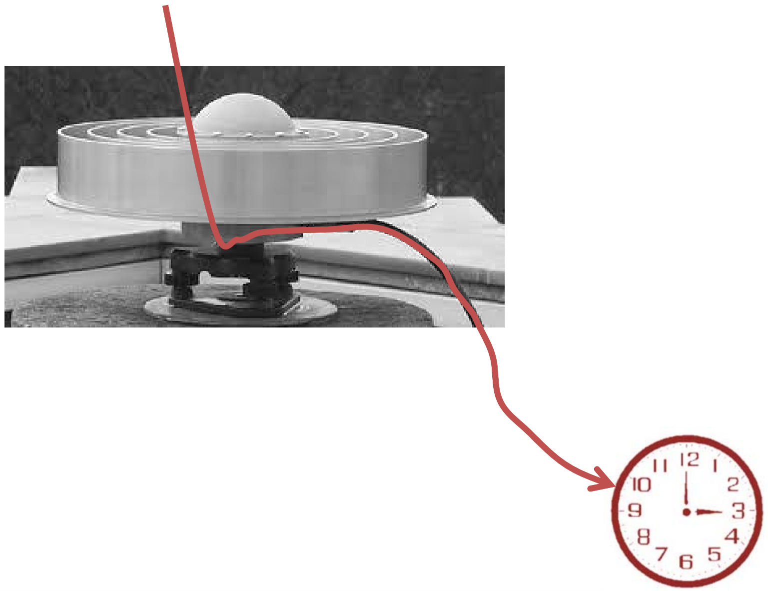
$$P_i^k = \left| \left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k} \right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i} \right) \right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k \right)$$

$$L_i^k = \left| \left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k} \right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i} \right) \right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k \right)$$
$$+ \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

GNSS observation equation

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

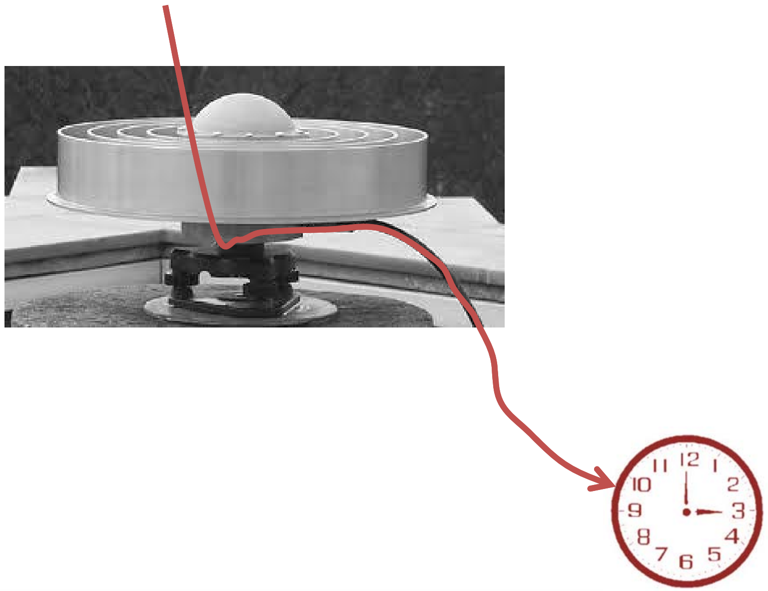


GNSS observation equation

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

a_i, α_i hardware delay in the receiver at the station *i* for code and phase measurements

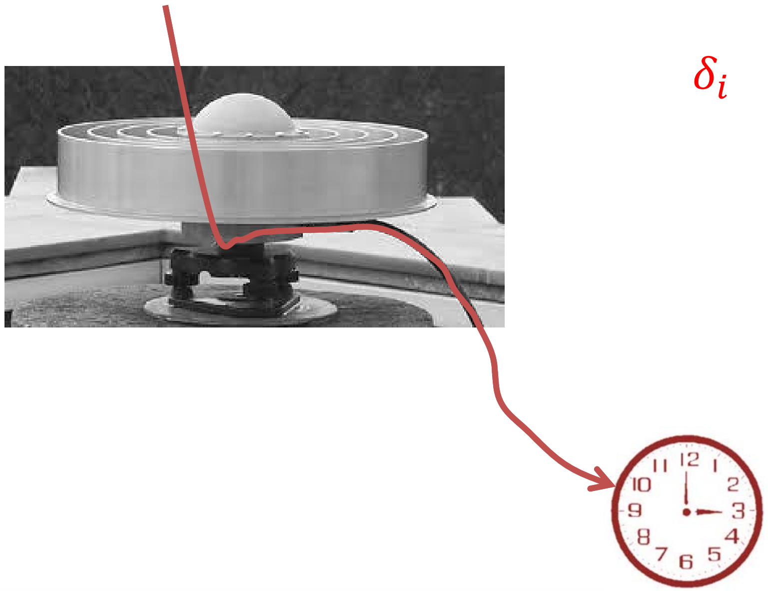


GNSS observation equation

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

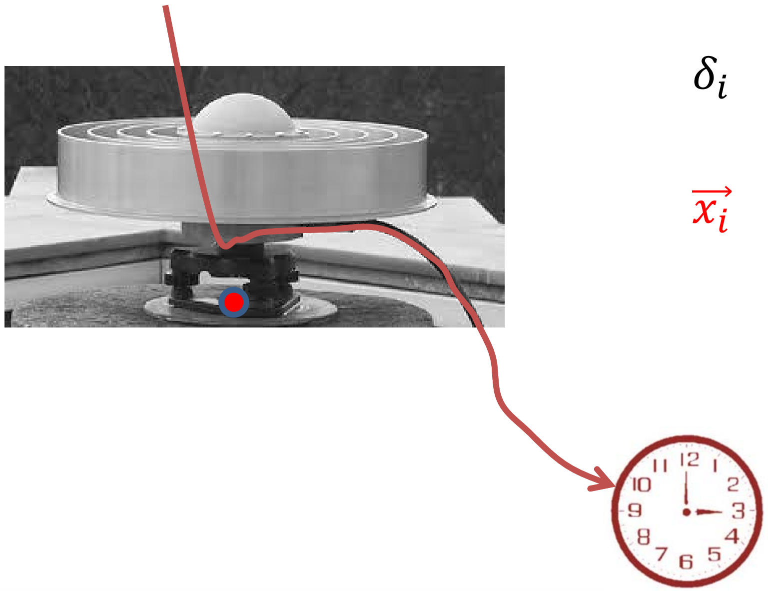
a_i,α_i	hardware delay in the receiver at the station *i* for code and phase measurements
δ_i	clock correction of the receiver at the station *i* with respect to GPS time



GNSS observation equation

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

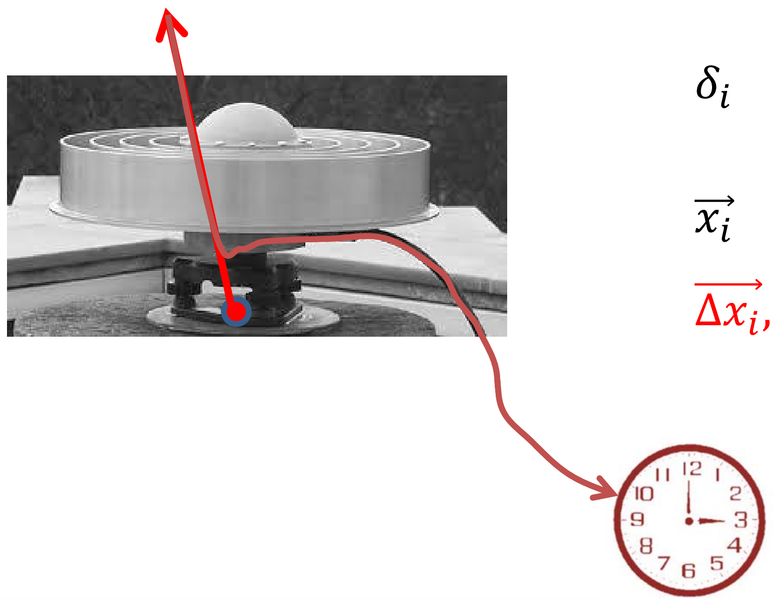


a_i, α_i	hardware delay in the receiver at the station *i* for code and phase measurements
δ_i	clock correction of the receiver at the station *i* with respect to GPS time
$\overrightarrow{x_i}$	position vector of marker at station *i*

GNSS observation equation

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

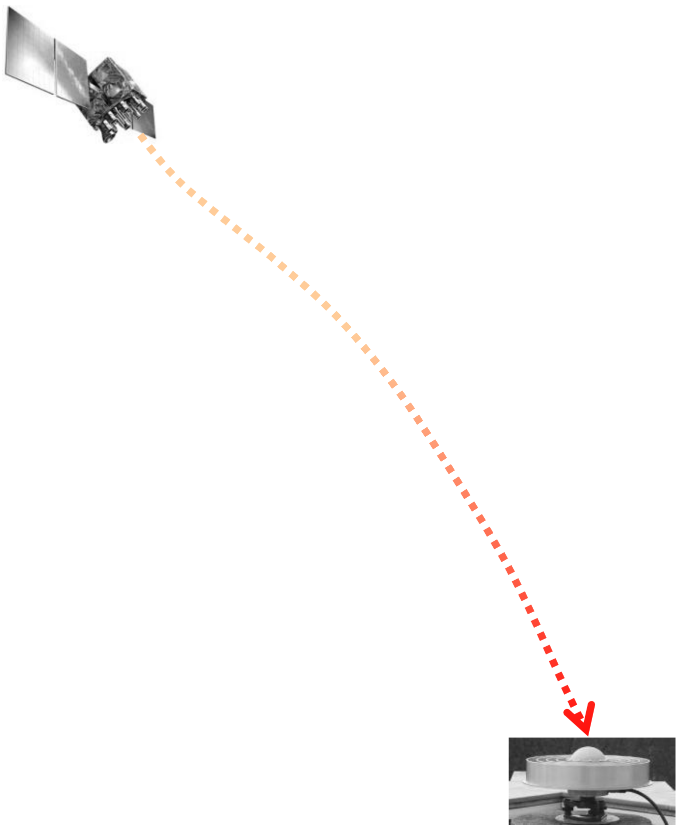


a_i, α_i	hardware delay in the receiver at the station *i* for code and phase measurements
δ_i	clock correction of the receiver at the station *i* with respect to GPS time
$\overrightarrow{x_i}$	position vector of marker at station *i*
$\overrightarrow{\Delta x_i}$, $\overrightarrow{\Delta \chi_i}$	vector from the marker of the station *i* to the antenna signal reception point for code and phase observations

GNSS observation equation

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c\cdot(\delta_i + a_i) - c\cdot\left(\delta^k + a^k\right)$$

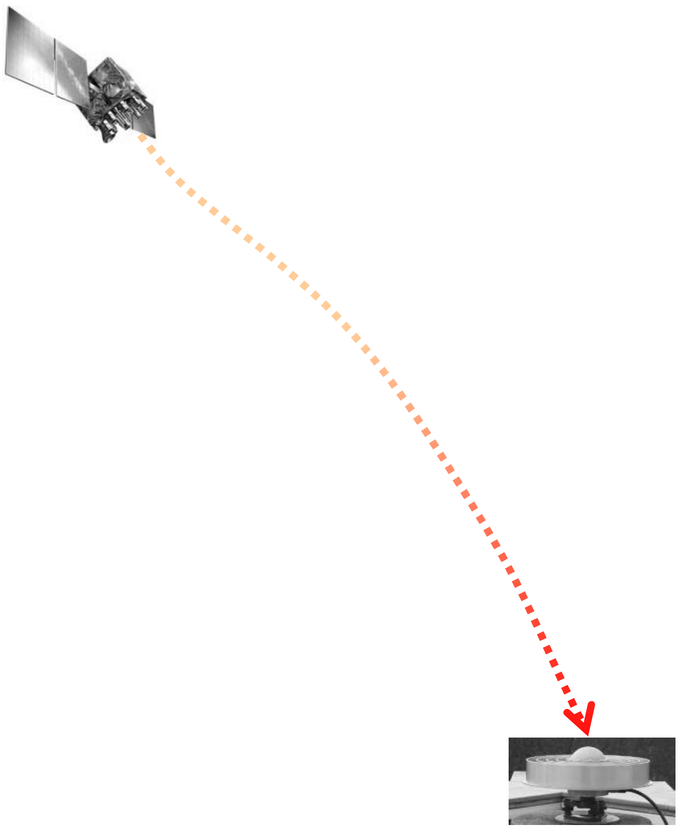
$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta\chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta\chi_i}\right)\right| + T_i^k - I_i^k + c\cdot(\delta_i + \alpha_i) - c\cdot\left(\delta^k + \alpha^k\right) + \lambda^k\cdot N_i^k + \lambda^k\cdot\Delta\varphi_i^k$$



GNSS observation equation

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

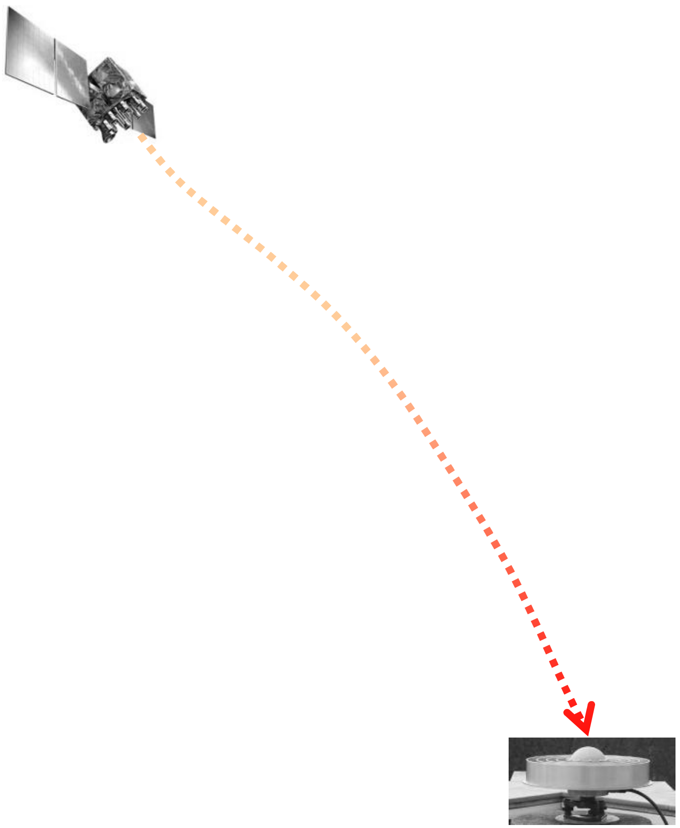


N_i^k phase ambiguity (one and the same for one pass)

GNSS observation equation

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$



N_i^k phase ambiguity (one and the same for one pass)

$\Delta\varphi_i^k$ initial phase shift between the oscillators at station *i* and satellite *k*

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

P_i^k, L_i^k	code/phase observation of station *i* to satellite *k*
$\overrightarrow{x^k}$, $\overrightarrow{x_i}$	position vector of station *i* and satellite *k*, respectively
$\overrightarrow{\Delta x^k}$, $\overrightarrow{\Delta \chi^k}$	vector from the center of mass of the satellite *k* to the antenna signal emission point for code and phase observations
$\overrightarrow{\Delta x_i}$, $\overrightarrow{\Delta \chi_i}$	vector from the marker of the station *i* to the antenna signal reception point for code and phase observations
T_i^k, I_i^k	signal delay in the troposphere and ionosphere

Warning:
There are many further terms like multi-path, relativistic corrections, etc. that are not relevant in this context. They will be introduced tomorrow.

c	speed of light
N_i^k	phase ambiguity (one and the same for one pass)
$\Delta\varphi_i^k$	initial phase shift between the oscillators at station *i* and satellite *k*
λ^k	wavelength of the carrier phase (satellite *k*)

Dependency of the terms

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

The following parameters depend on

- **GNSS**: (GPS or GLONASS or ...)

Dependency of the terms

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

The following parameters depend on

- **GNSS**: (GPS or GLONASS or ...)
  Code: $\overrightarrow{\Delta x_i}$
  Phase: $\overrightarrow{\Delta \chi_i}$

Dependency of the terms

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta\chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta\chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right) + \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

The following parameters depend on

- **GNSS**: (GPS or GLONASS or ...)
  Code: $\overrightarrow{\Delta x_i}$ a_i
  Phase: $\overrightarrow{\Delta\chi_i}$ α_i

Dependency of the terms

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

The following parameters depend on

- **GNSS**: (GPS or GLONASS or ...)

  Code: $\overrightarrow{\Delta x_i}$ a_i δ^k

  Phase: $\overrightarrow{\Delta \chi_i}$ α_i δ^k

Dependency of the terms

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

The following parameters depend on

- **GNSS**: (GPS or GLONASS or ...)

  Code: $\overrightarrow{\Delta x_i}$ a_i δ^k

  Phase: $\overrightarrow{\Delta \chi_i}$ α_i δ^k

  ISB: Inter-system bias

Dependency of the terms

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right) + \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

The following parameters depend on

- **GNSS**: (GPS or GLONASS or ...)

  Code: $\overrightarrow{\Delta x_i}$ a_i δ^k

  Phase: $\overrightarrow{\Delta \chi_i}$ α_i δ^k

  ISB: Inter-system bias

- **Frequency**: (f_1 or f_2 or f_n for GLONASS or ...)

Dependency of the terms

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

The following parameters depend on

- **GNSS**: (GPS or GLONASS or ...)

  Code: $\overrightarrow{\Delta x_i}$ a_i δ^k

  Phase: $\overrightarrow{\Delta \chi_i}$ α_i δ^k

  ISB: Inter-system bias

- **Frequency**: (f_1 or f_2 or f_n for GLONASS or ...)

  Code: $\overrightarrow{\Delta x^k}$ $\overrightarrow{\Delta x_i}$

  Phase: $\overrightarrow{\Delta \chi^k}$ $\overrightarrow{\Delta \chi_i}$

Dependency of the terms

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c\cdot(\delta_i + a_i) - c\cdot\left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c\cdot(\delta_i + \alpha_i) - c\cdot\left(\delta^k + \alpha^k\right)$$
$$+\lambda^k\cdot N_i^k + \lambda^k\cdot\Delta\varphi_i^k$$

The following parameters depend on

- **GNSS**: (GPS or GLONASS or ...)

  Code: $\overrightarrow{\Delta x_i}$ a_i δ^k

  Phase: $\overrightarrow{\Delta \chi_i}$ α_i δ^k

  ISB: Inter-system bias

- **Frequency**: (f_1 or f_2 or f_n for GLONASS or ...)

  Code: $\overrightarrow{\Delta x^k}$ $\overrightarrow{\Delta x_i}$ a_i a^k

  Phase: $\overrightarrow{\Delta \chi^k}$ $\overrightarrow{\Delta \chi_i}$ α_i α^k

Dependency of the terms

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c\cdot(\delta_i + a_i) - c\cdot\left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c\cdot(\delta_i + \alpha_i) - c\cdot\left(\delta^k + \alpha^k\right)$$
$$+\lambda^k\cdot N_i^k + \lambda^k\cdot\Delta\varphi_i^k$$

The following parameters depend on

- **GNSS**: (GPS or GLONASS or ...)

Code:	$\overrightarrow{\Delta x_i}$	a_i	δ^k	**ISB: Inter-system bias**
Phase:	$\overrightarrow{\Delta \chi_i}$	α_i	δ^k	

- **Frequency**: (f_1 or f_2 or f_n for GLONASS or ...)

Code:	$\overrightarrow{\Delta x^k}$	$\overrightarrow{\Delta x_i}$	a_i	a^k	(I_i^k)
Phase:	$\overrightarrow{\Delta \chi^k}$	$\overrightarrow{\Delta \chi_i}$	α_i	α^k	(I_i^k)

Dependency of the terms

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

The following parameters depend on

- **GNSS**: (GPS or GLONASS or ...)
  Code: $\overrightarrow{\Delta x_i}$ a_i δ^k
  Phase: $\overrightarrow{\Delta \chi_i}$ α_i δ^k
  ISB: Inter-system bias
- **Frequency**: (f_1 or f_2 or f_n for GLONASS or ...)
  Code: $\overrightarrow{\Delta x^k}$ $\overrightarrow{\Delta x_i}$ a_i a^k
  Phase: $\overrightarrow{\Delta \chi^k}$ $\overrightarrow{\Delta \chi_i}$ α_i α^k
  IFB: Inter-frequency bias

Dependency of the terms

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right) + \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

The following parameters depend on

- **GNSS**: (GPS or GLONASS or ...)

Code:	$\overrightarrow{\Delta x_i}$	a_i	δ^k
Phase:	$\overrightarrow{\Delta \chi_i}$	α_i	δ^k

ISB: Inter-system bias

- **Frequency**: (f_1 or f_2 or f_n for GLONASS or ...)

Code:	$\overrightarrow{\Delta x^k}$	$\overrightarrow{\Delta x_i}$	a_i	a^k
Phase:	$\overrightarrow{\Delta \chi^k}$	$\overrightarrow{\Delta \chi_i}$	α_i	α^k

IFB: Inter-frequency bias

- **Signal type**: (C1P/C or C2P/C or ...)

Dependency of the terms

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right) + \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

The following parameters depend on

- **GNSS**: (GPS or GLONASS or ...)
  Code: $\overrightarrow{\Delta x_i}$ a_i δ^k
  Phase: $\overrightarrow{\Delta \chi_i}$ α_i δ^k
  ISB: Inter-system bias
- **Frequency**: (f_1 or f_2 or f_n for GLONASS or ...)
  Code: $\overrightarrow{\Delta x^k}$ $\overrightarrow{\Delta x_i}$ a_i a^k
  Phase: $\overrightarrow{\Delta \chi^k}$ $\overrightarrow{\Delta \chi_i}$ α_i α^k
  IFB: Inter-frequency bias
- **Signal type**: (C1P/C or C2P/C or ...)
  Code: a_i a^k

Dependency of the terms

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

The following parameters depend on

- **GNSS**: (GPS or GLONASS or ...)
  Code: $\overrightarrow{\Delta x_i}$ a_i δ^k
  Phase: $\overrightarrow{\Delta \chi_i}$ α_i δ^k
  ISB: Inter-system bias

- **Frequency**: (f_1 or f_2 or f_n for GLONASS or ...)
  Code: $\overrightarrow{\Delta x^k}$ $\overrightarrow{\Delta x_i}$ a_i a^k
  Phase: $\overrightarrow{\Delta \chi^k}$ $\overrightarrow{\Delta \chi_i}$ α_i α^k
  IFB: Inter-frequency bias

- **Signal type**: (C1P/C or C2P/C or ...)
  Code: a_i a^k
  DCB: Differential code bias

Dependency of the terms

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

The following parameters depend on

- **GNSS**: (GPS or GLONASS or ...)
  Code: $\overrightarrow{\Delta x_i}$ a_i δ^k
  Phase: $\overrightarrow{\Delta \chi_i}$ α_i δ^k
  ISB: Inter-system bias
- **Frequency**: (f_1 or f_2 or f_n for GLONASS or ...)
  Code: $\overrightarrow{\Delta x^k}$ $\overrightarrow{\Delta x_i}$ a_i a^k
  Phase: $\overrightarrow{\Delta \chi^k}$ $\overrightarrow{\Delta \chi_i}$ α_i α^k
  IFB: Inter-frequency bias
- **Signal type**: (C1P/C or C2P/C or L2P/C or ...)
  Code: a_i a^k **DCB: Differential code bias**
  Phase: α_i α^k **(Quarter cycle problem)**

Dependency of the terms

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

The following parameters depend on

- **GNSS**:

  Code: $\overrightarrow{\Delta x_i}$ a_i δ^k

  Phase: $\overrightarrow{\Delta \chi_i}$ α_i δ^k

  ISB: Inter-system bias

- **Frequency**:

  Code: $\overrightarrow{\Delta x^k}$ $\overrightarrow{\Delta x_i}$ a_i a^k

  Phase: $\overrightarrow{\Delta \chi^k}$ $\overrightarrow{\Delta \chi_i}$ α_i α^k

  IFB: Inter-frequency bias

- **Signal type**:

  Code: a_i a^k

  DCB: Differential code bias

Dependency of the terms

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

	Antenna		Hardware (receiver)			
GNSS:						
Code:		$\overrightarrow{\Delta x_i}$	a_i		(δ^k)	**ISB: Inter-system bias**
Phase:		$\overrightarrow{\Delta \chi_i}$	α_i		(δ^k)	
Frequency:						
Code:	$\overrightarrow{\Delta x^k}$	$\overrightarrow{\Delta x_i}$	a_i	a^k		**IFB: Inter-frequency bias**
Phase:	$\overrightarrow{\Delta \chi^k}$	$\overrightarrow{\Delta \chi_i}$	α_i	α^k		
Signal type:						
Code:			a_i	a^k		**DCB: Differential code bias**

Biases when processing code data

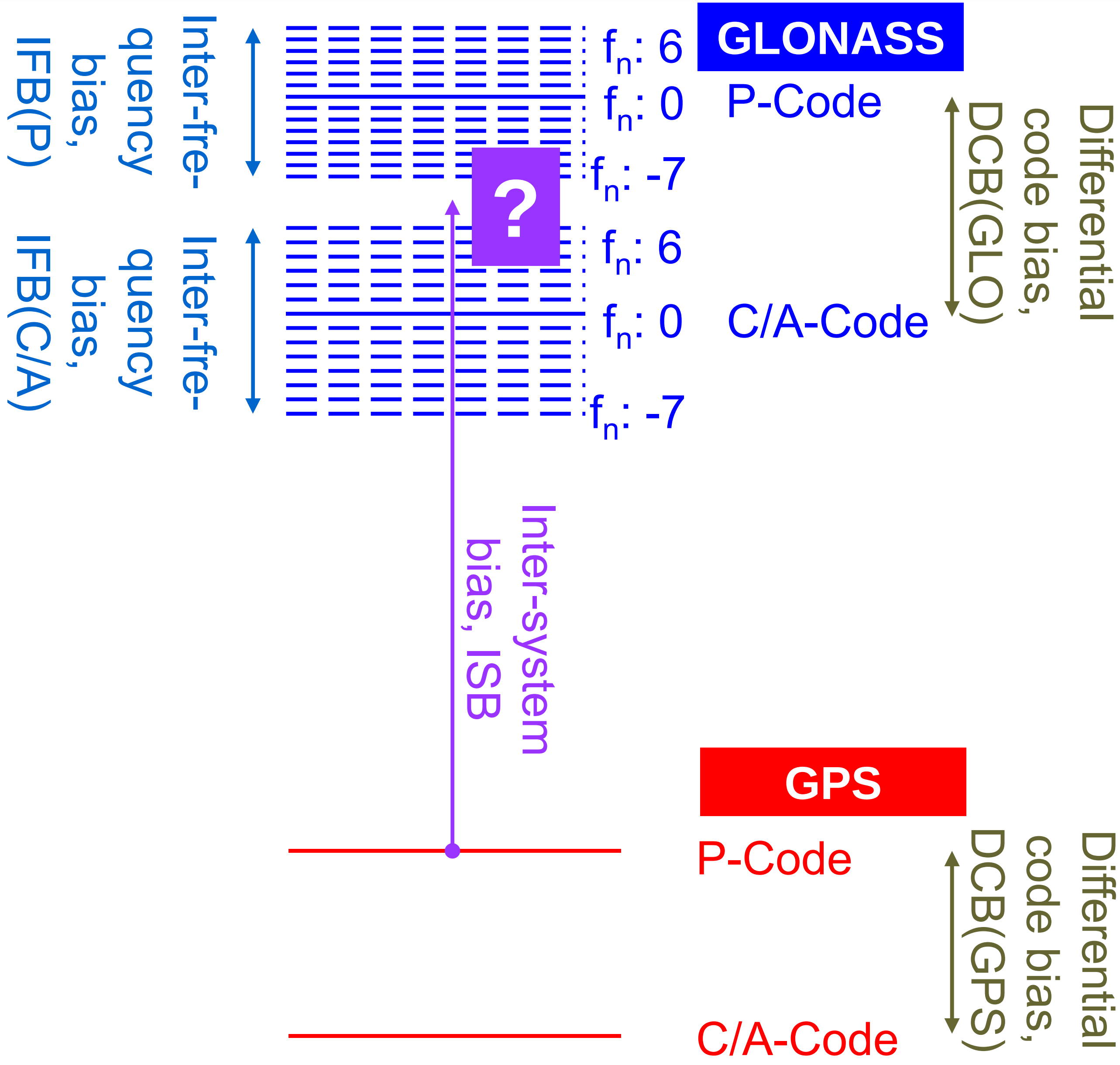
If we focus on processing code measurements we have to consider:

- **DCB: differential code bias**
  different hardware delays for P– and C–Code
  bias at the *receiver and satellite*

- **ISB: inter–system bias**
  different hardware delays for measurements of different GNSS
  bias only at the *receiver*

- **IFB: inter–frequency bias**
  frequency–dependent hardware delays for the different GLONASS–signals
  bias at the *receiver*
  (also at the satellite when frequency is changed)

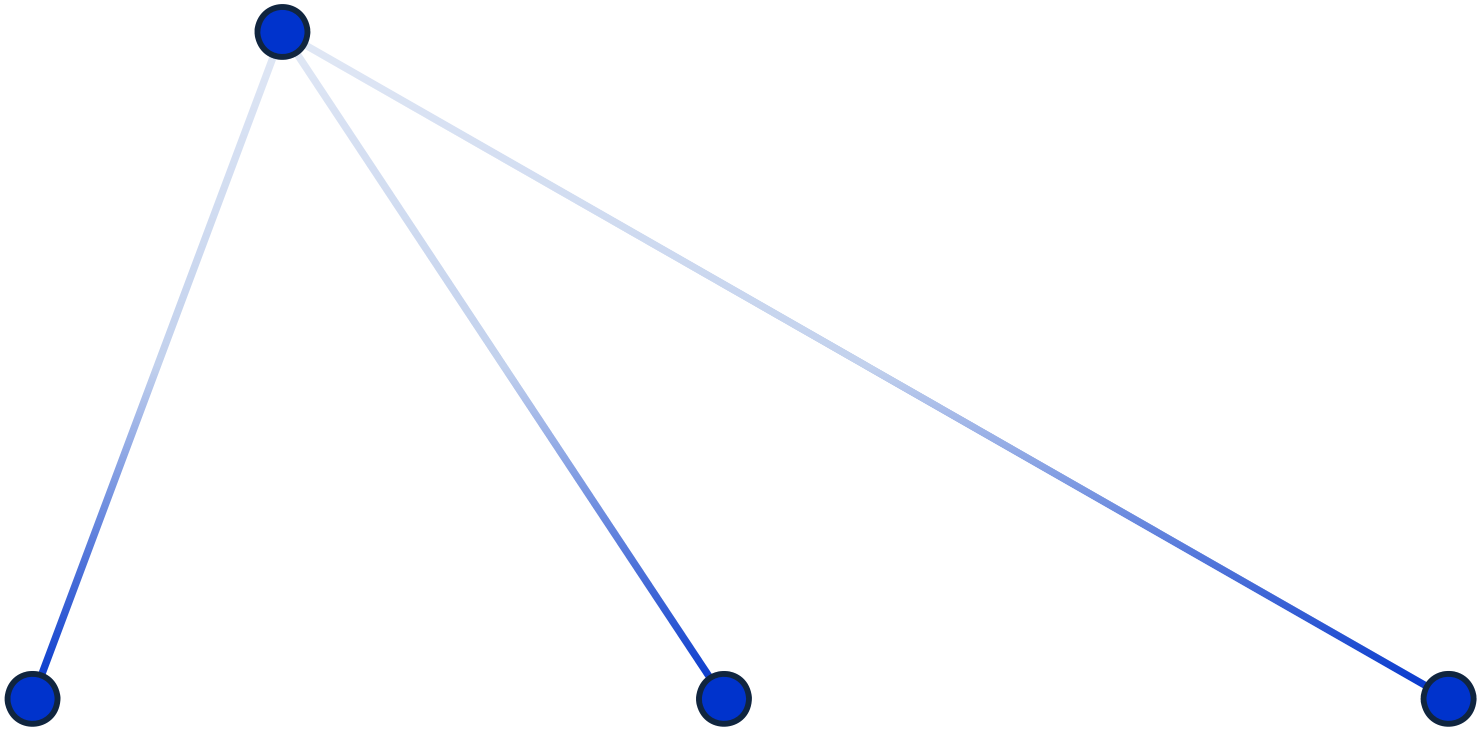
Relation between receiver code biases



We can only extract the sum of delays from a GPS/GLONASS data processing.

Why do we need these biases?

GPS sat. k



GPS rec. (C1P-Code)

GPS-sat. clock:
$\delta^k + a^k(C1P)$

GPS rec. (C1P-Code)

GPS-sat. clock:
$\delta^k + a^k(C1P)$

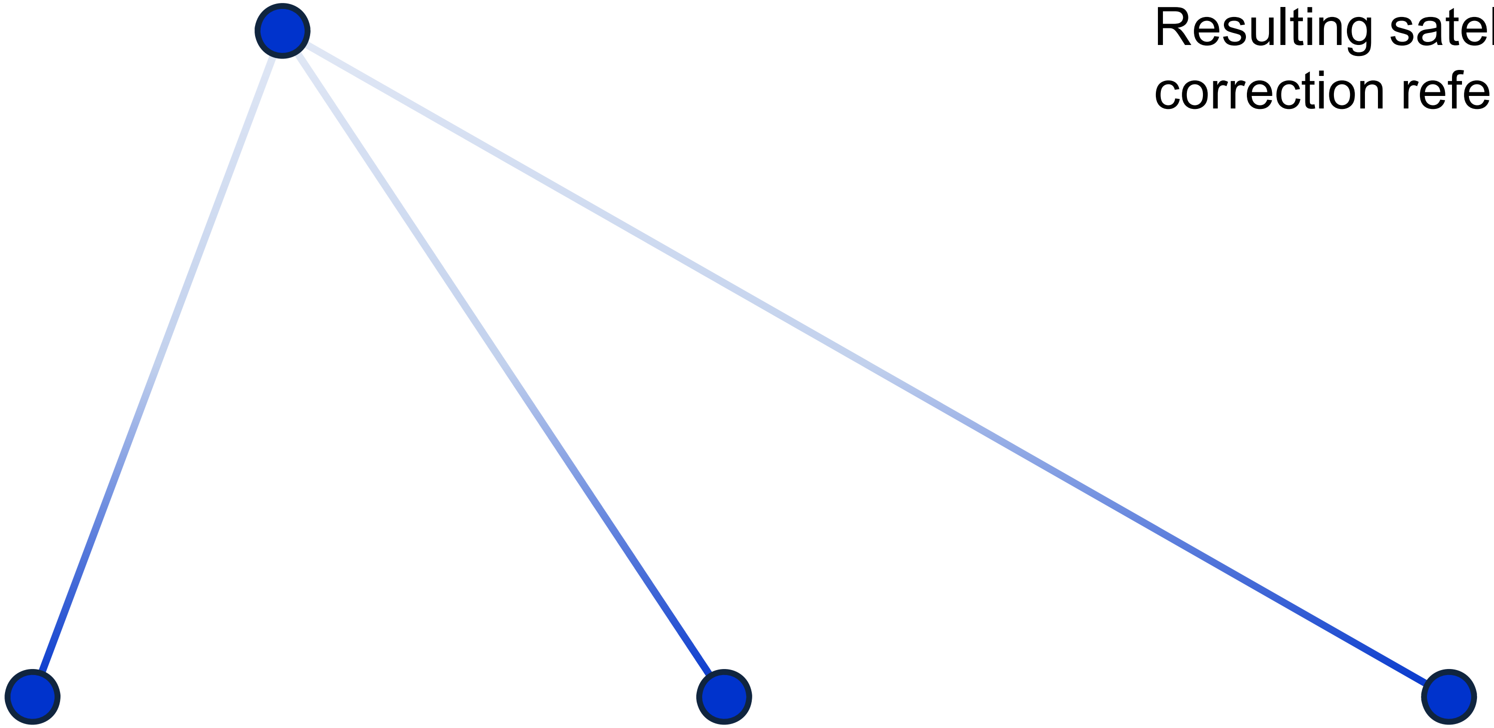
GPS rec. (C1C-Code)

GPS-sat. clock:
$\delta^k + a^k(C1C)$

Why do we need these biases?

GPS sat. k

Resulting satellite clock correction refers to C1P



GPS rec. (C1P-Code)

GPS-sat. clock:
$\delta^k + a^k(C1P)$

GPS rec. (C1P-Code)

GPS-sat. clock:
$\delta^k + a^k(C1P)$

GPS rec. (C1C-Code)

GPS-sat. clock:
$\delta^k + a^k(C1C)$
$+DCB^k\ (C1P - C1C)$

Why do we need these biases?

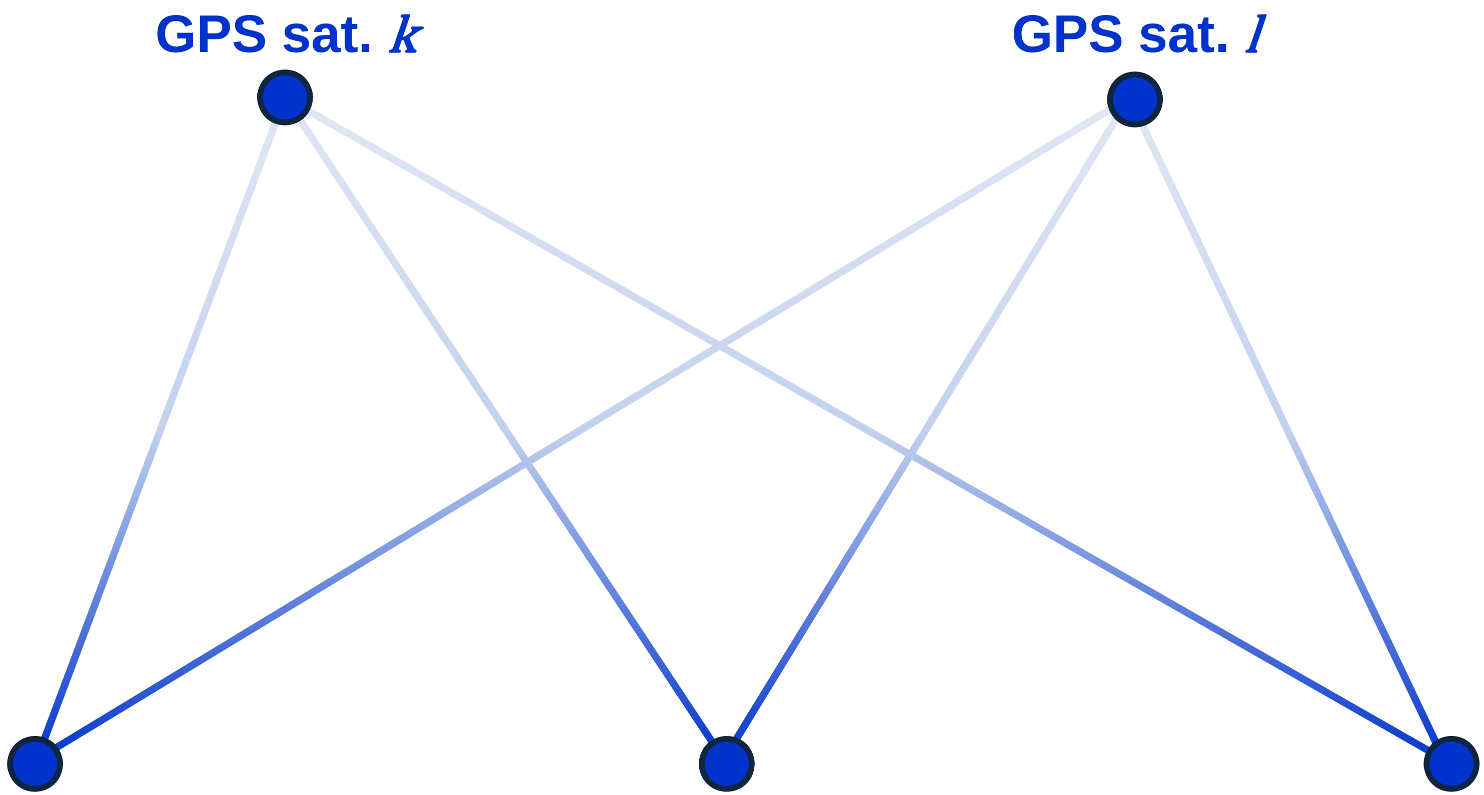
GPS sat. k

Resulting satellite clock correction refers to C1C

Whether choosing C1P or C1C as reference is fully equivalent.
Choosing C1C or C1P for the satellite clock is purely cententional.
The IGS follows the convention that the satellite clocks refer to the P-Code.

GPS rec. (C1P-Code)	**GPS rec. (C1P-Code)**	**GPS rec. (C1C-Code)**
GPS-sat. clock: $\delta^k + a^k(C1P)$ $+DCB^k\ (C1C - C1P)$	*GPS-sat. clock:* $\delta^k + a^k(C1P)$ $+DCB^k\ (C1C - C1P)$	*GPS-sat. clock:* $\delta^k + a^k(C1C)$

Why do we need these biases?

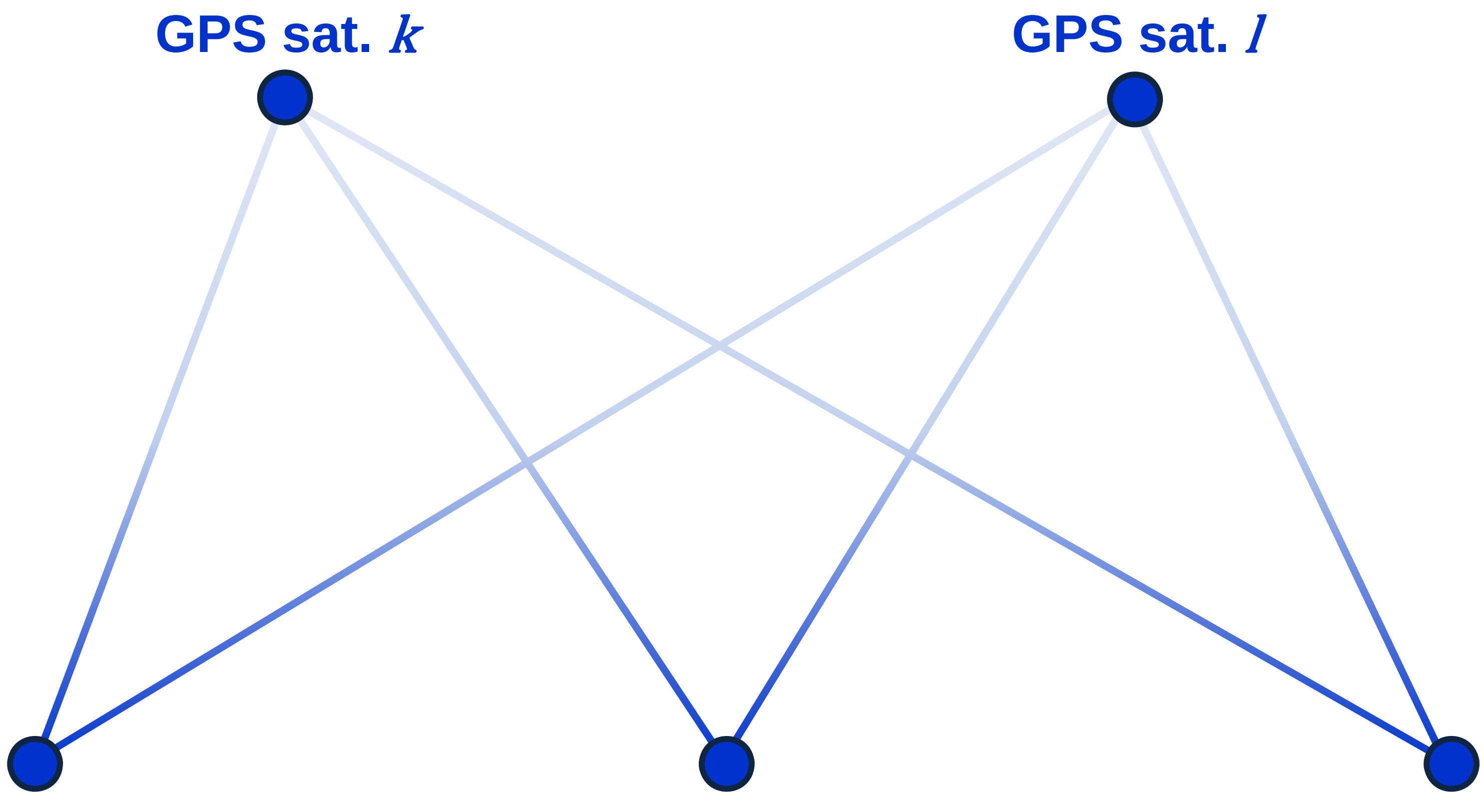


GPS rec.
k: C2P-Code
l: C2P-Code
GPS-sat. clock:
$k: \delta^k + a^k(C2P)$
$l: \delta^l + a^l(C2P)$

GPS rec.
k: C2P-Code
l: C2C-Code
GPS-sat. clock:
$k: \delta^k + a^k(C2P)$
$l: \delta^l + a^l(C2C)$

GPS rec.
k: C2P-Code
l: C2C-Code
GPS-sat. clock:
$k: \delta^k + a^k(C2P)$
$l: \delta^l + a^l(C2C)$

Why do we need these biases?

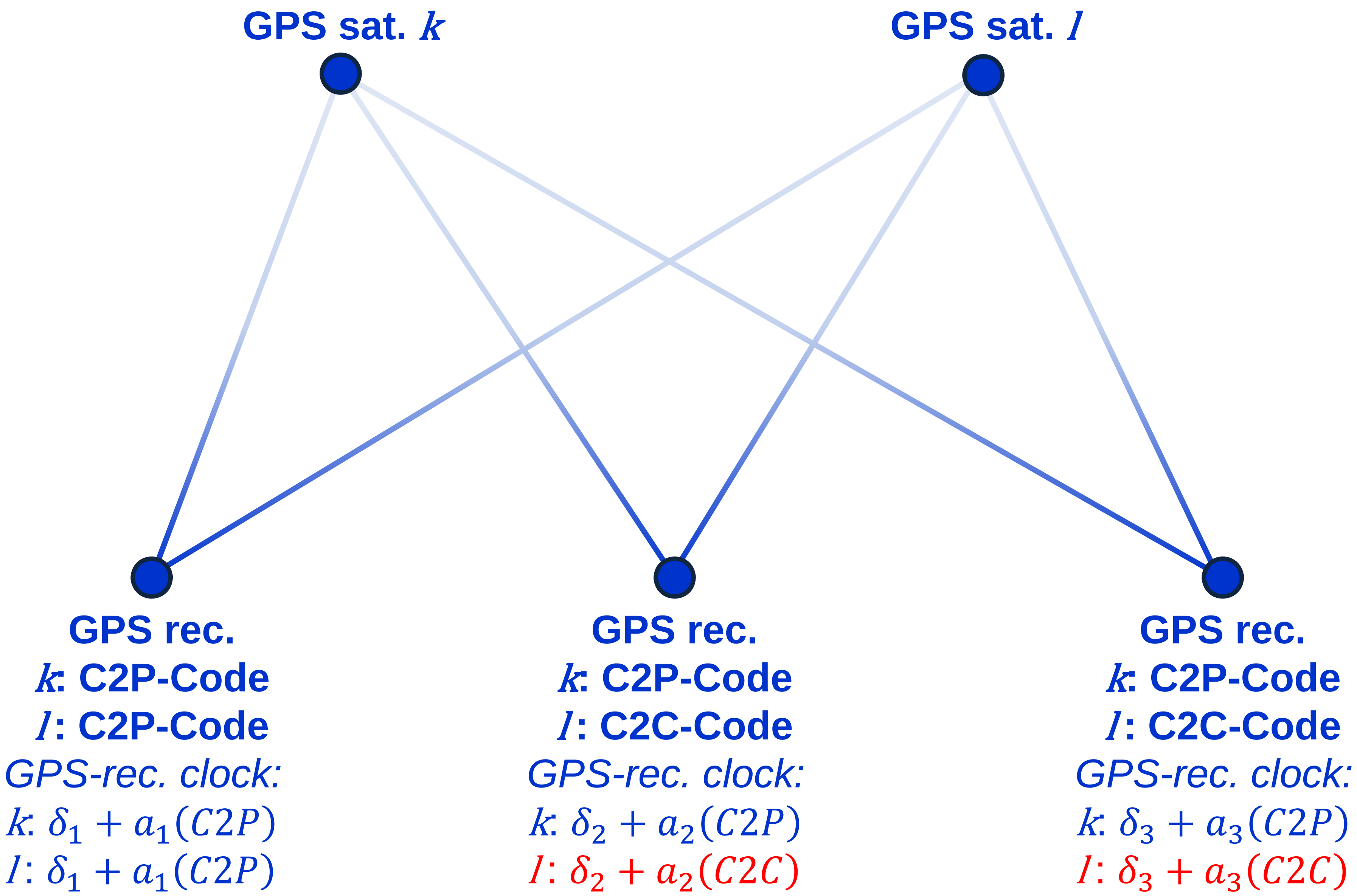


GPS rec.
***k*: C2P-Code**
***l*: C2P-Code**
GPS-sat. clock:
$k: \delta^k + a^k(C2P)$
$l: \delta^l + a^l(C2P)$

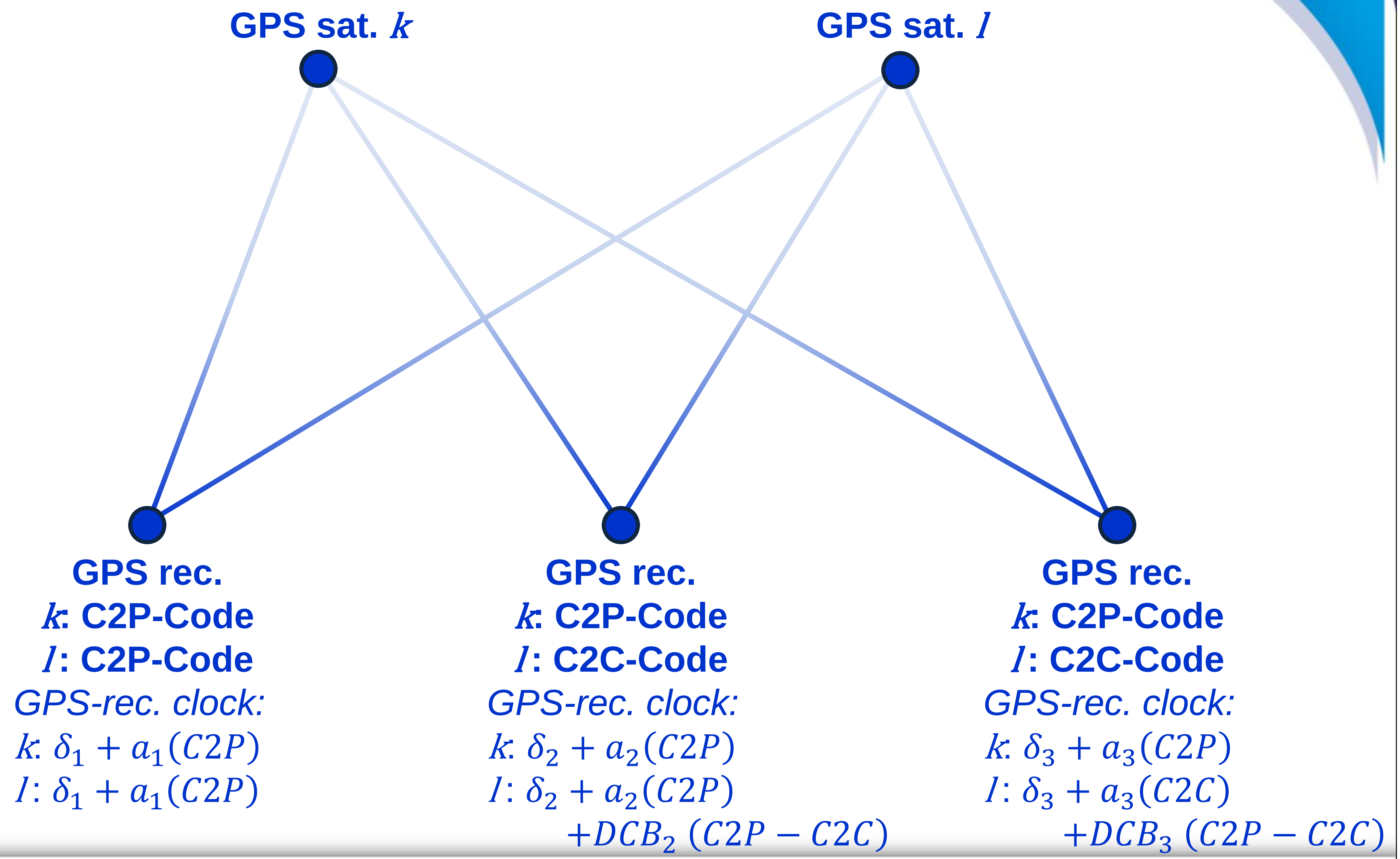
GPS rec.
***k*: C2P-Code**
***l*: C2C-Code**
GPS-sat. clock:
$k: \delta^k + a^k(C2P)$
$l: \delta^l + a^l(C2C)$
$+DCB^l\ (C2P - C2C)$

GPS rec.
***k*: C2P-Code**
***l*: C2C-Code**
GPS-sat. clock:
$k: \delta^k + a^k(C2P)$
$l: \delta^l + a^l(C2C)$
$+DCB^l\ (C2P - C2C)$

Why do we need these biases?



Why do we need these biases?



DCBs in a GPS network solution

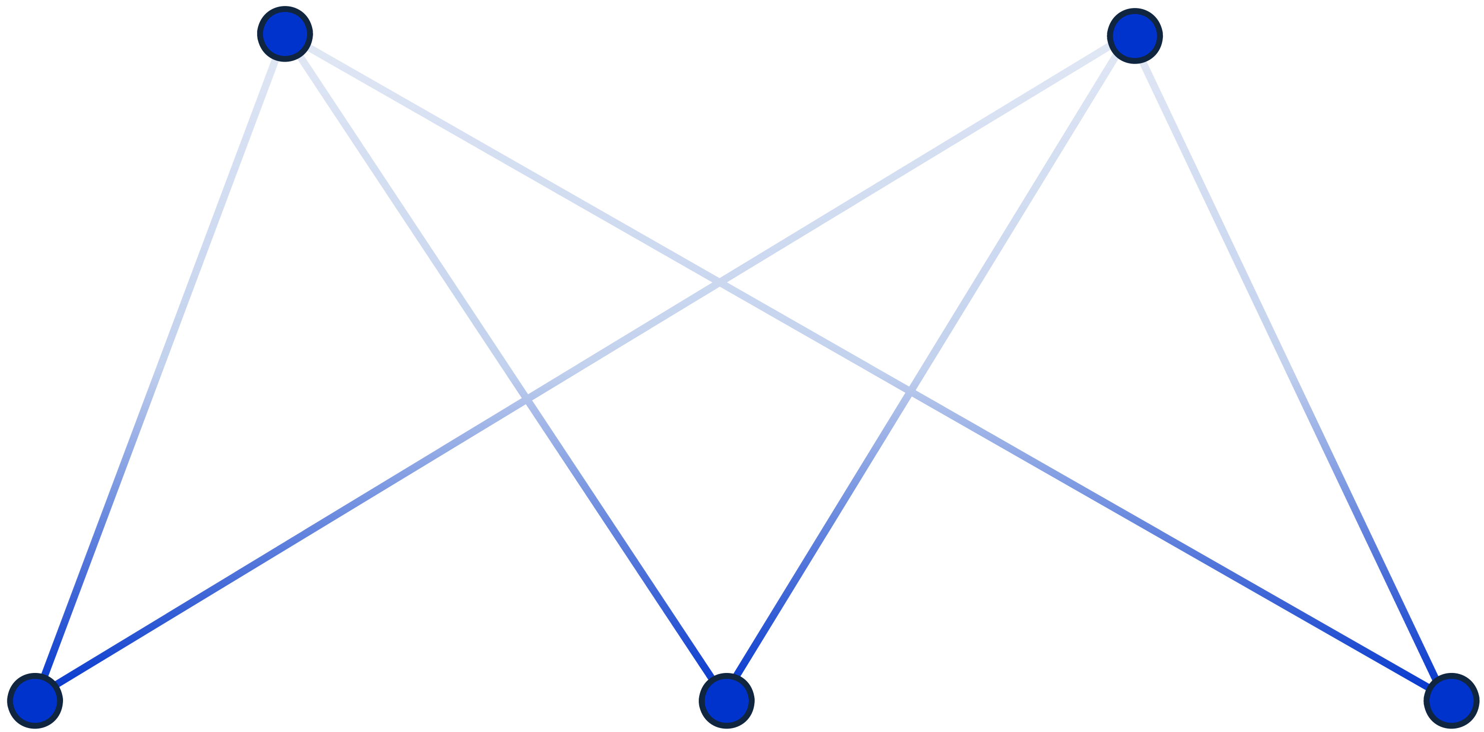
Depending on the code measurements of the individual receivers we can get:

- C1P-C1C or P1-C1 DCBs for all GPS satellites,
- C2P-C2C or P2-C2 DCBs for Block IIR-M (or later) satellites,
- C2P-C2C or P2-C2 DCBs for receivers if it tracks GPS satellites with P- and C-code on the second frequency at the same time.

As soon as we get a mixture between all these observation types in one network solution we need

- either to correct the DCBs in the data processing
- or to estimate DCB parameters
  - P1-C1: Your reference clock only belongs to either the P- or C/A-code class – you need an additional reference for the satellite related biases.
  - P2-C2: You have these DCBs at the satellites and receivers at the same time – you need additional references for the satellite and receiver related biases.

Why do we need these biases?

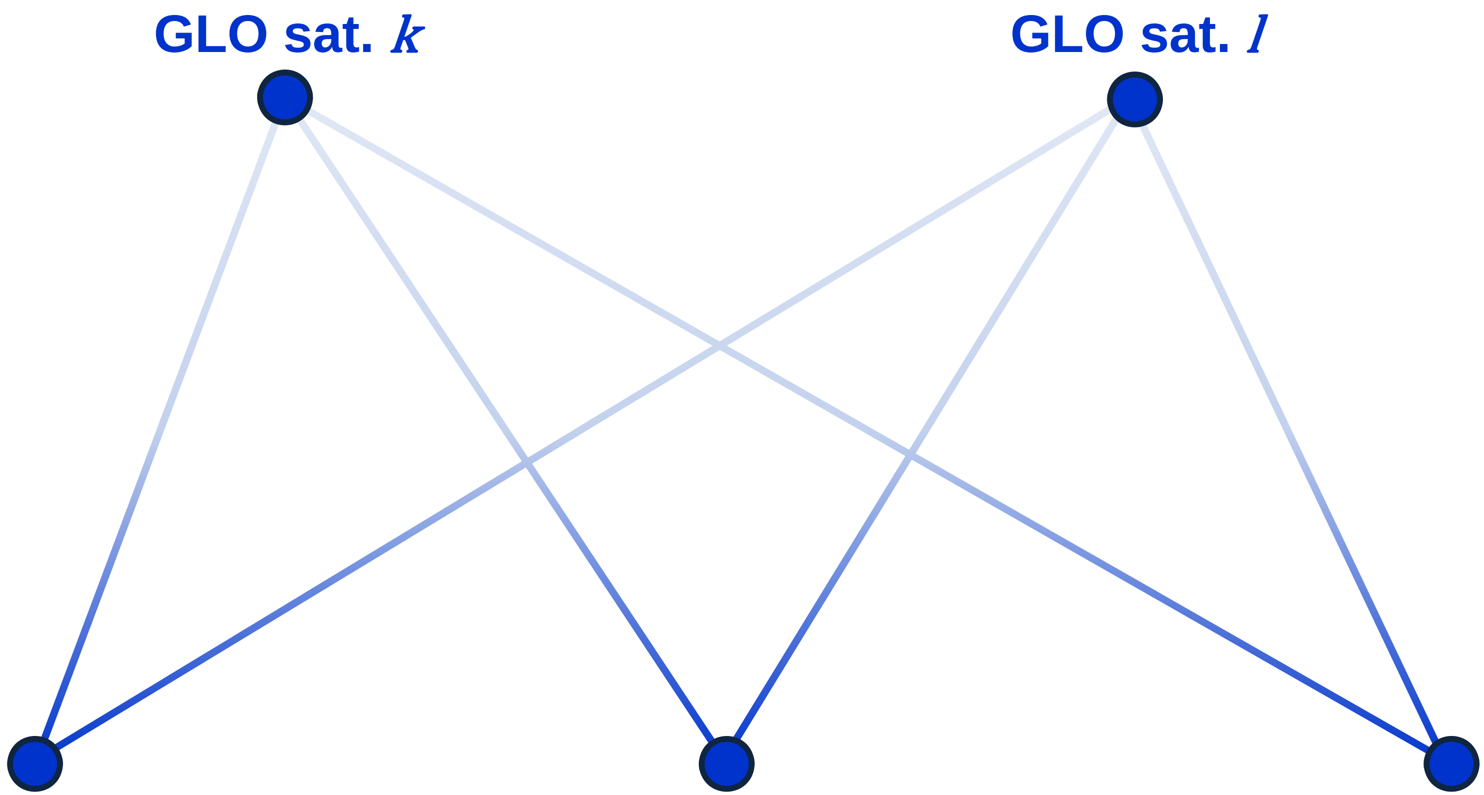


GLO rec.
***k*: C1P-Code**
***l*: C1P-Code**
GLO-sat. clock:
$k\!: \delta^k + a^k(C1P)$
$l: \delta^l + a^l(C1P)$

GLO rec.
***k*: C1P-Code**
***l*: C1P-Code**
GLO-sat. clock:
$k\!: \delta^k + a^k(C1P)$
$l: \delta^l + a^l(C1P)$

GLO rec.
***k*: C1P-Code**
***l*: C1P-Code**
GLO-sat. clock:
$k\!: \delta^k + a^k(C1P)$
$l: \delta^l + a^l(C1P)$

Why do we need these biases?



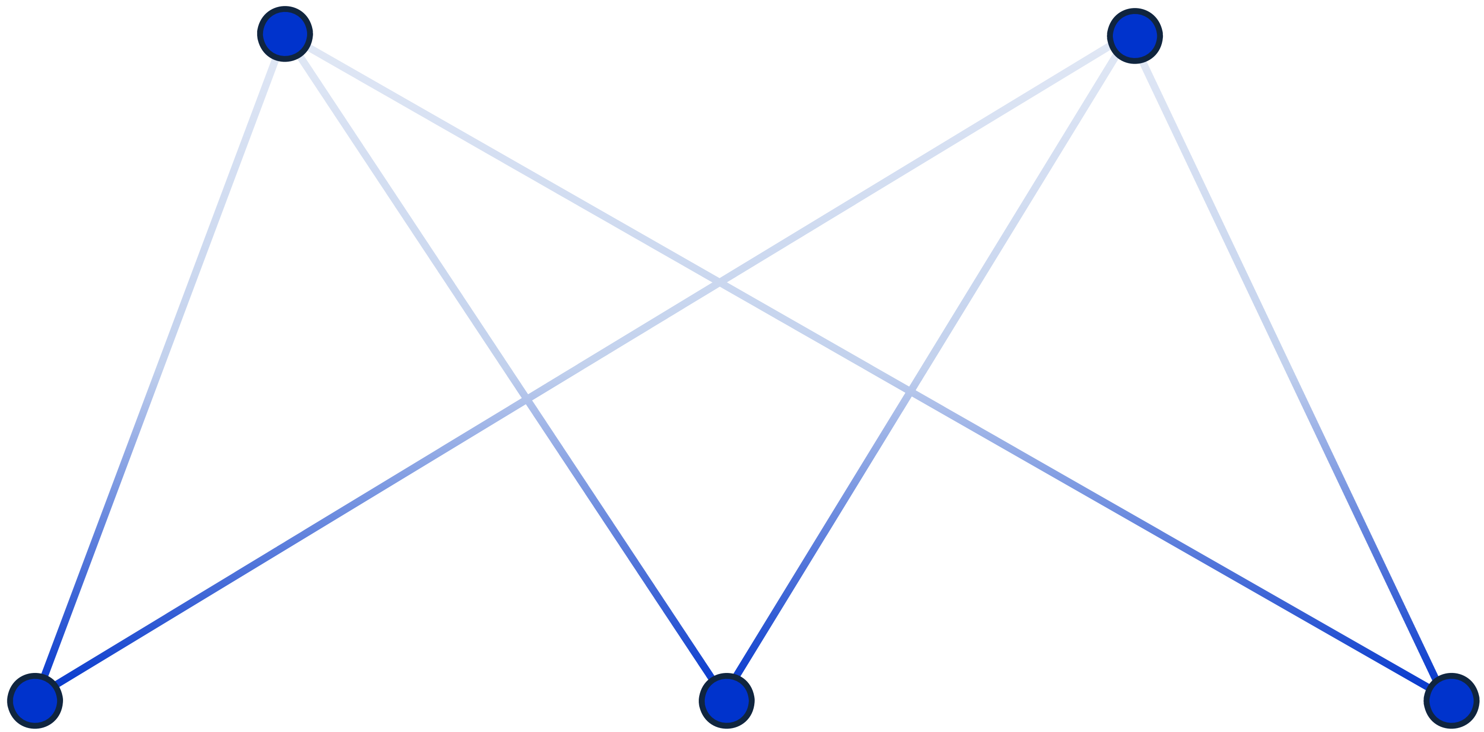
GLO rec.
***k*: C1P-Code**
***l*: C1P-Code**
GLO-sat. clock:
$k{:}\ \delta^k + a^k(C1P)$
$l{:}\ \delta^l + a^l(C1P)$

GLO rec.
***k*: C1C-Code**
***l*: C1C-Code**
GLO-sat. clock:
$k{:}\ \delta^k + a^k(C1C)$
$l{:}\ \delta^l + a^l(C1C)$

GLO rec.
***k*: C1C-Code**
***l*: C1C-Code**
GLO-sat. clock:
$k{:}\ \delta^k + a^k(C1C)$
$l{:}\ \delta^l + a^l(C1C)$

Why do we need these biases?

GLO sat. k | **GLO sat. l**

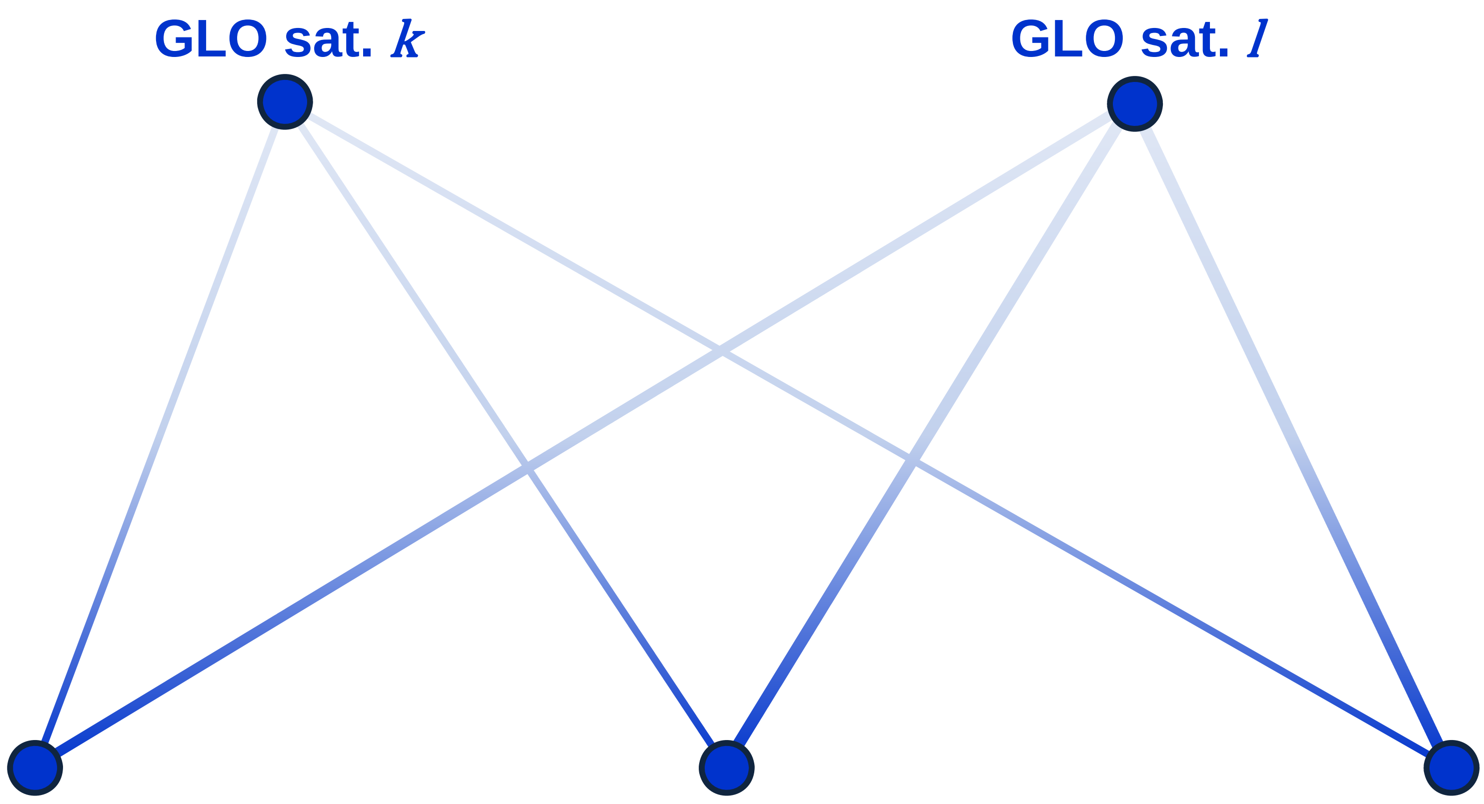


GLO rec.
k: C1P-Code
l: C1P-Code
GLO-sat. clock:
k: $\delta^k + a^k(C1P)$
l: $\delta^l + a^l(C1P)$

GLO rec.
k: C1C-Code
l: C1C-Code
GLO-sat. clock:
k: $\delta^k + a^k(C1C)$
$+DCB^k\ (C1P - C1C)$
l: $\delta^l + a^l(C1C)$
$+DCB^l\ (C1P - C1C)$

GLO rec.
k: C1C-Code
l: C1C-Code
GLO-sat. clock:
k: $\delta^k + a^k(C1C)$
$+DCB^k\ (C1P - C1C)$
l: $\delta^l + a^l(C1C)$
$+DCB^l\ (C1P - C1C)$

Why do we need these biases?



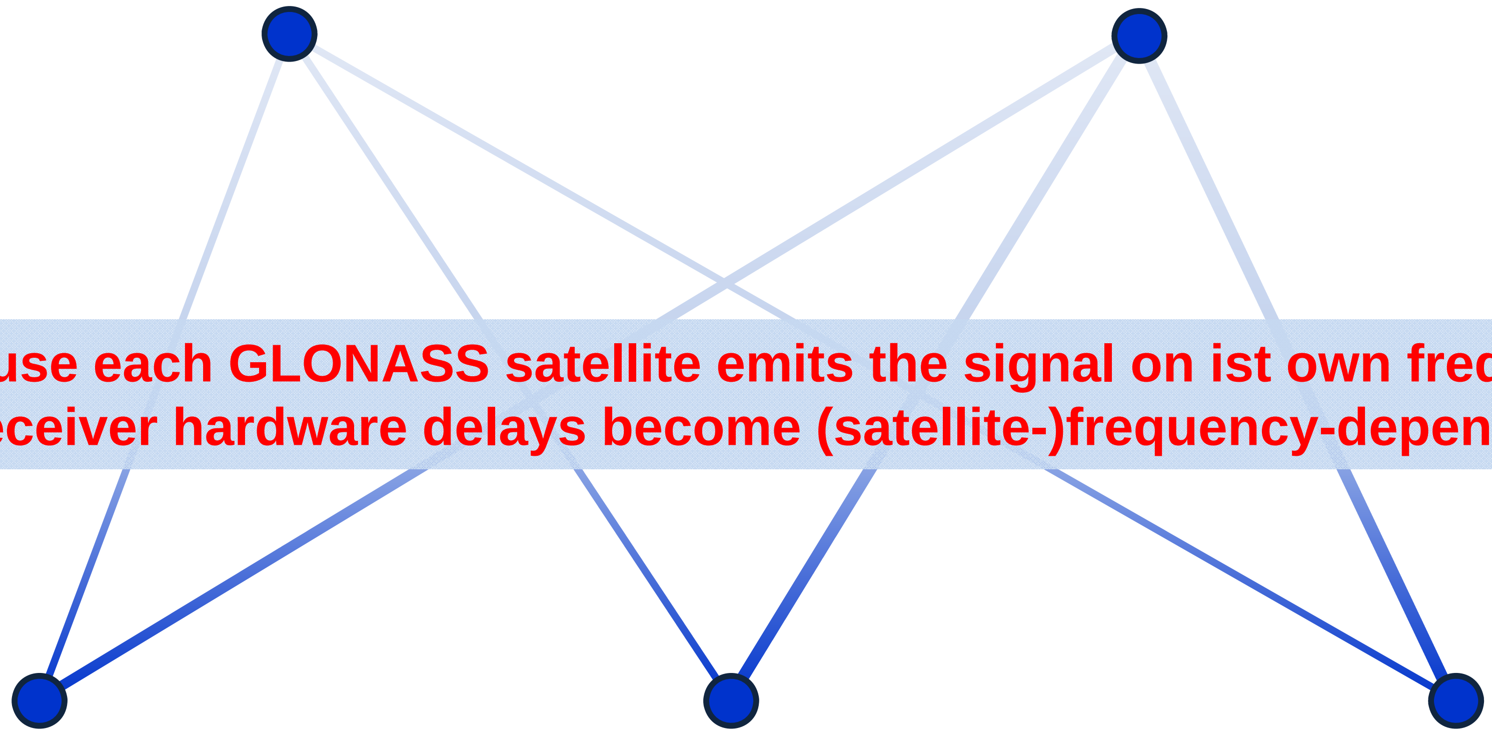
GLO rec.
k: C1P-Code
l: C1P-Code
GLO-rec. clock:
k: $\delta_1 + a_1(C1P)$
l: $\delta_1 + a_1(C1P)$

GLO rec.
k: C1C-Code
l: C1C-Code
GLO-rec. clock:
k: $\delta_2 + a_2(C1C)$
l: $\delta_2 + a_2(C1C)$

GLO rec.
k: C1C-Code
l: C1C-Code
GLO-rec. clock:
k: $\delta_3 + a_3(C1C)$
l: $\delta_3 + a_3(C1C)$

Why do we need these biases?

GLO sat. *k*　　　　**GLO sat. *l***



Because each GLONASS satellite emits the signal on ist own frequency the receiver hardware delays become (satellite-)frequency-dependent.

GLO rec.	GLO rec.	GLO rec.
***k*: C1P-Code**	***k*: C1C-Code**	***k*: C1C-Code**
***l*: C1P-Code**	***l*: C1C-Code**	***l*: C1C-Code**
GLO-rec. clock:	*GLO-rec. clock:*	*GLO-rec. clock:*
k: $\delta_1 + a_1(C1P)^k$	k: $\delta_2 + a_2(C1C)^k$	k: $\delta_3 + a_3(C1C)^k$
l: $\delta_1 + a_1(C1P)^l$	l: $\delta_2 + a_2(C1C)^l$	l: $\delta_3 + a_3(C1C)^l$

DCBs in a GLONASS network solution

Depending on the code measurements of the individual receivers we can get:

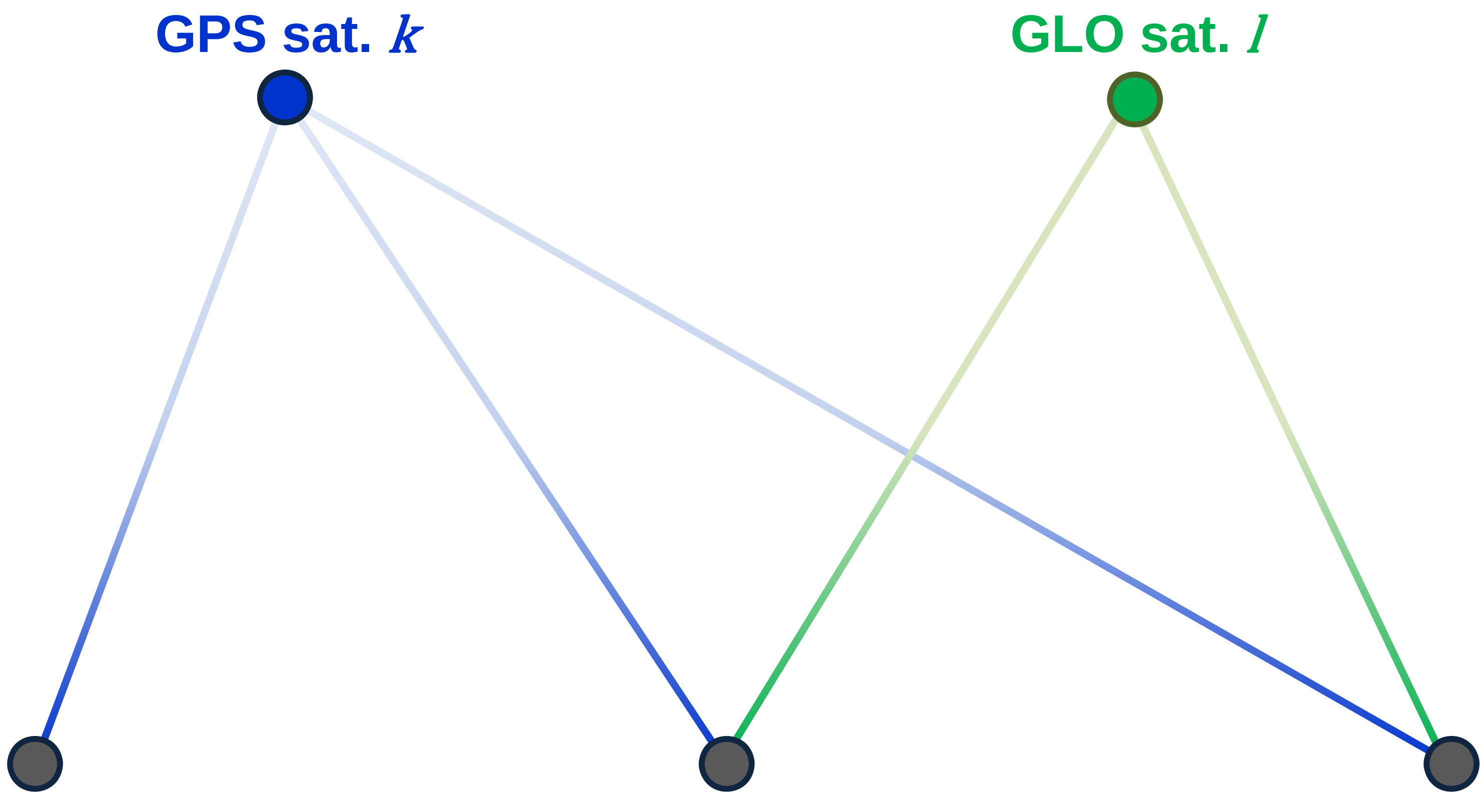
- C1P-C1C or P1-C1 DCBs for all GLONASS satellites,
- C2P-C2C or P2-C2 DCBs for all GLONASS satellites.

As soon as we get a mixture between all these observation types in one network solution we need

- either to correct the DCBs in the data processing
- or to estimate DCB parameters
  - P1-C1 and P2-C2: Your reference clock only belongs to either the P- or C-code class – you need an additional reference for the satellite related biases.

Note that we need to consider in addition an inter-frequency bias (IFB) because each GLONASS satellite emits the signal on another frequency.

Why do we need these biases?



GPS rec.

k: C1P-Code

GNSS-sat. clock:

$k: \delta^k + a^k(C1P)$

GNSS rec.

k: C1P-Code

l: C1P-Code

GNSS-sat. clock:

$k: \delta^k + a^k(C1P)$

$l: \delta^l + a^l(C1P)$

GNSS rec.

k: C1C-Code

l : C1C-Code

GNSS-sat. clock:

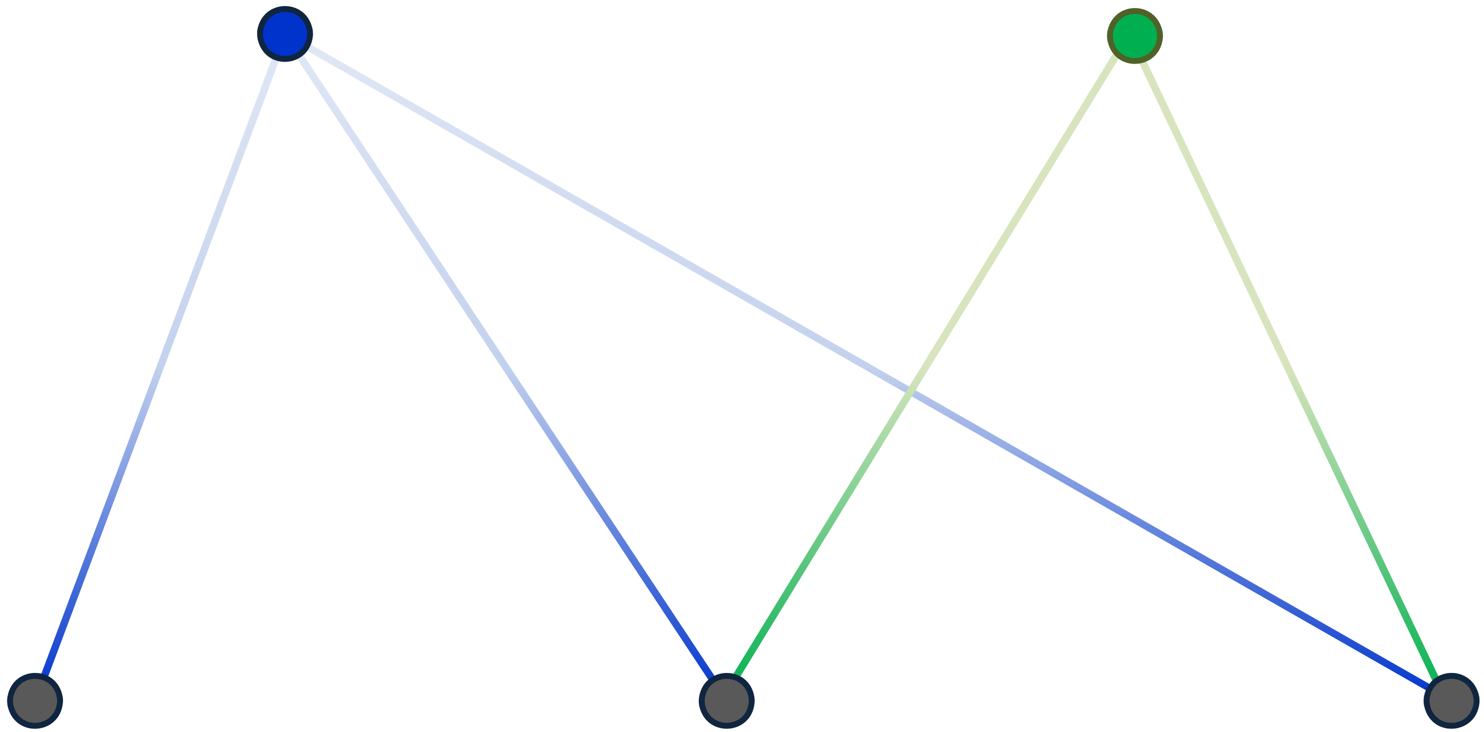
$k: \delta^k + a^k(C1C)$

$l: \delta^l + a^l(C1C)$

Why do we need these biases?

GPS sat. *k*

GLO sat. *l*



GPS rec.

***k*: C1P-Code**

GNSS-sat. clock:

$k: \delta^k + a^k(C1P)$

GNSS rec.

***k*: C1P-Code**

***l*: C1P-Code**

GNSS-sat. clock:

$k: \delta^k + a^k(C1P)$

$l: \delta^l + a^l(C1P)$

GNSS rec.

***k*: C1C-Code**

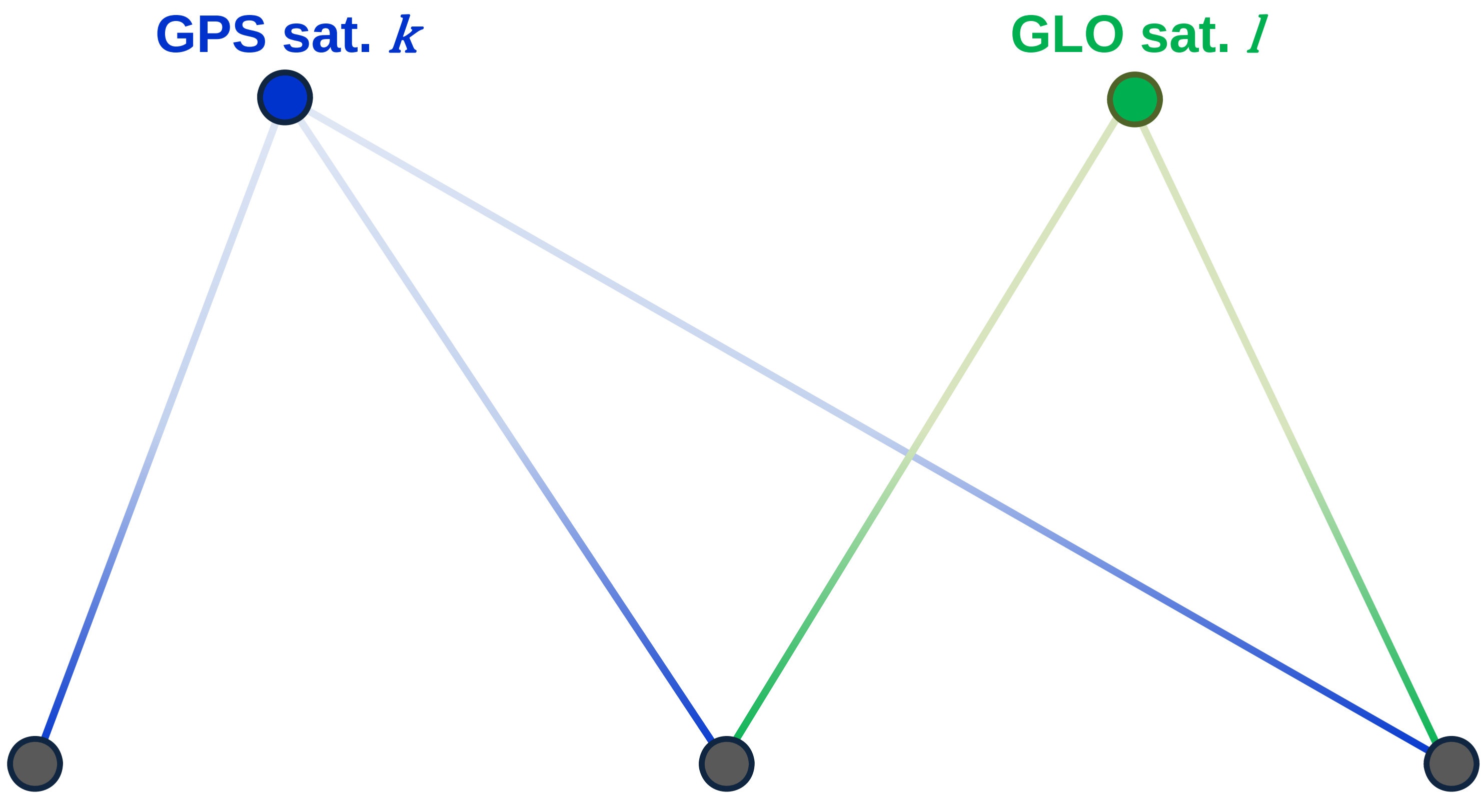
***l* : C1C-Code**

GNSS-sat. clock:

$k: \delta^k + a^k(C1C)$
$\quad +DCB^k\ (C1P - C1C)$

$l: \delta^l + a^l(C1C)$
$\quad +DCB^l\ (C1P - C1C)$

Why do we need these biases?



GPS rec.

k: C1P-Code

GNSS-rec. clock:

$k: \delta_1 + a_1(C1P)$

GNSS rec.

k: C1P-Code

l: C1P-Code

GNSS-rec. clock:

$k: \delta_2 + a_2(C1P)^{GPS}$

$l: \delta_2 + a_2(C1P)^{GLO}$

GNSS rec.

k: C1C-Code

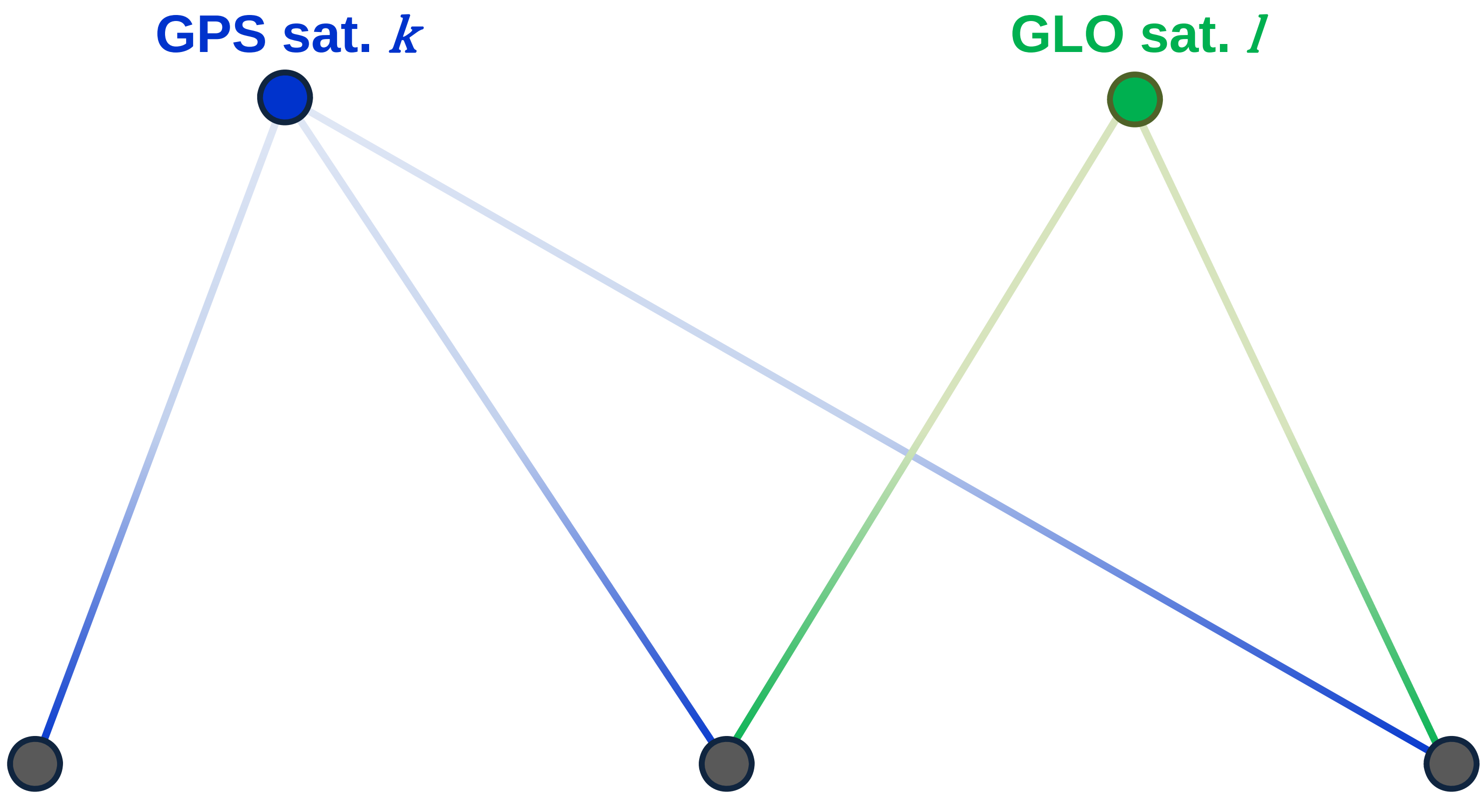
l : C1C-Code

GNSS-rec. clock:

$k: \delta_3 + a_3(C1C)^{GPS}$

$l: \delta_3 + a_3(C1C)^{GLO}$

Why do we need these biases?



GPS rec.
***k*: C1P-Code**

GNSS-rec. clock:
$k: \delta_1 + a_1(C1P)$

GNSS rec.
***k*: C1P-Code**
***l*: C1P-Code**

GNSS-rec. clock:
$k: \delta_2 + a_2(C1P)^{GPS}$
$l: \delta_2 + a_2(C1P)^{GPS}$
$+ISB_2(C1P)$

GNSS rec.
***k*: C1C-Code**
***l* : C1C-Code**

GNSS-rec. clock:
$k: \delta_3 + a_3(C1C)^{GPS}$
$l: \delta_3 + a_3(C1C)^{GPS}$
$+ISB_3(C1C)$

Bias in a GPS/GLONASS network solution

We can see all DCBs from a GPS and GLONASS network solution and the GLONASS IFB in a combine GPS/GLONASS network solution.

Note that we need to consider in addition an inter-system bias (ISB) at each combined GPS/GLONASS receiver.

All these biases are hardware related (with respect to the satellites or receivers). **Consequently we can only assess them as one single parameter $a_i = DCB + IFB + ISB$.**

- References are needed for
  - P1-C1 DCB for GPS satellites,
  - P2-C2 DCB for GPS satellites and GPS receivers tracking C2C,
  - ISB for combined GPS/GLONASS tracking receivers,
  - IFB for GLONASS tracking receivers.

Bias in a GPS/GLONASS network solution

In consequence the estimated biases depend on the realization of the reference (e.g., selection of a reference or list of stations in case of zero-mean conditions).

These biases need to be considered (estimated or corrected) at any time when different types of code measurements are involved.

Typical examples are:

- Receiver/satellite clock estimation in a zero-difference network solution.
- Melbourne-Wübbena linear combination for ambiguity resolution (even in the double-difference analysis).

An alternative approach to obtain the DCBs is to inspect RINEX observation files containing the full list of observations.

Direct access from RINEX files

If RINEX observation files contain all possible code measurements

GPS: C1P C1C C2P C2C

GLONASS: C1P C1C C2P C2C

the following differences can be evaluated to derive the DCBs:

$(C1P)^{GPS} - (C1C)^{GPS} = DCB_{GPS}\,(P1\text{-}C1) - DCB^{GPS}\,(P1\text{-}C1)$

$(C2P)^{GPS} - (C2C)^{GPS} = DCB_{GPS}\,(P2\text{-}C2) - DCB^{GPS}\,(P2\text{-}C2)$

$(C1P)^{GLO} - (C1C)^{GLO} = DCB_{GLO}\,(P1\text{-}C1) - DCB^{GLO}\,(P1\text{-}C1)$

$(C2P)^{GLO} - (C2C)^{GLO} = DCB_{GLO}\,(P2\text{-}C2) - DCB^{GLO}\,(P2\text{-}C2)$

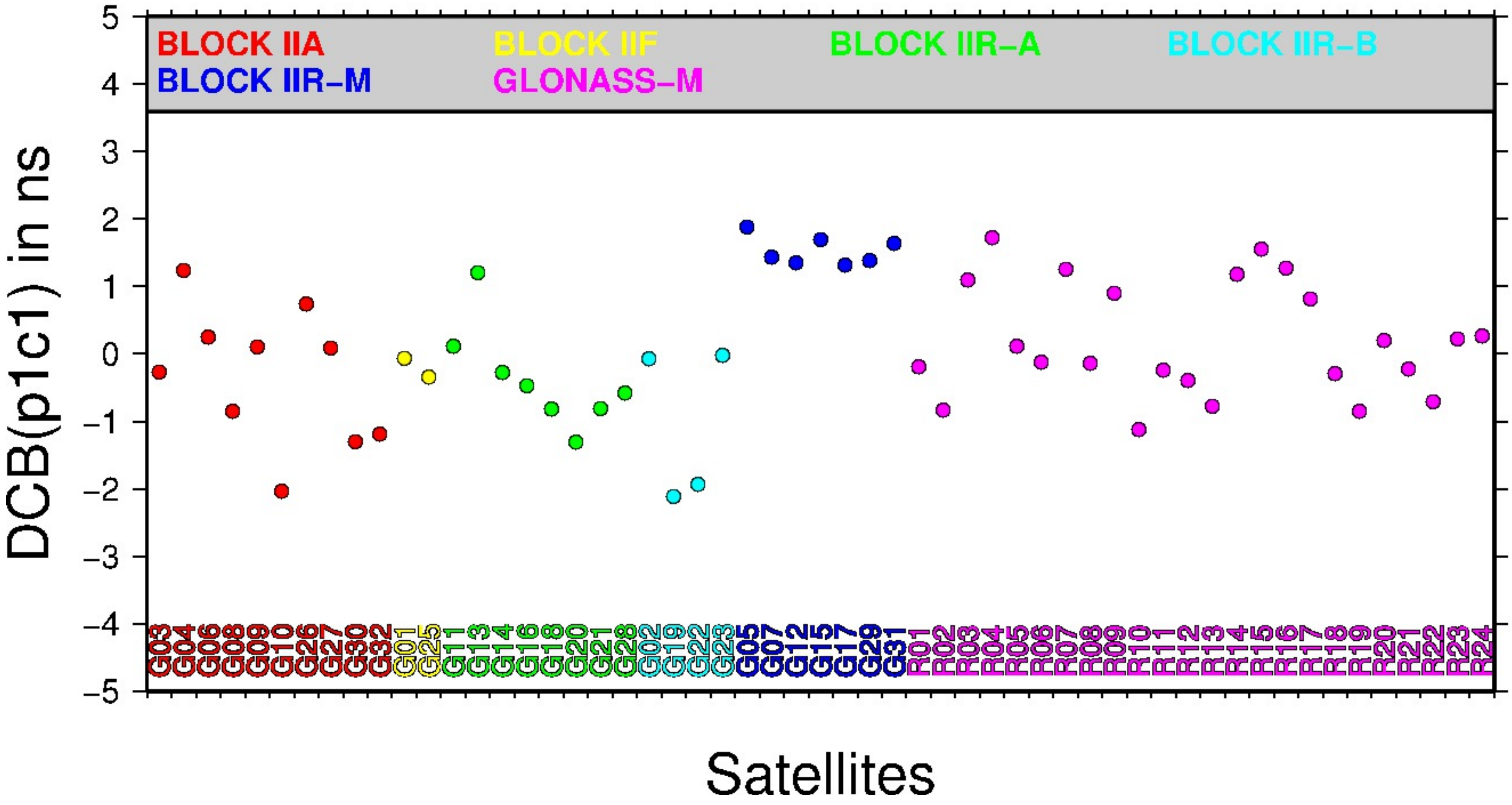
Because each observation contains the DCBs for the receiver and satellite we need again a convention regarding the reference (e.g., zero-mean condition for all satellites).

This direct DCB determination approach is the only way to get access to the GLONASS DCB values independent from the inter-system bias.

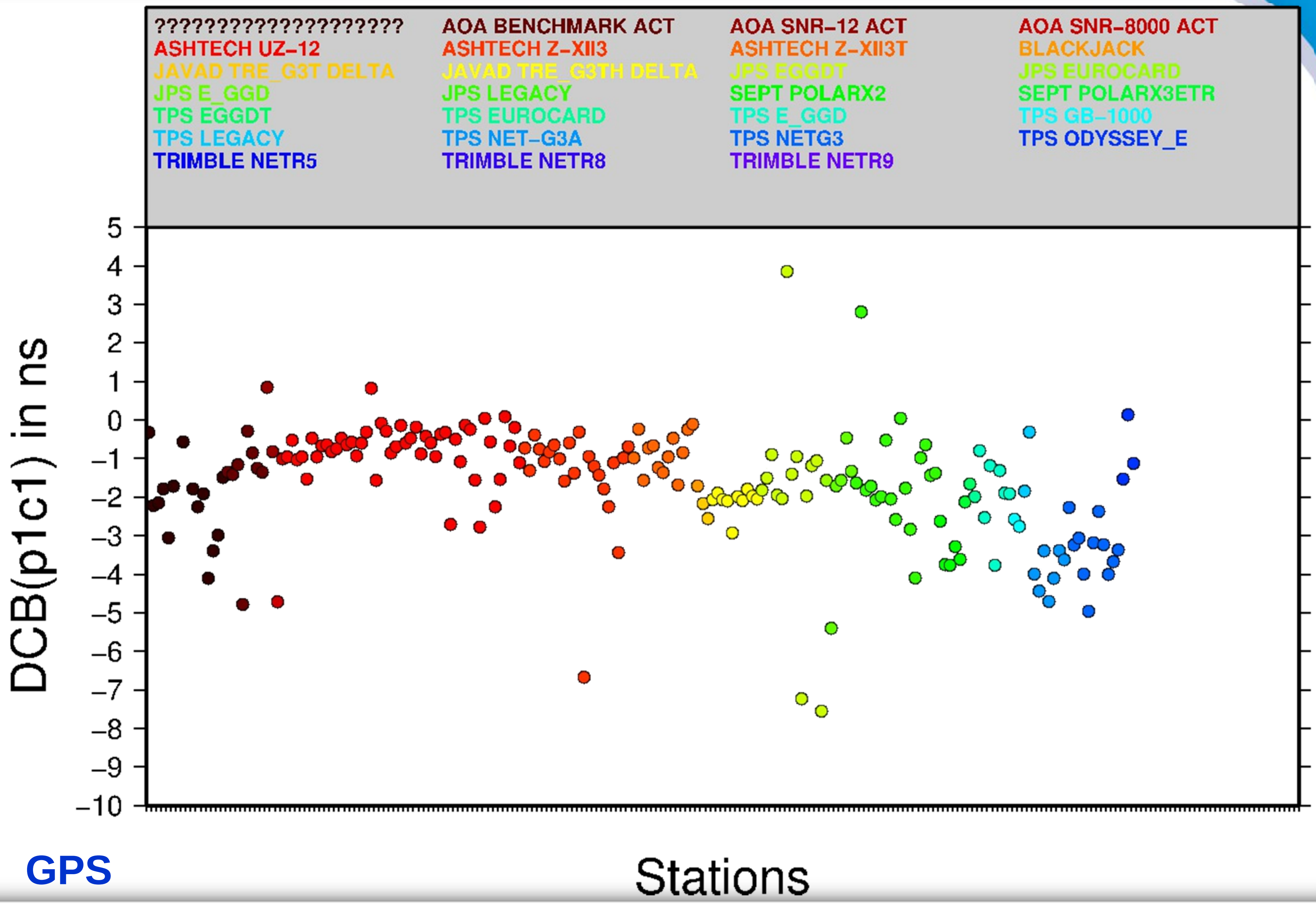
DCBs from RINEX files

CODE's GNSS P1-C1 DCB monthly solution,

computed for December 2011 (directly from RINEX)

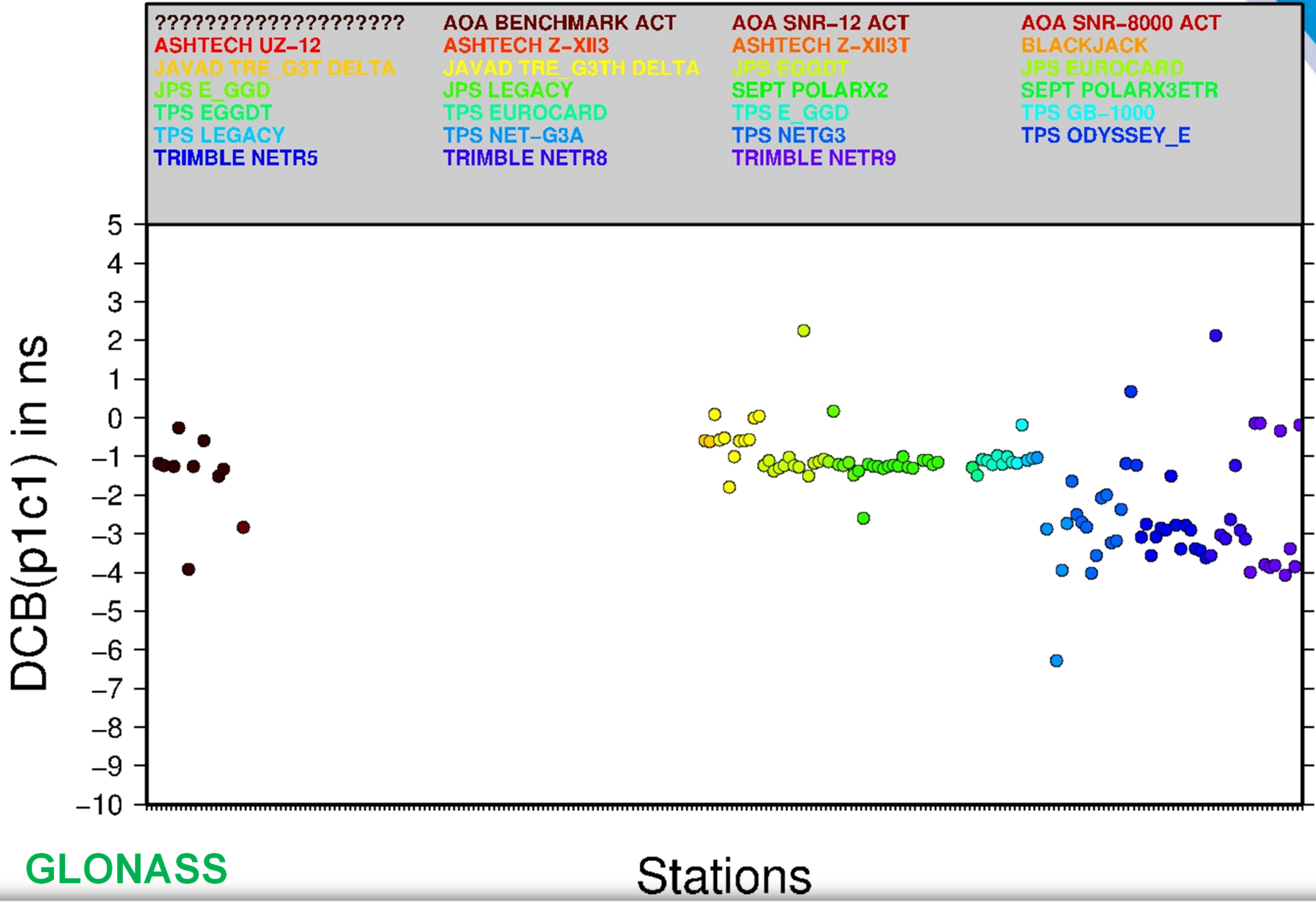


DCBs from RINEX files



GPS

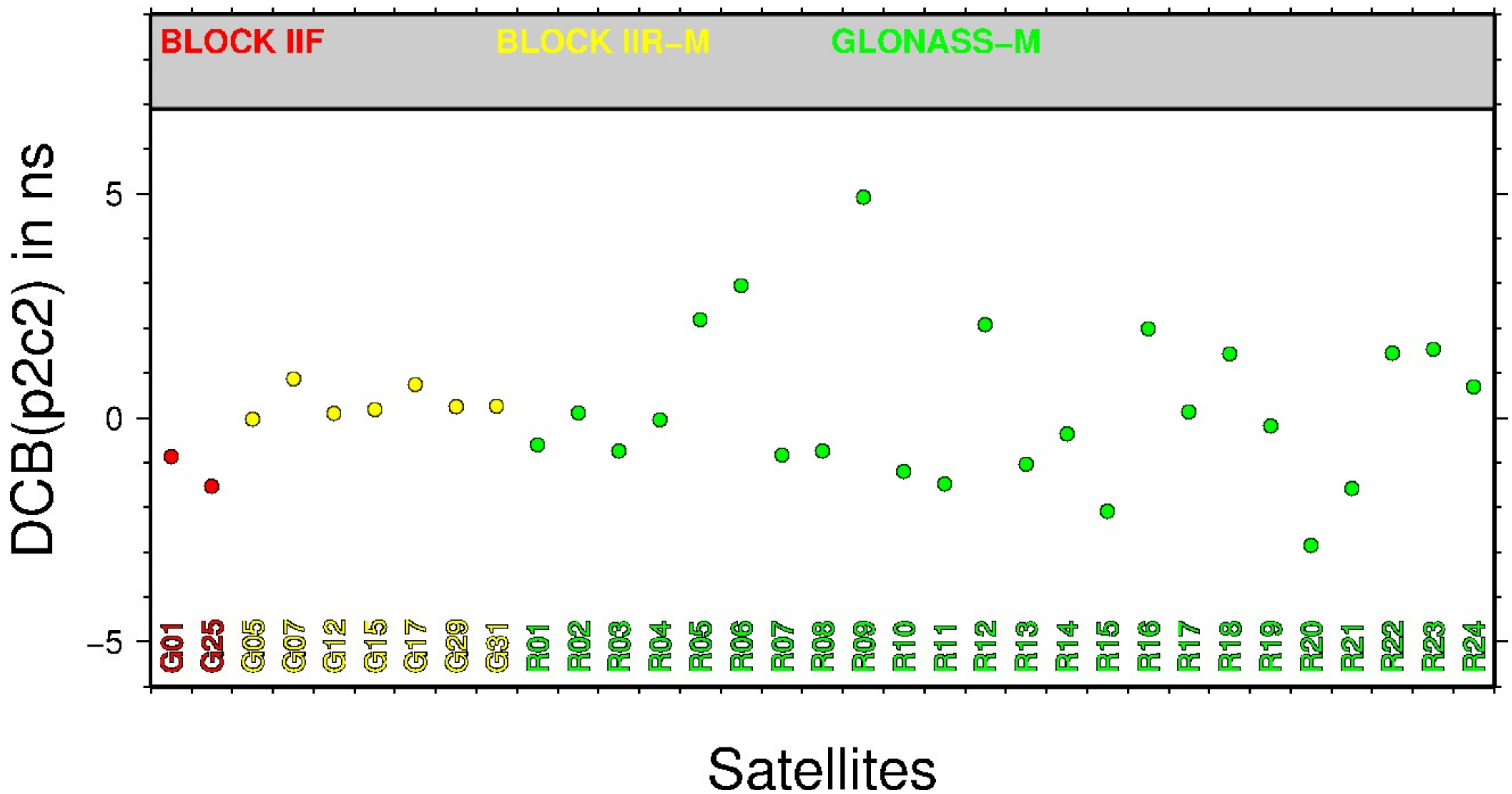
DCBs from RINEX files



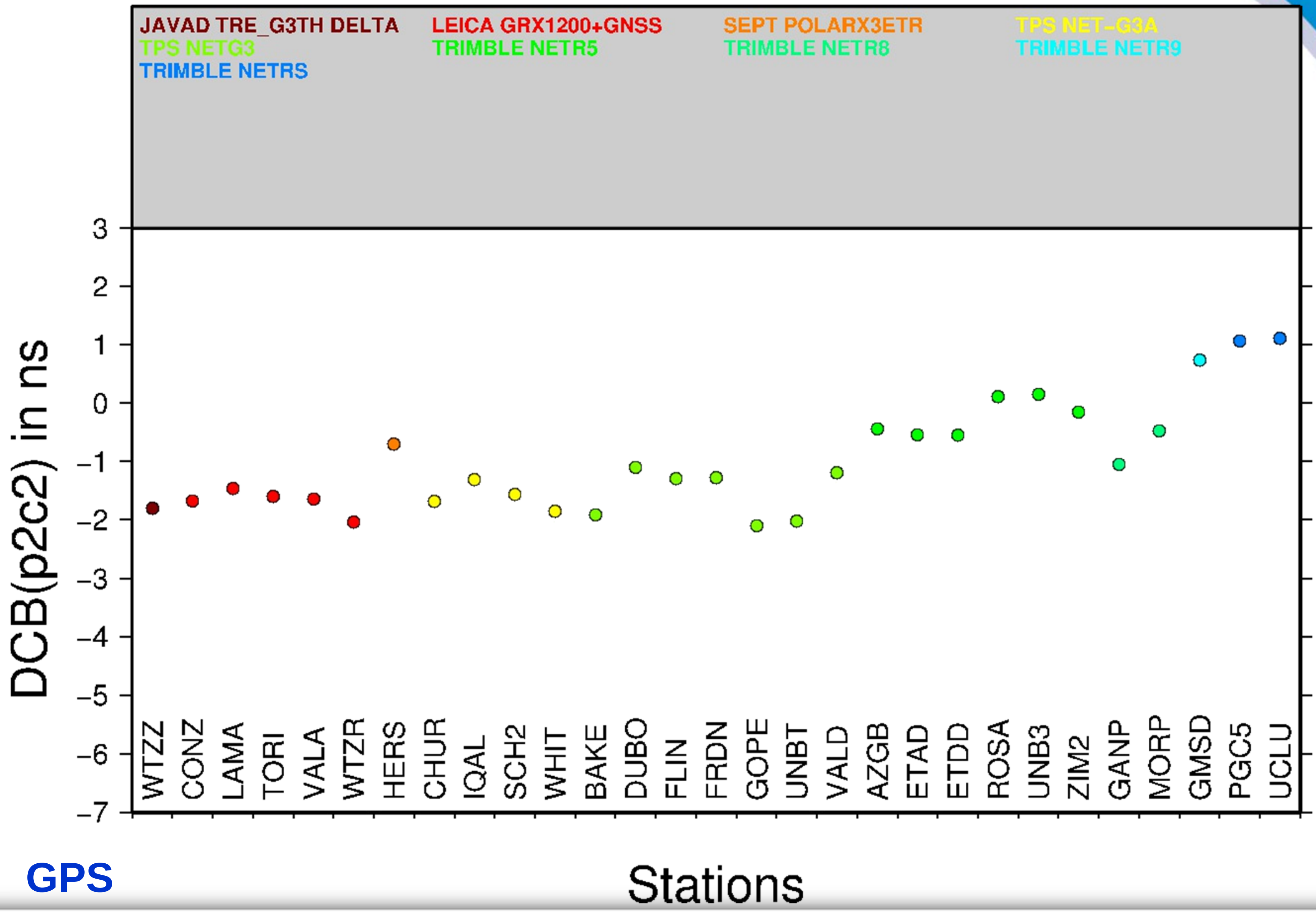
GLONASS

DCBs from RINEX files

CODE's GNSS P2-C2 DCB monthly solution,
computed for December 2011 (directly from RINEX)

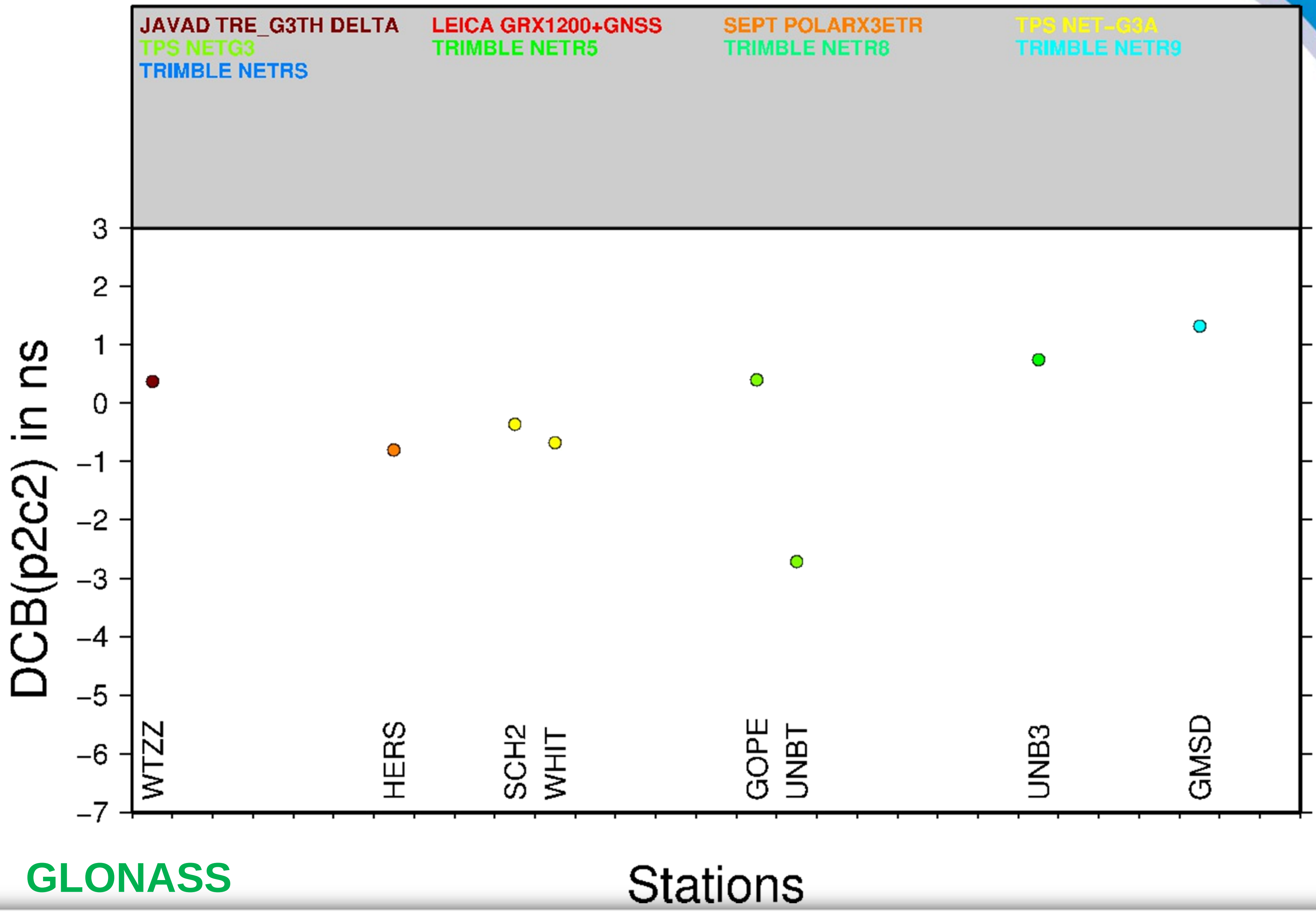


DCBs from RINEX files



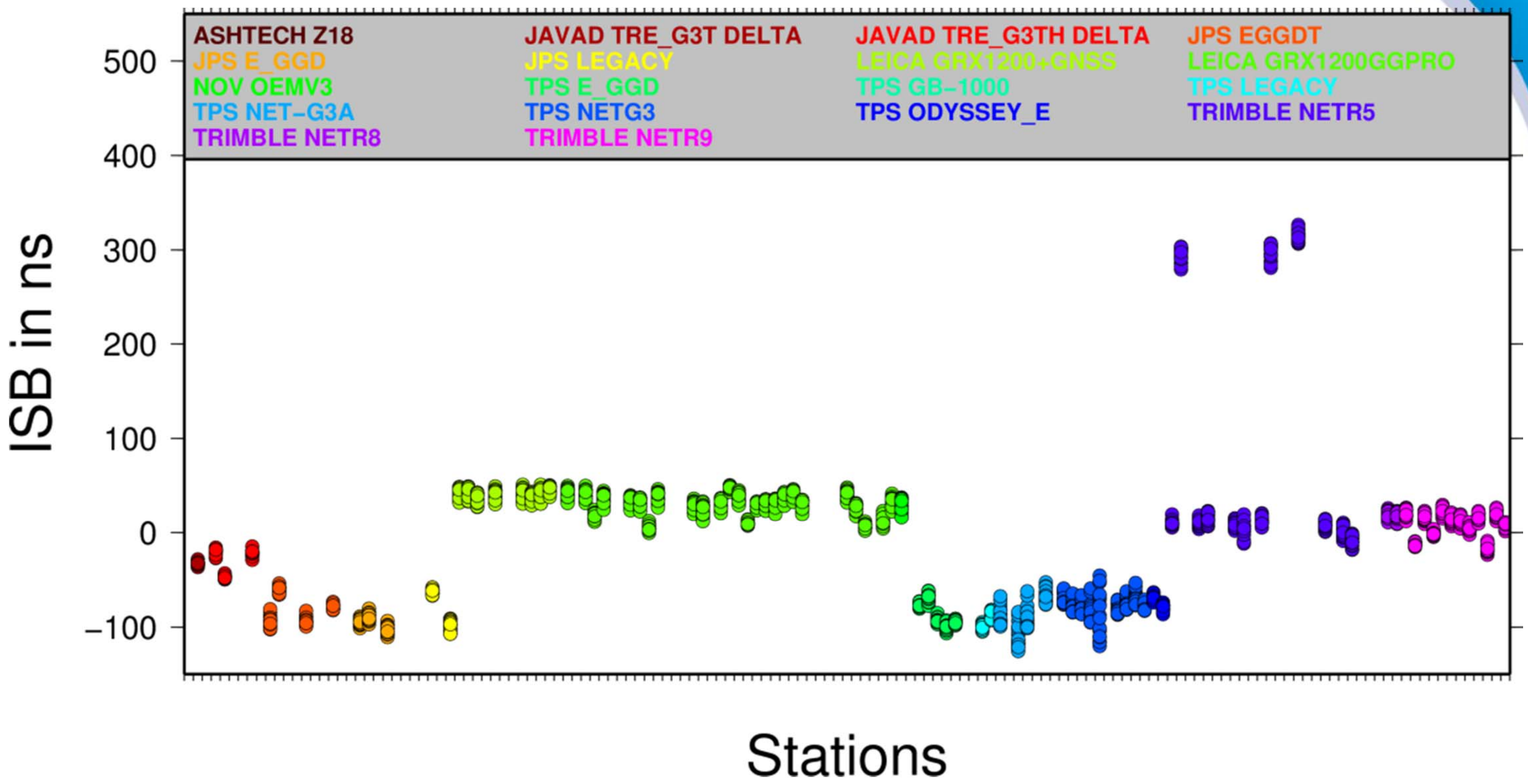
GPS

DCBs from RINEX files



GLONASS

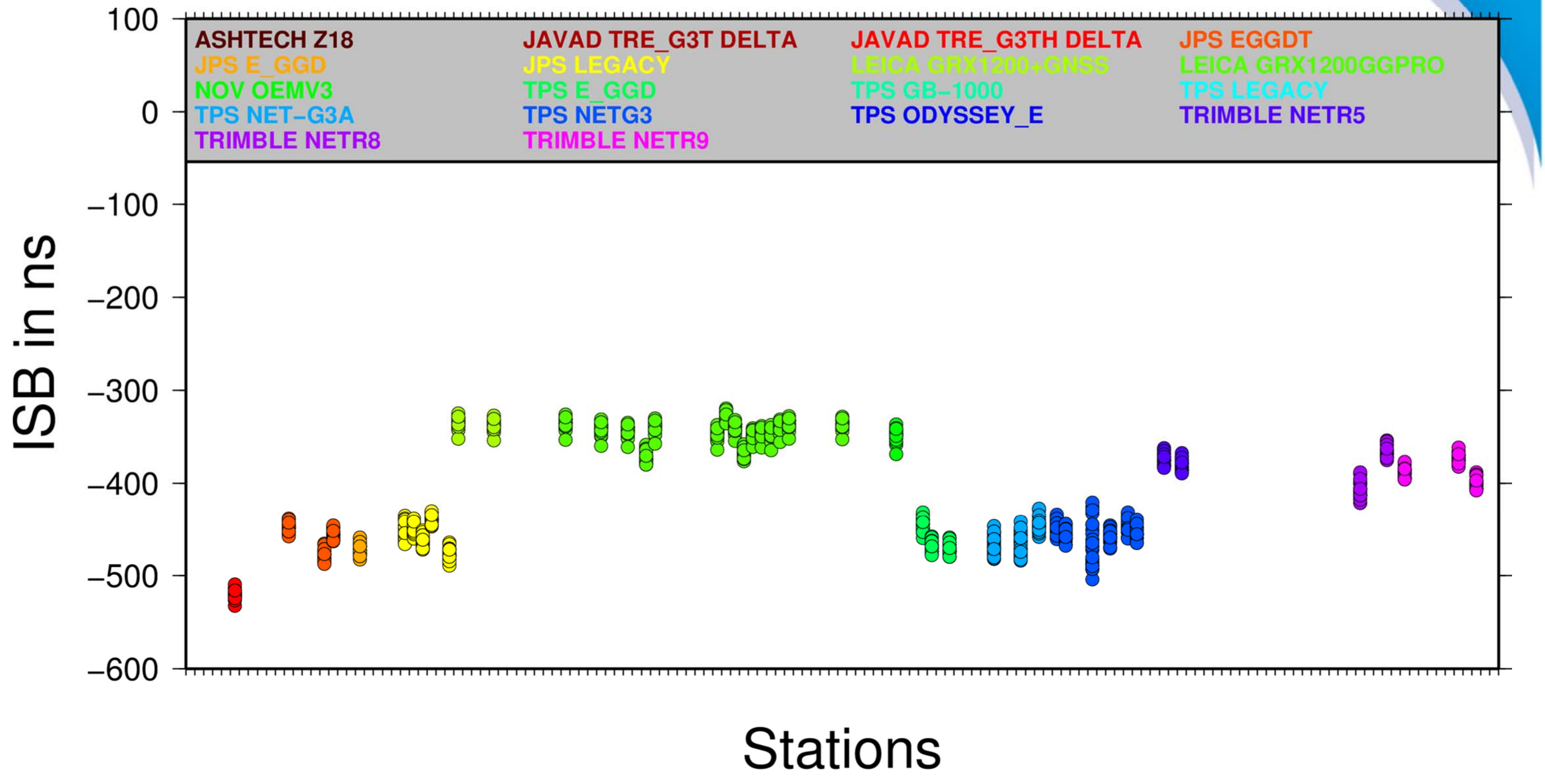
ISB/IFB from a GPS/GLONASS solution



ISB/IFB from CODE

test solution submitted to the IGS workshop on GNSS biases in January 2012

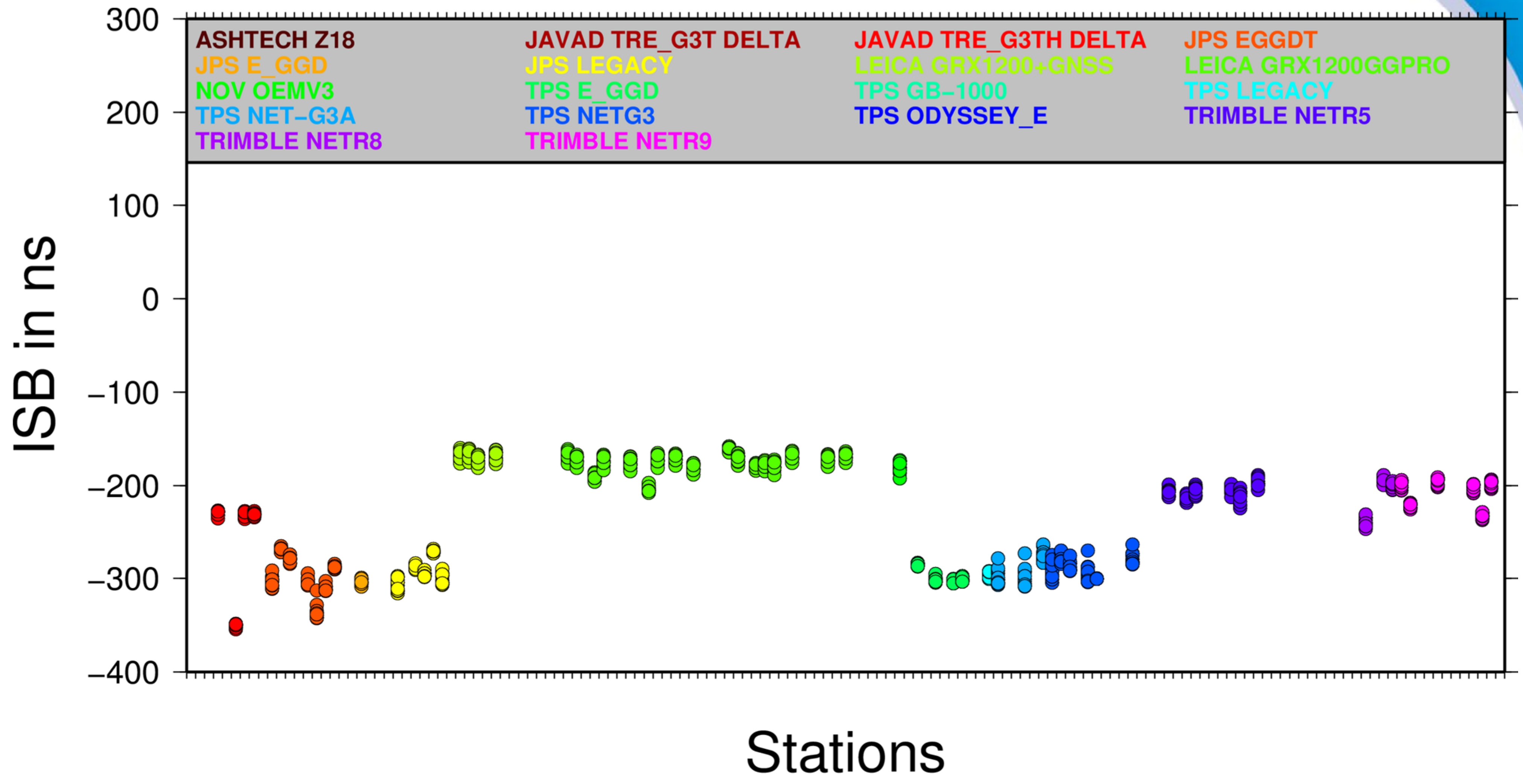
ISB/IFB from a GPS/GLONASS solution



ISB/IFB from ESA

test solution submitted to the IGS workshop on GNSS biases in January 2012

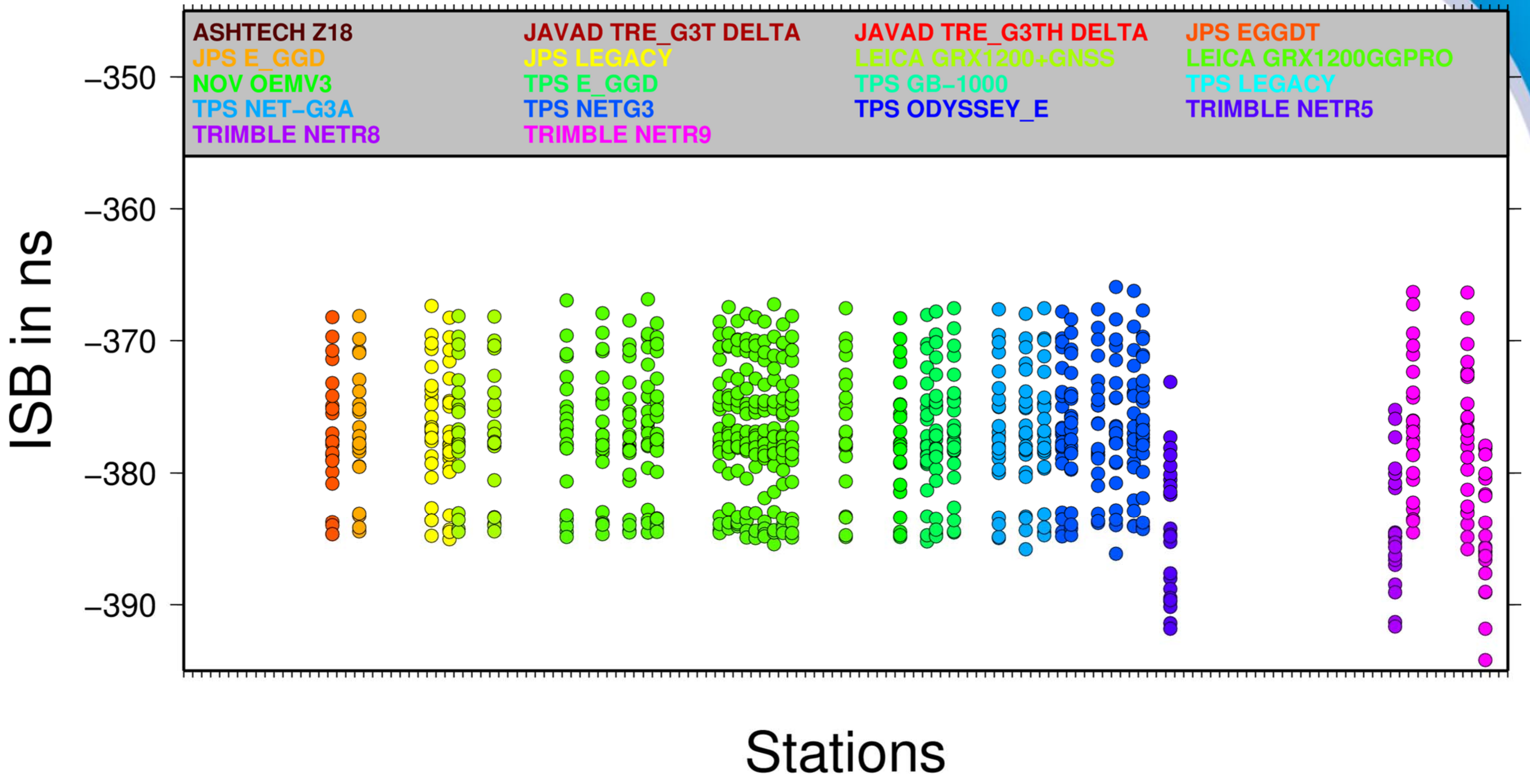
ISB/IFB from a GPS/GLONASS solution



ISB/IFB from GFZ

test solution submitted to the IGS workshop on GNSS biases in January 2012

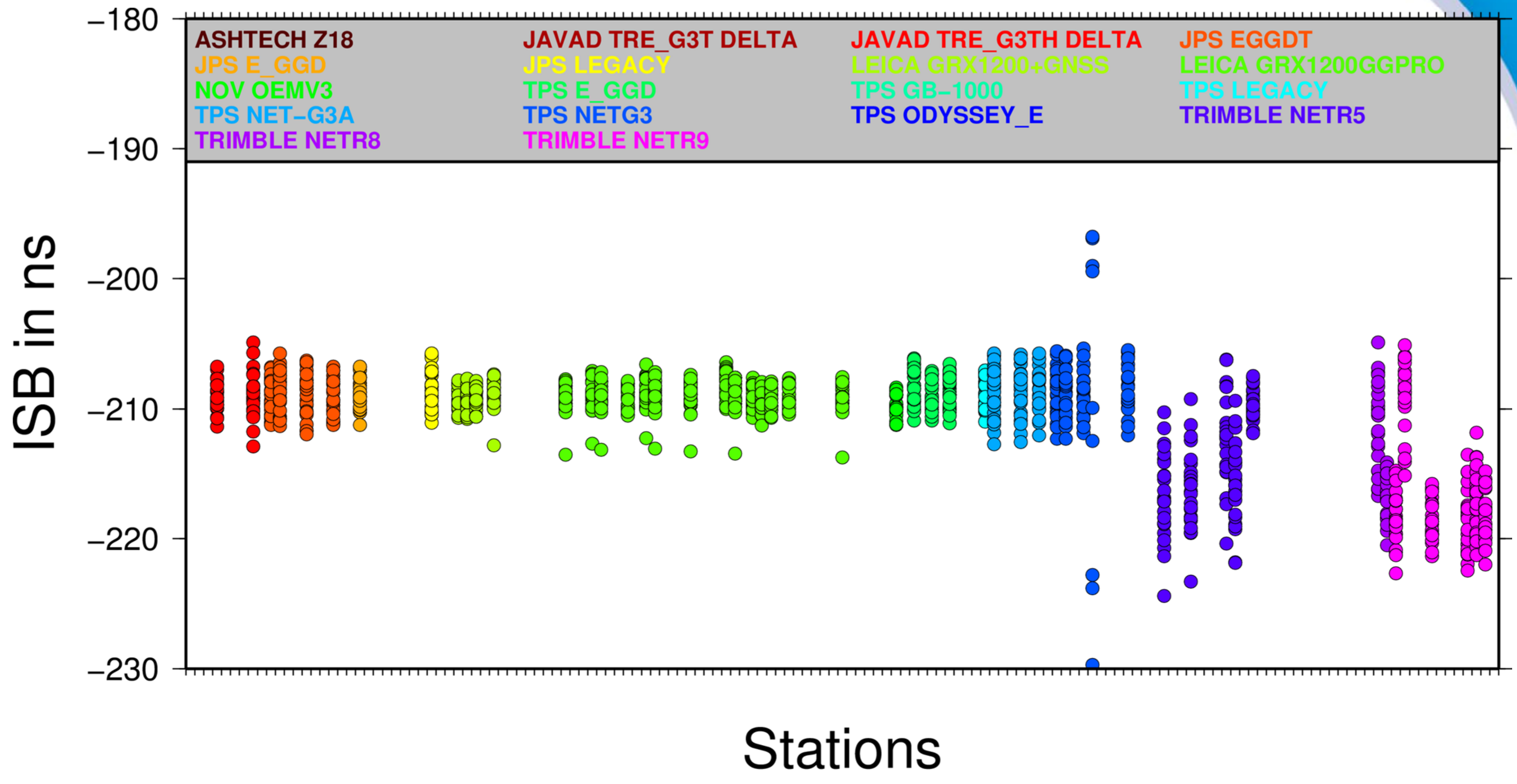
ISB/IFB from a GPS/GLONASS solution



ISB/IFB: Differences CODE-ESA

test solution submitted to the IGS workshop on GNSS biases in January 2012

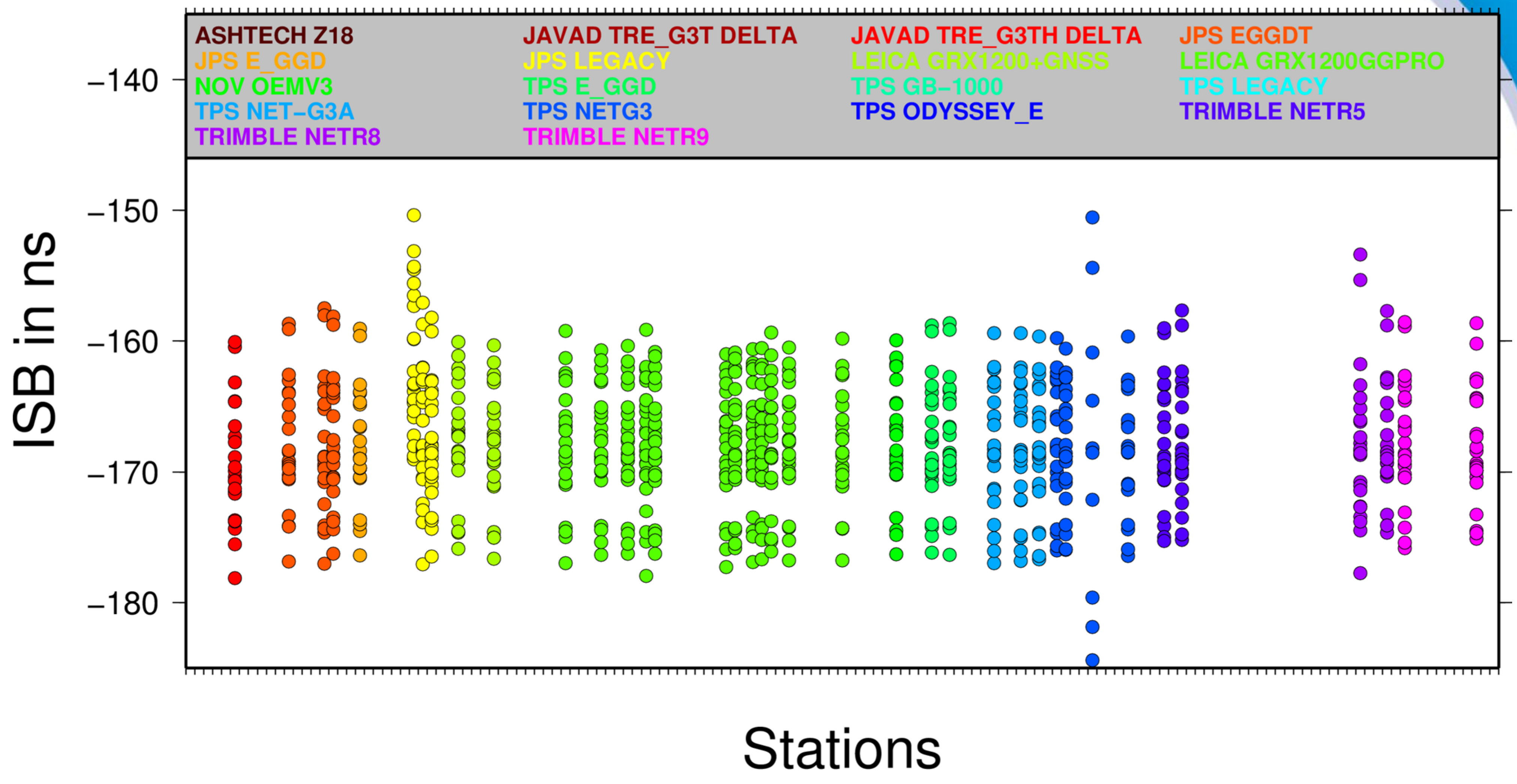
ISB/IFB from a GPS/GLONASS solution



ISB/IFB: Differences CODE-GFZ

test solution submitted to the IGS workshop on GNSS biases in January 2012

ISB/IFB from a GPS/GLONASS solution



ISB/IFB: Differences GFZ-ESA

test solution submitted to the IGS workshop on GNSS biases in January 2012

ISB/IFB from a GPS/GLONASS solution

Differences between ISB characteristic of the receivers

Difference		Number of stations	Mean in ns	Median in ns	RMS in ns
CODE	GFZ	52	-210.6	-209.4	4.9
CODE	ESA	39	-377.5	-377.6	5.1
GFZ	ESA	36	-167.7	-168.2	6.1
CODE	GRGS	50	-371.9	-372.1	18.7
GFZ	GRGS	46	-162.1	-163.0	19.2
ESA	GRGS	34	6.1	5.8	20.6

- High consistency (low RMS) with a proper IFB—handling (enough weight for the code measurements?)
- Test whether the ACs select the same type of code observations (CODE differs from ESA and GFZ)

Further biases

- When forming linear combinations from the P_1 and P_2 measurements
  $$LC = k_1 \cdot P_1 + k_2 \cdot P_2$$
  the original P1-C1, P2-C2 DCB values have to be applied with the corresponding coefficients:
  $$DCB(LC) = k_1 \cdot DCB(P1C1) + k_2 \cdot DCB(P2C2)$$

- Alternative factors need to apply when P_2 or C_2 is not directly tracked (e.g., cross-correlation technique).

- When extracting the ionosphere information by a $P_1 - P_2$ linear combination, the differences between the hardware delays for P_1 and P_2 at the receiver and satellite need to be considered as an additional type of DCBs: DCB(P1P2)

- With more GNSS and their new signals more groups of DCBs will become relevant (e.g, third frequency for GPS and GLONASS).

Dependency of the terms

$$P_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta x^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta x_i}\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot \left(\delta^k + a^k\right)$$

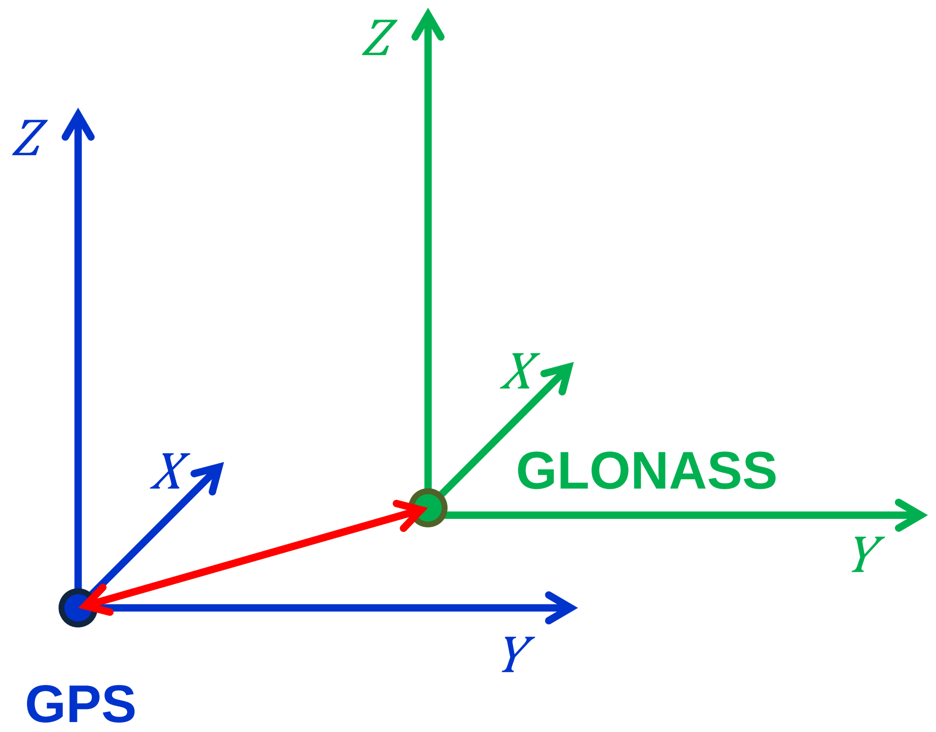
$$L_i^k = \left|\left(\overrightarrow{x^k} + \overrightarrow{\Delta \chi^k}\right) - \left(\overrightarrow{x_i} + \overrightarrow{\Delta \chi_i}\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot \left(\delta^k + \alpha^k\right)$$
$$+\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k$$

	Antenna		Hardware (receiver)			
GNSS:						
Code:		$\overrightarrow{\Delta x_i}$	a_i		(δ^k)	**ISB: Inter-system bias**
Phase:		$\overrightarrow{\Delta \chi_i}$	α_i		(δ^k)	
Frequency:						
Code:	$\overrightarrow{\Delta x^k}$	$\overrightarrow{\Delta x_i}$	a_i	a^k		**IFB: Inter-frequency bias**
Phase:	$\overrightarrow{\Delta \chi^k}$	$\overrightarrow{\Delta \chi_i}$	α_i	α^k		
Signal type:						
Code:			a_i	a^k		**DCB: Differential code bias**

GLONASS-GPS translation bias

A GNSS antenna should be individually calibrated for each GNSS to consider the system-dependency of the $\overrightarrow{\Delta\chi_i}$ term.

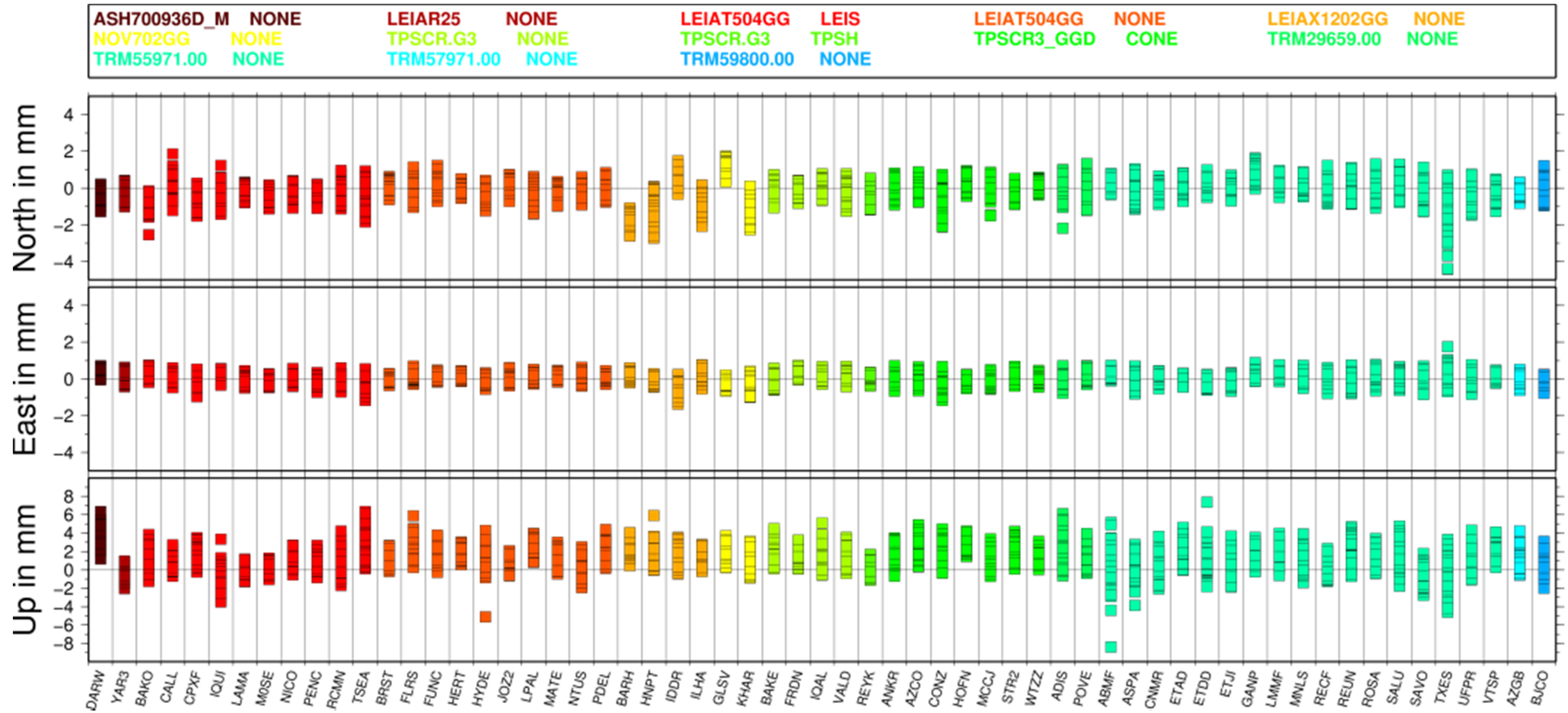
The coordinate GLONASS-GPS translation bias shall compensate for a potential deficiency in the GNSS-specific calibration of the antenna phase center offset.



- Station coordinate from GPS-only
- Station coordinate from GLONASS-only
- Vector between GPS- and GLONASS coordinates
- Two independent networks with independent datum definition
- Zero-mean condition over all GLONASS-GPS bias in XYZ

GPS/GLONASS-Bias

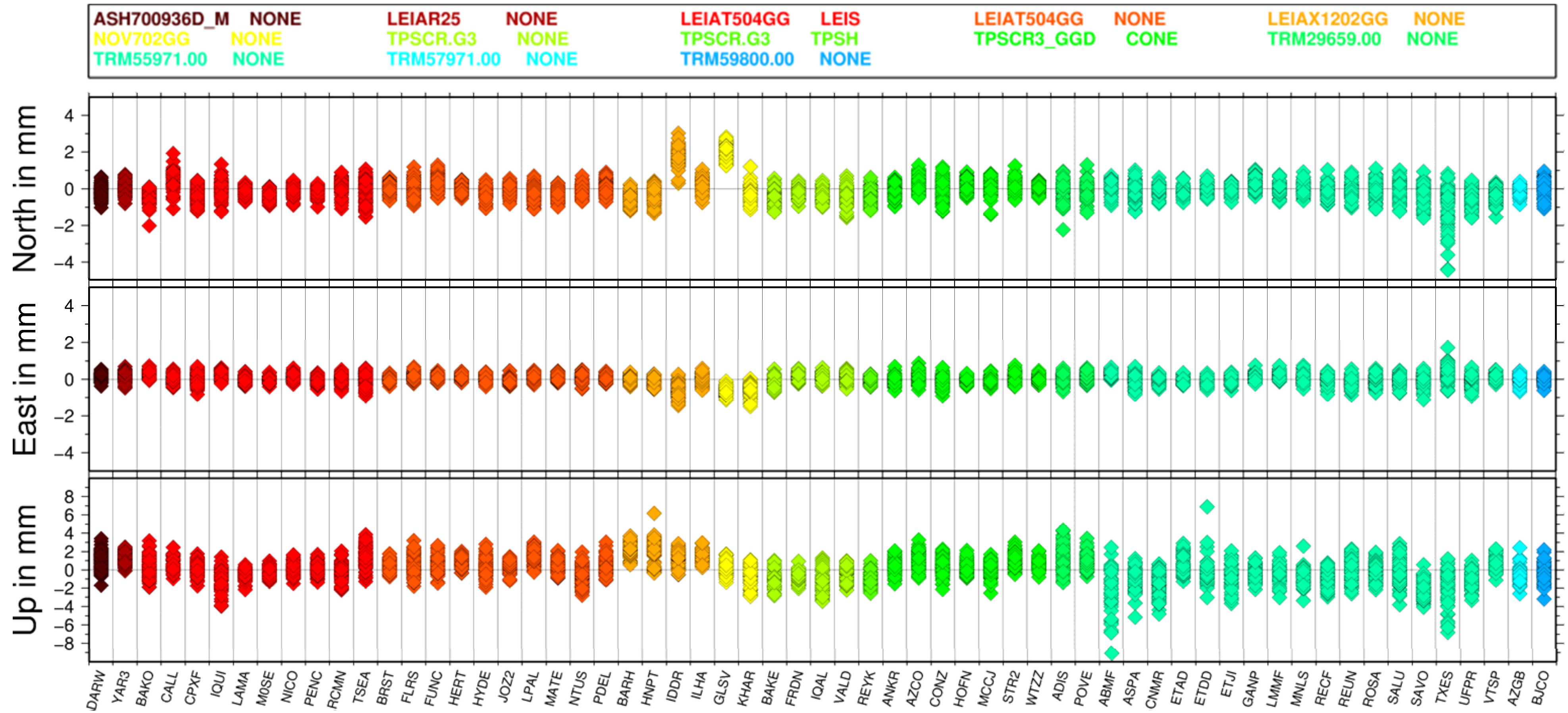
Differences between weekly coordinate solutions for GPS/GLONASS stations with and without estimating GLONASS-GPS translation biases



Receiver/satellite antenna model: IGS05

GPS/GLONASS-Bias

Differences between weekly coordinate solutions for GPS/GLONASS stations with and without estimating GLONASS-GPS translation biases

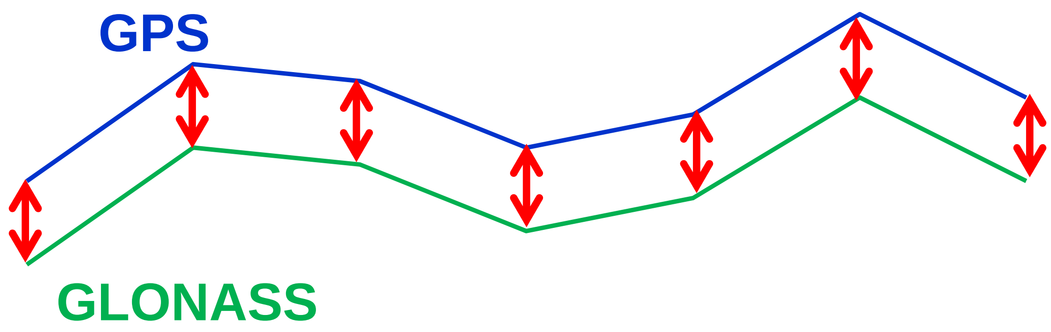


Receiver/satellite antenna model: IGS08

GLONASS-GPS translation bias

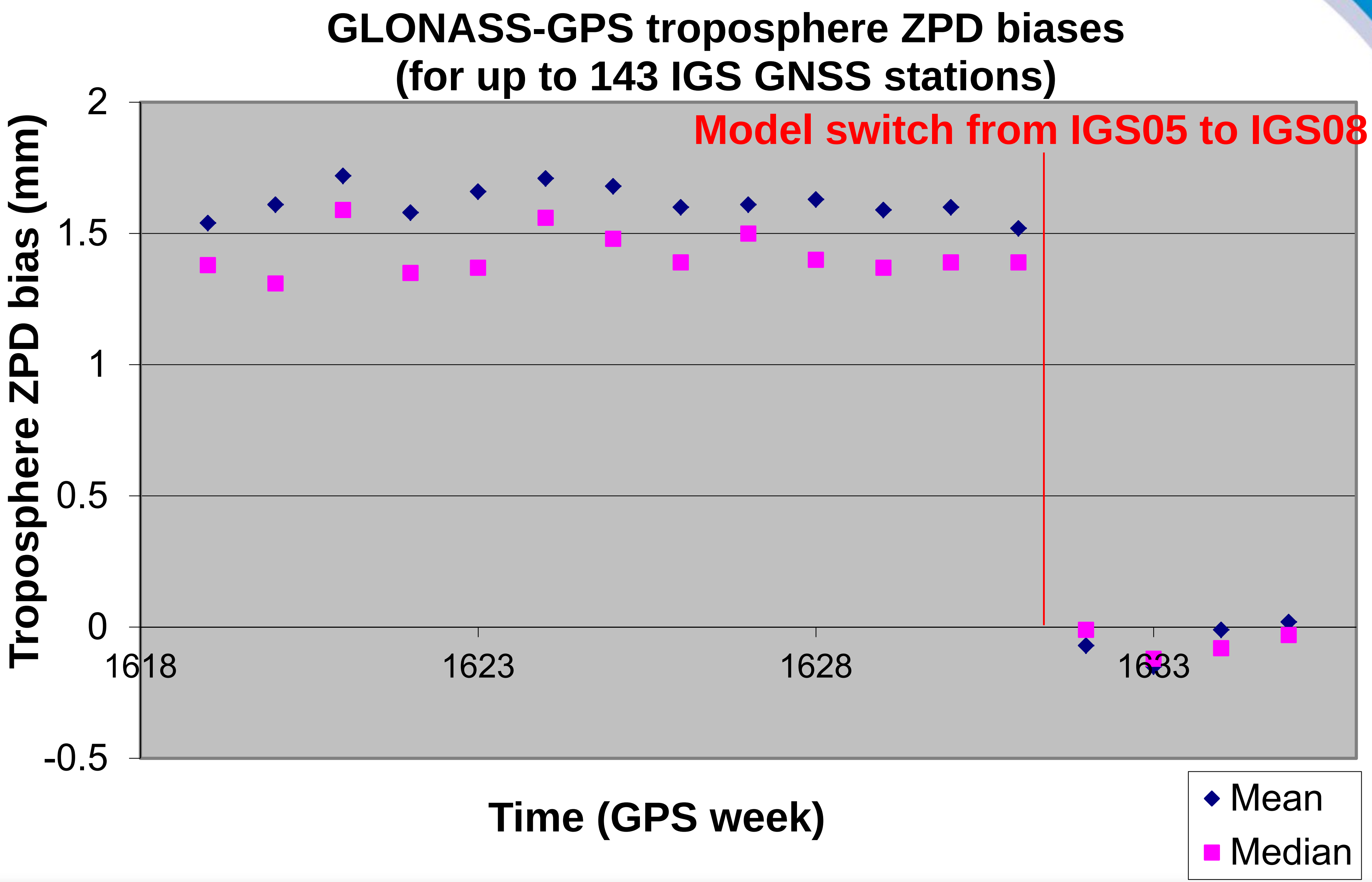
A GNSS antenna should be individually calibrated for each GNSS to consider the system-dependensy of the $\overrightarrow{\Delta\chi_i}$ term.

The troposphere GLONASS-GPS translation bias shall compensate for a potential deficiency in the GNSS-specific calibration of the antenna phase center variation.

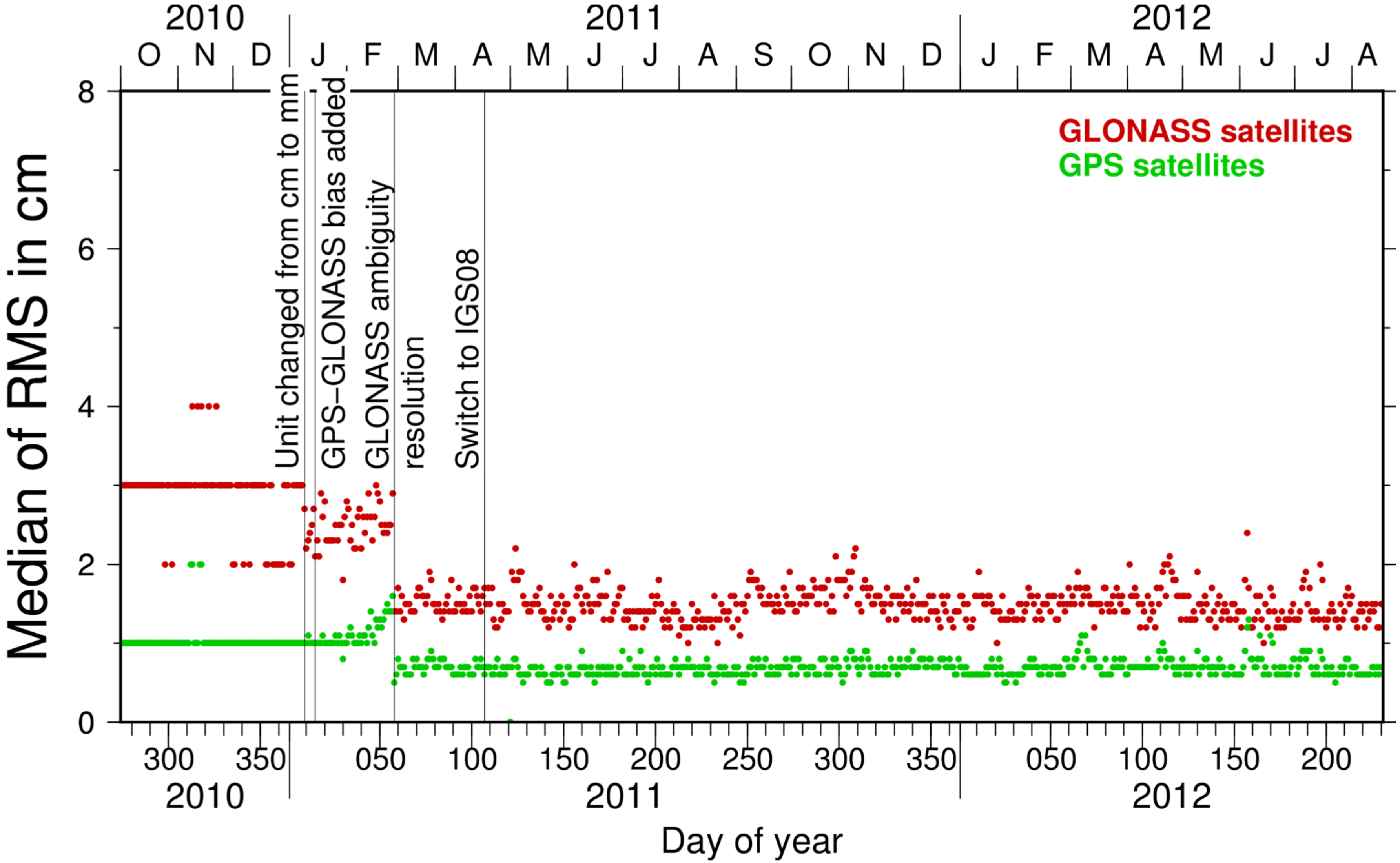


- Troposphere estimates from GPS-only
- Troposphere estimates from GLONASS-only
- Difference between GLONASS- and GPS troposphere series
- No further condition is necessary.

GLONASS-GPS translation bias



CODE processing changes in 2011



Operational series from CODE

Outline

- **Introduction**
- **Orbit Determination (at CODE)**
- **Code Biases:**

Merci pour votre attention !