Multi-GNSS and Real-time Service in the IGS

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2500 Calvert Street NW

Washington DC

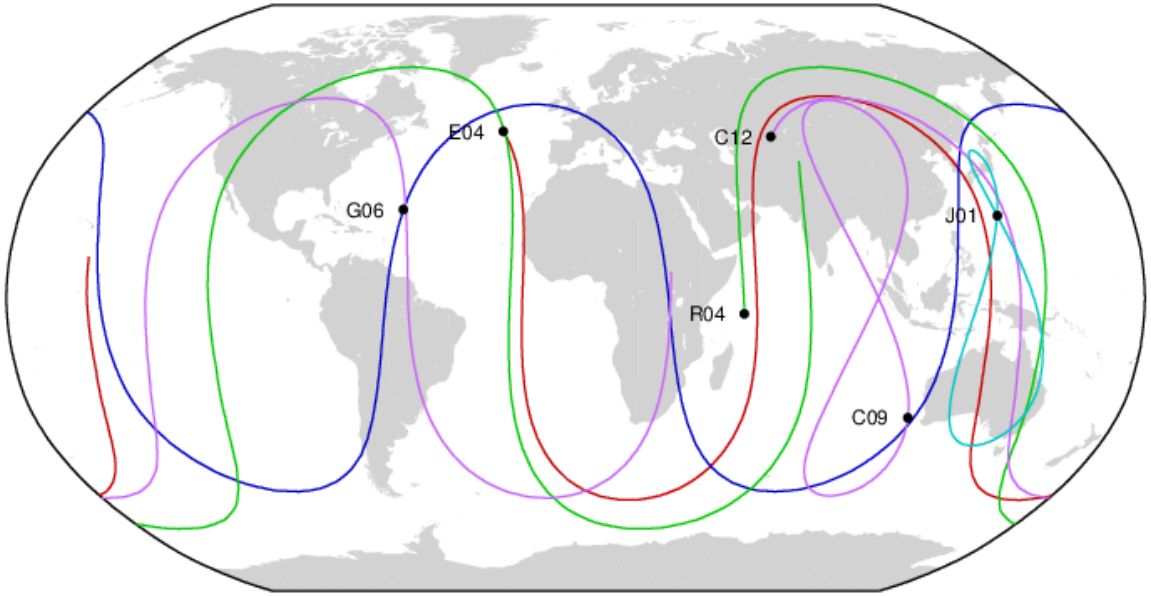
Content

- **GNSS Status 2014**
- **The IGS Real Time Experiment**
- **The IGS/MGEX Experiment**

GPS, GLONASS, Galileo, BeiDou, QZSS

System	Revolution Period	Inclination	# Orbital Planes
GPS	11^h58^m	55 deg	6
GLONASS	11^h16^m	65 deg	3
Galileo	14^h05^m	55 deg	3
BeiDou	12^h53^m	55 deg	3
QZSS	23^h56^m	43 deg	3

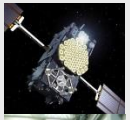
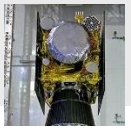
GPS, GLONASS, Galileo, BeiDou, QZSS



Daily Groundtracks of GPS, GLONASS, Galileo, BeiDou, QZSS (geosynchronous, GPS augmentation).

(GPS, QZSS), GLONASS, Galileo have 1-day, 8-days, 10-days repeat cycles. BeiDou MEOs one of 7 days.

Constellation Status (Apr. 2014)

System		Blocks	Signals	Sats*)
GPS		IIA	L1 C/A, L1/L2 P(Y)	8
		IIR-A/B	Same	12
		IIR-M	+L2C	7
		IIF	+L5	4(+1)
GLONASS		M	L1/L2 C/A + P	24
		K	+L3	(1)
BeiDou		GEO	B1, B2, B3	5
		IGSO	same	5
		MEO	same	4
Galileo		IOV	E1, (E6), E5a/b/ab	(4)
QZSS		IGSO	L1 C/A, L1C, SAIF L2C, E6 LEX, L5	1
IRNSS		IGSO	L5, S	(2)

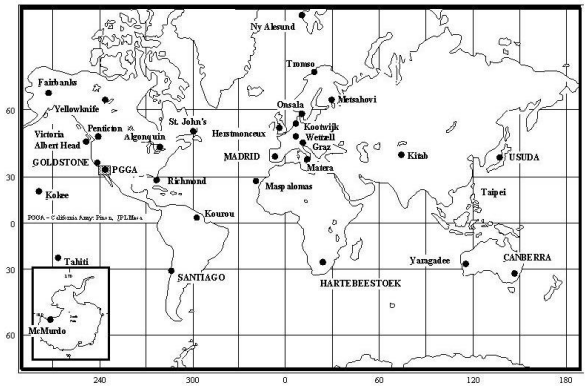
*) not yet declared healthy/operational

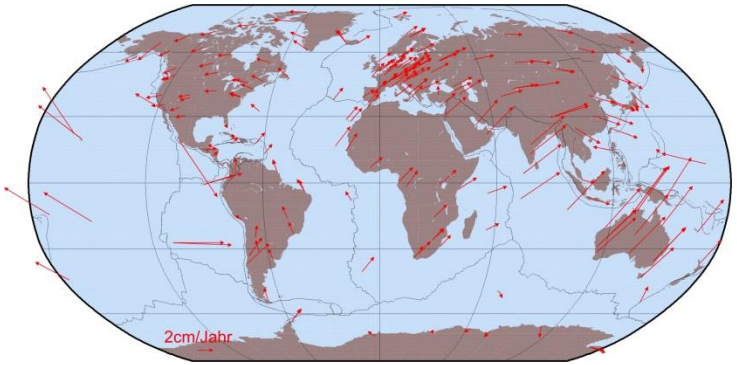
The IGS

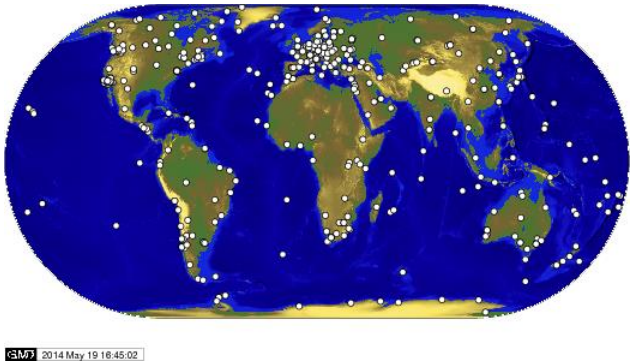
- The creation of the IGS was initiated in 1989 with I.I. Mueller, G. Mader, B. Melbourne, and Ruth Neilan as protagonists
- The IGS became an official IAG service in 1994.
- The IGS first was a pure GPS Service, it was renamed as the International GNSS Service in 2004.
- Today the IGS is a truly interdisciplinary, multi-GNSS service in support of Earth Sciences and Society.
- Since its creation the IGS Central Bureau is located in the USA with Ruth Neilan as director – who stands for providing continuity and leadership.

The IGS

Station Locations for the IGS Pilot Campaign, 1992







IGS Network in May 2014

Monitor station motion in „real time“

In 1992 the IGS was based on about 20 geodetic receivers, 400+ receivers are active and their data retrievable today

Multi-GNSS Experiment (MGEX)

Multi-GNSS Experiment (MGEX)

- **MGEX call-for-participation released mid-2011 (ongoing)**
- **Steered by Multi-GNSS Working Group (MGWG)**

Some 27 contributing agencies from 16 countries

Global tracking network, mostly real-time

- **State-of-the-art receivers and antenna**
- **Tracking of Galileo, BeiDou, QZSS, SBAS (but no IRNSS, yet)**

Free and open access

- **Data archives at CDDIS, IGN, BKG (RINEX 3.x)**
- **Real-time NTRIP caster (RTCM3-MSM)**
- **Product archive at CDDIS**

Multi-GNSS Experiment (MGEX)

MGEX is based onTwo legacy systems (GPS and GLONASS), four new constellations, numerous SBAS satellites

Inflationary increase in frequencies and signals

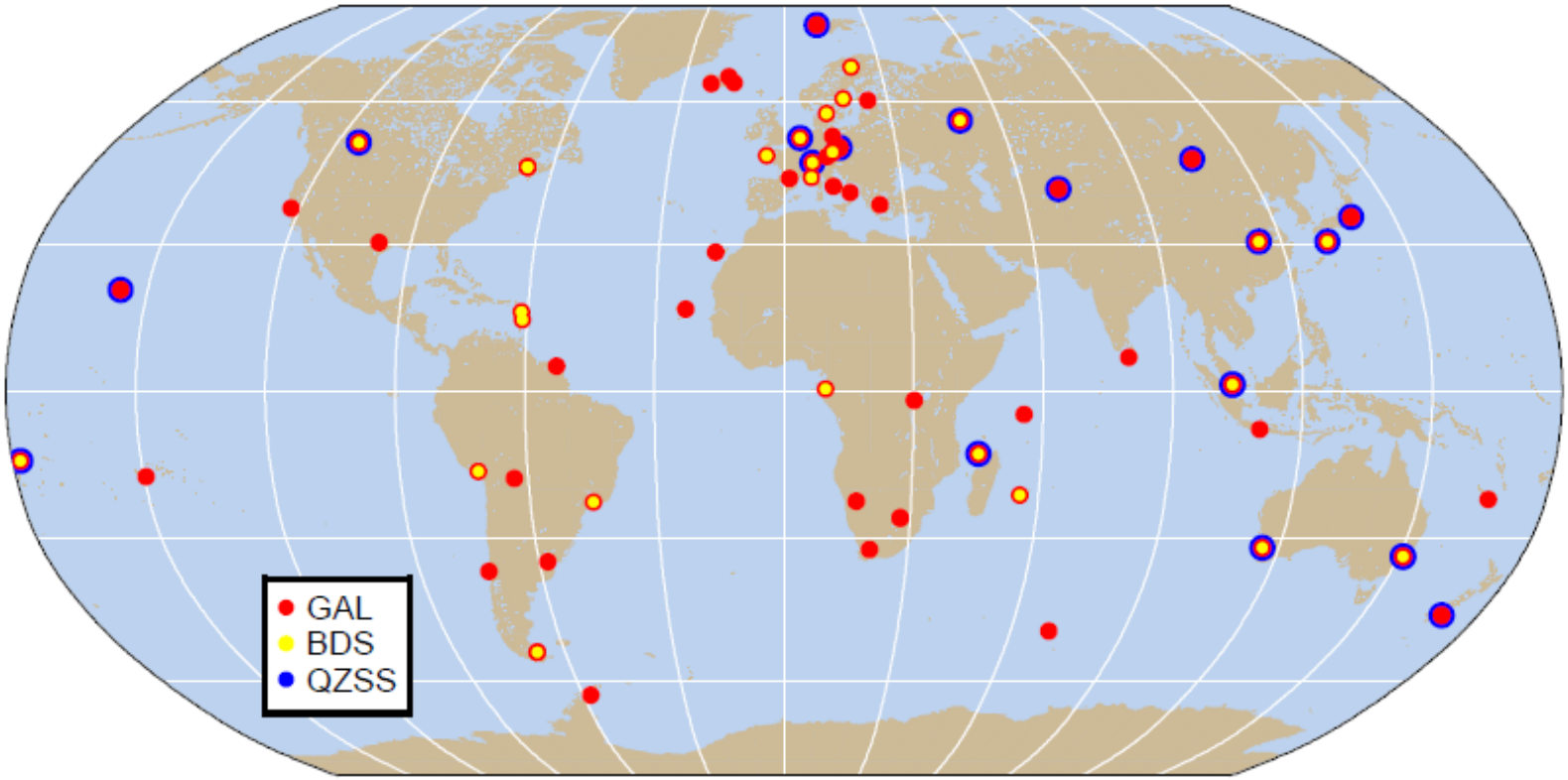
(Credit: D. Turner, ION-GNSS-2010)

Need for active investment into

- **Infrastructure**
- **Algorithms & tools**
- **Services**

to maintain IGS „gold standard“ and to enable full exploitation of new capabilities in science and engineering

IGS MGEX Real-time Network



~70 Stations (Apr. 2014)

MGEX R/T Caster: http://mgex.igs-ip.net/

IGS MGEX Equipment

- heterogeneous equipment environment
- many combinations
- cross-validation of equipment performance
- high robustness
- open to new equipment

MGEX Analysis Centers and Products

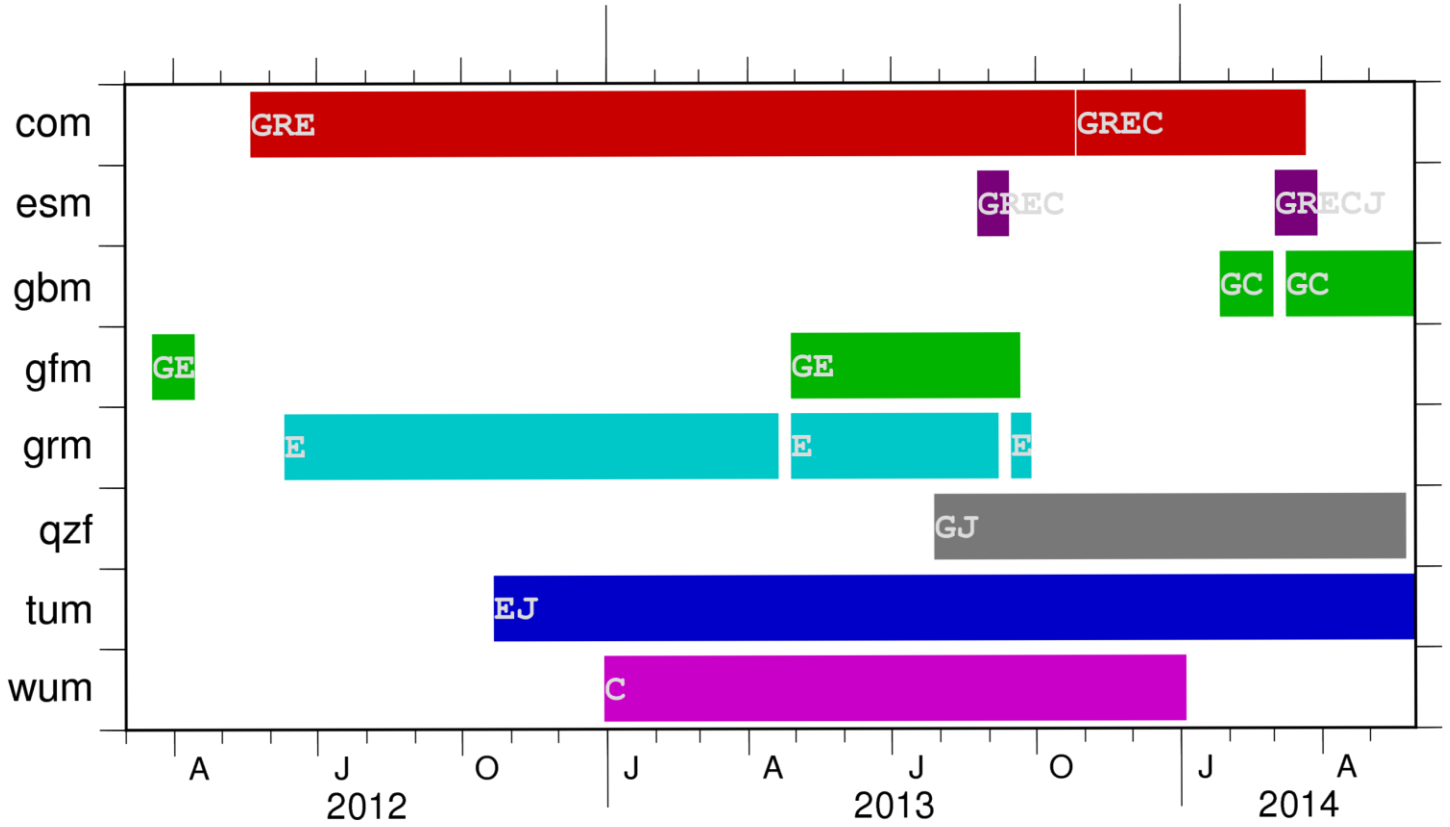
Institution	Tag	Systems
CNES/CLS, France	**grm**	**GAL**
CODE(AIUB), Switzerland	**com**	**GPS+GLO+GAL**
ESA/ESOC, Germany	**esm(1)**	**GPS+GAL(+GLO+BDS+QZS)**
GFZ, Germany	**gfm** **gfb**	**GPS+GAL** **GPS+BDS**
JAXA, Japan	**qzf(2)**	**QZS**
TUM, Germany	**tum**	**GAL+QZS**
Wuhan Univ., China	**wum**	**GPS+BDS**

Products provided at ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex/

(1) Selected short arc campaigns, only

(2) Copy of JAXA precise orbit and clock product

MGEX Product Availability



G: GPS, R: GLONASS, E: Galileo, C: Beidou, J: QZSS

Galileo Orbit and Clock Products

Routine products from 4 ACs

- Different s/w packages and processing strategies
- ESA PCO/PCVs used by CODE & GFZ, otherwise MGEX PCOs

Orbit performance assessment

- 3-day solutions (COD, GFZ, TUM) 2-3x better than 1-day (CNES)
- 10-15 cm level (3D rms) consistency
- 5-8 cm day boundary discontinuities
- 10 cm rms SLR residuals

(Steigenberger et al., ASR, submitted)

Constellation Broadcast Messages

„All-in-one“ multi-GNSS broadcast ephemeris file formed from concatenated broadcast information of all constellations

Covers all constellations (GPS+GLO+GAL+BDS+QZSS+SBAS) except IRNSS (presently approx. 85 satellites)

Available from Jan 2013

ftp://cddis.gsfc.nasa.gov/gnss/data/campaign/mgex/daily/rinex3/*yyyy*/brdm

```
 3.02           NAVIGATION DATA     M (Mixed)           RINEX VERSION / TYPE
BCEmerge            congo               20130610 034603 GMT PGM / RUN BY / DATE
Merged GPS/GLO/GAL/BDS/QZS/SBAS navigation file              COMMENT
based on CONGO and MGEX tracking data                        COMMENT
DLR: O. Montenbruck;  TUM: P. Steigenberger                  COMMENT
GAUT  2.7939677238e-09-8.881784197e-16 428400 1743 1743    0 TIME SYSTEM CORR
GLGP -3.7439167500e-07 0.000000000e+00 518400 1743 1743    0 TIME SYSTEM CORR
GLUT -2.0954757929e-07 0.000000000e+00 518400 1743 1743    0 TIME SYSTEM CORR
GPGA -1.4551915228e-09 4.440892099e-15 518400 1743 1743    0 TIME SYSTEM CORR
GPUT  0.0000000000e+00-2.664535259e-15 233472 1744 1744    0 TIME SYSTEM CORR
QZUT -3.9290171117e-09 1.243449788e-14 230400 1744 1744    0 TIME SYSTEM CORR
    16                                                       LEAP SECONDS
                                                             END OF HEADER
…
```

Standardization Efforts

Continued interactions of MGWG with:

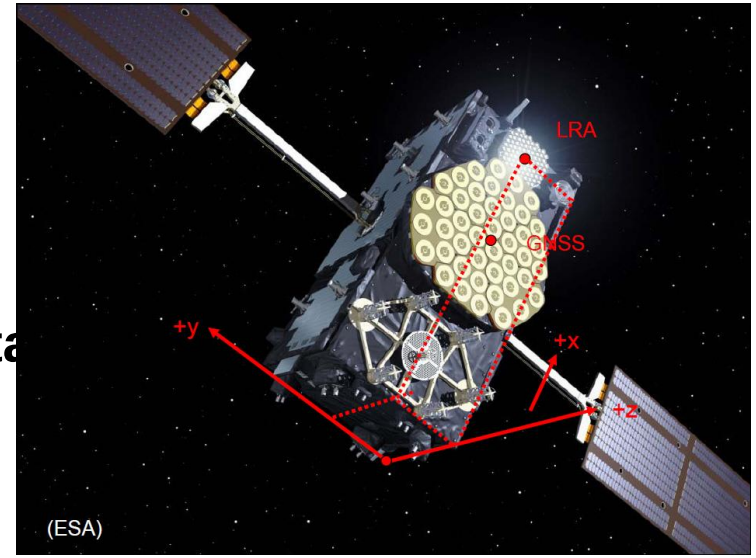
- GNSS system providers
- Equipment manufacturers
- Other IGS Working Groups (Ant WG, Bias WG, RT WG)

Recommendations, conventions and processing standards:

- Attitude models
- Antenna offsets and patterns

Data formats:

- Observations and navigation data (RINEX, RTCM3-MSM)
- Biases (SINEX?)
- Orbits



Public Outreach

- **Regular presentations at relevant GNSS and geodesy-related conferences**
- **Magazine articles**
- **Board participation (e.g., ICG)**

IGS Real-time GNSS Service

Bundesamt für Kartographie und Geodäsie

Open Data

- Observations & derived products freely available
- Streaming data over IP Networks in real-time
- Best effort operations, distributed governance
- Funded by national agencies, institutions, science
- Playing some global coordination role

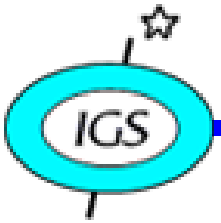
Open Source

- Supporting Real-time GNSS tools for Linux, Solaris, Window, Mac
- Multi-stream decoder, feeding GNSS engines, etc.
- Combining, encoding and uploading orbit/clock corrections
- Precise Point Positioning options
- Support of all GNSS through RINEX-3

Open Standards

- Standardization in RTCM is understood as key issue
- Concepts and messages for all types of corrections
- Make PPP an optional alternative to Network RTK

IGS Real-time GNSS Service



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Bundesamt für Kartographie und Geodäsie

esa

Natural Resources Canada

CZECH TECHNICAL UNIVERSITY

cnes

gmv INNOVATING SOLUTIONS

GFZ Helmholtz-Zentrum POTSDAM

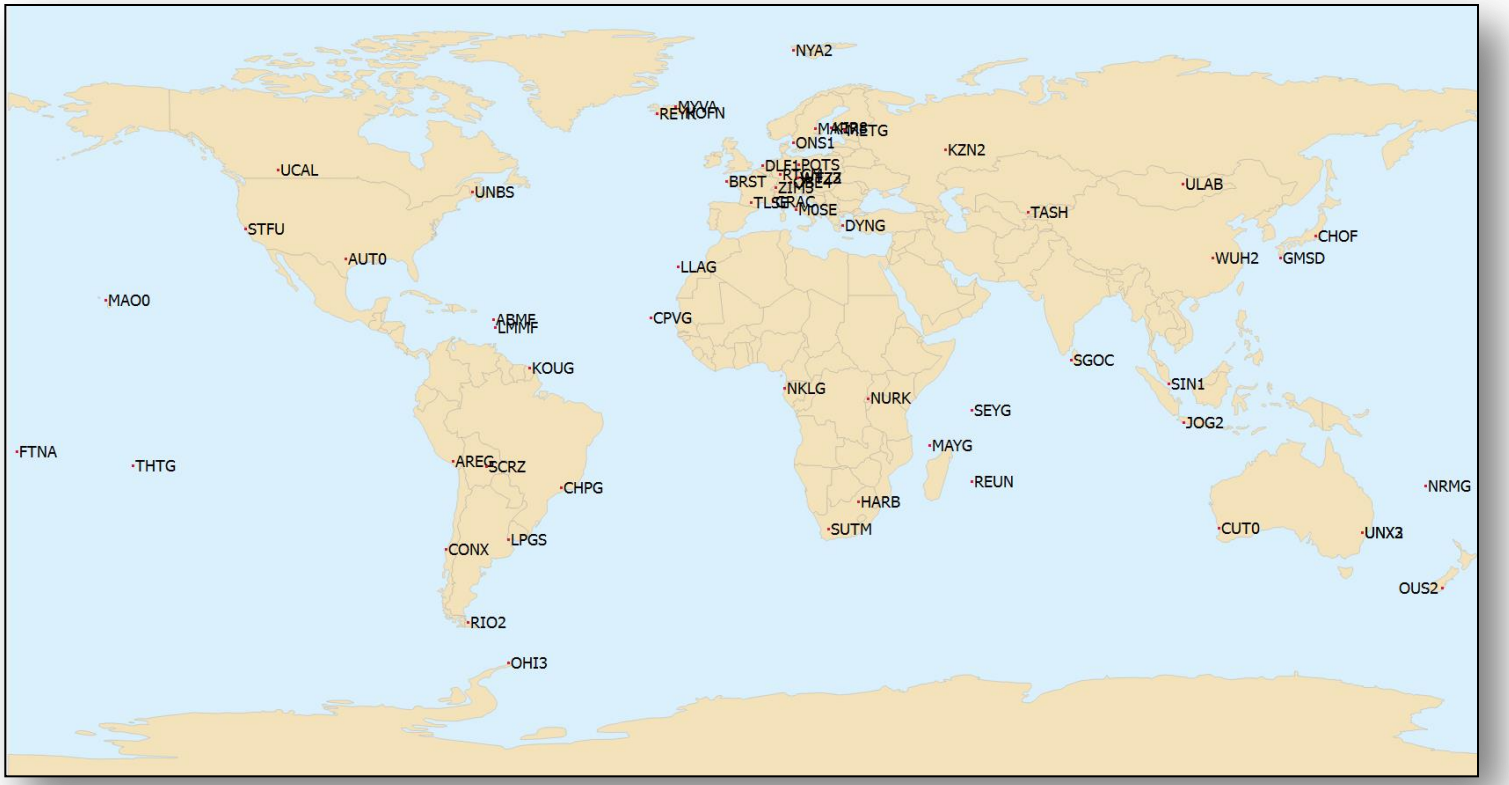
DLR

WUHAN UNIVERSITY

International Association of Geodesy

IGS Real-time GNSS Service

Bundesamt für Kartographie und Geodäsie



GPS, GLONASS, Galileo, BeiDou, QZSS, SBAS

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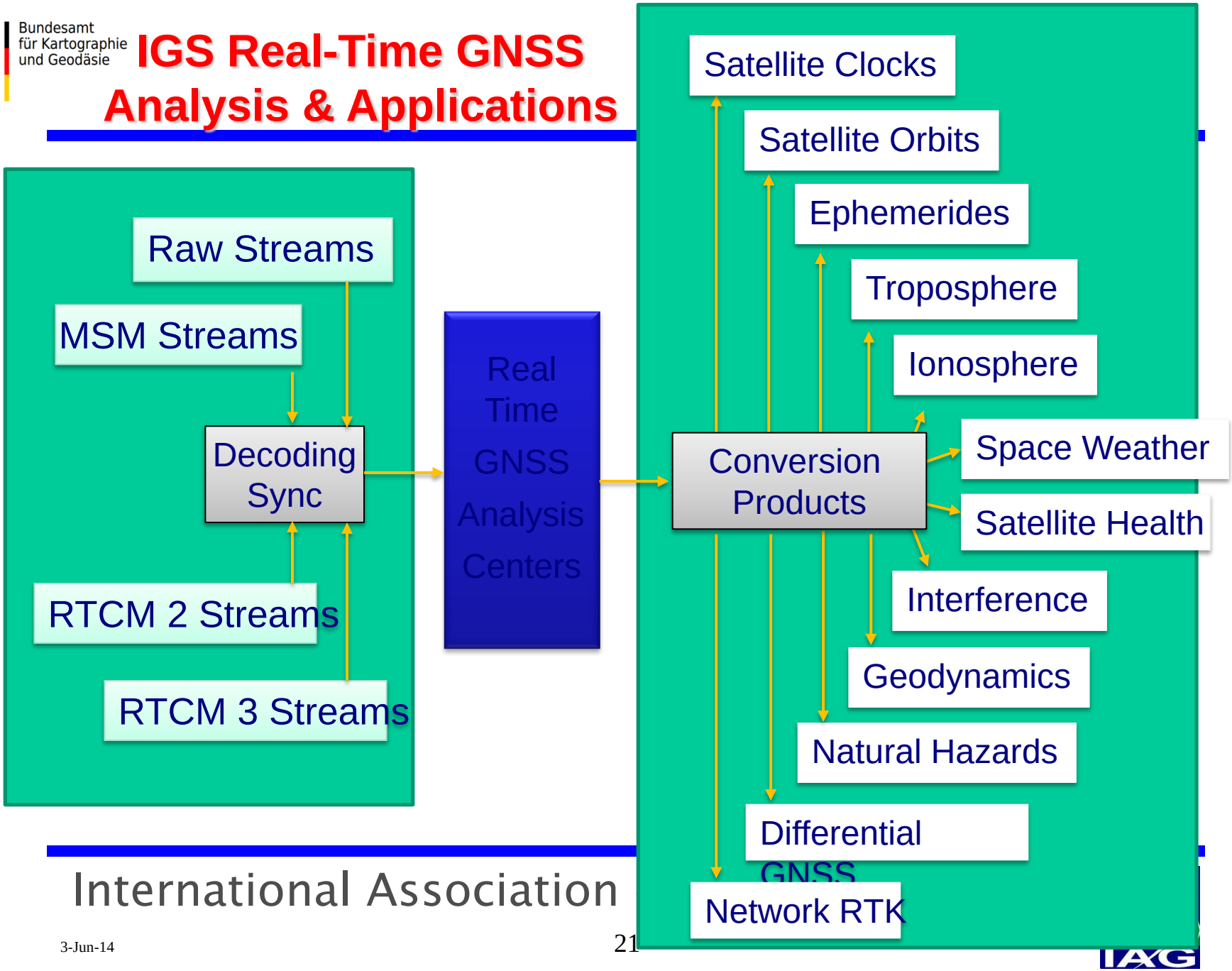
IGS Real-Time GNSS Analysis & Applications



International Association

24/7 Combined Orbit & Clock PPP Service

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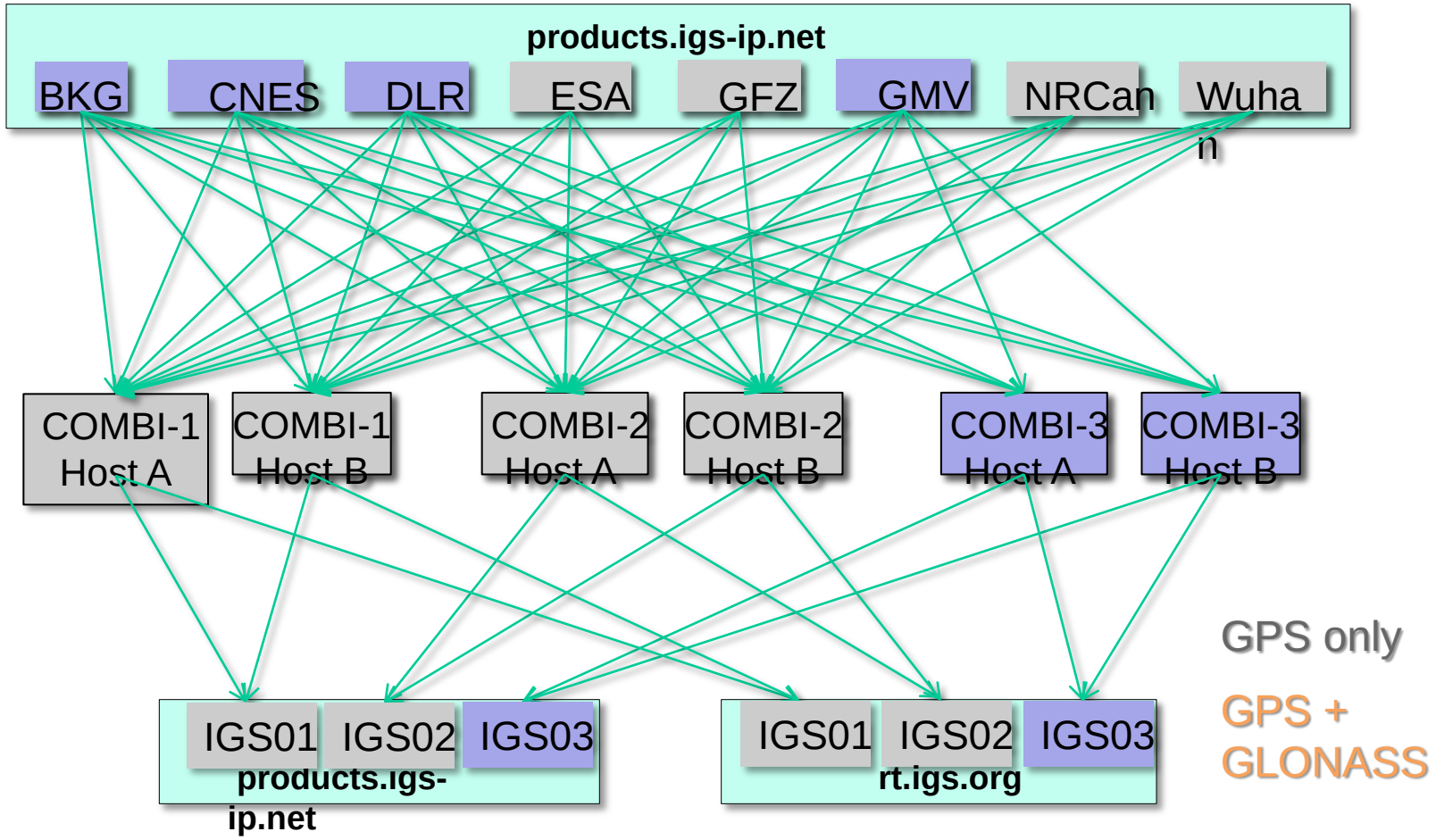

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Precise Point Positioning using IGS RT Service

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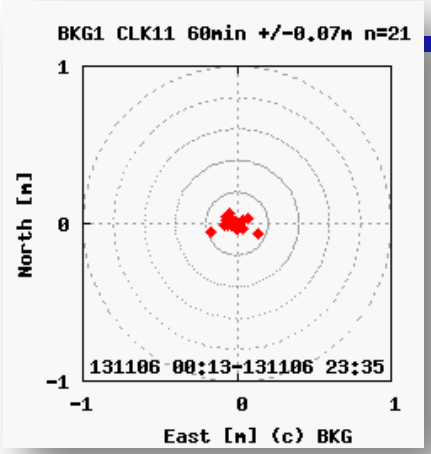
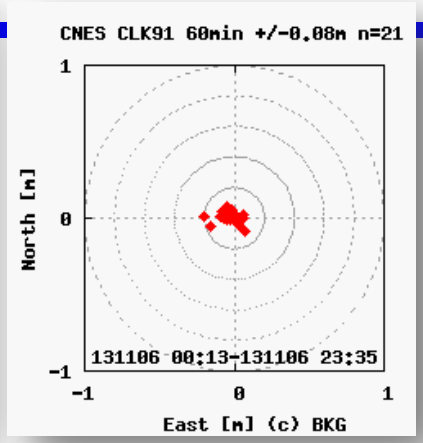
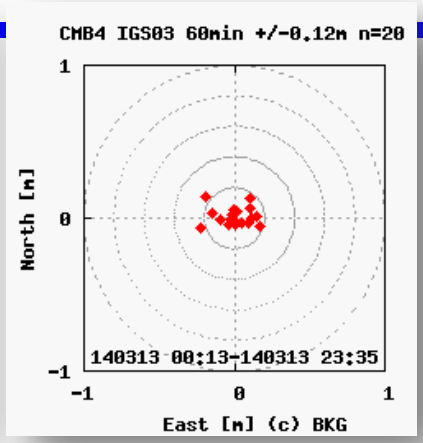
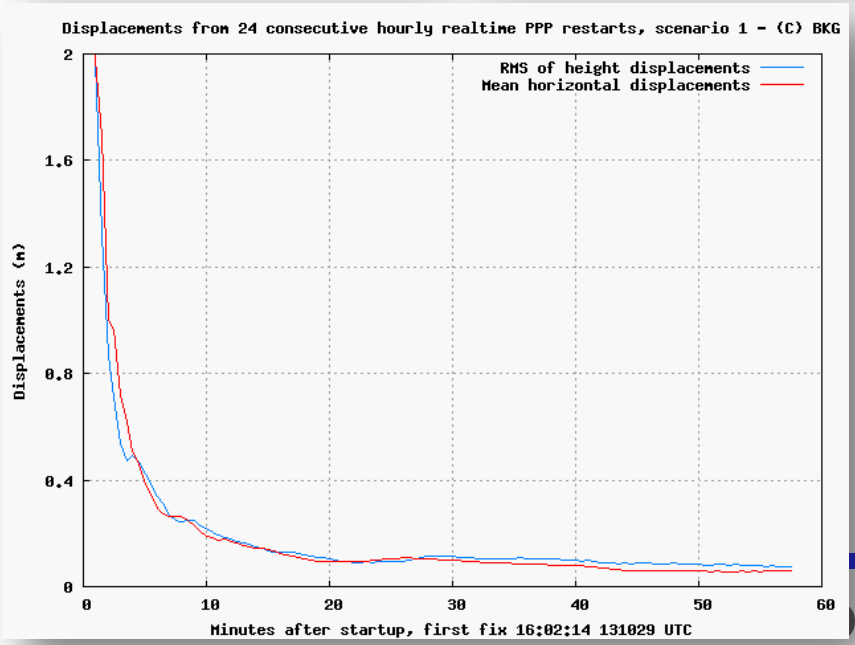
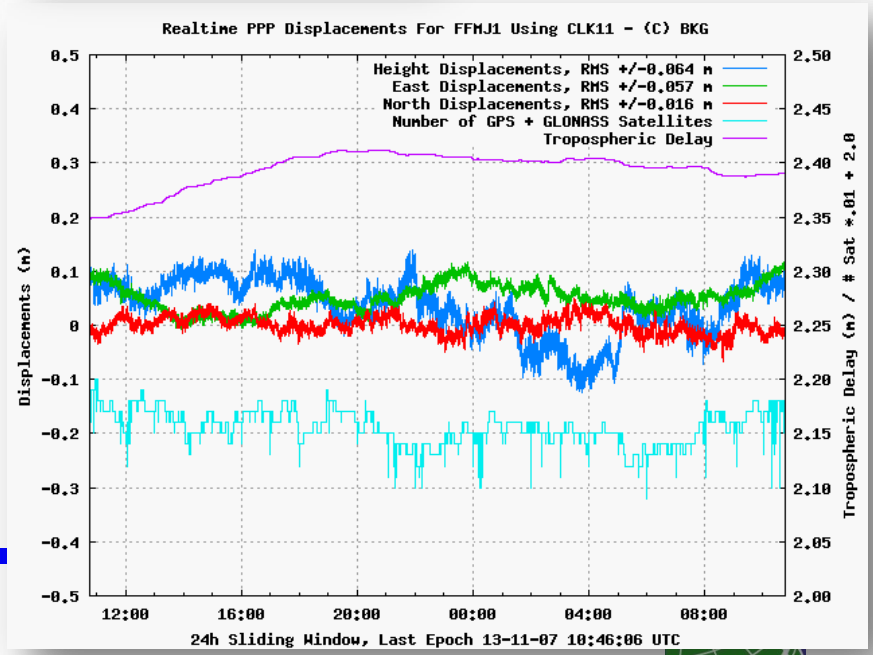






GPS + GLONASS Performance





Number of Listeners to IGS Ntrip Broadcasters 24h Sliding Window

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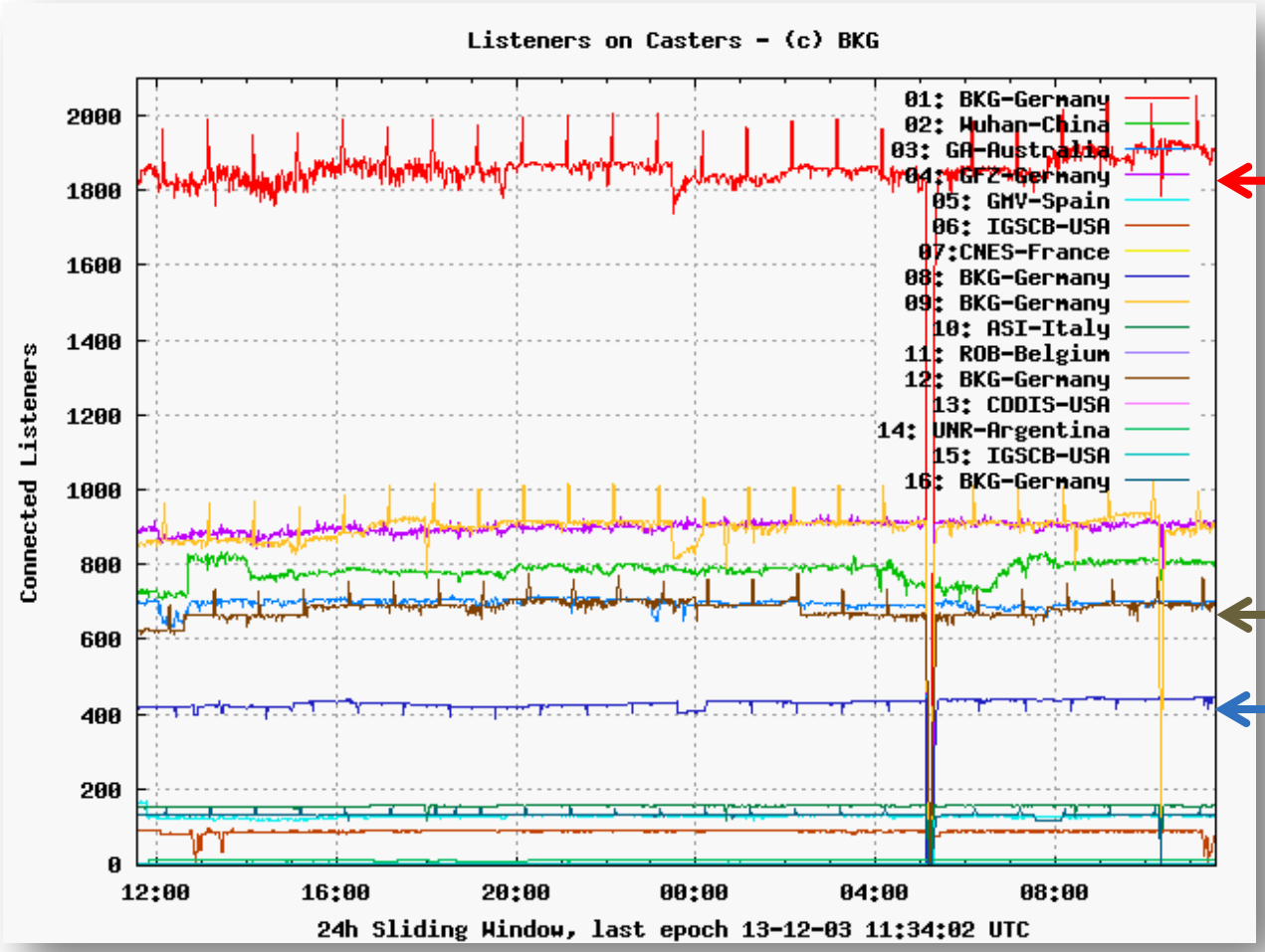


GNSS Observations
www.igs-ip.net

Multi-GNSS Obs.

mgex.igs-ip.net

Orbits & Clocks
products.igs-ip.net

International Association of Geodesy

The IGS RT Service does not compete with commercial PPP services because it …

Bundesamt für Kartographie und Geodäsie

- **Only maintains best effort services**
- **Cannot provide any service guarantee**
- **Does not include dense regional/local networks**
- **Therefore cannot achieve higher accuracy & reduced convergence time levels where commercialization becomes profitable**
- **Only supports communication over IP networks**
- **Has no influence on the implementation of open PPP standards in receiver firmware**
- **Is always less accurate with its combined solution than the best individual AC solutions (an unavoidable consequence from combining excellent and poor solutions)**

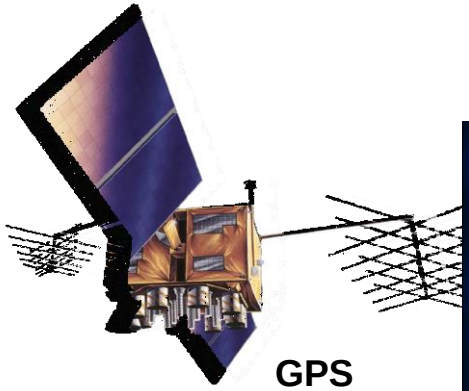
Backup Slides

GPS, GLONASS, Galileo

GPS: USA , 32 satellites in 6 planes
GLONASS: 24 satellites in 3 planes

Galileo: 4 IOV-satellites launched in 2011 & 2012

All GLONASS and Galileo satellites are equipped with SLR reflectors



GPS

GLONASS

Galileo

BeiDou and QZSS

BeiDou (Chinese System) shall consist of

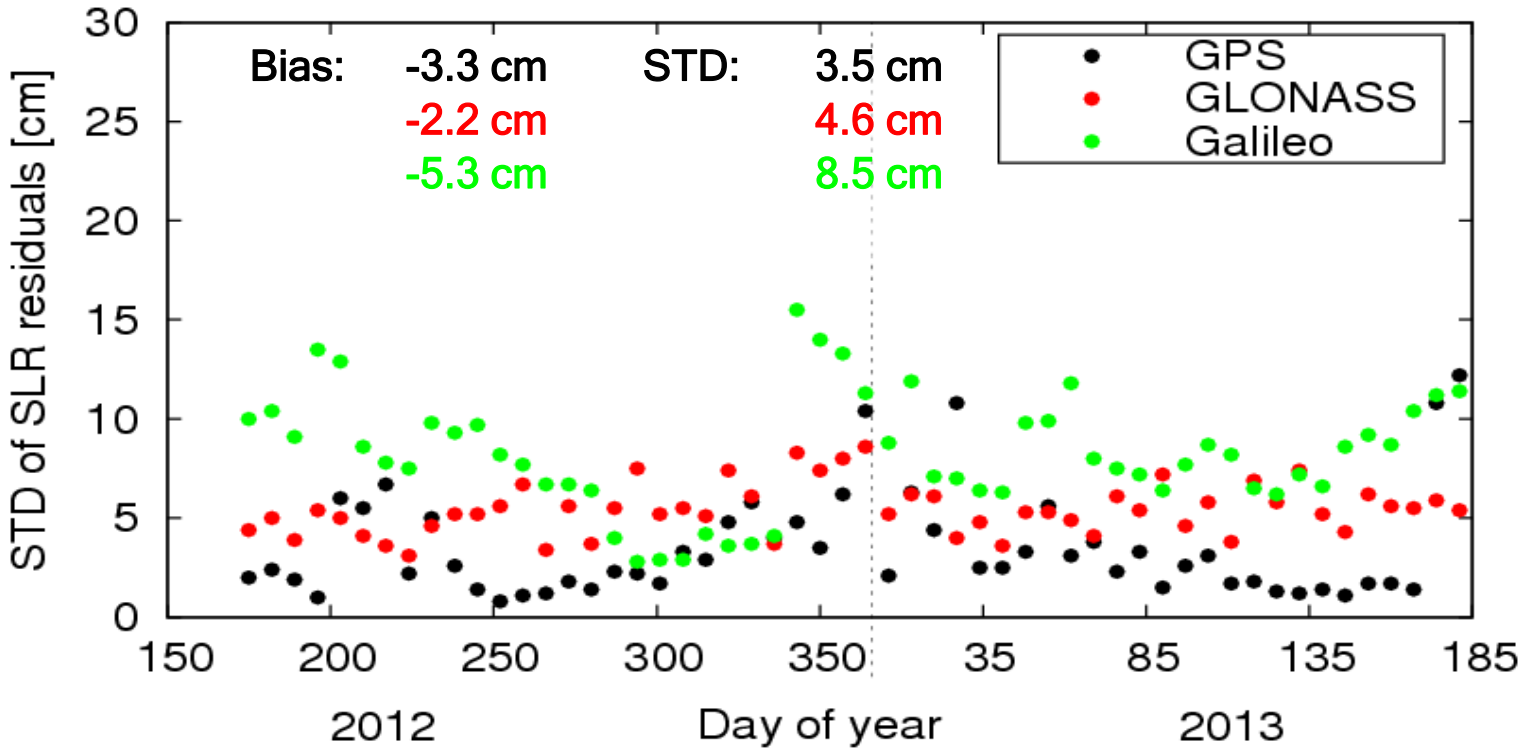
- 27 Mean Earth Orbiters (GPS-like)
- 5 geostationary satellites (GEO, GSO)
- 5 geosynchronous satellites (inclination of 55 deg) (IGSO)
- By end of 2012 5 GEO, 4 MEO, and 5 IGSOs were active

QZSS (Japanese System)

- 3 geosynchronous satellites/orbits
- HEOs (Highly Inclined elliptical orbits; i=43 deg, e=0.075)
- Currently one (QZS1) active

Orbit validation: SLR residuals

STD of SLR residuals per week: GNSS-wise



Broadcast Performance Assessment

Broadcast orbits and clocks from combined „brdm“ product

MGEX precise orbit and clock products

Signal in Space Range Error (SISRE)

System		SISRE (orb) [m]	SISRE (orb,SLR) [m]	SISRE [m]
GPS	all	0.24	-	0.71
	IIA	0.31	0.27	1.09
	IIR	0.21	-	0.53
	IIF(Rb)	0.18	-	0.34
GLO		0.54	0.51	1.97
GAL		0.76	0.81	1.64
BDS	all	1.02	1.77	1.46
	MEO+IGSO	0.57	0.68	1.02
QZS		0.50	0.40	0.57

(Montenbruck et al. 2014, GPS Solutions, submitted)

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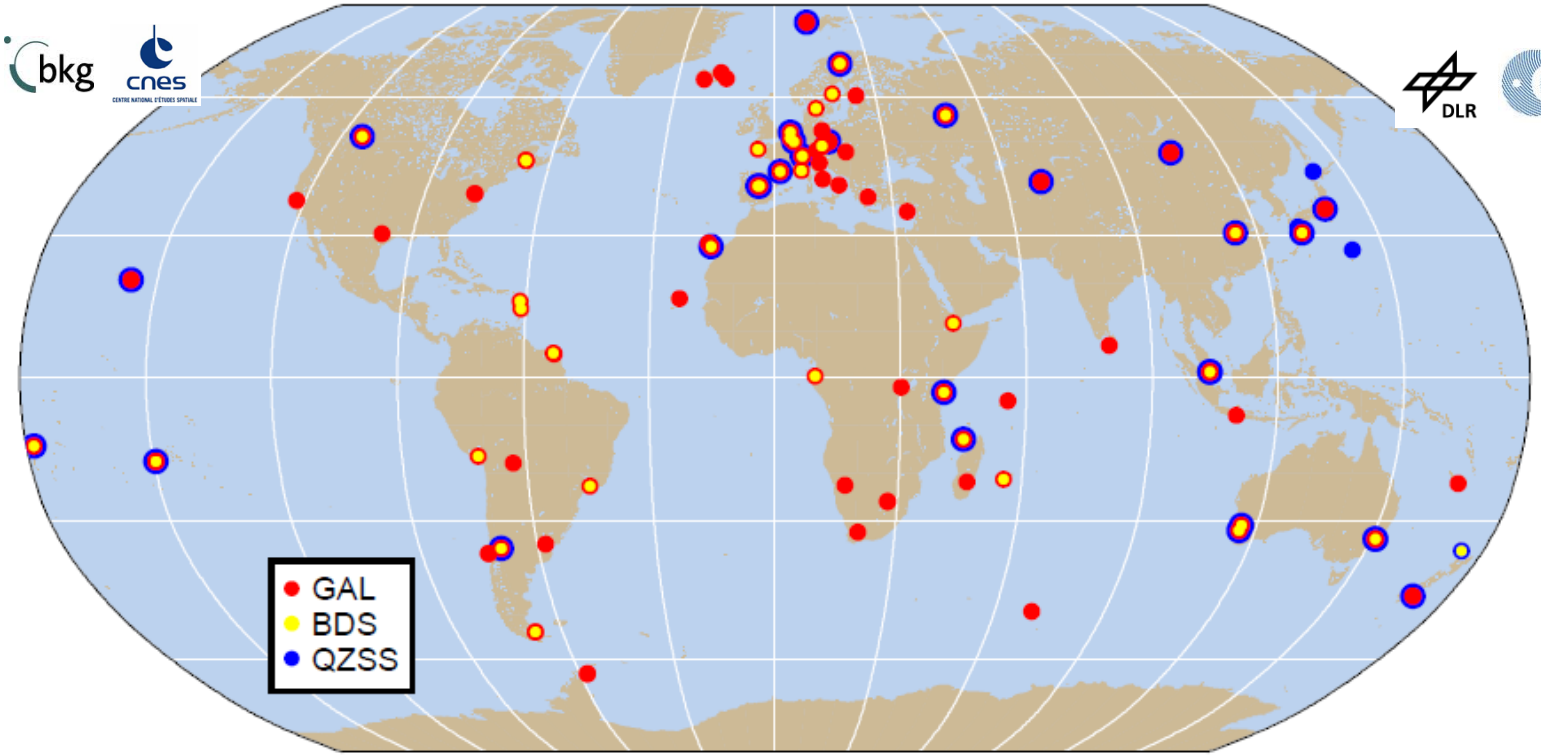
The IGS MGEX Network



~100 stations, ~80 sites (Apr. 2014)

Archive: ftp://cddis.gsfc.nasa.gov/pub/gps/data/campaign/mgex/

IGS MGEX – http://igs.org/mgex/

- Central portal for MGEX related information
- Entry point for data and product servers
- Clone for international access at UNAVCO (http://igsws.unavco.org/mgex/)

Summary and Conclusions

IGS Multi-GNSS Experiment launched in 2012

- **Early familiarization with new signals and constellations**

Substantial achievements in multi-GNSS

- **Global network (~100 stations), tracking of „all“ systems**
- **Orbit and clock products from 2++ ACs for GPS+GAL/BDS/QZS**
- **Differential code bias and and broadcast ephemeris products**

Concerns

- **Current lack of quality control for MGEX data**
- **Divergence of MGEX from legacy IGS**
- **Lack of spacecraft information (antennas, attitude, SRP) from system providers (Galileo and BeiDou, SBAS, IRNSS)**

Participation of new analysis centers encouraged