Multi-GNSS: Users' perspective

Gerhard Beutler
Astronomical Institute, University of Bern (AIUB)
IAG representative on PNT Advisory Board

based on material provided by
O. Montenbruck[1], R. Dach[2], L. Prange[2],
E. Brockmann[3], S. Lutz[3]

1) DLR, DE, 2) AIUB, CH, 3) swisstopo, CH

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Multi-GNSS: the systems 2016

System	Block	Signals	Satellites
GPS	IIR	L1 C/A, L1/L2 P(Y)	12
	IIR-M	L1 C/A, L1/L2 P(Y), L2C, L1/L2 M	7
	IIF	L1 C/A, L1/L2 P(Y), L2C, L1/L2 M, L5	12
GLONASS	M	L1/L2 C/A & P	23
	M+	L1/L2 C/A & P, L3	1
	K	L1/L2 C/A & P, L3	1+(1)
BeiDou-2	MEO	B1-2, B2, B3	3
	IGSO	B1-2, B2, B3	6
	GEO	B1-2, B2, B3	5+(1)
BeiDou-3	MEO	B1-2, B1, B2, B3ab	2+(1)
	IGSO	B1-2, B1, B2, B3ab	2
Galileo	IOV	E1, E6, E5a/b/ab	3+(1)
	FOC	E1, E6, E5a/b/a	6+(4)
QZSS	I	L1 C/A, L1C, L1 SAIF, L2C, L6 LEX, L5	1
IRNSS	IGSO	L5/S SPS & RS	4
	GEO	L5/S SPS & RS	3

From Montenbruck et al (2016)

Status: October 2016

4 global systems (GPS, GLONASS, BeiDou-3, Galileo),

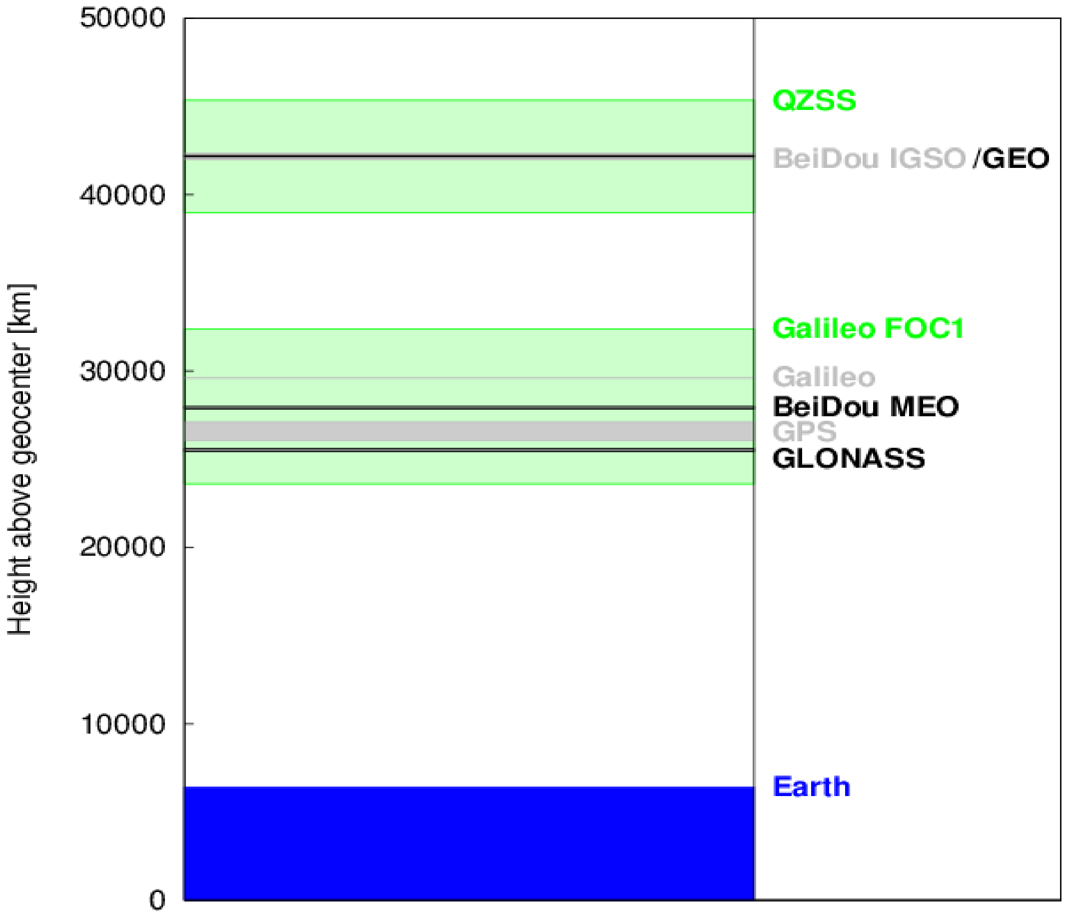
3 regional systems (QZSS, IRNSS, BeiDou-2)

GPS, GLONASS, BeiDou-2 and IRNSS operational with 31, 24, and 9 satellites, respectively

Galileo, BeiDou-3, QZSS are "under construction"

IRNSS is fully deployed, as well.

Multi-GNSS: the systems 2016



- >80 GNSS & RNSS satellites with different orbit characteristics (semi-major axes *a*, eccent-ricities *e*, inclinations *i*) and different signals, tracking modes.
- QZSS and Galileo FOC1 satellites have elliptic orbits (e≈0.075, e≈0.16, respectively)

The MGEX ground-tracking network

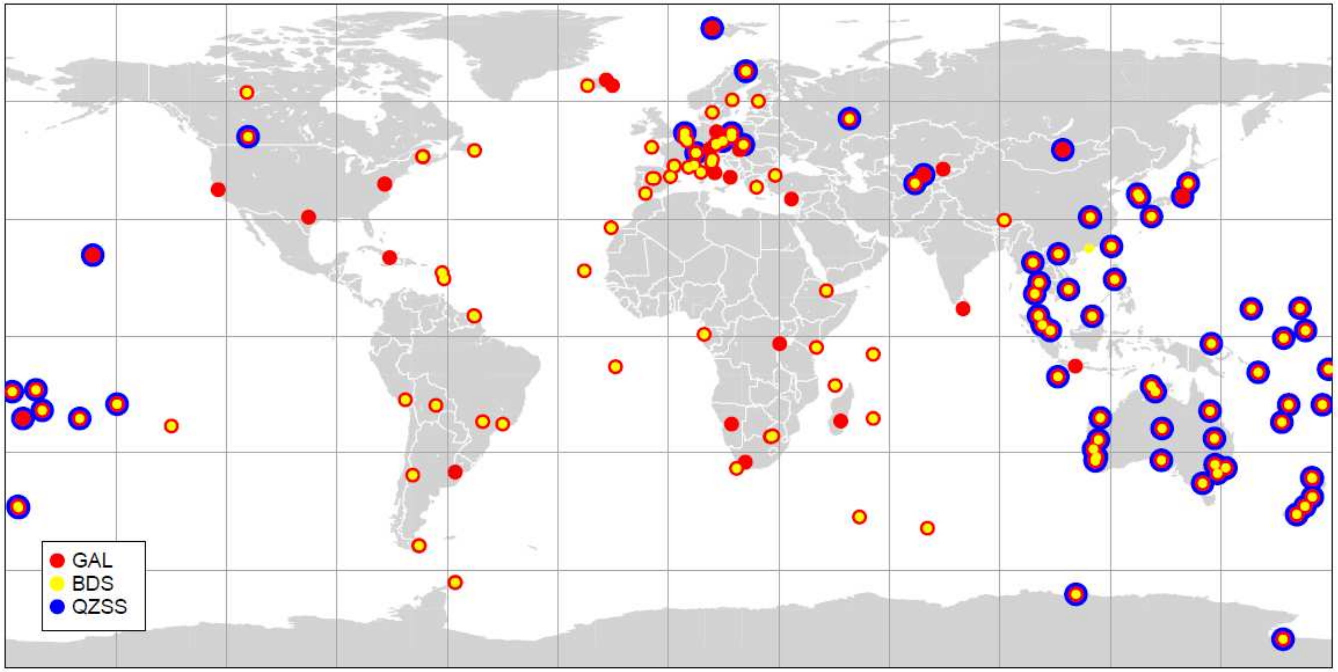
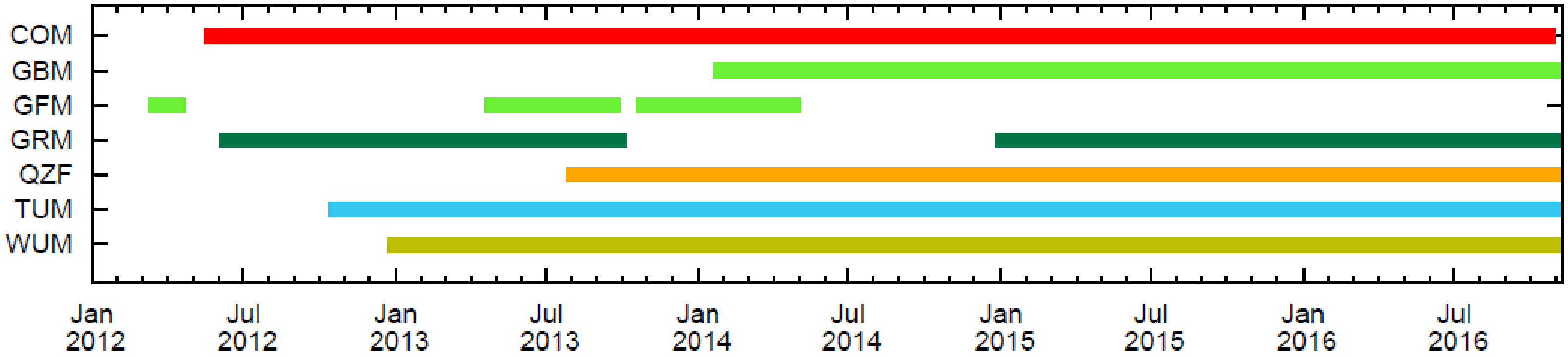


Figure 2: IGS multi-GNSS stations in October 2016.

Currently, about 170 Multi-GNSS stations track a combination of Galileo, Beidou, QZSS, in addition to GPS and GLONASS. QZSS is of interest in the Western Pacific and Oceanic regions.

MGEX Analysis

Institution	Abbr.	Constellations	SP3	CLK	SNX	ERP	BSX
CNES/CLS	GRM	GPS+GLO+GAL	15 min	30 s	x	–	–
CODE	COM	GPS+GLO+GAL+BDS+QZS	15 min	5 min	–	x	x
GFZ	GBM	GPS+GLO+GAL+BDS+QZS	5 min	30 s	–	x	x
JAXA	QZF	GPS+QZS	5 min	–	–	–	–
TUM	TUM	GAL+QZS	5 min	–	–	–	–
Wuhan Univ.	WUM	GPS+GLO+GAL+BDS+QZS	15 min	5 min	–	x	–



MGEX Analysis Centers (ACs) and products (orbits, clocks, coordinates of ground tracking network, Earth rotation parameters, intersystem biases)

MGEX Analysis

Table 9: RMS values derived from orbit comparisons for the time period 1 January – 30 June 2016. All values are given in cm.

	GPS	GLONASS	Galileo		BeiDou			QZSS	
			IOV	FOC	MEO	IGSO	GEO	YS	ON
Radial	1 – 3	4 – 11	6 – 10	4 – 10	3 – 11	11 – 23	54	10 – 24	30 – 71
Along-Track	2 – 4	4 – 12	10 – 18	10 – 19	10 – 21	24 – 39	298	28 – 57	84 – 133
Cross-Track	2 – 3	3 – 9	9 – 20	6 – 14	6 – 10	17 – 23	410	16 – 39	59 – 156
3D	3 – 6	6 – 17	16 – 29	14 – 26	12 – 26	32 – 51	510	40 – 73	123 – 240

Current orbit quality per coordinate, from MGEX comparisons:

GPS: 1-4 cm

GLO: 4-12 cm

Galileo: 4-14 cm

BeiDou: MEO < 20 cm, IGSO: < 30 cm, GEO: < 400 cm

QZSS, Yaw-Steering (YS): < 50 cm, Orbit-Normal mode (ON): < 160 cm

MGEX, SLR Validation

Table 10: SLR residual offsets and standard deviations for the time period 1 January – 30 June 2016. All values are given in cm.

	GLONASS	Galileo IOV	Galileo FOC	BeiDou MEO	BeiDou IGSO	BeiDou GEO	QZSS
COM	0.5 ± 5.0	-4.3 ± 4.5	-3.5 ± 4.3	-3.4 ± 6.5	-2.8 ± 14.5		-2.0 ± 26.0
GBM	1.0 ± 5.5	-1.7 ± 8.0	-3.0 ± 8.2	-0.3 ± 3.5	-1.1 ± 6.5	-44.7 ± 42.0	15.4 ± 26.5
GRM	0.2 ± 5.2	-0.3 ± 4.5	-1.3 ± 4.7				
QZF							-13.8 ± 16.2
TUM		-6.1 ± 8.8	-4.6 ± 8.6				8.1 ± 28.9
WUM	1.0 ± 5.4	-2.0 ± 4.2	-6.2 ± 9.0	-2.5 ± 4.2	-3.4 ± 8.2	-37.7 ± 29.2	13.1 ± 25.8

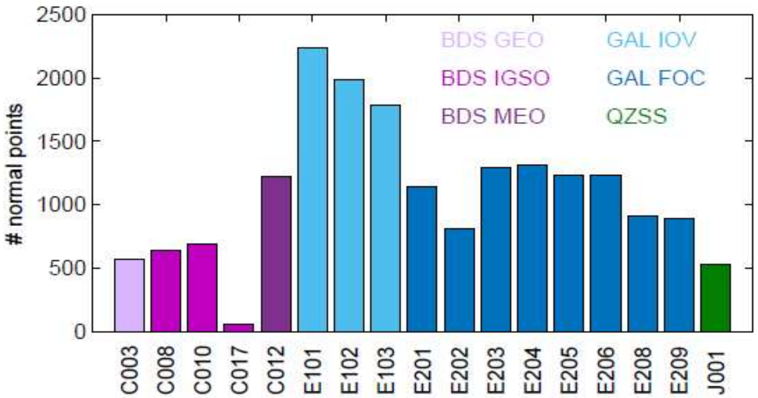


Figure 4: Number of SLR normal points of the new satellite navigation systems for the time period 1 January – 30 June 2016 as used for the analysis in Table 10. Satellites are identified by their space vehicle number (SVN).

SLR is the only independent validation technique for GNSS- and RNSS-derived orbits. All, except the GPS satellites, have SLR reflectors! Offsets indicate orbit model deficiencies!

MGEX@CODE

- 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

Bundesamt für Kartographie und Geodäsie

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Technische Universität München

CODE Ultra–Rapid Solution

CODE Rapid Solution

CODE Final Solution

Reprocessing Solution (CODE and AIUB)

CODE MGEX Solution

Ultra-Rapid solutions are available four times/day with a latency of three hours, rapid solutions once per day with a latency of about half a day, final solution once per week with a latency < 1 week, MGEX solution once per week, with a latency < 1 week

MGEX@CODE

CODE participates as COM Analysis Center in the IGS MGEX (Multi-GNSS Experiment and Pilot Project).

COM regularly analyzes five systems, namely

- GPS, GLONASS, Galileo, Beidou, QZSS

About 80 satellites and 160 permanent sites of the MGEX network contribute to the COM solutions.

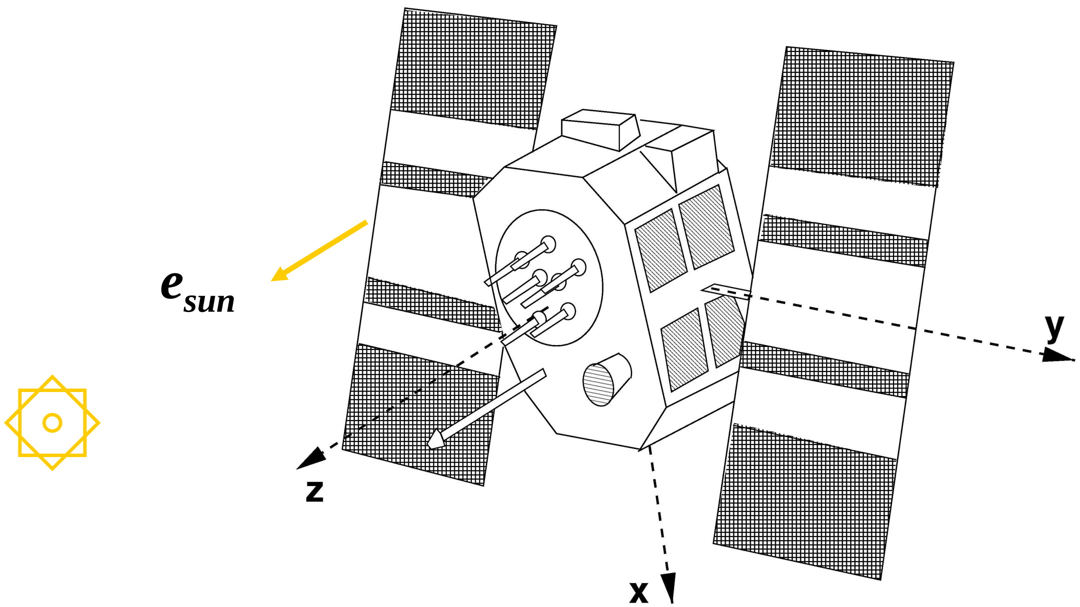
COM solutions include satellite orbits, satellite clock correction, ERPs, inter-system biases

In the long term CODE plans to incorporate all GNSS into its routine solutions.

In the framework of the COM solutions CODE contributes to implementing ``exotic'' satellite attitude/SRP models

Public access to MGEX monitoring results via FTP:
=> ftp://ftp.unibe.ch/aiub/CODE_MGEX/

MGEX@CODE

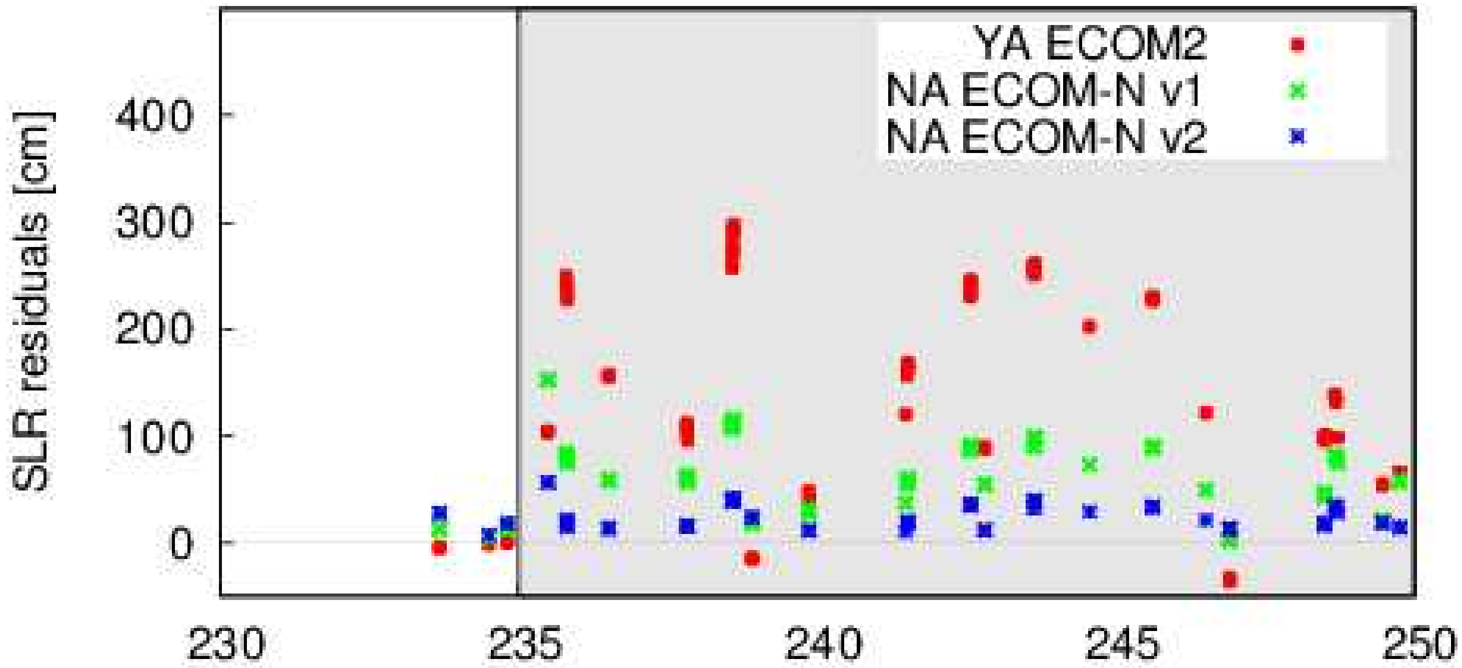


Satellite-fixed Cartesian coordinate system (x,y,z), unit vector e_{sun} pointing from satellite to Sun is perpendicular to solar panels under Yaw-steering.

QZSS and BeiDou switch to orbit normal (ON) steering mode, when the Sun is close to the satellites' orbital planes.

MGEX@CODE

SLR residuals of QZS-1 with SRP models (arc-length 1 day)



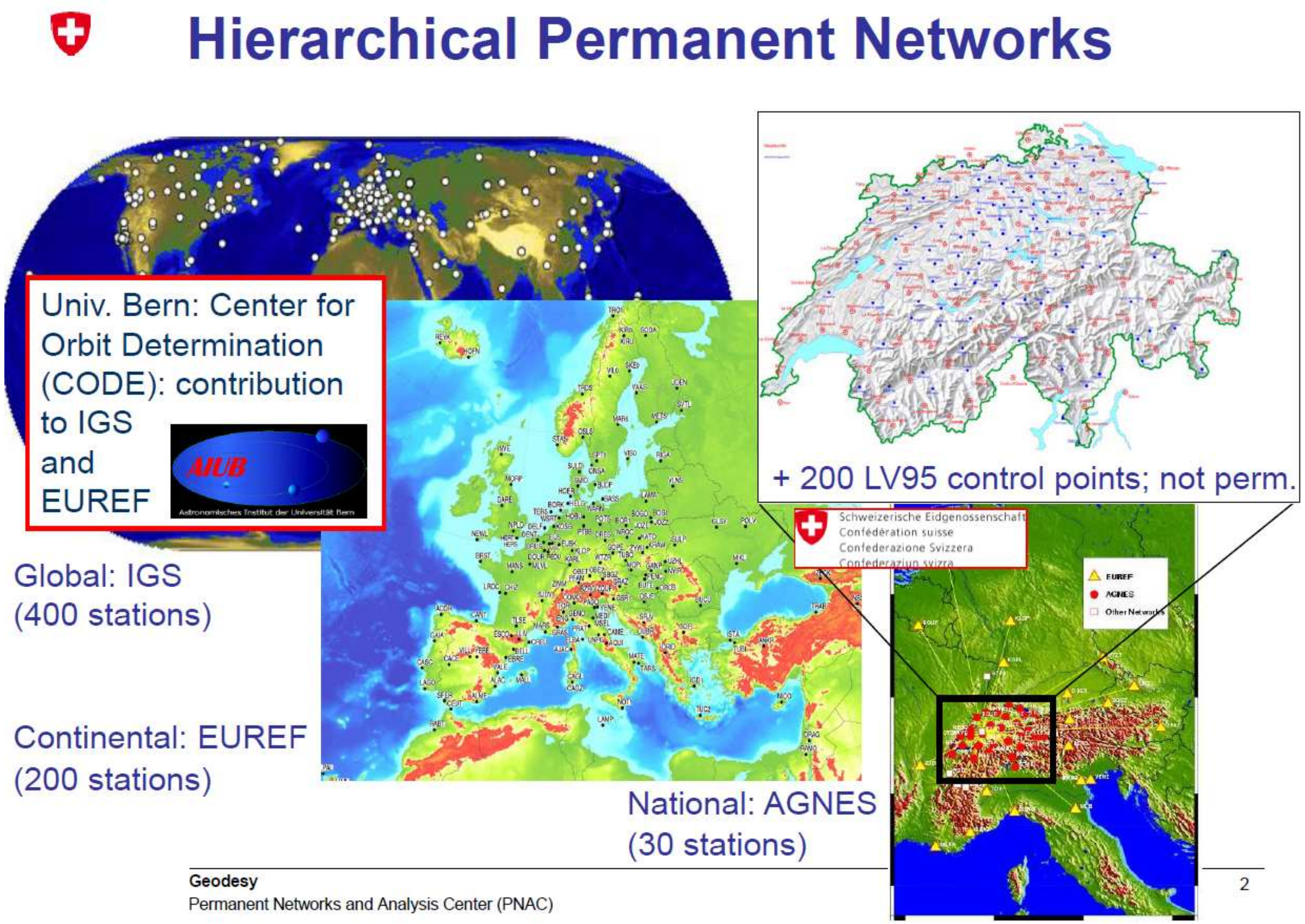
Yaw-Steering SRP (red) is not sufficient for ON mode
Experimental ECOM-N… models (green, blue) better represent SRP
Additional Challenge: switching epochs between YS and ON are unknown

MGEX@swisstopo

swisstopo

- is the national mapping agency of Switzerland, responsible for Swiss first order network ("Landesvermessung")
- operates "AGNES", a multi-purpose GNSS network
- is an Analysis Center of EUREF, the IAG Commission establishing the European Reference Frame.
- and AIUB/CODE closely cooperate in the field of GNSS research and applications.

MGEX@swisstopo



MGEX@swisstopo: Motivation

PPP for product/strategy evaluation

- Kin. coordinate repeatabilities over one week for ZIM3

V_B	V_USE	North [mm]	East [mm]	Up [mm]	#OBS/Epo
COD	G	8.52	9.57	16.07	10.1
COD	GR	5.67 (-33%)	5.32 (-44%)	11.67 (-27%)	18.3 (+81%)
COM*	G	11.23	11.42	21.79	9.9
COM	GR	6.86 (-39%)	7.03 (-38%)	14.56 (-33%)	17.7 (+79%)
COM	GRE	6.54 (-42%)	6.50 (-43%)	13.29 (-39%)	21.4 (+116%)
COM	GREC	6.27 (-44%)	6.21 (-46%)	13.22 (-39%)	24.2 (+144%)
GBM	G	9.06	9.78	17.46	10.1
GBM	GR	5.82 (-36%)	5.50 (-44%)	12.46 (-29%)	18.2 (+80%)
GBM	GRE	5.65 (-38%)	5.00 (-49%)	11.87 (-32%)	22.0 (+118%)
GBM	GREC*	5.78 (-36%)	10.24 (+5%)	13.49 (-23%)	25.4 (+151%)

*COM: Satellite clocks have 300 s sampling, all others 30 s

*GBM: Issue with C05 (GEO), which is not included in COM

- General benefit adding more GNSS

MGEX@swisstopo

Multi-Purpose Network AGNES

Automated GNSS Network for Switzerland (AGNES)
used for

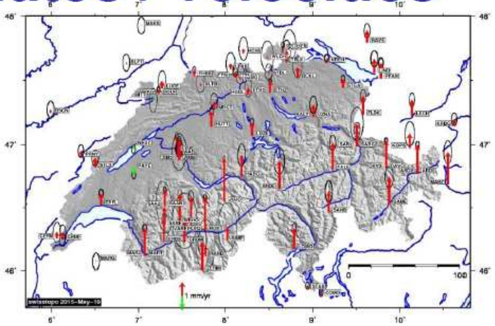
- Positioning
- Reference Frame Maintenance
- Federal Surveying
- Science
  - GPS-Meteorology
  - Tectonics

AGNES as an active provider of the reference frame

- GLONASS support since Mid 2007
- GPS+GLO+GAL+BDS support since 2015/2016

MGEX@swisstopo

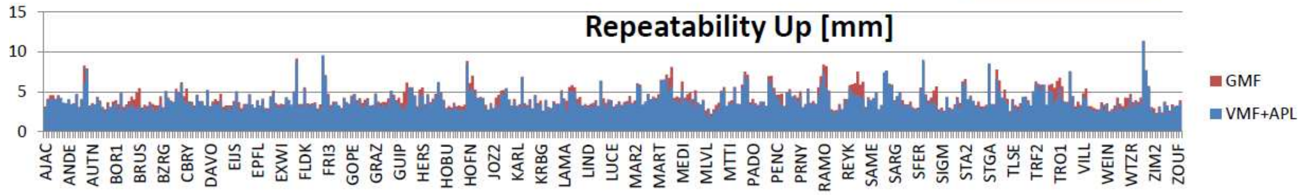
Reprocessing: coordinates / velocities



- Velocity estimates based on repro + operational; impact small: standard dev. vertical ±0.25 mm/yr
- Coordinate repeatability based on Vienna mapping is slightly better (height component)

434 stations	North [mm]	East [mm]	Up [mm]
GMF	1.54	1.41	4.53
VMF+APL	1.51	1.37	4.08

- 10 %

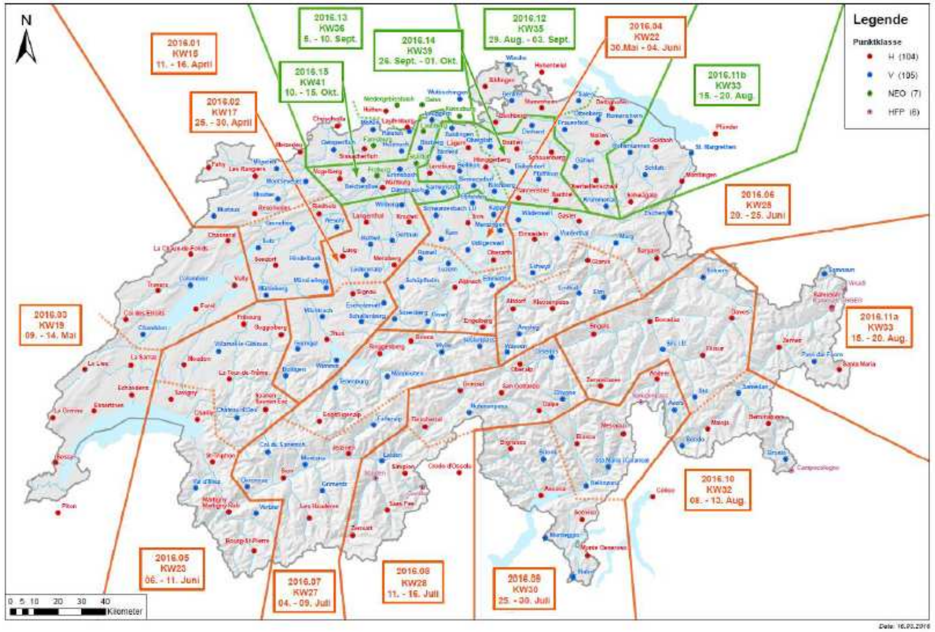


Geodesy
Permanent Networks and Analysis Center (PNAC) 11

MGEX@swisstopo

CHTRF2016 Multi-GNSS campaign

- All ~200 reference points measured this summer and analysed in Multi-GNSS style



International Association of Geodesy

MGEX@swisstopo

CHTRF2016 Multi-GNSS campaign

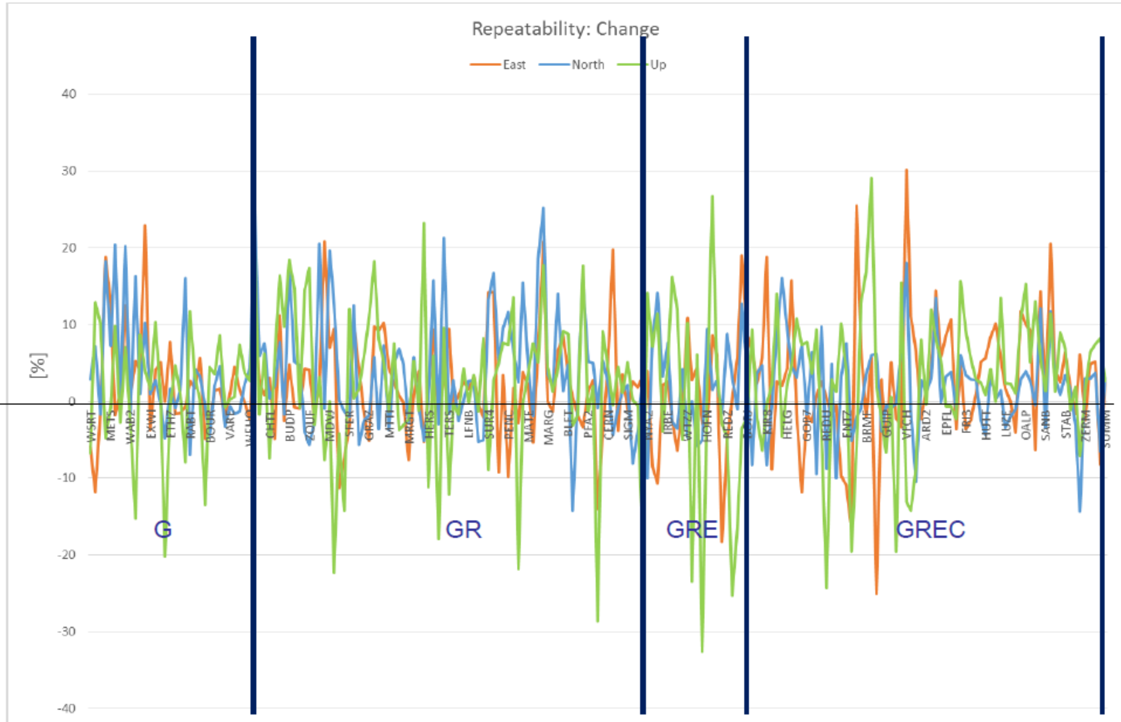
- 10 operators
- 15 weeks (Mo – Sa)
- April 11 – October 14, 2016
- ~ 44 hours of measurements per point
- All data analysed already (Multi-GNSS)
  - Horizontal position ~ 1 cm with official coordinates
  - Vertical position: to be validated (switch from relative to absolute antenna PCVs)

MGEX@swisstopo

AGNES Multi-GNSS prototype

- 206 stations, new vs old processing scheme

worse



improved

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Oliver Montenbruck[a], Peter Steigenberger[a], Lars Prange[b], Zhiguo Deng[c], Qile Zhao[d], Felix Perosanz[e], Ignacio Romero[f], Carey Noll[g], Andrea Stürze[h], Georg Weber[i], Ralf Schmid[j], Ken MacLeod[k], Stefan Schaer[l]

[a]*Deutsches Zentrum für Luft- und Raumfahrt (DLR), German Space Operations Center (GSOC), 82234 Weßling, Germany*
[b]*Astronomisches Institut der Universität Bern (AIUB), Sidlerstrasse 5, 3012 Bern, Switzerland*
[c]*Deutsches GeoForschungsZentrum (GFZ), Telegrafenberg, 14473 Potsdam, Germany*
[d]*GNSS Research Center, Wuhan University, No.129 Luoyu Road, Wuhan 430079, China*
[e]*Centre National d'Etudes Spatiales (CNES), 18, avenue Edouard Belin, 31401 Toulouse Cedex 9, France*
[f]*European Space Agency (ESA), European Space Operations Centre (ESOC), Robert-Bosch-Straße 5, 64293 Darmstadt, Germany*
[g]*Goddard Space Flight Center (GSFC), Code 690.1, Greenbelt, MD 20771, USA*
[h]*Bundesamt für Kartographie und Geodäsie (BKG), Richard-Strauss-Allee 11, 60598 Frankfurt/Main, Germany*
[i]*Ntrip Enterprise, Rotdornweg 98, 60433 Frankfurt/Main, Germany*
[j]*Technische Universität München, Deutsches Geodätisches Forschungsinstitut (DGFI-TUM), Arcisstraße 21, 80333 München, Germany*
[k]*Canadian Geodetic Survey, Natural Resources Canada (NRCan), 588 Booth Street, Ottawa, Ontario, Canada*
[l]*Bundesamt für Landestopografie swisstopo, Seftigenstrasse 264, 3084 Wabern, Switzerland*

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ORIGINAL ARTICLE

CODE's five-system orbit and clock solution—the challenges of multi-GNSS data analysis

Lars Prange[1] · Etienne Orliac[1] · Rolf Dach[1] · Daniel Arnold[1] · Gerhard Beutler[1] · Stefan Schaer[2] · Adrian Jäggi[1]

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