

Multiconstellation GNSS with the advent of Galileo

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Astronomisches Institut, Universität Bern

1st GAL WORKSHOP
24. May 2013, Como, Italy

Outline

IGS MGEX: What and Why?

CODE–Contribution to IGS MGEX

Why going from GPS–only to multi–GNSS?

Summary

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CODE–Contribution to IGS MGEX

Why going from GPS–only to multi–GNSS?

Summary

GNSS: Situation today



USA: GPS

Global Positioning System

GNSS: Situation today



USA: GPS

Global Positioning System

32 active satellites (nominal: 24)

GNSS: Situation today



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Russia: ГЛОНАСС

Глобальная навигационная спутниковая система

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Russia: GLONASS

Global Satellite Navigation System

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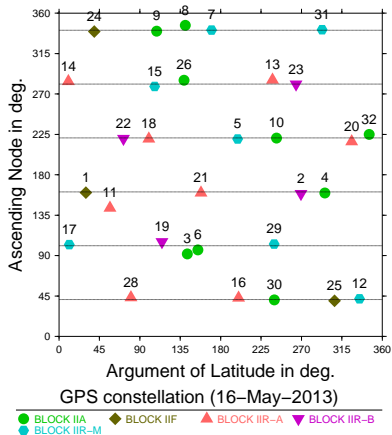


Europe: Galileo

Nominal constellation of 27 satellites

GPS: Global Positioning System

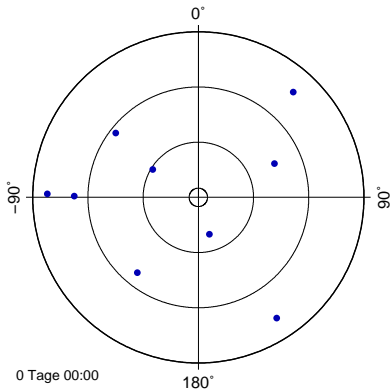
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- Semi-major axis $a = 26\,500$ km, inclination $i = 55^\circ$
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same geometry: 1 sidereal day
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Elevation–Azimuth–Diagram for Como



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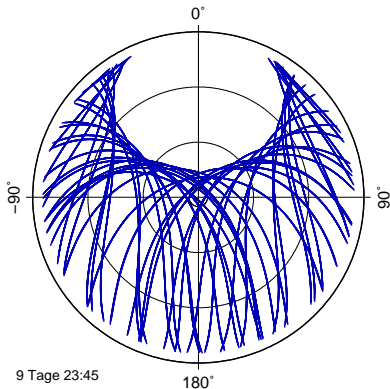
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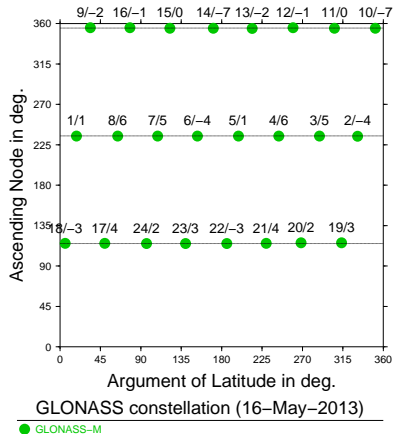
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GLONASS: Global Navigation Satellite System

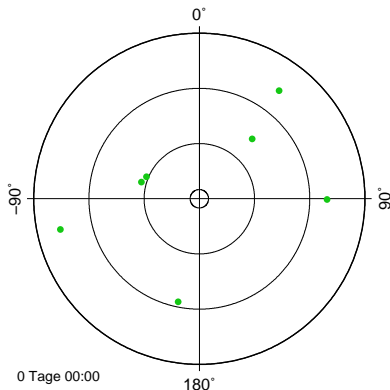
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- Revolution period $11^{\text{h}}\ 16^{\text{m}}$
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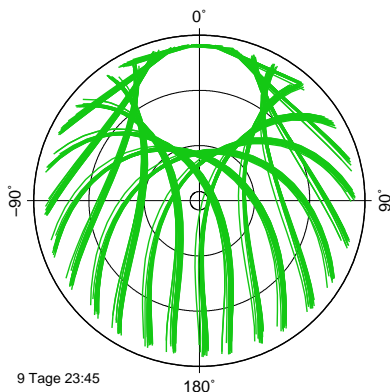
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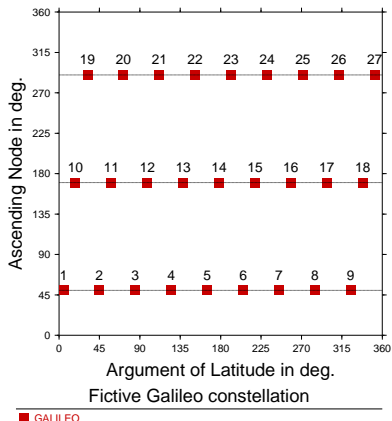
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Galileo: the European GNSS

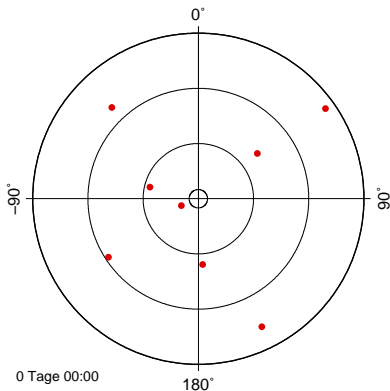
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- Semi-major axis $a = 30\,000$ km, inclination $i = 56^\circ$
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- Repeation rates: same geometry and same constellation: 10 sidereal days



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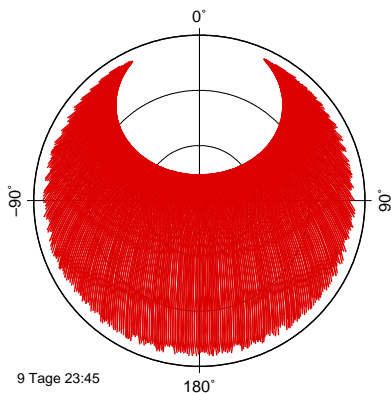
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Orbit characteristics of the GNSS



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update to 3 frequencies; new signals



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Nominal constellation of 27 satellites
Different signals on 5 frequencies (3 ranges)

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Europe: Galileo

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China: BeiDou

Nominal constellation of 27 MEO satellites
Signals on 3 frequencies

Range of GNSS–Signals

GNSS signals

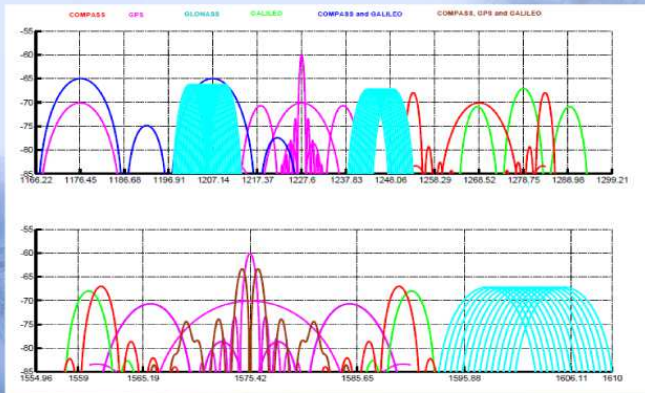


Figure: GNSS spectrum (after China ICG presentation)
from *Inside GNSS magazine*, Vol. 4(5), Sep/Oct. 2009

IGS–MGEX campaign

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

IGS–MGEX campaign

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

This Call for Participation for the IGS Multi-GNSS Experiment — IGS M-GEX — 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.

IGS–MGEX campaign

- **IGS–MGEX: IGS Multi–GNSS Experiment**
- **August 2011: Call for Participation:**
 - current modernization programs for **GPS** and **GLONASS**
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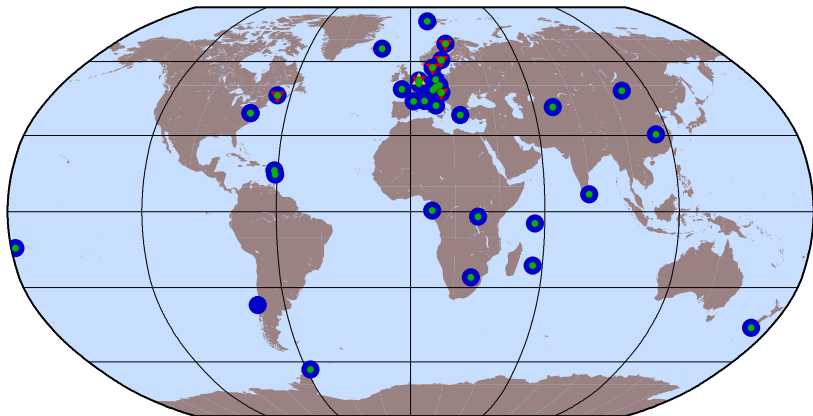
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Development of the IGS-MGEX network

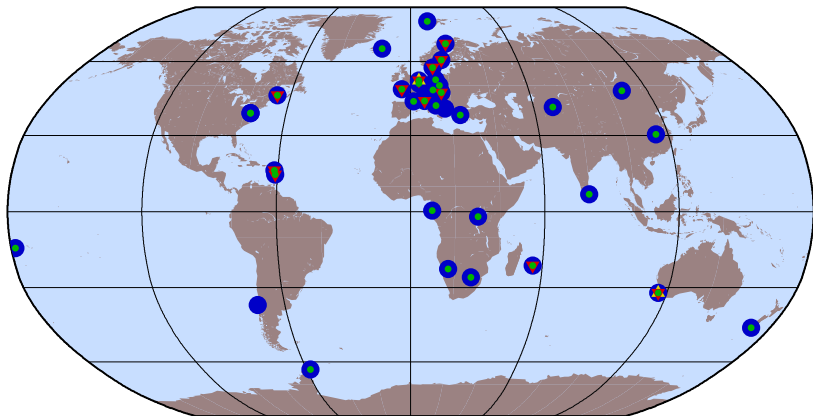


Tracking status by 2012-JUL-01







- | | |
|---|--|
|  GPS(L5)+Galileo+BeiDou+QZSS (1) |  GPS(L5)+Galileo+BeiDou (5) |
|  GPS(L5)+Galileo+QZSS (0) |  GPS(L5)+Galileo (29) |
|  (GPS+)+QZSS (0) |  GPS(L5) (2) |

Extracted from available RINEX3 observations files

Development of the IGS-MGEX network

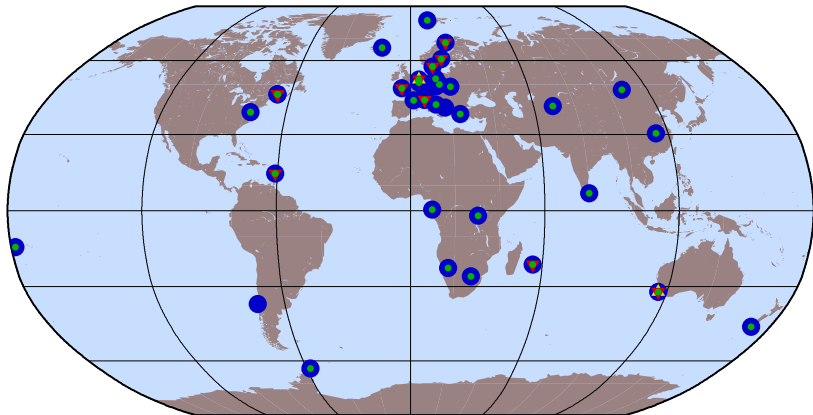


Tracking status by 2012–AUG–20







- | | |
|---|---|
|  GPS(L5)+Galileo+BeiDou+QZSS (2) |  GPS(L5)+Galileo+BeiDou (10) |
|  GPS(L5)+Galileo+QZSS (0) |  GPS(L5)+Galileo (22) |
|  (GPS+)+QZSS (0) |  GPS(L5) (6) |

Extracted from available RINEX3 observations files

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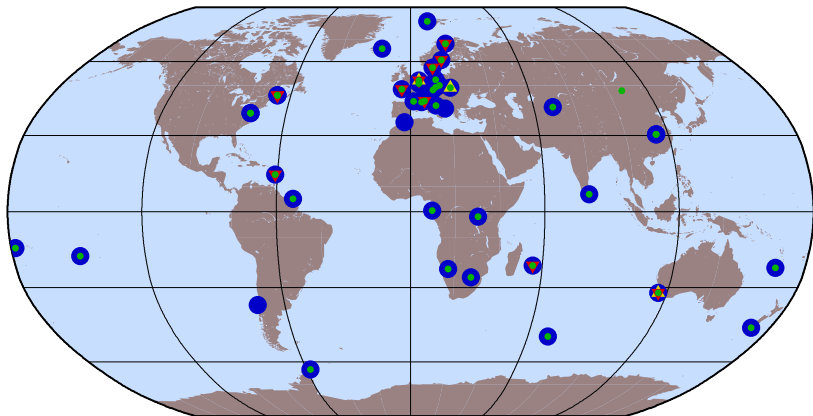


Tracking status by 2012-OCT-09







- | | |
|---|--|
|  GPS(L5)+Galileo+BeiDou+QZSS (2) |  GPS(L5)+Galileo+BeiDou (9) |
|  GPS(L5)+Galileo+QZSS (0) |  GPS(L5)+Galileo (21) |
|  (GPS+)+QZSS (0) |  GPS(L5) (5) |

Extracted from available RINEX3 observations files

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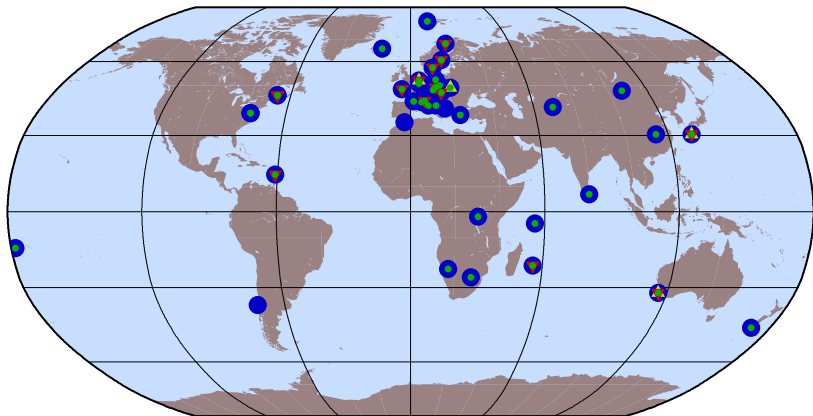


Tracking status by 2012-NOV-28







- | | |
|---|--|
|  GPS(L5)+Galileo+BeiDou+QZSS (2) |  GPS(L5)+Galileo+BeiDou (9) |
|  GPS(L5)+Galileo+QZSS (1) |  GPS(L5)+Galileo (27) |
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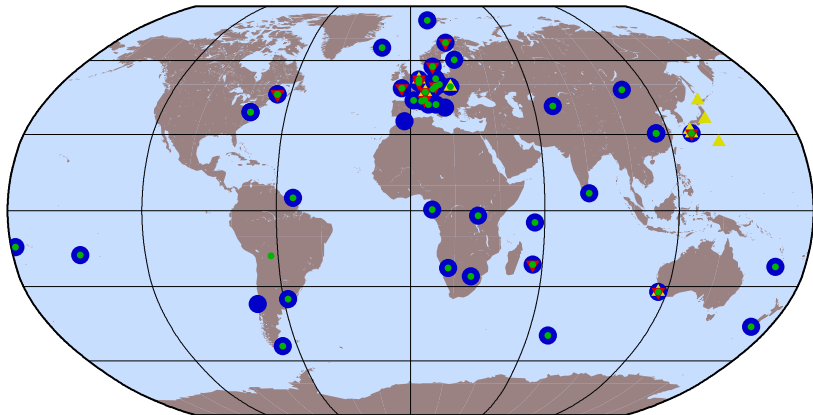


Tracking status by 2013-JAN-17







- | | |
|---|---|
|  GPS(L5)+Galileo+BeiDou+QZSS (3) |  GPS(L5)+Galileo+BeiDou (11) |
|  GPS(L5)+Galileo+QZSS (1) |  GPS(L5)+Galileo (23) |
|  (GPS+)+QZSS (0) |  GPS(L5) (5) |

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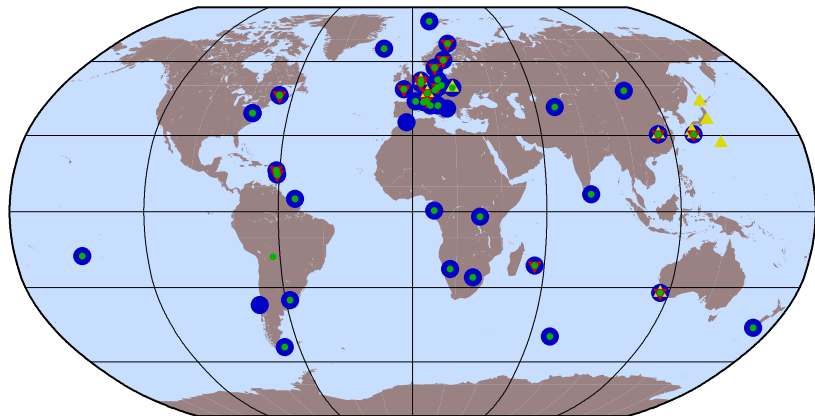


Tracking status by 2013-MAR-08







- | | |
|---|--|
|  GPS(L5)+Galileo+BeiDou+QZSS (4) |  GPS(L5)+Galileo+BeiDou (9) |
|  GPS(L5)+Galileo+QZSS (1) |  GPS(L5)+Galileo (30) |
|  (GPS+)+QZSS (4) |  GPS(L5) (5) |

Extracted from available RINEX3 observations files

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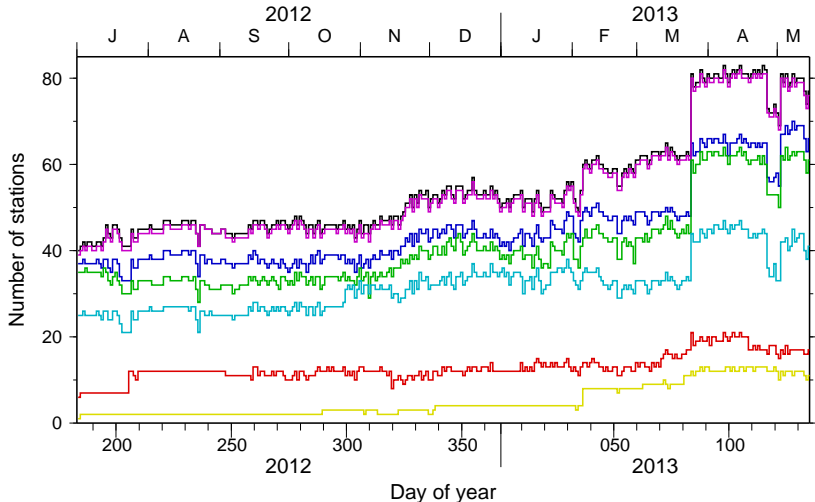


Tracking status by 2013-APR-02

- | | |
|---|---|
|  GPS(L5)+Galileo+BeiDou+QZSS (5) |  GPS(L5)+Galileo+BeiDou (15) |
|  GPS(L5)+Galileo+QZSS (3) |  GPS(L5)+Galileo (38) |
|  (GPS+)+QZSS (4) |  GPS(L5) (4) |

Extracted from available RINEX3 observations files

Development of the IGS-MGEX network



Legend:
GPS(L5) GLONASS Galileo SBAS BeiDou QZSS

R. Dach, L. Prange et al.: Multiconstellation GNSS with the advent of Galileo
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Solutions in the frame of IGS–MGEX

Institution	Constellations	Availability (week/day)
CNES/CLS	Galileo	since 1692/1
COD	GPS+GLONASS+Galileo	since 1689/5
GFZ	GPS+Galileo	1680/0-1683/6
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Remarks:

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2. COD and GFZ: fully combined multi–GNSS solutions
GNES/CLS and TUM: separate solutions introducing results from an independent GPS–solution
3. COD–solution is for political reasons only available on a non–operational basis.

CODE–Contribution to IGS MGEX

IGS MGEX: What and Why?

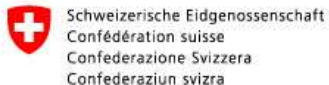
CODE–Contribution to IGS MGEX

Why going from GPS–only to multi–GNSS?

Summary

The CODE analysis center

- 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).



Technische Universität München

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- CODE started operating on 21 June 1992.

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- Initially about 20, today more than 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 all European global analysis centers join this a strategy for their final products: ESOC, GFZ, GRGS, NRCan.

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 resulting in 60 satellites

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- Product list: daily orbits (SP3) and ERPs
- Distribution: <ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/>
- Timespan covered: GPS-weeks 1689–1720 (DOY 12/146–12/364)

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Timespan covered:	GPS-weeks 1689–1720 (DOY 12/146–12/364)
Processing scheme:	double-difference network processing
Orbit characteristic:	3-day long arcs

Why multi-day arcs?

Number of observations per satellite and day, 15 minutes sampling

Date	E11	E12	E19	E20
2012-DEC-15	1702	1613	1877	1693
2012-DEC-16	2015	1946	2032	2039
2012-DEC-17	1938	2011	1766	1929
2012-DEC-18	1604	1680	1694	1593
2012-DEC-19	1949	1809	2039	1973
2012-DEC-20	2010	2023	1934	2025
2012-DEC-21	1681	1835	1594	1658
2012-DEC-22	1798	1640	1963	1794
2012-DEC-23	2026	1999	2028	2034
2012-DEC-24	1839	1976	1665	1835

Remark:

The same set of (Galileo-capable) tracking stations is used for each of these days/satellites.

Why multi-day arcs?

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Date	E11	E12	E19	E20
2012-DEC-15	1702	1613	1877	1693
2012-DEC-16	2015	1946	2032	2039
2012-DEC-17	1938	2011	1766	1929
2012-DEC-18	1604	1680	1694	1593
2012-DEC-19	1949	1809	2039	1973
2012-DEC-20	2010	2023	1934	2025
2012-DEC-21	1681	1835	1594	1658
2012-DEC-22	1798	1640	1963	1794
2012-DEC-23	2026	1999	2028	2034
2012-DEC-24	1839	1976	1665	1835

Remark:

The same set of (Galileo-capable) tracking stations is used for each of these days/satellites.

Why multi-day arcs?

Number of observations per satellite and day, 15 minutes sampling

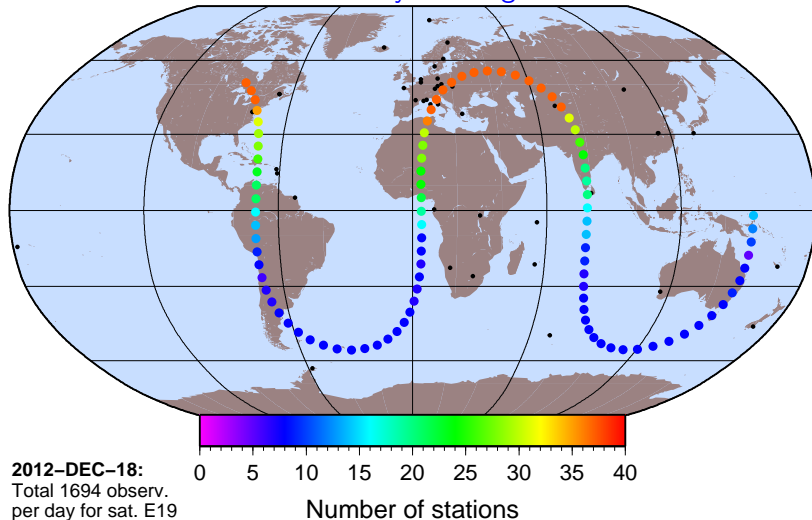
Date	E11	E12	E19	E20	G11	G12	G19	G20
2012-DEC-15	1702	1613	1877	1693	1797	1842	1832	1814
2012-DEC-16	2015	1946	2032	2039	1800	1846	1833	1813
2012-DEC-17	1938	2011	1766	1929	1794	1839	1827	1817
2012-DEC-18	1604	1680	1694	1593	1796	1842	1826	1811
2012-DEC-19	1949	1809	2039	1973	1798	1843	1832	1815
2012-DEC-20	2010	2023	1934	2025	1792	1842	1835	1817
2012-DEC-21	1681	1835	1594	1658	1791	1841	1829	1826
2012-DEC-22	1798	1640	1963	1794	1793	1844	1830	1815
2012-DEC-23	2026	1999	2028	2034	1795	1846	1831	1813
2012-DEC-24	1839	1976	1665	1835	1790	1838	1834	1817

Remark:

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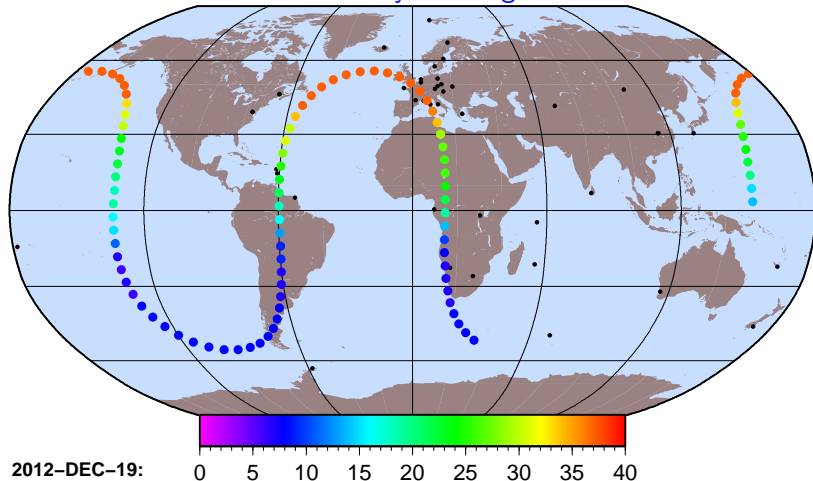
Why multi-day arcs?

Number of stations simultaneously tracking the satellite E19



Why multi-day arcs?

Number of stations simultaneously tracking the satellite E19



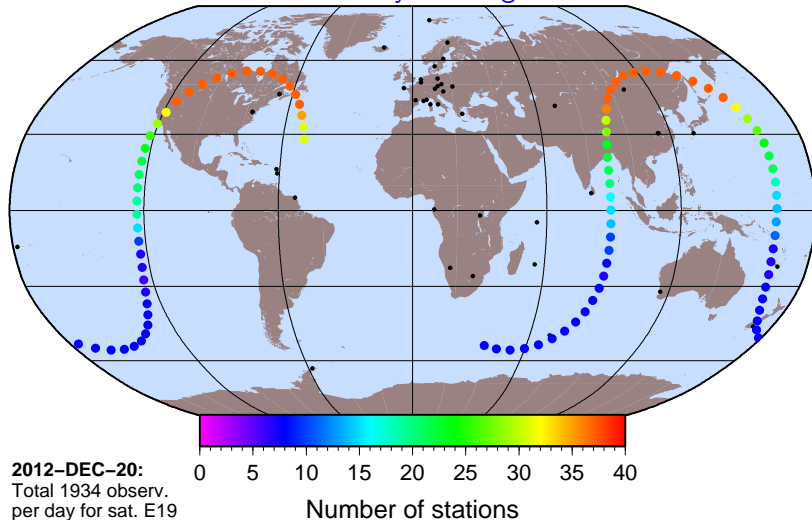
2012-DEC-19:
Total 2039 observ.
per day for sat. E19

0 5 10 15 20 25 30 35 40

Number of stations

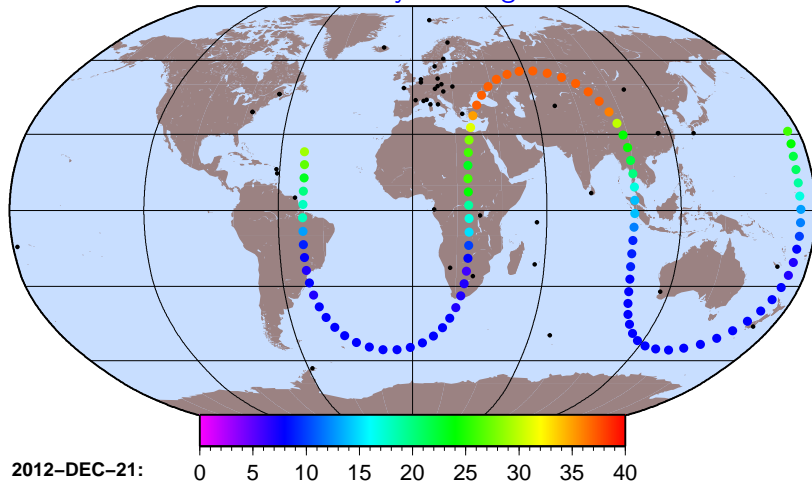
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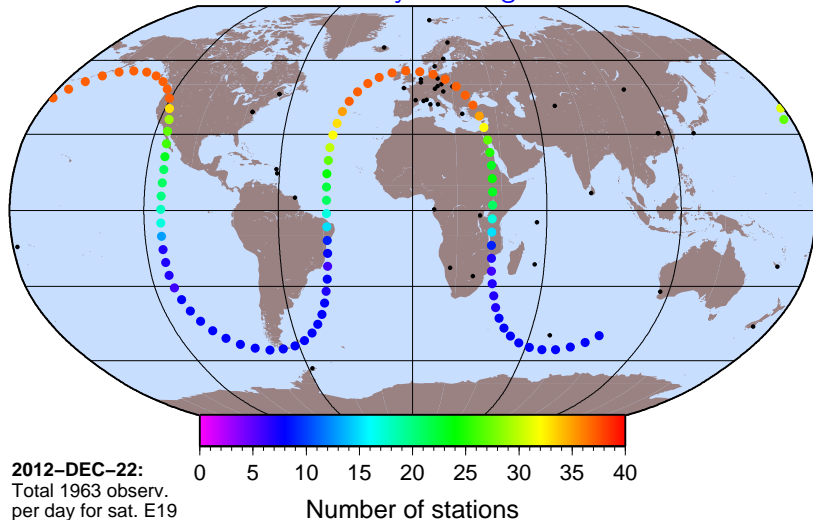


2012-DEC-21:
Total 1594 observ.
per day for sat. E19

Number of stations

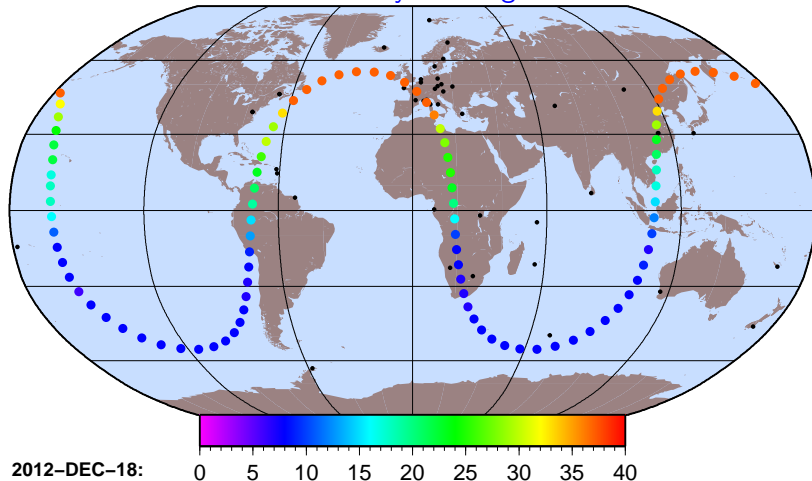
Why multi-day arcs?

Number of stations simultaneously tracking the satellite E19



Why multi-day arcs?

Number of stations simultaneously tracking the satellite G19



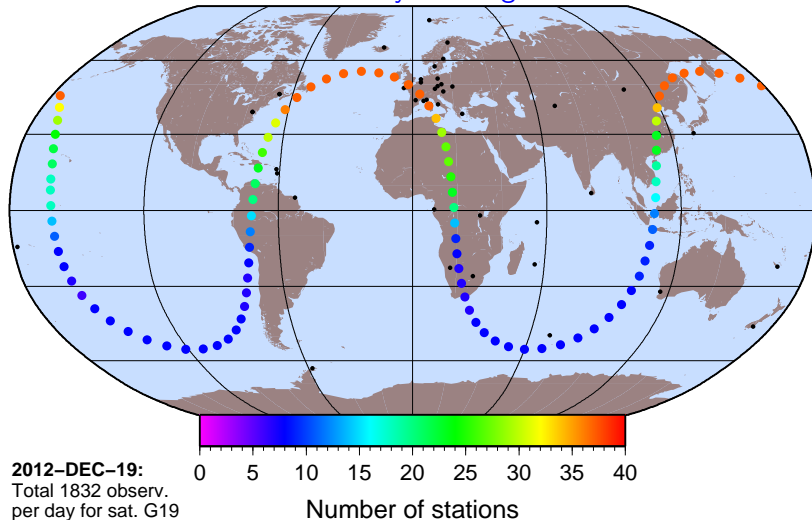
2012-DEC-18:
Total 1826 observ.
per day for sat. G19

0 5 10 15 20 25 30 35 40

Number of stations

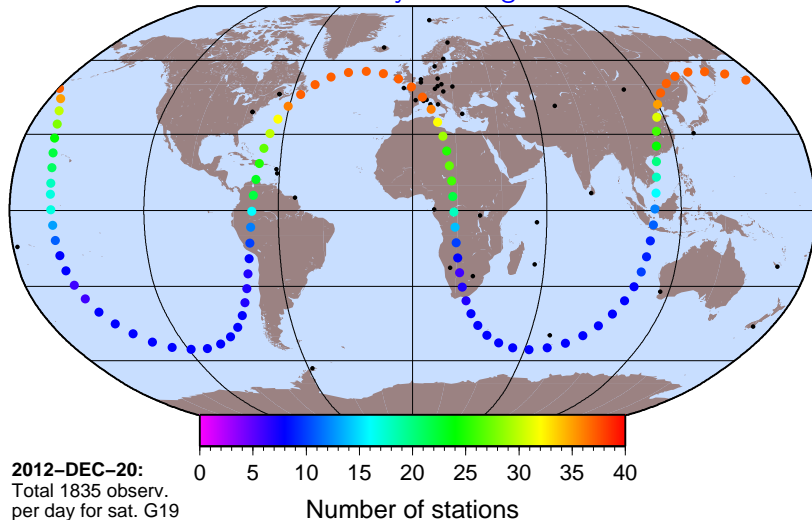
Why multi-day arcs?

Number of stations simultaneously tracking the satellite G19



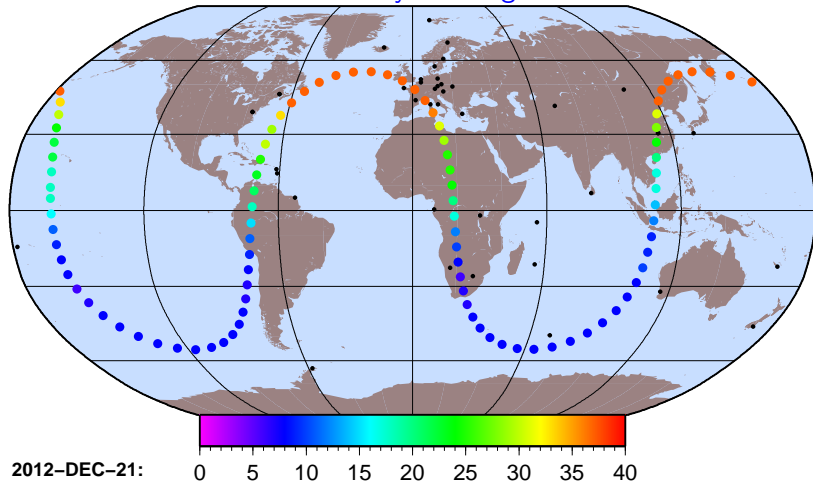
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Number of stations simultaneously tracking the satellite G19



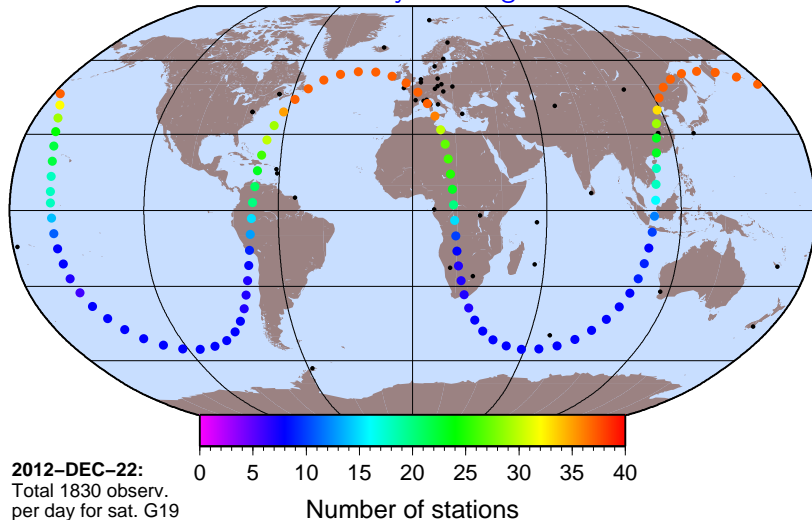
2012-DEC-21:
Total 1829 observ.
per day for sat. G19

0 5 10 15 20 25 30 35 40

Number of stations

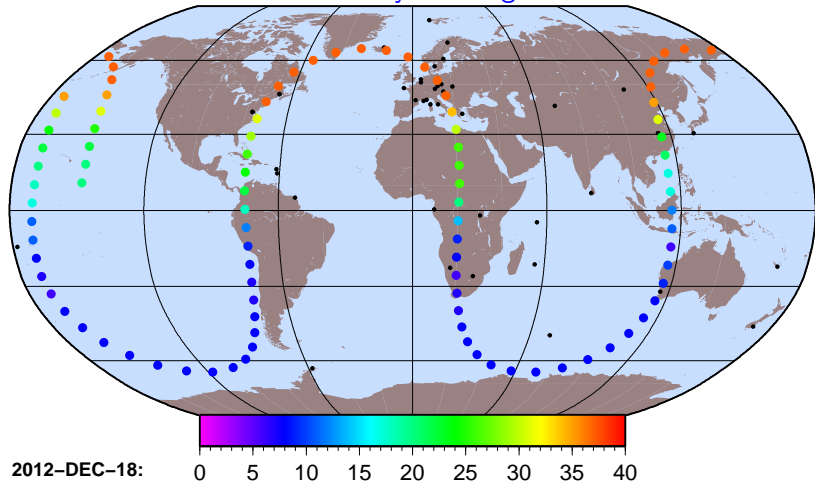
Why multi-day arcs?

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Why multi-day arcs?

Number of stations simultaneously tracking the satellite R19



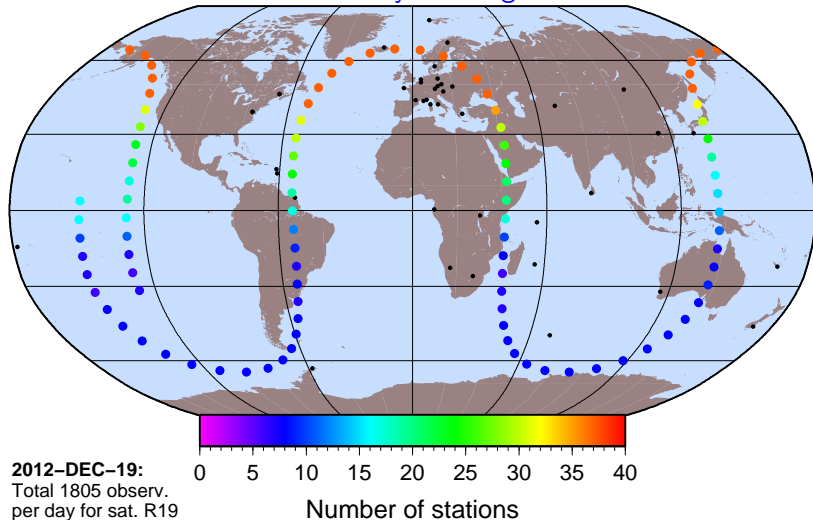
2012-DEC-18:
Total 1892 observ.
per day for sat. R19

0 5 10 15 20 25 30 35 40

Number of stations

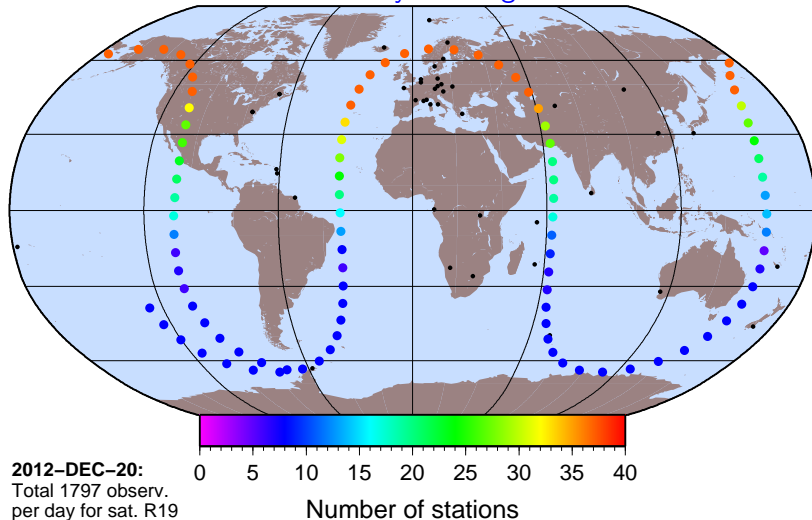
Why multi-day arcs?

Number of stations simultaneously tracking the satellite R19



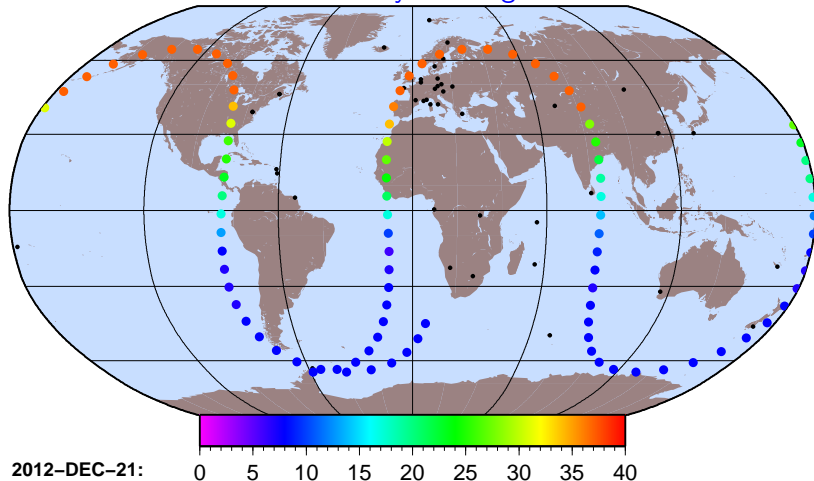
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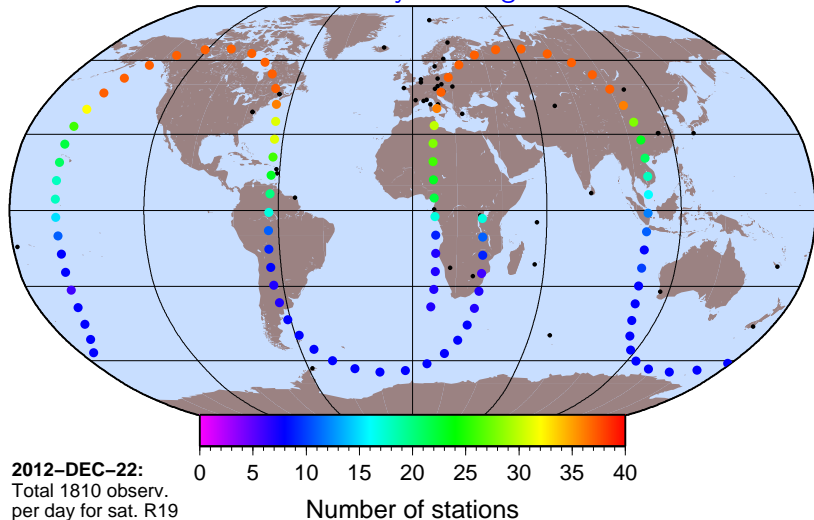
2012-DEC-21:
Total 1805 observ.
per day for sat. R19

0 5 10 15 20 25 30 35 40

Number of stations

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Number of stations simultaneously tracking the satellite R19



Why multi-day arcs?

Number of observations per satellite and day, 15 minutes sampling

Date	E11	E12	E19	E20	G11	G12	G19	G20
2012-DEC-15	1702	1613	1877	1693	1797	1842	1832	1814
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2012-DEC-19	1949	1809	2039	1973	1798	1843	1832	1815
2012-DEC-20	2010	2023	1934	2025	1792	1842	1835	1817
2012-DEC-21	1681	1835	1594	1658	1791	1841	1829	1826
2012-DEC-22	1798	1640	1963	1794	1793	1844	1830	1815
2012-DEC-23	2026	1999	2028	2034	1795	1846	1831	1813
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Date	E11	E12	E19	E20	R11	R12	R19	R20
2012-DEC-15	1702	1613	1877	1693	1835	1796	1871	1798
2012-DEC-16	2015	1946	2032	2039	1945	1838	1958	1882
2012-DEC-17	1938	2011	1766	1929	1971	1944	1968	1963
2012-DEC-18	1604	1680	1694	1593	1937	1964	1892	1965
2012-DEC-19	1949	1809	2039	1973	1822	1931	1805	1895
2012-DEC-20	2010	2023	1934	2025	1805	1817	1797	1814
2012-DEC-21	1681	1835	1594	1658	1805	1803	1805	1800
2012-DEC-22	1798	1640	1963	1794	1796	1798	1810	1802
2012-DEC-23	2026	1999	2028	2034	1880	1794	1916	1808
2012-DEC-24	1839	1976	1665	1835	1965	1884	1967	1922

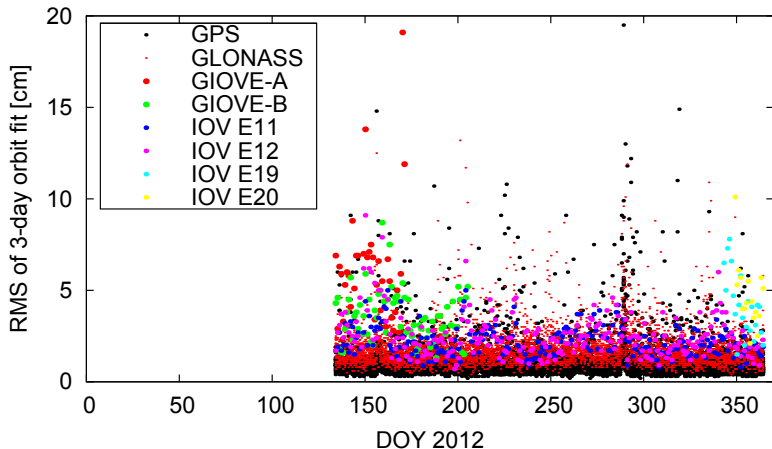
Remark:

The same set of (Galileo-capable) tracking stations is used for each of these days/satellites.

Quality of the MGEX orbit solutions

RMS of an orbit fit through 3 consecutive orbits

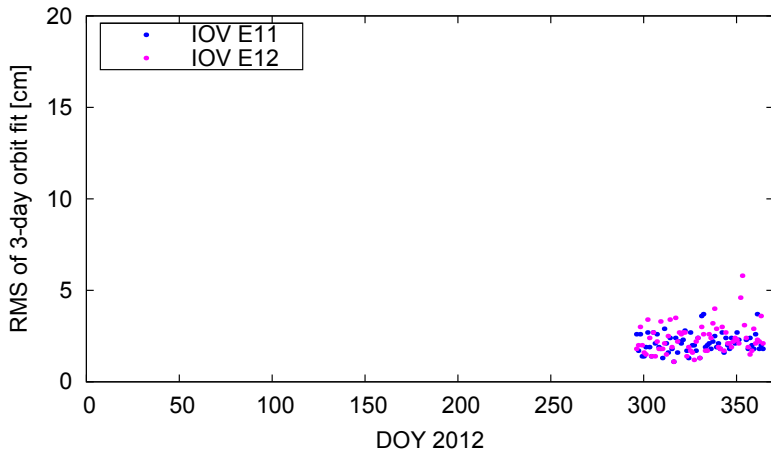
MGEX–Solutions from **CODE**:



Quality of the MGEX orbit solutions

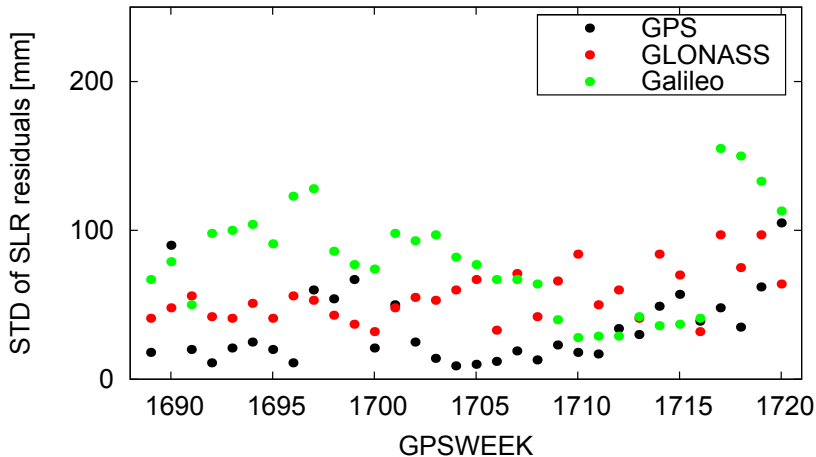
RMS of an orbit fit through 3 consecutive orbits

MGEX-Solutions from **TUM**:



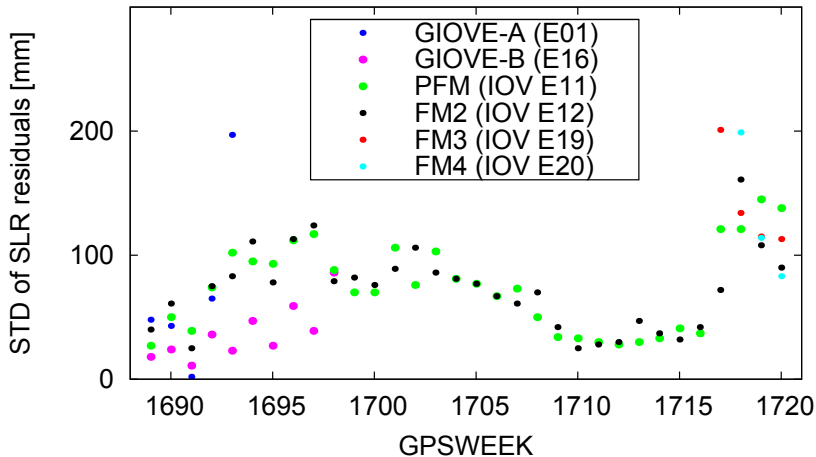
Quality of the MGEX orbit solutions

Standard deviation of SLR-residuals wrt the GNSS orbits over 1 week
MGEX-Solutions from **CODE**:



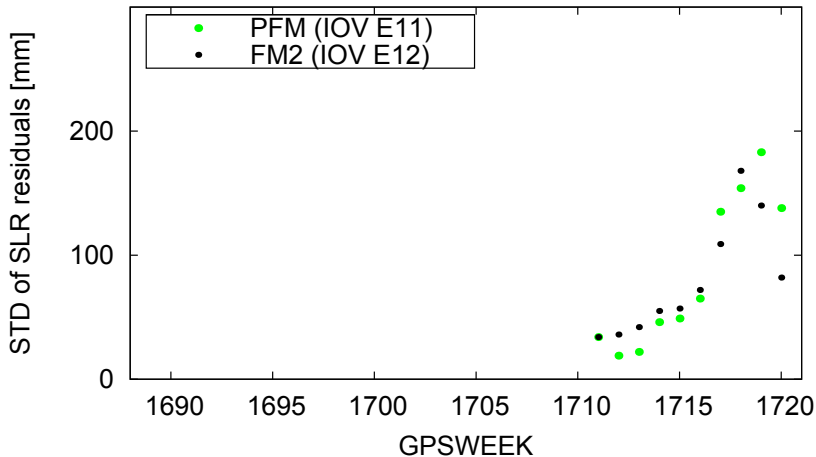
Quality of the MGEX orbit solutions

Standard deviation of SLR-residuals wrt the GNSS orbits over 1 week
MGEX-Solutions from **CODE**:



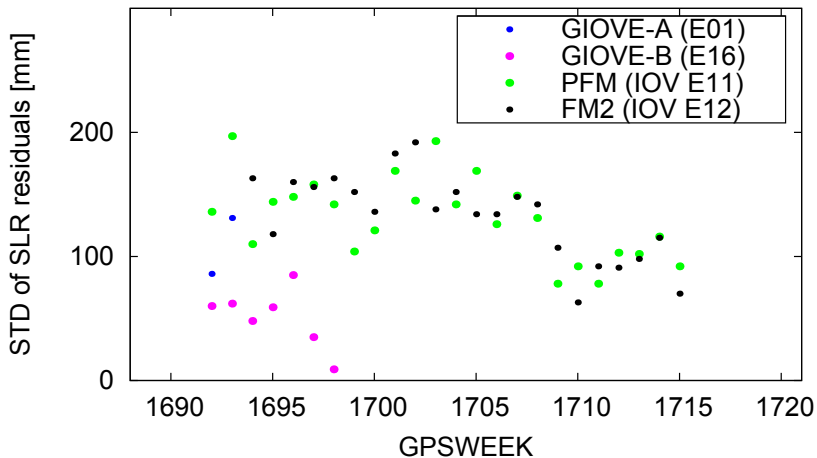
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MGEX-Solutions from **TUM**:



Quality of the MGEX orbit solutions

Standard deviation of SLR-residuals wrt the GNSS orbits over 1 week
MGEX-Solutions from **CNES/CLS**:



The CODE MGEX–solution for clocks

GNSS considered: 32 GPS + 4 Galileo; resulting in 36 satellites

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E1 (L1) + E5a (L5) (Galileo)

The CODE MGEX–solution for clocks

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Signal frequencies:	L1+ L2 (GPS), E1 (L1) + E5a (L5) (Galileo)
Product list:	epoch–wise clock corrections per rec. and sat.; inter–system biases per rec.
Distribution:	ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/
Timespan covered:	GPS-weeks 1710–1720 (DOY 12/288–12/364)

PPP solution using CODE MGEX-products

Static PPP: GPS-only, **GPS+Galileo**

Difference to CODE MGEX network solution:

Station	North [mm]		East [mm]		Up [mm]	
	mean	STD	mean	STD	mean	STD
BRUX	1.9	1.2	-4.3	3.2	-1.3	5.3
	1.5	1.4	-5.1	3.1	-1.5	4.8
CUT0	-0.5	1.2	0.3	2.8	-3.6	5.0
	0.0	1.3	0.8	3.1	-4.5	5.1
USN4	-0.4	1.5	0.3	2.5	-1.9	4.2
	-0.4	1.6	2.2	10.5	-3.6	11.2
USN5	-0.4	1.4	0.0	1.8	-2.3	3.8
	-0.2	1.5	-0.8	8.2	-2.9	4.9
WTZZ	0.6	2.1	-0.5	3.1	0.8	6.1
	0.6	2.1	-1.1	3.3	0.6	6.0

(computed from 10 days by the end of 2012)

PPP solution using CODE MGEX-products

Kinematic PPP: GPS-only, **GPS+Galileo**

Difference to CODE MGEX network solution:

Station	North [mm]		East [mm]		Up [mm]	
	mean	STD	mean	STD	mean	STD
BRUX	1.5	7.7	-4.4	7.8	-0.8	18.5
	1.1	8.2	-4.5	9.0	-0.5	29.5
CUT0	0.8	12.8	-1.6	23.9	-3.7	29.6
	0.9	16.8	-1.6	26.3	-4.6	30.7
USN4	-1.2	6.7	-1.3	8.2	2.1	19.1
	-1.0	6.7	-0.7	8.3	1.5	19.7
USN5	-1.0	7.3	-0.6	8.4	2.3	20.2
	-1.1	10.6	-0.4	10.4	2.2	22.2
WTZZ	0.2	9.9	-0.5	9.1	0.0	22.8
	0.1	9.6	-0.7	8.8	0.3	22.1

(computed from 10 days by the end of 2012)

PPP solution using CODE MGEX-products

Static PPP for BRUX: Galileo-only

Difference to CODE MGEX network solution:

Date	Number of observations	North [mm]	East [mm]	Up [mm]	3D [mm]
2012-Dec-20	440	-1.8	8.3	14.0	16.4
2012-Dec-21	585	-2.9	-12.0	-42.0	43.8
2012-Dec-22	516	-76.6	14.2	-19.8	80.4
2012-Dec-23	446	55.8	-6.8	335.0	340.7
2012-Dec-24	546	2.0	-31.4	-54.1	62.6
2012-Dec-25	610	-4.4	-3.1	8.7	10.2
2012-Dec-26	448	6.4	-6.0	-84.3	84.8
2012-Dec-27	471	20.1	-23.4	-16.6	35.0
2012-Dec-28	674	-27.8	0.6	-11.7	30.2
2012-Dec-29	438	91.5	-54.7	6.2	106.8

PPP solution using CODE MGEX-products

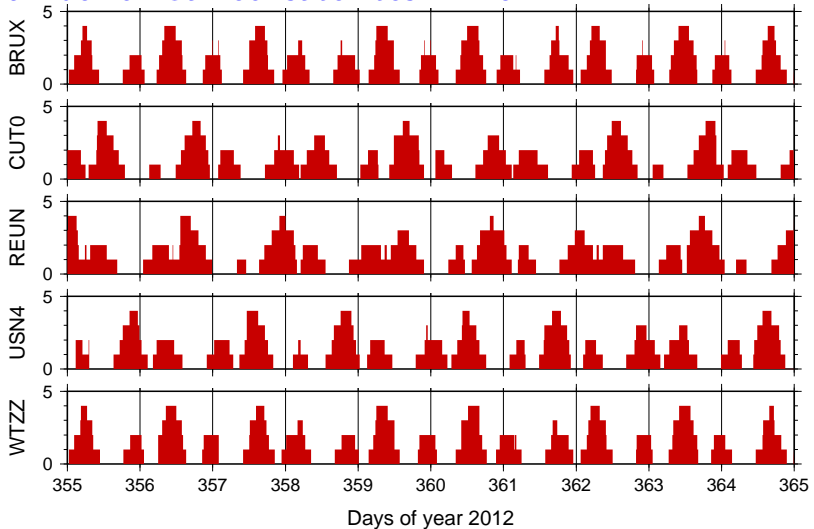
Static PPP for USN4: Galileo-only

Difference to CODE MGEX network solution:

Date	Number of observations	North [mm]	East [mm]	Up [mm]	3D [mm]
2012-Dec-20	460	85.7	-80.8	72.9	138.5
2012-Dec-21	232	3266.7	-870.4	7438.2	8170.4
2012-Dec-22	730	7.0	-60.3	-92.9	111.0
2012-Dec-23	556	-24.3	-12.0	37.5	46.3
2012-Dec-24	280	-198.1	595.0	-372.5	729.4
2012-Dec-25	610	24.9	-89.6	-64.1	112.9
2012-Dec-26	682	67.1	11.1	-5.1	68.2
2012-Dec-27	412	-199.6	89.1	-37.0	221.7
2012-Dec-28	396	43.5	-27.4	129.6	139.4
2012-Dec-29	772	-10.8	-21.6	-37.4	44.5

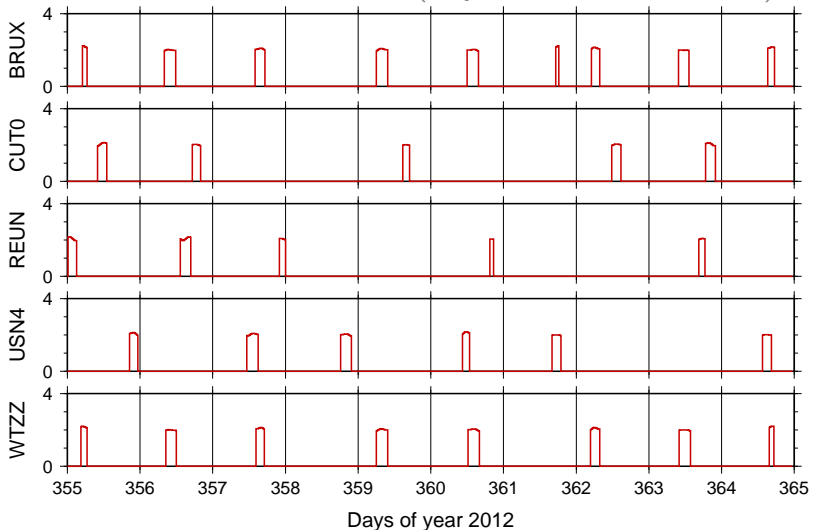
PPP solution using CODE MGEX-products

Number of Galileo-satellites in view



PPP solution using CODE MGEX-products

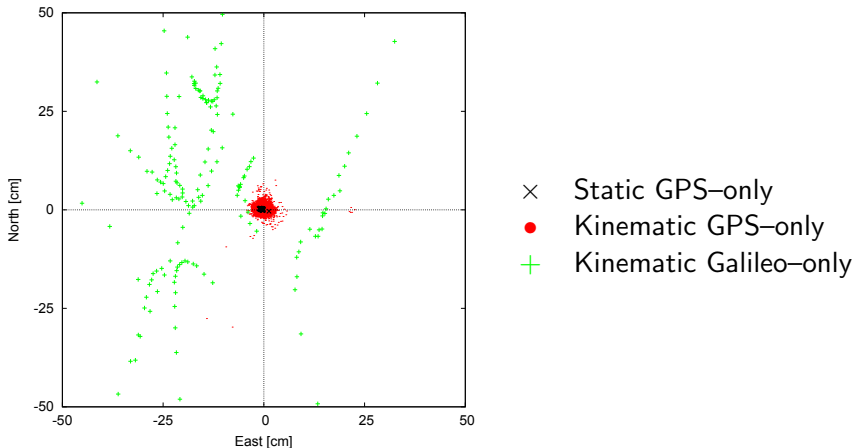
PDOP for Galileo-satellites (only, if >4 satellites in view)



R. Dach, L. Prange et al.: Multiconstellation GNSS with the advent of Galileo
1st GAL WORKSHOP, 24. May 2013, Como, Italy

PPP solution using CODE MGEX-products

Differences between static and kinematic coordinates
for station **BRUX**



Why going from GPS-only to multi-GNSS?

IGS MGEX: What and Why?

CODE-Contribution to IGS MGEX

Why going from GPS-only to multi-GNSS?

Summary

More systems: more problems

- Receiver and antenna technique becomes more complex.
(e.g., calibration of the antenna phase center variations)

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- More data need to be handled. (labelled with the correct data type)
- More satellite types need to be modelled.



GPS Block IIF



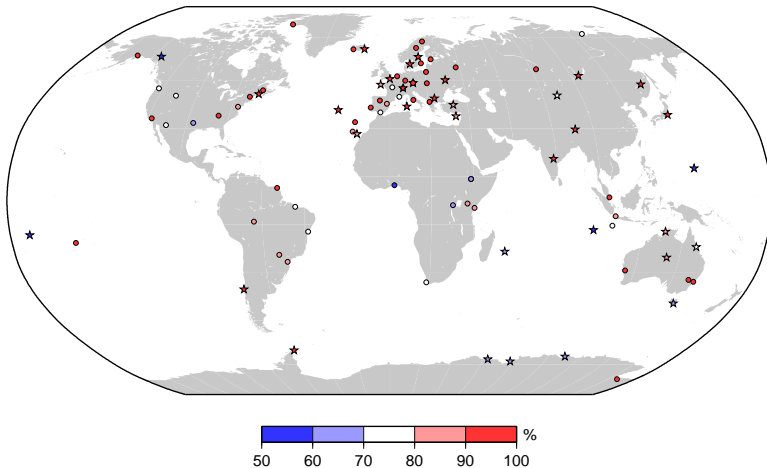
GLONASS-M



Galileo IOV

More systems: reducing GNSS-specific effects

92 globally distributed GPS/GLONASS stations, 2008–2010



PhD thesis from M. Meindl: *Geodätisch-geophysikalische Arbeiten in der Schweiz*, vol. 83.

More systems: reducing GNSS-specific effects

Solution	Description
GPS	single system: GPS
GLO	single system: GLONASS
CMB	GPS/GLONASS; common receiver clock for both systems, but one ISB per day

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Median of station coordinate repeatability

Solution	N	E	U	Total
CMB	2.1 mm	2.1 mm	5.6 mm	3.6 mm
GPS	2.2 mm	2.2 mm	5.8 mm	4.0 mm
GLO	4.6 mm	5.7 mm	9.7 mm	7.3 mm

PhD thesis from M. Meindl: *Geodätisch-geophysikalische Arbeiten in der Schweiz*, vol. 83.

More systems: reducing GNSS-specific effects

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More systems: reducing GNSS-specific effects

Solution	Description
GPS	single system: GPS
GLO	single system: GLONASS
CMB	GPS/GLONASS; common receiver clock for both systems, but one ISB per day

Differences in the satellite positions at the day boundaries

Solution	GPS satellites	GLONASS satellites
CMB	5.4 cm	8.8 cm
GPS	5.6 cm	
GLO		11.6 cm

PhD thesis from M. Meindl: *Geodätisch-geophysikalische Arbeiten in der Schweiz*, vol. 83.

More systems: reducing GNSS-specific effects

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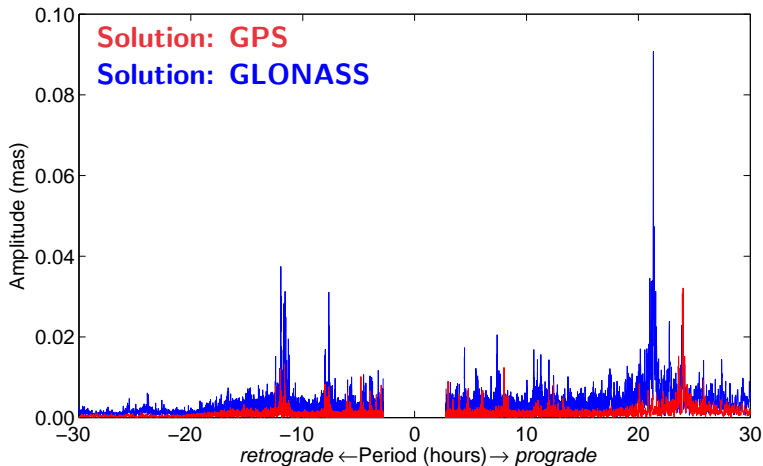
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Solution	GPS satellites	GLONASS satellites
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More systems: reducing GNSS-specific effects

Spectra of the daily ERP series, 2008–2010



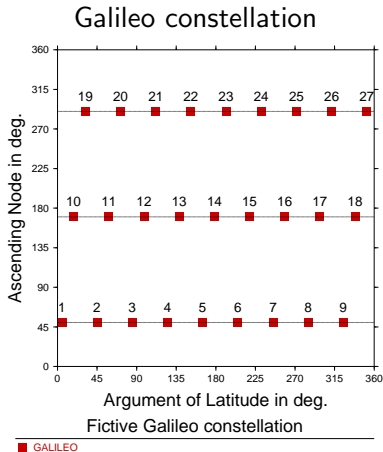
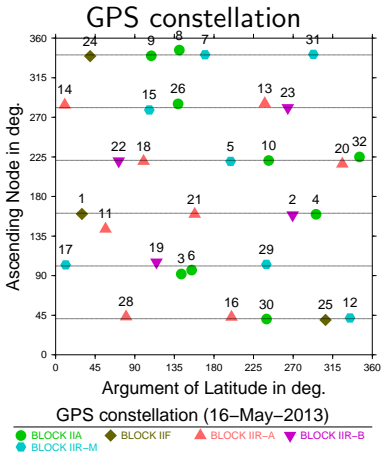
R. Dach, L. Prange et al.: Multiconstellation GNSS with the advent of Galileo
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Looking at the satellite geometry

Status of the GNSS-constellations

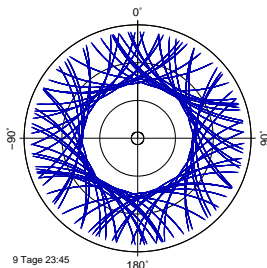
Day of year 2013:136 (16. May 2013)



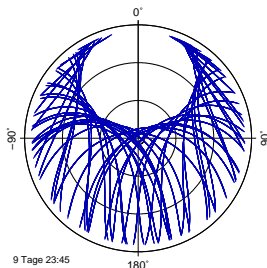
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Looking at the satellite geometry

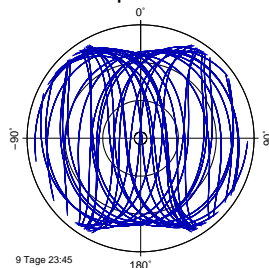
Station at the pole



Mid-latitude station



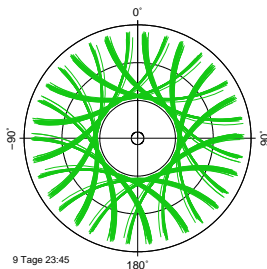
Station at the equator



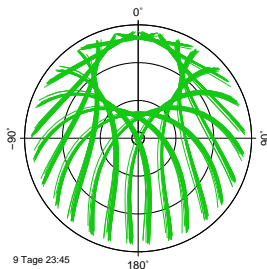
- **GPS**: all satellites fly only on its own sky track.

Looking at the satellite geometry

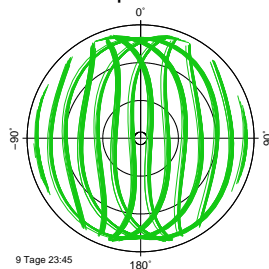
Station at the pole



Mid-latitude station



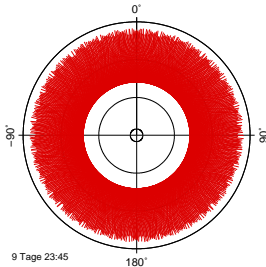
Station at the equator



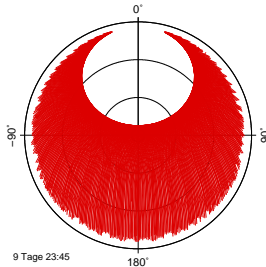
- **GPS**: all satellites fly only on its own sky track.
- **GLONASS**: all satellites fly on one and the same sky track.

Looking at the satellite geometry

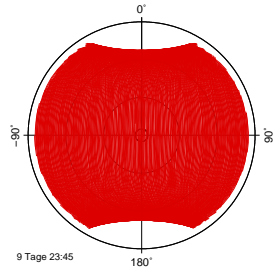
Station at the pole



Mid-latitude station



Station at the equator



- **GPS**: all satellites fly only on its own sky track.
- **GLONASS**: all satellites fly on one and the same sky track.
- **Galileo**: the satellite tracks cover the full sky.

PDOP: measuring the satellite geometry

PDOP: Position Dilution of Precision

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$$\mathbf{C}_{YY} = \begin{bmatrix} q_{XX} & q_{XY} & q_{XZ} \\ q_{YX} & q_{YY} & q_{YZ} \\ q_{ZX} & q_{ZY} & q_{ZZ} \end{bmatrix}$$
$$PDOP = \sqrt{q_{XX} + q_{YY} + q_{ZZ}}$$

PDOP: Position Dilution of Precision

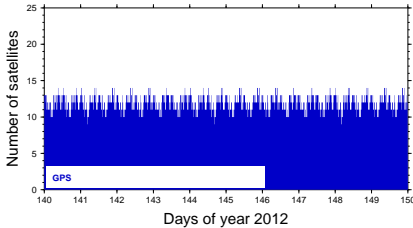
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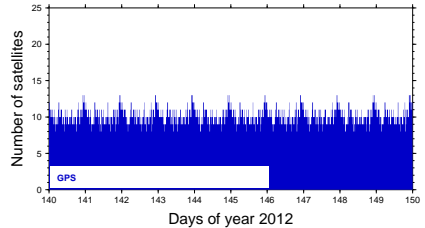
- **The smaller the PDOP value is the better a position can be derived.**

PDOP: satellite geometry for ground stations

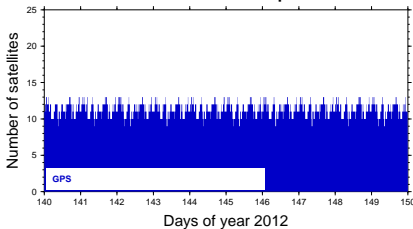
Station at the pole



Mid-latitude station



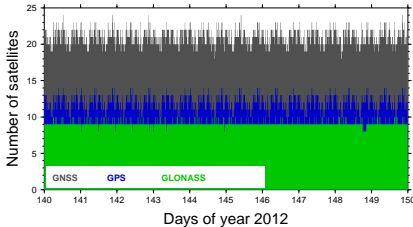
Station at the equator



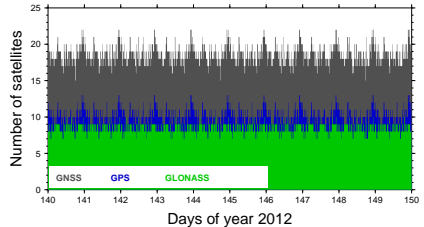
- **GPS:** the variation of the number of observed satellites shows a clear daily pattern in all latitudes.

PDOP: satellite geometry for ground stations

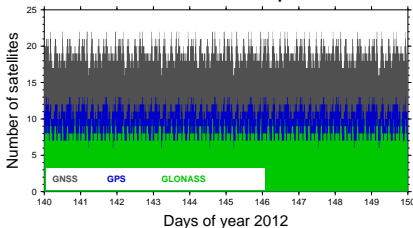
Station at the pole



Mid-latitude station



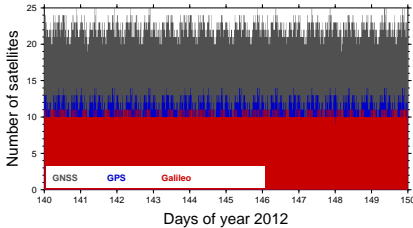
Station at the equator



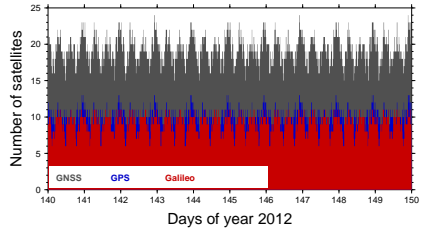
- **GPS**: the variation of the number of observed satellites shows a clear daily pattern in all latitudes.
- **GLONASS**: small variations in the number of observed satellites can be found at the pole and mid-latitudes but the three orbital planes dominate at the equator.

PDOP: satellite geometry for ground stations

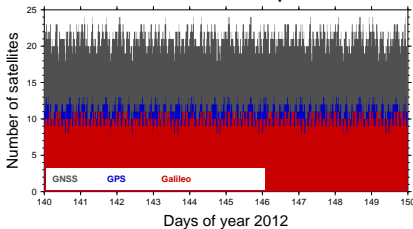
Station at the pole



Mid-latitude station



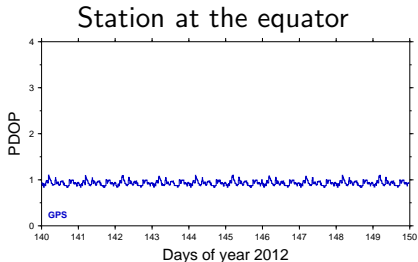
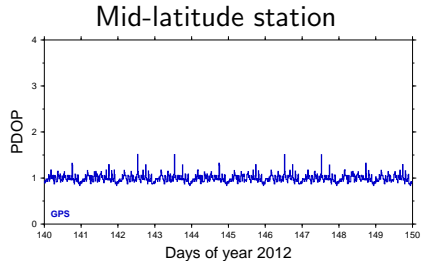
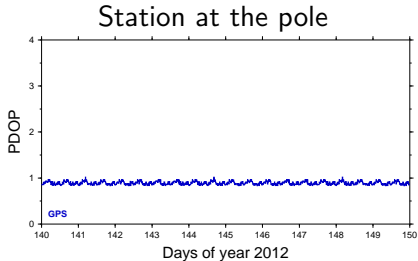
Station at the equator



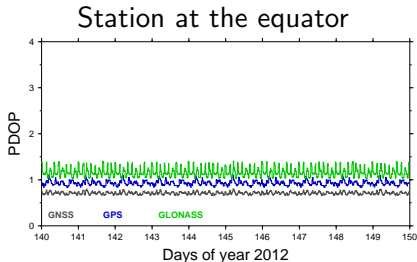
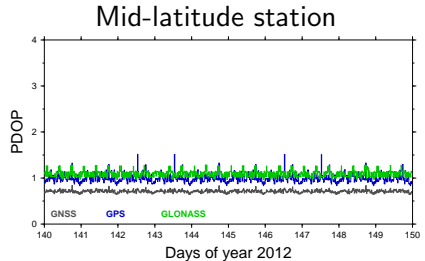
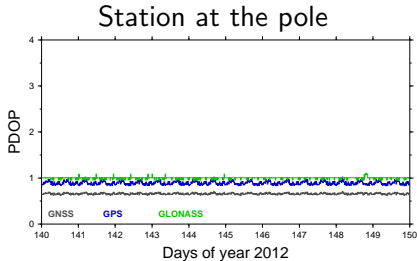
- **GPS:** the variation of the number of observed satellites shows a clear daily pattern in all latitudes.

- **Galileo:** small variations in the number of observed satellites can

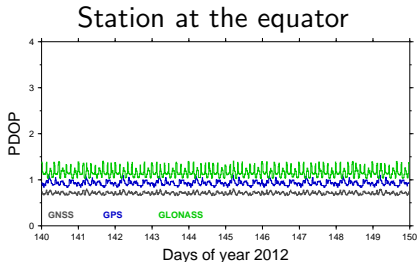
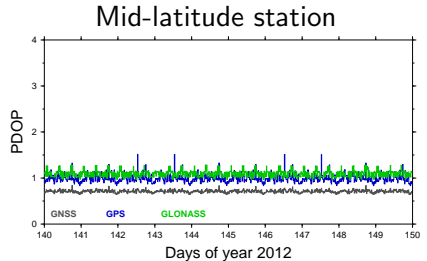
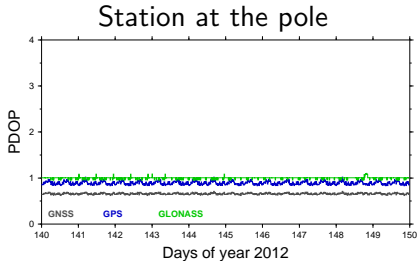
PDOP: satellite geometry for ground stations



PDOP: satellite geometry for ground stations



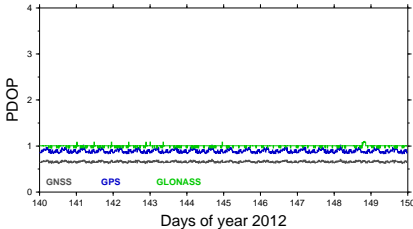
PDOP: satellite geometry for ground stations



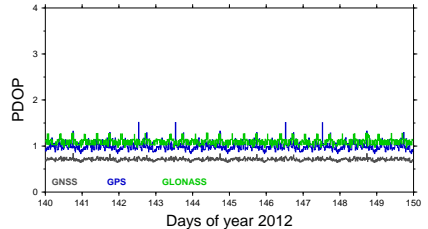
- The variation of the PDOP in time is analogue to the variation of the number of satellites in view.

PDOP: satellite geometry for ground stations

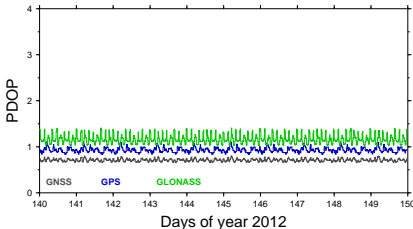
Station at the pole



Mid-latitude station



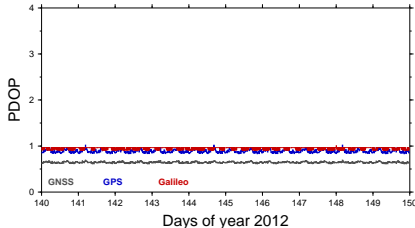
Station at the equator



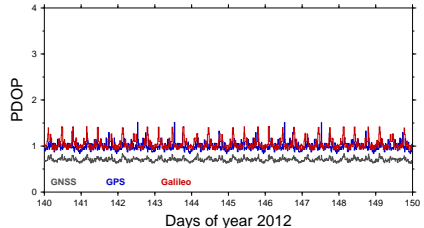
- The variation of the PDOP in time is analogue to the variation of the number of satellites in view.
- The combination of the measurements from both systems helps to **reduce the system-specific variations and improve the satellite geometry in general.**

PDOP: satellite geometry for ground stations

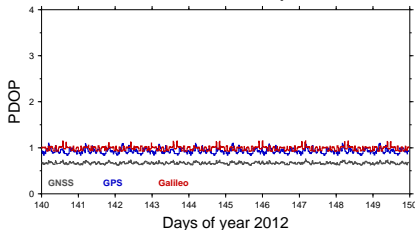
Station at the pole



Mid-latitude station

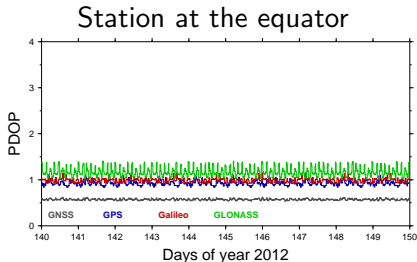
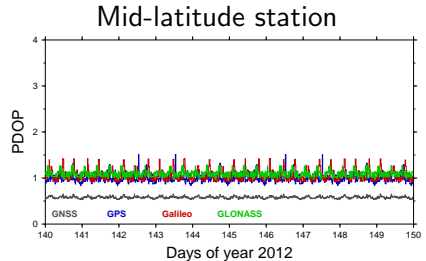
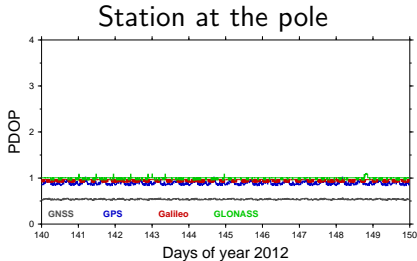


Station at the equator



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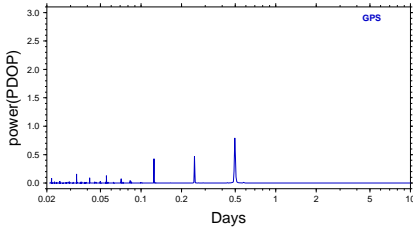
PDOP: satellite geometry for ground stations



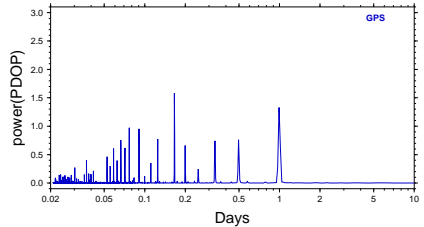
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PDOP: satellite geometry for ground stations

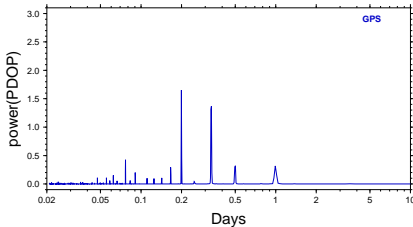
Station at the pole



Mid-latitude station

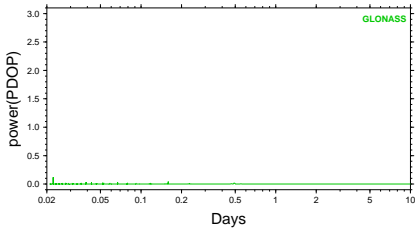


Station at the equator

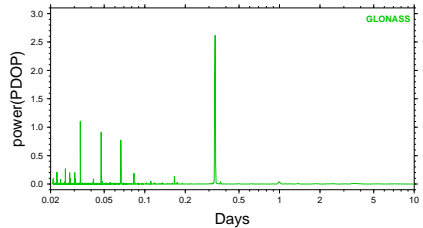


PDOP: satellite geometry for ground stations

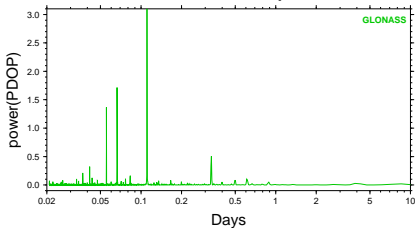
Station at the pole



Mid-latitude station

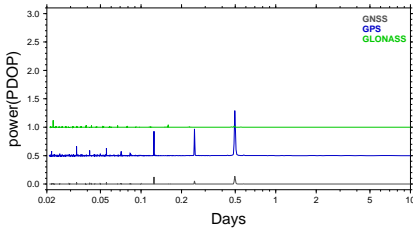


Station at the equator

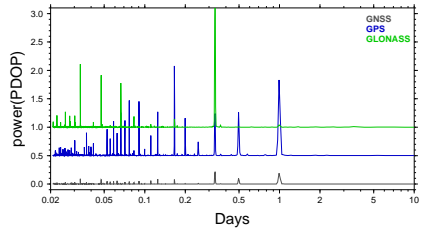


PDOP: satellite geometry for ground stations

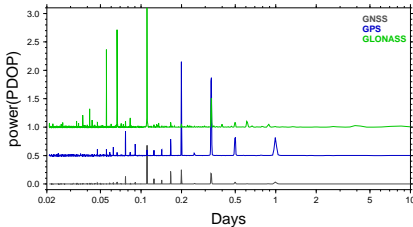
Station at the pole



Mid-latitude station



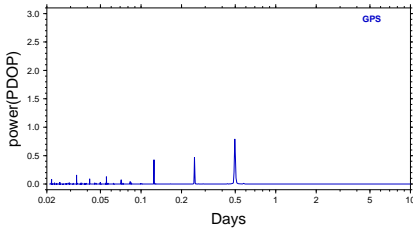
Station at the equator



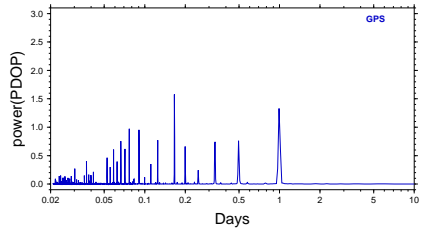
- The combination of the measurements from several systems **reduces the system-specific variations in the PDOP.**

PDOP: satellite geometry for ground stations

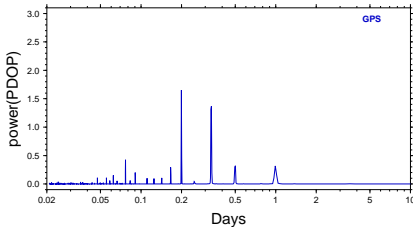
Station at the pole



Mid-latitude station



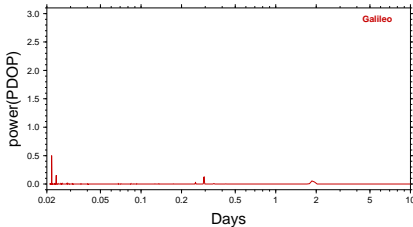
Station at the equator



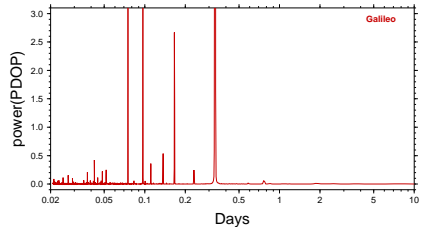
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PDOP: satellite geometry for ground stations

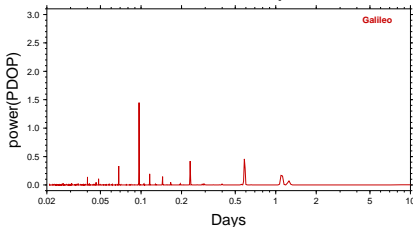
Station at the pole



Mid-latitude station



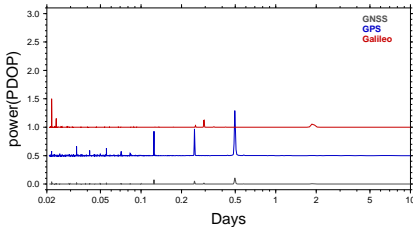
Station at the equator



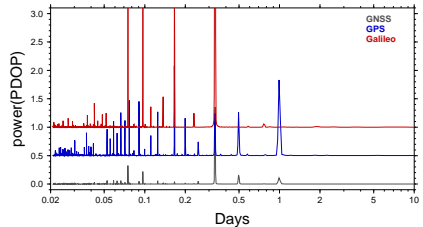
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PDOP: satellite geometry for ground stations

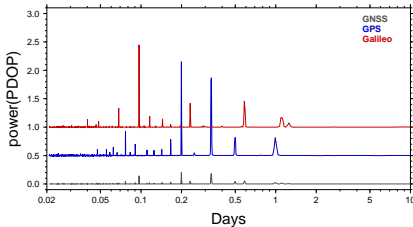
Station at the pole



Mid-latitude station



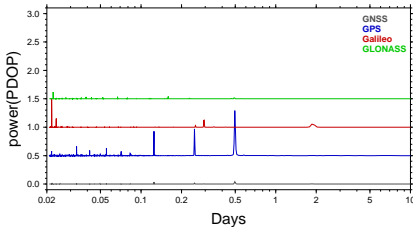
Station at the equator



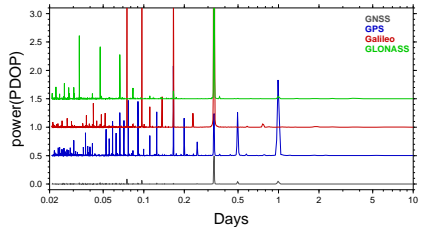
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PDOP: satellite geometry for ground stations

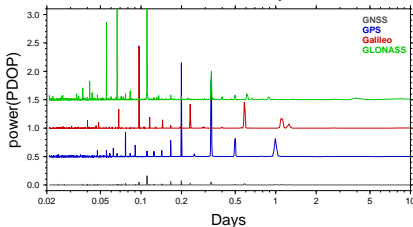
Station at the pole



Mid-latitude station



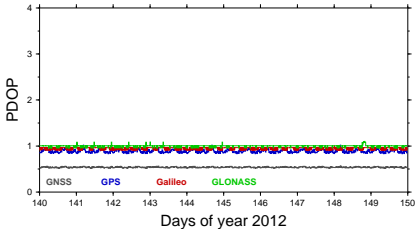
Station at the equator



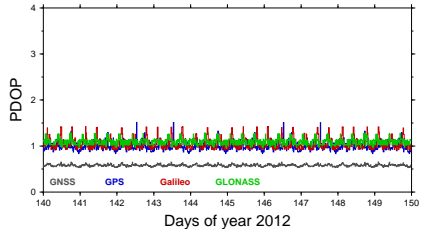
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Extended positioning stability

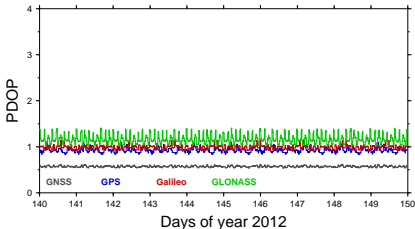
Station at the pole



Mid-latitude station



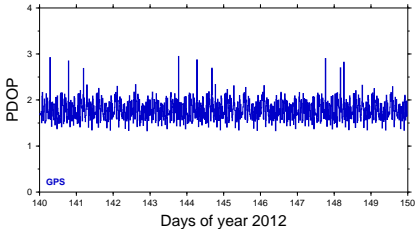
Station at the equator



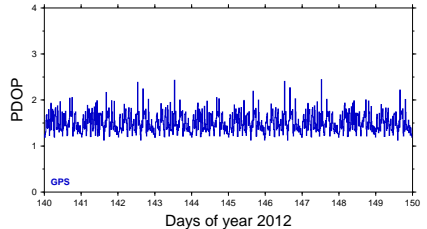
- Partials of the **station coordinates** are considered.

Extended positioning stability

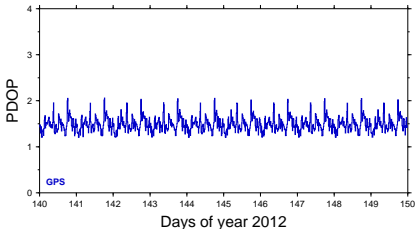
Station at the pole



Mid-latitude station



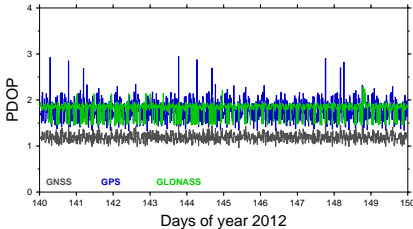
Station at the equator



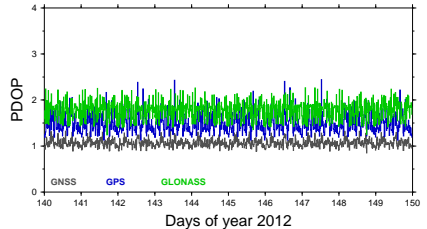
- Partials of the **station coordinates** and **receiver clocks** are considered.

Extended positioning stability

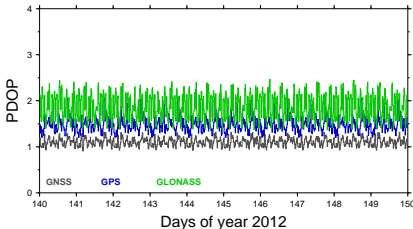
Station at the pole



Mid-latitude station



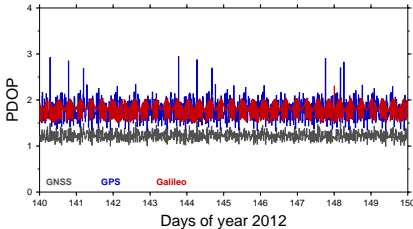
Station at the equator



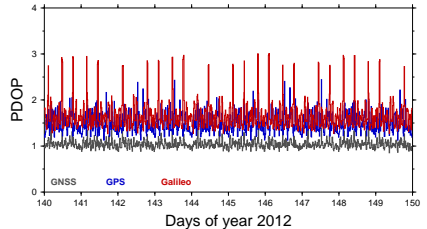
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Extended positioning stability

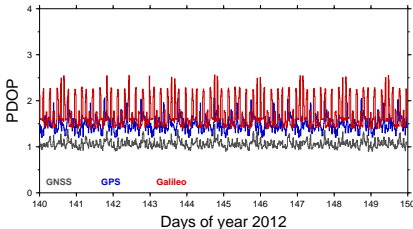
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Mid-latitude station



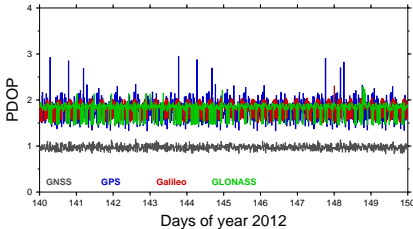
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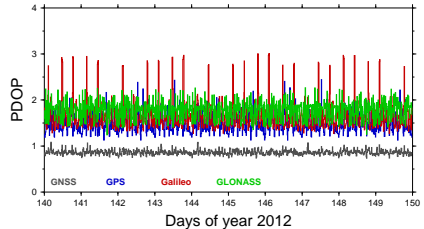
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Extended positioning stability

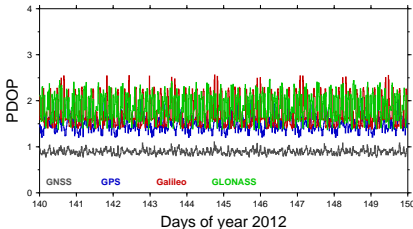
Station at the pole



Mid-latitude station



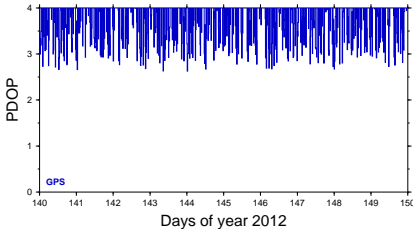
Station at the equator



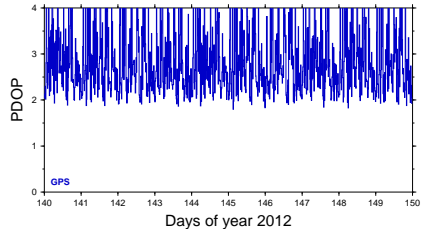
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Extended positioning stability

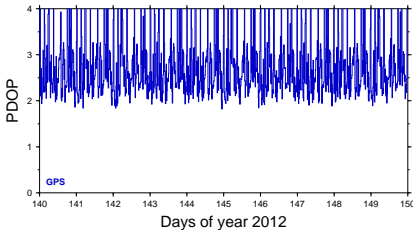
Station at the pole



Mid-latitude station



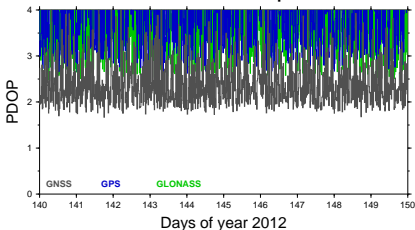
Station at the equator



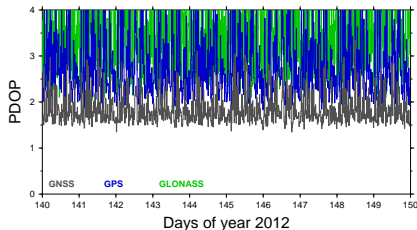
- Partials of the **station coordinates**, **receiver clocks**, and **troposphere** (per epoch) are considered.

Extended positioning stability

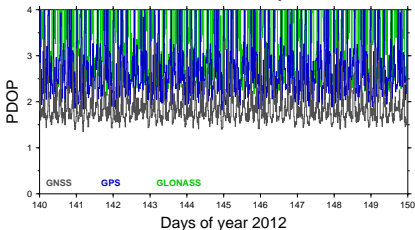
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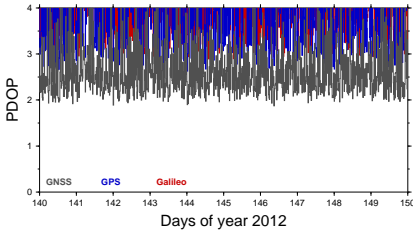
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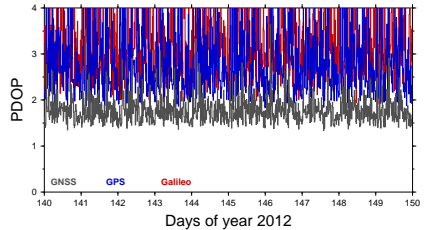
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Extended positioning stability

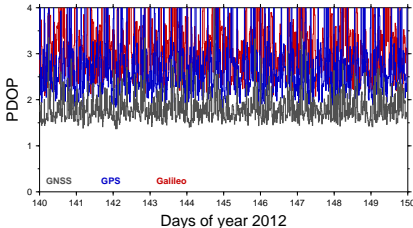
Station at the pole



Mid-latitude station



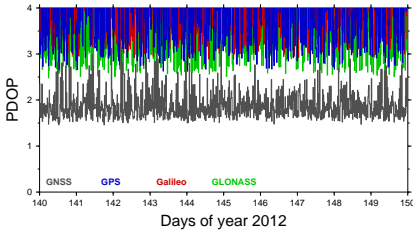
Station at the equator



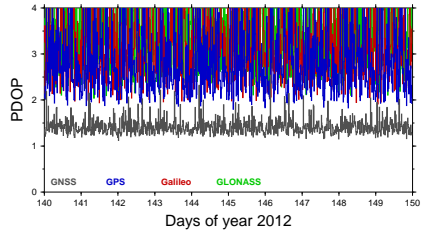
- Partials of the **station coordinates**, **receiver clocks**, and **troposphere** (per epoch) are considered.

Extended positioning stability

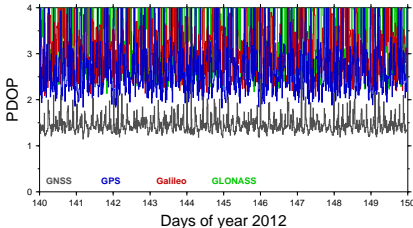
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Correlation between parameters:

H_k Height component of station k

δ_k Receiver clock correction with respect to GPS system time at station k

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h_k^i Elevation angle for an observation at station k to satellite i

$$\frac{\partial L_k^i}{\partial H_k} = -\sin h_k^i$$

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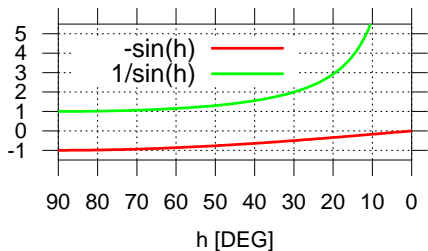
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Extended positioning stability

Correlation coefficients for a station at the equator:

h_{\max}	h_{\min}	$\rho(H_k, \Delta_{\text{tropo}_k})$	$\rho(H_k, \delta_k)$	$\rho(\Delta_{\text{tropo}_k}, \delta_k)$
90°	5°	-0.802	0.949	-0.907
90°	10°	-0.907	0.975	-0.968
90°	15°	-0.943	0.985	-0.983
90°	20°	-0.964	0.990	-0.990

Correlation coefficients for a station at the pole:

h_{\max}	h_{\min}	$\rho(H_k, \Delta_{\text{tropo}_k})$	$\rho(H_k, \delta_k)$	$\rho(\Delta_{\text{tropo}_k}, \delta_k)$
45°	5°	-0.868	0.967	-0.946
45°	10°	-0.937	0.984	-0.980
45°	15°	-0.967	0.992	-0.990
45°	20°	-0.983	0.996	-0.995

Summary

R. Dach, L. Prange et al.: Multiconstellation GNSS with the advent of Galileo
1st GAL WORKSHOP, 24. May 2013, Como, Italy

Summary

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Consequence: *Processing of only dual–frequency data from GPS is meanwhile rather complex.*
(Keywords: different types of code measurements; quarter–cycle)

Summary

- Today we are living in the **dual-frequency** GNSS-world with **two operational systems**: GPS and GLONASS.
- Both systems are implementing **modernization programs**.
 - GPS and GLONASS become **triple-frequency** systems.
 - Since GPS Block IIF series a significantly **improved satellite clock performance** is available (interpolation for high-rate applications).

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- **New GNSS are under development** and have first prototype satellites in space: Galileo and BeiDou.
- We have to consider the **consistently combined processing** of measurements from different GNSS.
 - challenge for science and research
 - simply more observations become available (beneficial in particular for kinematic applications)

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- We have to consider the **consistently combined processing** of measurements from different GNSS.
- **Let us start in the new and colorful world with several GNSS, multiple signals:**
The future has started!

THANK YOU

for your attention



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<http://www.bernese.unibe.ch/publist>