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Multi-GNSS analysis at swisstopo: Developments and first results

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Content

- Why Multi-GNSS?
- Observation file monitoring
- Product evaluation with PPP
- Network solutions
- Summary and outlook

Why Multi-GNSS?
Global Navigation Satellite Systems

- Two established systems for two-frequency analysis:
  - GPS (USA)
  - GLONASS (RUS)

- Four new constellations being installed:
  - Galileo (EU)
  - BeiDou (CHN)
  - QZSS (JPN)
  - IRNSS (IND)

- More carrier frequencies as well as new and improved signals also for GPS and GLONASS

Why Multi-GNSS? Advantages for the user

- Improved visibility to the satellites
- Increased availability of signals
- Less susceptible if one satellite or system erroneous
- More combinations (frequencies, systems) and control of the background models by comparing different solutions possible
- RINEX-3 format description and Multi-GNSS ANTEX file available from the International GNSS Service (IGS, http://www.igs.org)
- Characteristics of the new constellations as well as observation data and products (e.g., satellite orbits and clocks) available from the IGS Multi-GNSS Experiment (MGEX, http://www.igs.org/mgex)
- Growing number of Multi-GNSS stations worldwide

Observation file monitoring Overview

- All Swiss national permanent stations are providing RINEX-3 data since summer 2015, most of them with Galileo and BeiDou observations

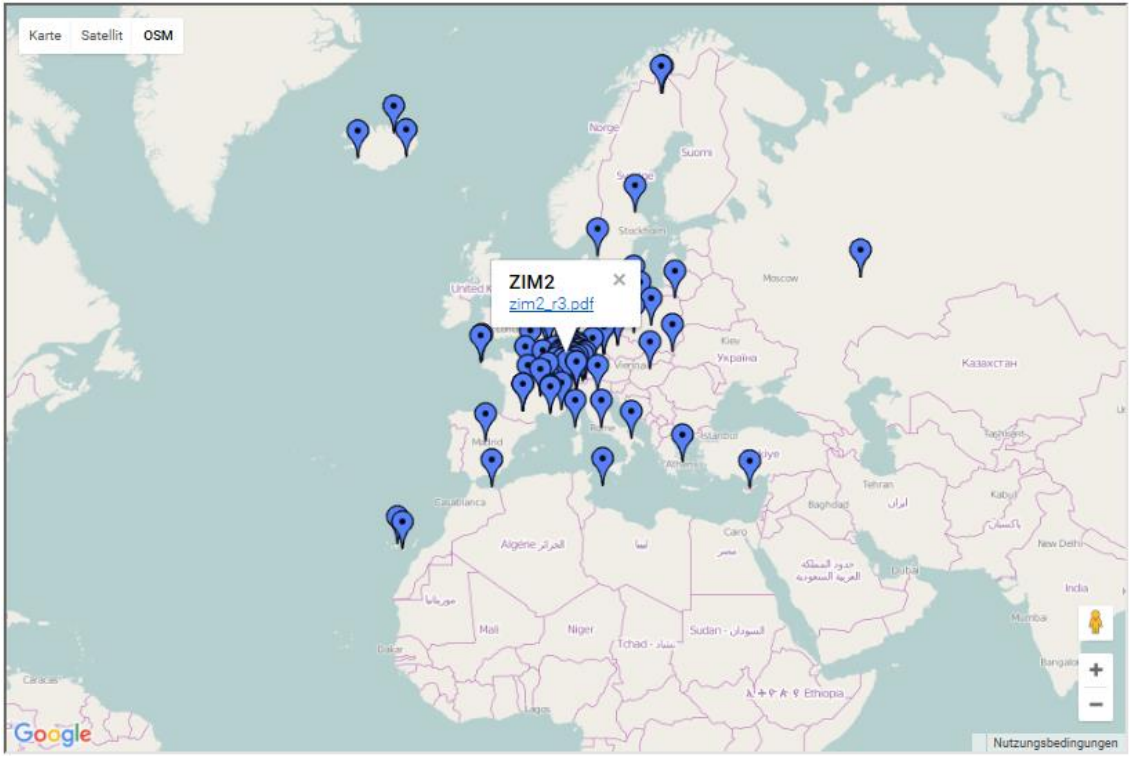
- An extended number of EPN stations providing RINEX-3 together with RINEX-2 observation files have been added to the operational analysis

- External software tools: G-Nut/Anubis by GOP and Ntrip Client by BKG
- Broadcast orbits from MGEX: ftp://cddis.gsfc.nasa.gov/gnss/data/campaign/mgex/daily/rinex3/yyyy/brdm

- Monitoring of availability, completeness, data problems, and data quality

- Resulting plots are regularly updated on the swisstopo website: http://www.swisstopo.admin.ch/internet/swisstopo/en/home/topics/survey/permnet/pnac.html

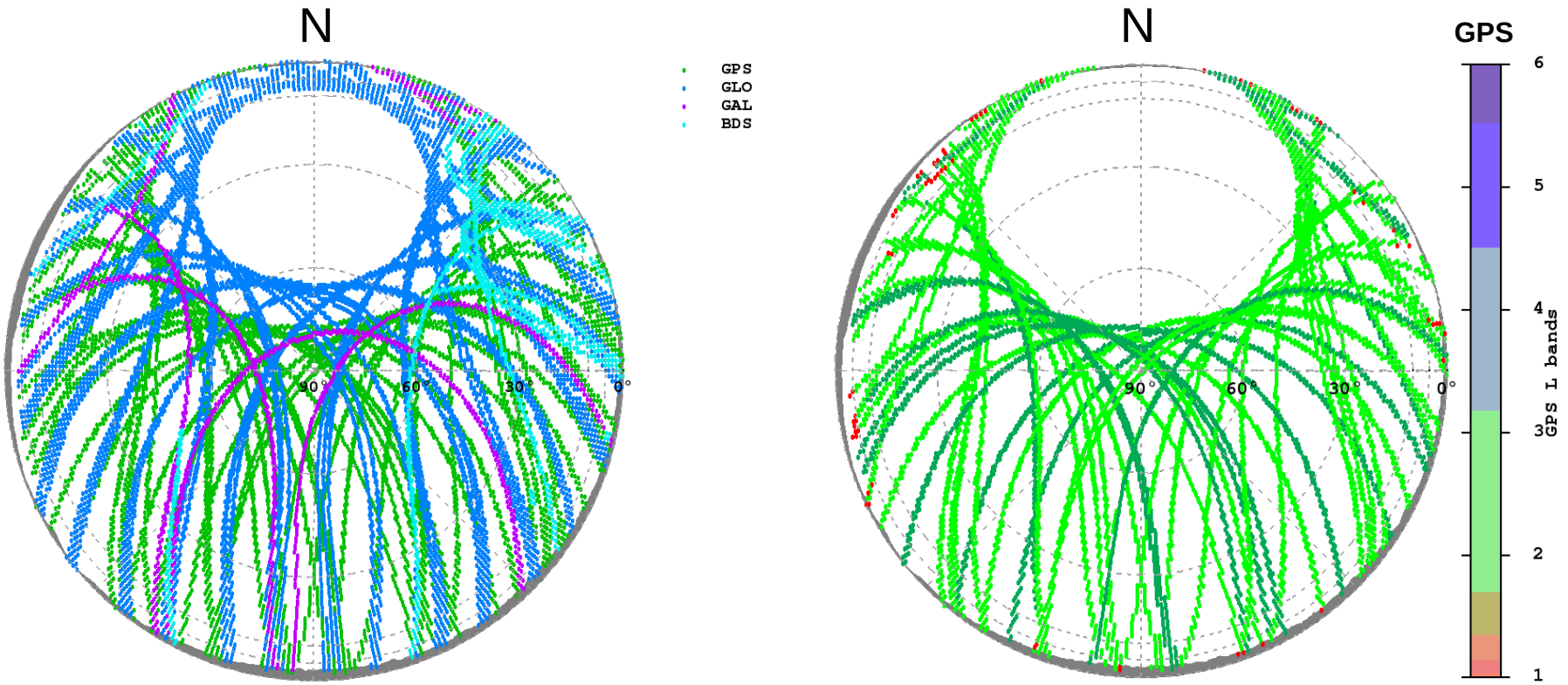
Observation file monitoring
Daily RINEX-3 monitor (DoY 15/284)



NAME	RECEIVER		ANTENNA		Vers	▾Int	nEpo	G	R	E	C	PDF
MATG 12734M010	LEICA GRX1200+GNSS	8.71/6.112	LEIAR25	NONE	3.01	30	2852	31	24	10	0	matg_r3.pdf
MELI 19379M001	LEICA GR10	3.03/6.214	LEIAR25.R4	LEIT	3.01	30	2880	32	24	0	0	meli_r3.pdf
AIGE	TRIMBLE NETR9	5.03	TRM59800.00	NONE	3.02	30	2880	31	24	8	9	aige_r3.pdf
AJAC 10077M005	LEICA GR25	3.11	TRM57971.00	NONE	3.02	30	2880	31	24	8	10	ajac_r3.pdf
ARD2	TRIMBLE NETR9	5.03	TRM59800.00	NONE	3.02	30	2880	31	24	8	9	ard2_r3.pdf
ARDE	TRIMBLE NETR9	5.03	TRM33429.20+GP	NONE	3.02	30	2880	31	0	0	0	arde_r3.pdf
AUTN 10080M001	LEICA GR25	3.11	TRM57971.00	NONE	3.02	30	2880	31	24	8	9	autn_r3.pdf
AXPV 10057M001	TRIMBLE NETR9	4.85	TRM57971.00	NONE	3.02	30	2880	31	24	10	10	axpv_r3.pdf

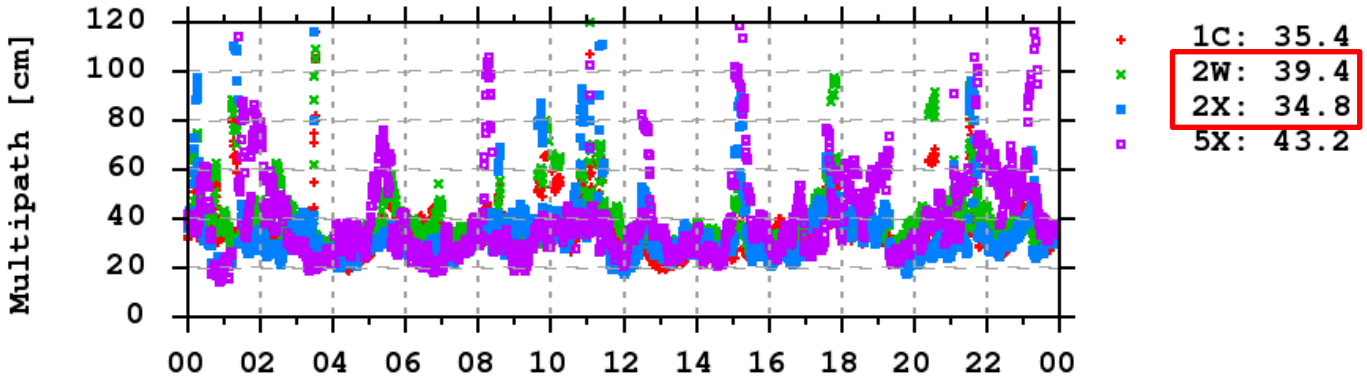
Observation file monitoring
Visibility and number of frequencies

- ZIM2 (Zimmerwald), DoY 15/284

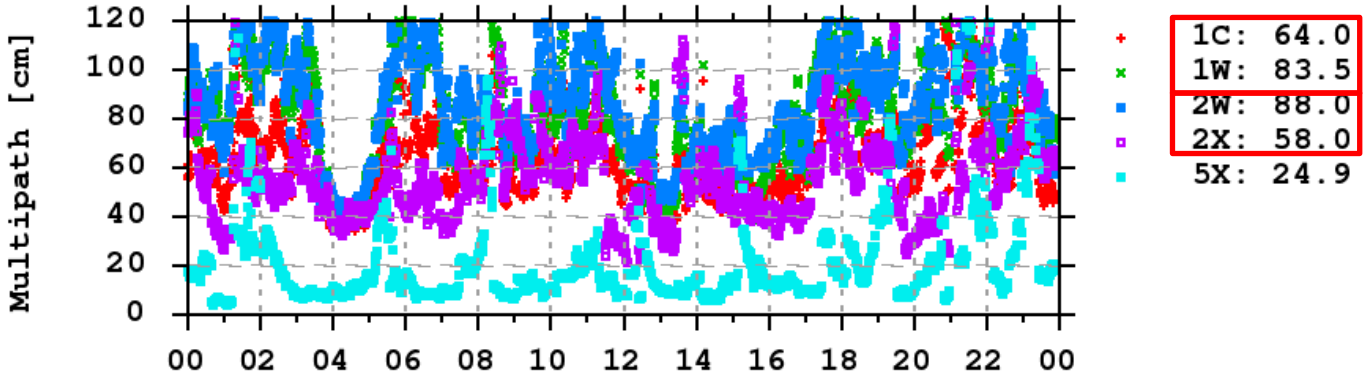


Observation file monitoring
GPS code multipath (DoY 15/284)

- ZIM2: TRIMBLE NETR 9 5.03



- ZIMJ: JAVAD TRE_G3TH DELTA 3.49



Product evaluation with PPP Overview

- Current development version of the Bernese GNSS Software from the Astronomical Institute of the University of Bern

- RINEX-2 and RINEX-3 tracking data
- Priority list for the different RINEX-3 observation codes

- Precise satellite orbits and clocks as well as Earth rotation parameters from CODE and GFZ
- Ionosphere and DCB information from CODE

- Precise Point Positioning (PPP)
  - Very sensitive w.r.t. the input products
  - Estimates: Daily and pseudo-kinematic coordinates, hourly troposphere parameters, DCBs, and station clocks

Product evaluation with PPP Bernese GNSS Software 5.3

- Source code may change without notification
- Orbit fit with analytical Earth radiation pressure and navigation antenna thrust as well as with the new empirical CODE model
- The new satellite systems and signals to be considered in the analysis have to be included in some general files
  - Satellite information (mass, radiation pressure, sensor offsets): SATELLIT.I08 + Galileo, BeiDou, and QZSS
  - Antenna phase center offsets and variations: PCV_LPT.I08 + igs08.atx w/o IRNSS
  - Observation type selection: OBS.SEL + Galileo, BeiDou, and QZSS observation codes

Product evaluation with PPP Bernese GNSS Software 5.3

- Observation code priority list for the assignment on two frequencies

```
Receiver type          S/S  O/F  RINEX observation codes and their priority
********************** ***  ***  *** *** *** *** *** *** *** *** *** ***

DEFAULT                G    L1   L1P L1C L1W L1X
                       G    L2   L2P L2C L2D L2S L2W L2X
                       R    L1   L1P L1C L1X
                       R    L2   L2P L2C L2X
                       E    L1   L1C L1X
                       E    L2   L5Q L5X
                       C    L1   L1I L1X
                       C    L2   L7I L7X
                       G    C1   C1P C1C C1W C1X
                       G    C2   C2P C2C C2D C2S C2W C2X
                      ...
```

G: GPS, R: GLONASS, E: Galileo, C: BeiDou
L.: Phase, C.: Code

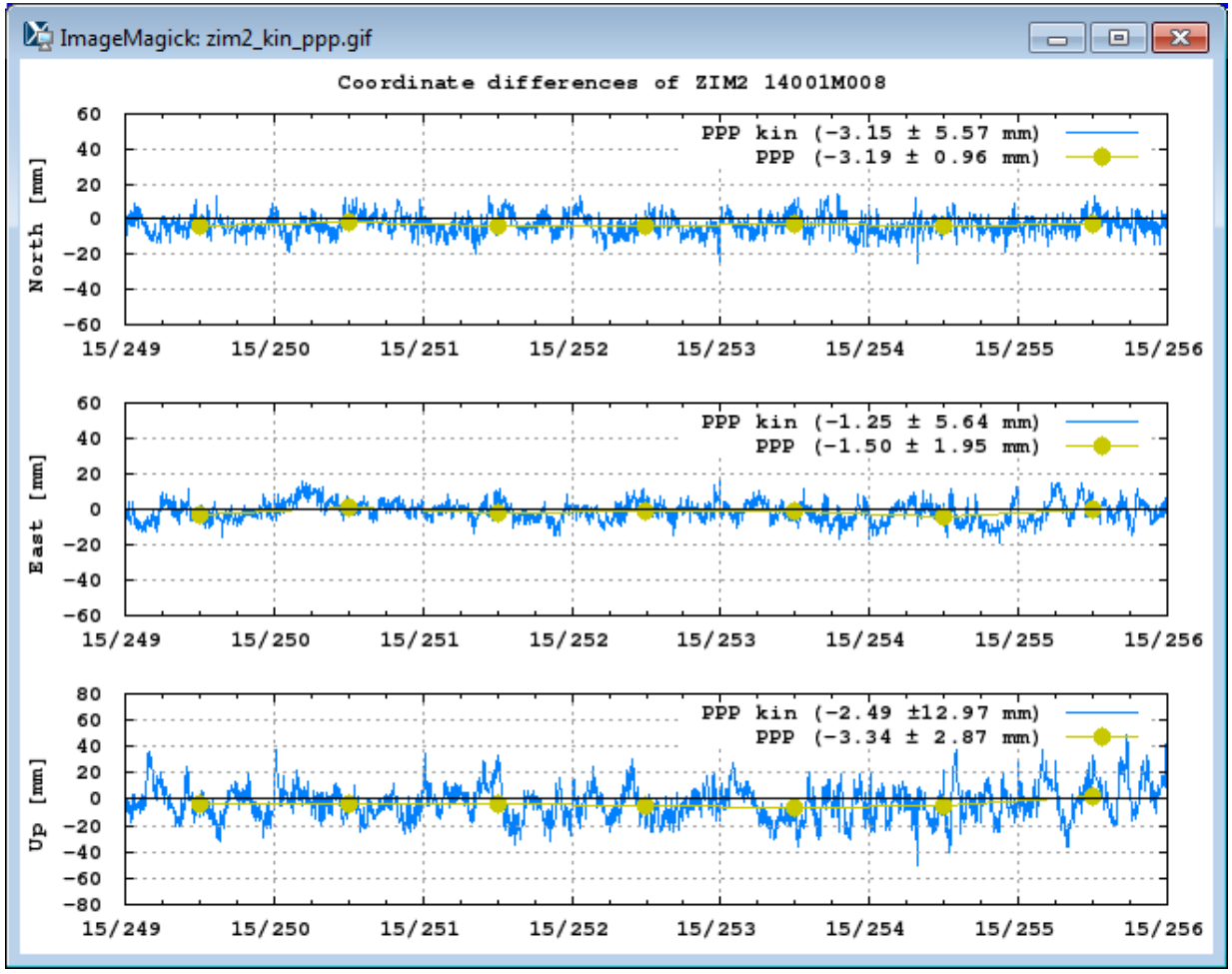
Product evaluation with PPP
Pseudo-kinematic coordinates

- Coordinate repeatability of station ZIM2, GPS week 1861
- Offsets w.r.t. to BSW 5.2 multi-day GPS/GLO network solution

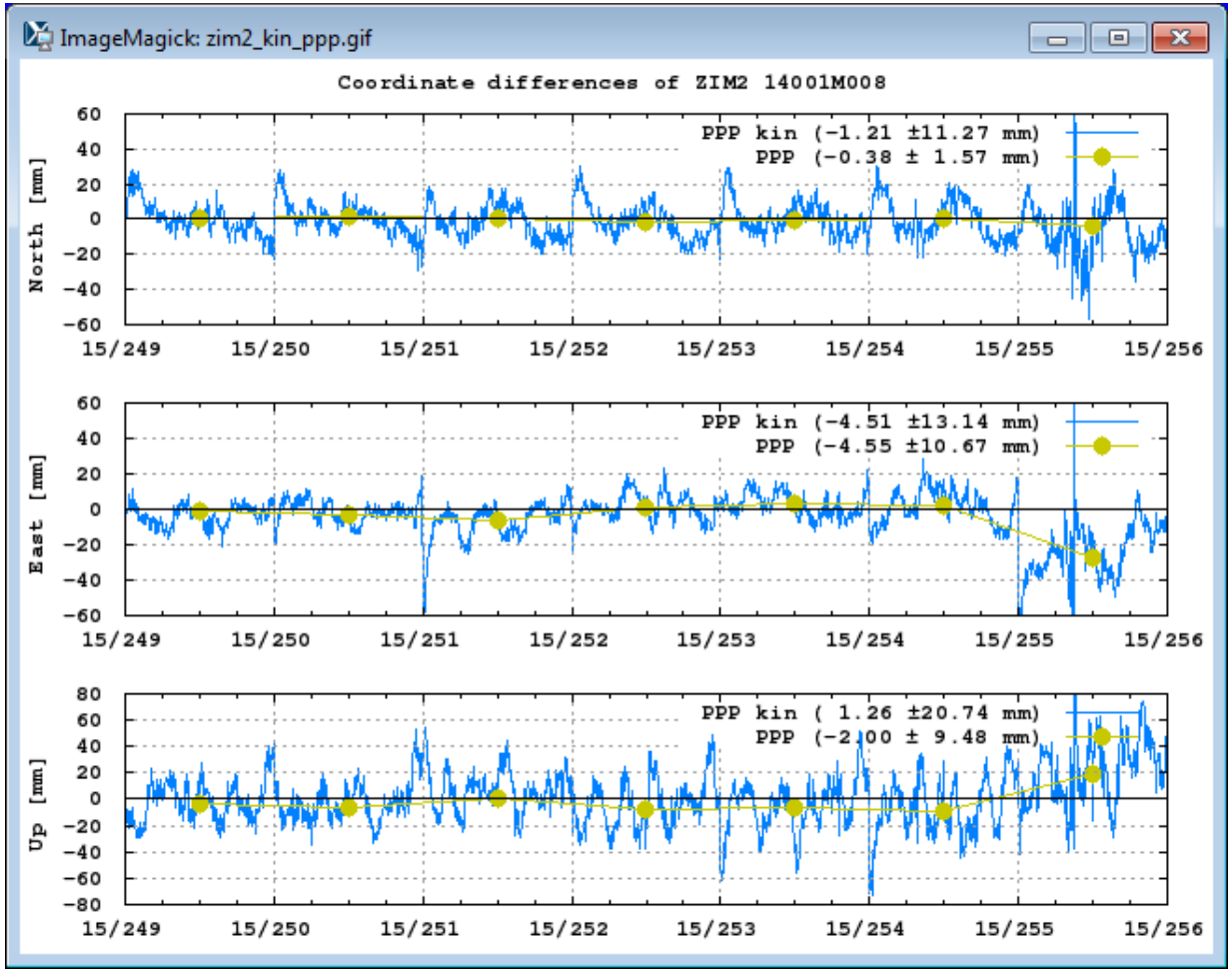
No	BSW	R	Prod	Sys	North [mm]	East [mm]	Up [mm]
1	5.2	2	COD	G	-3.4+-13.0	1.2+- 9.5	-0.3+-25.4
2	5.3	2	COD	G	-4.1+- 9.1	2.6+- 8.7	-2.4+-15.9
3	5.3	3	COD	G	-4.1+- 9.1	2.6+- 8.7	-2.4+-15.9
4	5.3	3	COM	G	-3.9+- 9.5	1.0+-10.3	3.1+-17.3
5	5.3	3	COM	GE	-3.4+- 9.2	-1.1+- 9.3	2.1+-16.7
6	5.3	3	COM	GC	-3.6+- 8.0	0.5+- 8.3	3.0+-15.2
7	5.3	3	COM	GR	-3.2+- 5.6	-0.7+- 5.7	-3.0+-13.1
8	5.3	3	COM	GRE	-3.2+- 5.6	-1.3+- 5.6	-2.5+-13.0
9	5.3	3	COM	GREC	-3.2+- 5.6	-1.3+- 5.6	-2.5+-13.0
10	5.3	3	GBM	GREC	-1.2+-11.3	-4.5+-13.1	1.3+-20.7

COD: CODE final, **COM**: CODE MGEX, **GBM**: GFZ MGEX

Product evaluation with PPP Pseudo-kinematic coordinates (No 9)



Product evaluation with PPP Pseudo-kinematic coordinates (No 10)



Network solutions Overview

- 32 RINEX-3 stations of the LPT network for the EUREF contribution

- Receiver types:
  - JAVAD TRE_G3TH DELTA
  - LEICA GR10
  - LEICA GR25
  - LEICA GRX1200+GNSS
  - SEPT POLARX4
  - SEPT POLARX4TR
  - TRIMBLE NETR9

- Standard double-difference processing for regional networks for static, dual-frequency stations with an advanced ambiguity resolution (AR) scheme including code-based AR for GPS

Network solutions
Weekly combination

- Weekly combination of daily solutions, GPS week 1861
- Minimum constraint no-net-translation condition w.r.t. IGb08

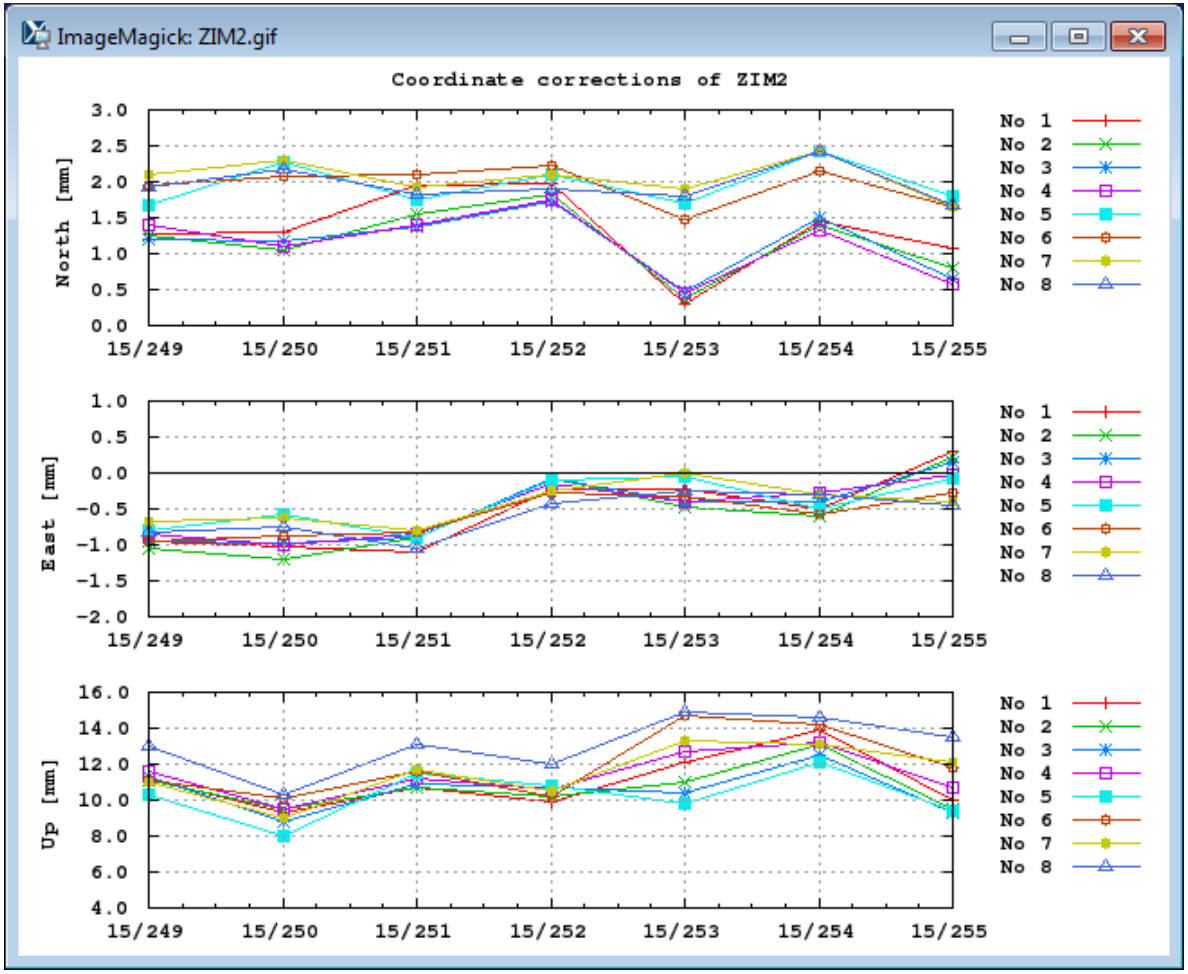
No	Prod	Sys	# obs	Param	aPost σ	χ^2/DOF	N	E	U
1	GBM	GREC	1866834	21130	1.34 mm	1.80	0.6	0.5	1.6
2	COM	GREC	1976398	21347	1.33 mm	1.78	0.5	0.5	1.3
3	COM	GRE	1858274	20724	1.33 mm	1.77	0.5	0.5	1.2
4	COM	GR	1720192	19626	1.33 mm	1.76	0.5	0.4	1.3
5	COM	GE	1049049	13097	1.29 mm	1.67	0.3	0.4	1.4
6	COM	GC	1029051	12609	1.29 mm	1.67	0.3	0.3	1.8
7	COM	G	910815	11987	1.28 mm	1.63	0.3	0.3	1.5
8	COM	G*	912380	11906	1.28 mm	1.63	0.3	0.3	1.6

Param: Daily coordinates, hourly troposphere, ambiguities

N,E,U: Coordinate repeatability in mm of ZIM2 in North, East, and Up

G*: 2X, 2W, 2S instead of 2S, 2W, 2X priority for GPS

Network solutions
Daily coordinate corrections



Summary

- Multi-GNSS analysis is beneficial but also challenging
- A fully automated monitoring of daily RINEX-2 and RINEX-3 observation files has been established at swisstopo
- The Bernese GNSS Software is capable to process RINEX-3 data (conversion to RINEX-2 with RNXSMT and OBS.SEL)
- Using the products from IGS MGEX Multi-GNSS analysis including Galileo and/or BeiDou is possible
- PPP results benefit greatly by adding more satellites and systems, however, the quality of the input product is crucial
- The influence of the new satellite constellations on the network solution is not (yet) as evident, modelling deficiencies and the observation type selection are of greater importance

Outlook

- More advanced alarming from the observation file monitoring and consideration of the hourly RINEX data flow
- Set-up and long-term analysis of GNSS-specific translation parameters for coordinates and troposphere: constant, periodic, or random noise?
- Inclusion and handling of Multi-GNSS biases

- Questions/Discussion:
  - Recommendation concerning satellite systems and RINEX-3 observation type selection for a future EUREF submission?
  - Test campaign to compare the Multi-GNSS solutions from different Analysis Centers (software, systems, models, strategies)?

Acknowledgments

- Jan Dousa and Pavel Vaclavovic from the Geodetic Observatory Pecný developing and maintaining the G-Nut/Anubis application for RINEX quality monitoring
  http://www.pecny.cz/Joomla25/index.php/gnss/sw/anubis

- The BNC development team
  http://software.rtcm-ntrip.org/wiki/BNC

- The Bernese GNSS Software development team at the Astronomical Institute of the University of Bern
  http://www.bernese.unibe.ch