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XXVI FIG CONGRESS

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Single base RTK solutions obtained individually with Galileo and BeiDou as well as in combination with other fully operational GNSS

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Outline:

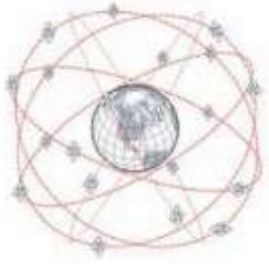
- Introduction
- Current status of the GNSSes
- Real Time Kinematic (RTK)
- Geodetic Network Establishment (CROPOS)
- RTK measurements
  - GNSS receivers & equipment
  - Mission planning
  - Accuracy & Precision estimation
- Conclusions

Introduction:

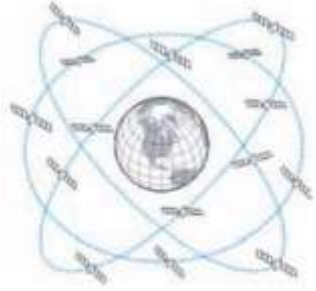
- Real Time Kinematic: Single-base & Networked
- GPS & GLONASS: Fully Operational GNSSes
- Galileo & Beidou: still under construction
- In 2006 some leading manufacturers (Leica, Topcon, Trimble) started a production of receivers with a capability of tracking Galileo (GIOVE) satellites
- Today, almost all recently produced GNSS receivers support a tracking of Galileo (GAL) and BeiDou (BEI) satellites
- A possibility and feasibility of GAL and BEI systems for single-base RTK positioning has been tested (assessed) and presented

Current status of GNSSes:

- GPS (first launch in 1978; FOC in 1995)
  - 31 satellites (12 Block IIR, 7 Block IIR-M, 12 Block F)
  - CDMA (L1, L2, L5); next generation Block III (L1C)
- GLONASS (first launch in 1982; FOC in 1996, again in 2011)
  - 23 satellites (GLONASS-M, GLONASS-K)
  - FDMA (CDMA on GLONASS-K)



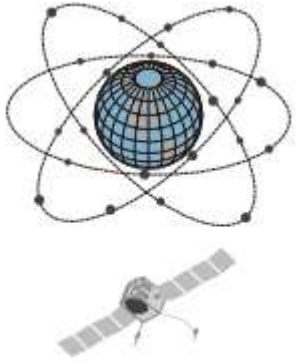
GPS
– 6 Orbital Planes
– 24 Satellites + Spare
– 55° Inclination Angle
– Altitude 20,200 km



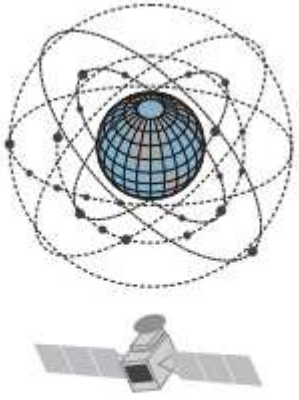
GLONASS
– 3 Orbital Planes
– 21 Satellites + 3 Spares
– 64.8° Inclination Angle
– Altitude 19,100 km

Current status of GNSSes:

- GALILEO (first launch in 2005; 2008 (GIOVE A&B);
  - FOC started in 2014 expected to be completed by 2020)
  - 22 satellites (14 usable, 2 testing, 4 under commissioning, 2 not usable/available)
- BeiDou
  - 28 satellites (15 included in operational constellation (Beidou-2); 13 not included in operational constellation (BeiDou-3)
  - FOC by 2020 (5 GEO, 3 IGSO, 27 MEO)



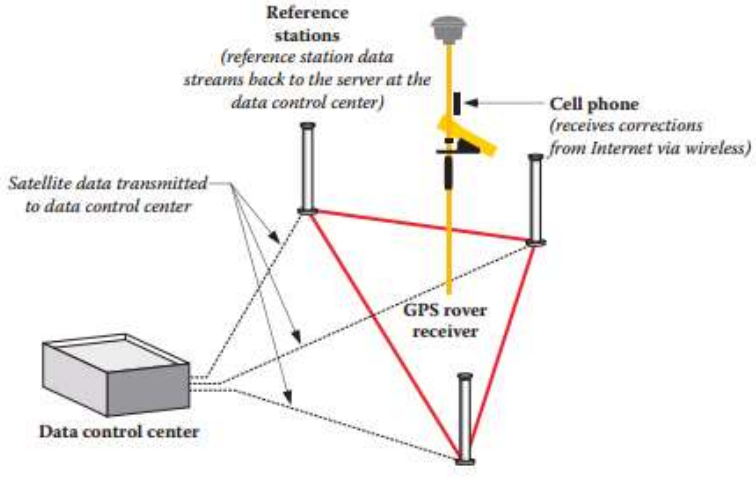
Galileo
3 Orbital planes
27 Satellites + 3 spares
56° Inclination angle
Altitude 23,222 km



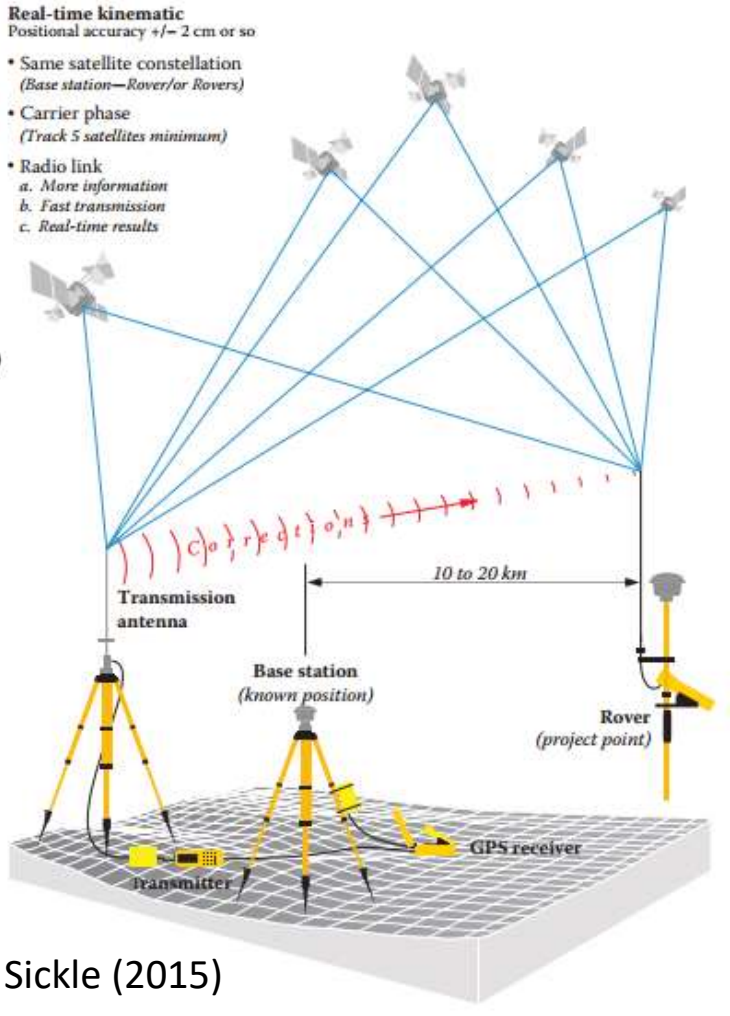
BeiDou
6 Orbital planes
35 Satellites + 5 GEO + 27 MEO + 3 IGSO
55° Inclination angle
Altitude 38,300 km, 21,500 km

Real Time Kinematic (RTK):

- Single base RTK (10-20 km for rapid and reliable ambiguity resolution)
  - TTFA depends on a distance-dependent biases (iono, tropo, orbit)
- Network RTK (distance-dependent biases are modelled)
  - CROPOS



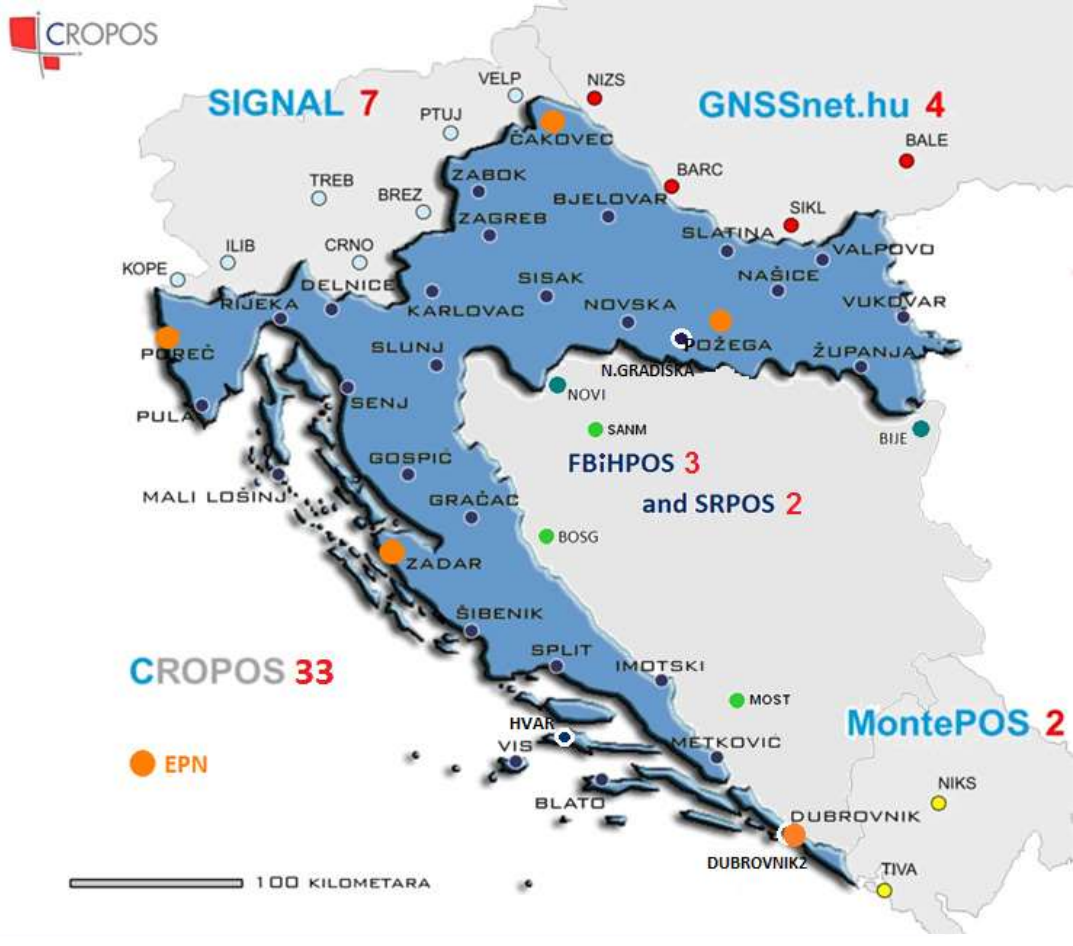
Van Sickle (2015)



Van Sickle (2015)

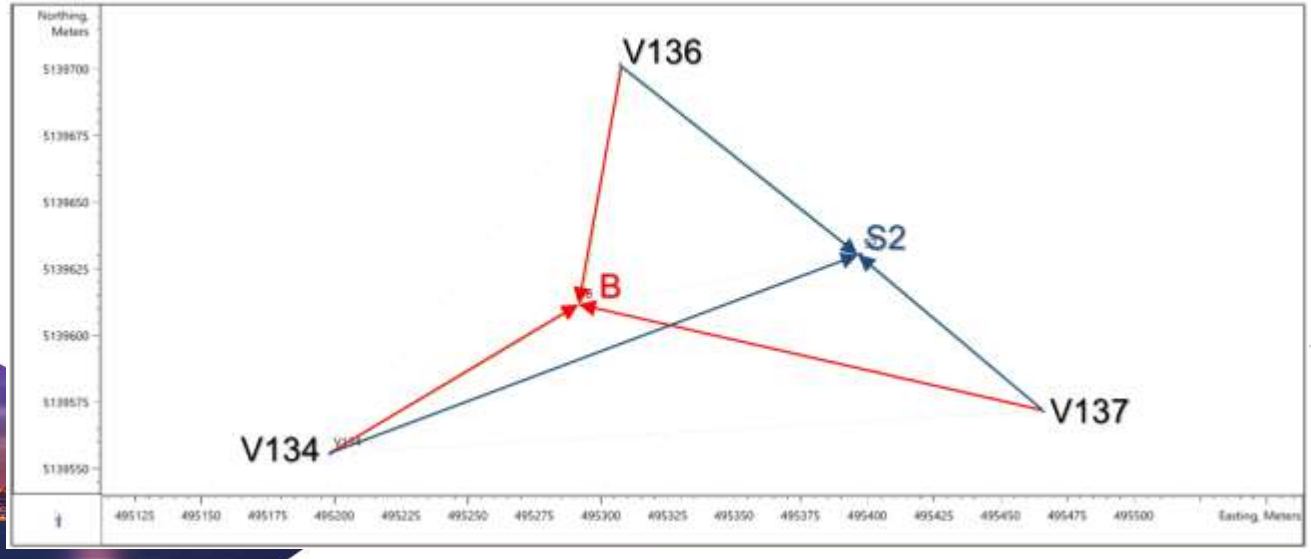
CROatian Position System (CROPOS):

- 33 national GNSS stations + 18 GNSS station from neighbouring networks
- ~ 70 km
- established in 12/2008
- DPS, Highly Precise Positiong Service (HPPS); Geodetic Precise Positiong Sservice (GPPS)
- VRS concept implementing Trimble's solution
- Currenty CROPOS supports GPS and GLONASS observations
- GPPS was used for geodetic network establishment



Geodetic Network and Static GNSS observations:

- 6 stations (S1, P1, P2, P3, **S2**, **B**)
- Static observations at S2 and B for 44 min
- CROPOS GPPS (Rinex 3.02): 3 VRS
- *Topcon Magnet Office Tools*
- *(E, N, h)*
- $\sigma(E) = 3$ mm; $\sigma(N) = 3$ mm; $\sigma(h) = 6$ mm



- Topcon Hiper SR (station S2) & Hiper HR (station B)

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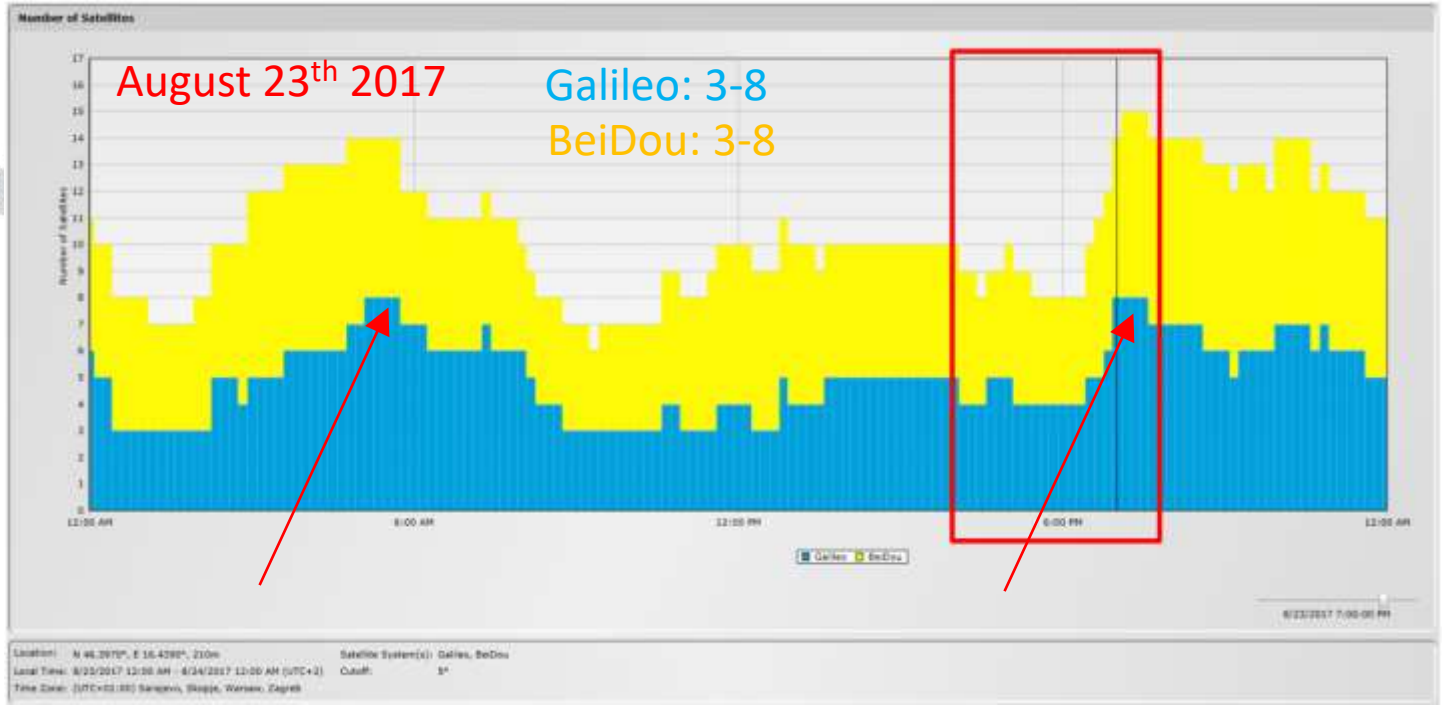
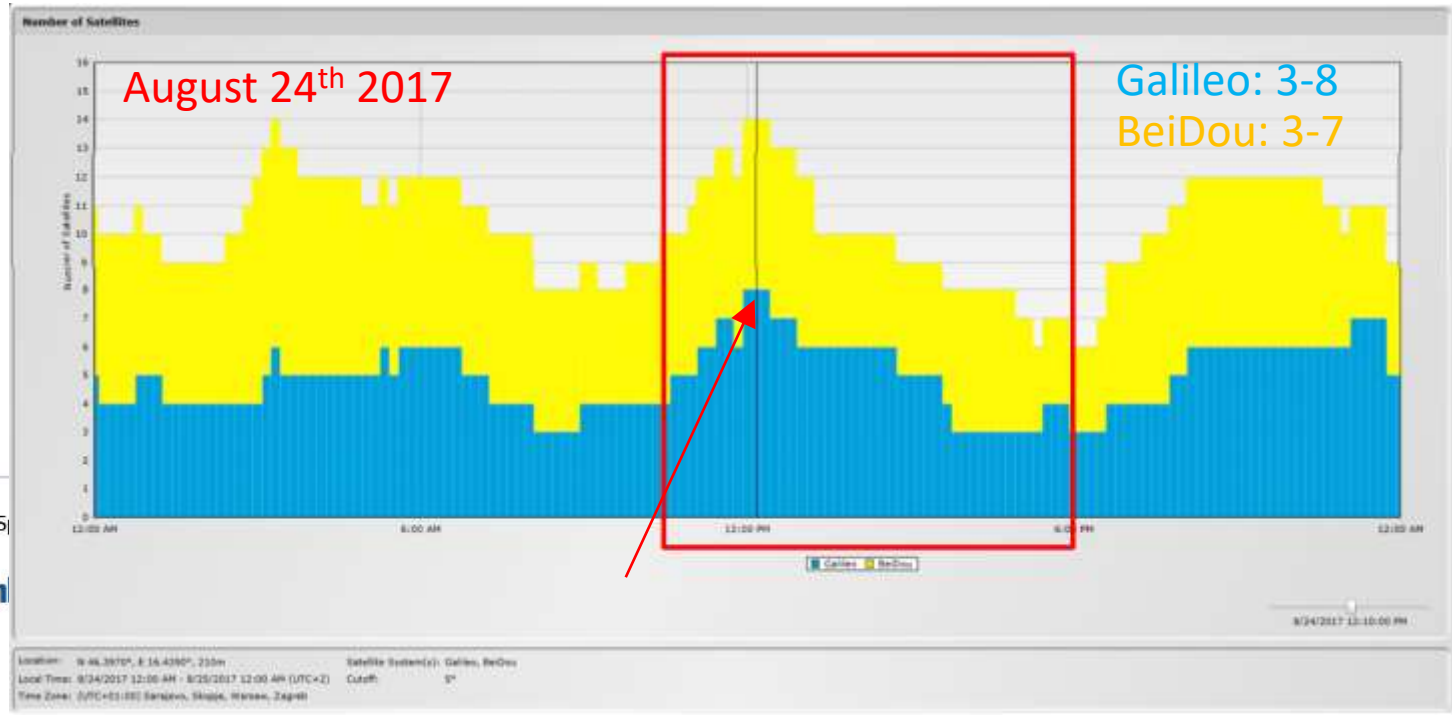
RTK measurements:

- GNSS receivers (base & rover) with a capability of tracking and positioning using GALILEO and BeiDou satellites
- Tracking vs. Positioning
- 2x Topcon Hiper HR (452 channels)
- FC-5000 controller with installed TRU
- Topcon Receiver Utility (TRU)
- Single-base RTK
- Topcon's *LongLink*

GNSS planning

- *GNSS Planning Online tool* http://www.trimble.com/GNSSPlanningOnline
- 2x Topcon Hiper HR receiver were available for two consecutive days: August 23th and 24th 2017.
- Planning has involved Galileo and BeiDou satellites only
- GPS (visible 8-12 SV)
- GLONASS (visible 6-10 SV)





RTK positioning:

- August 23th and 24th 2017
- Static observations → accuracy assessment
- Two consecutive days → precision assessment
- Base GNSS receiver set up on tripod
- Rover GNSS receiver on the range pole
- Base receiver started by TRU running on FC-5000 controller (set to track all visible and available satellites);
  RTCM 3.02 via LongLing Bluetooth connection

13 different satellite system combinations:

1. GPS+GLO+GAL+BEI (GGGB)
2. GPS+GLO+GAL (GPS.GLO.GAL)
3. GPS+GLO+BEI (GPS.GLO.BEI)
4. GPS+GAL+BEI (GPS.GAL.BEI)
5. GLO+GAL+BEI (GLO.GAL.BEI)
6. GPS+GLO (GPS.GLO)
7. GPS+BEI (GPS.BEI)
8. GPS+GAL (GPS.GAL)
9. GLO+BEI (GLO.BEI)
10. GLO+GAL (GLO.GAL)
11. GAL+BEI (GAL.BEI)
12. GAL only (GAL)
13. BEI only (BEI)

- Depending on the selected GNSS constellation combination, on the rover receiver with the TRU SW the chosen satellite systems were turned on or off an the observation taken

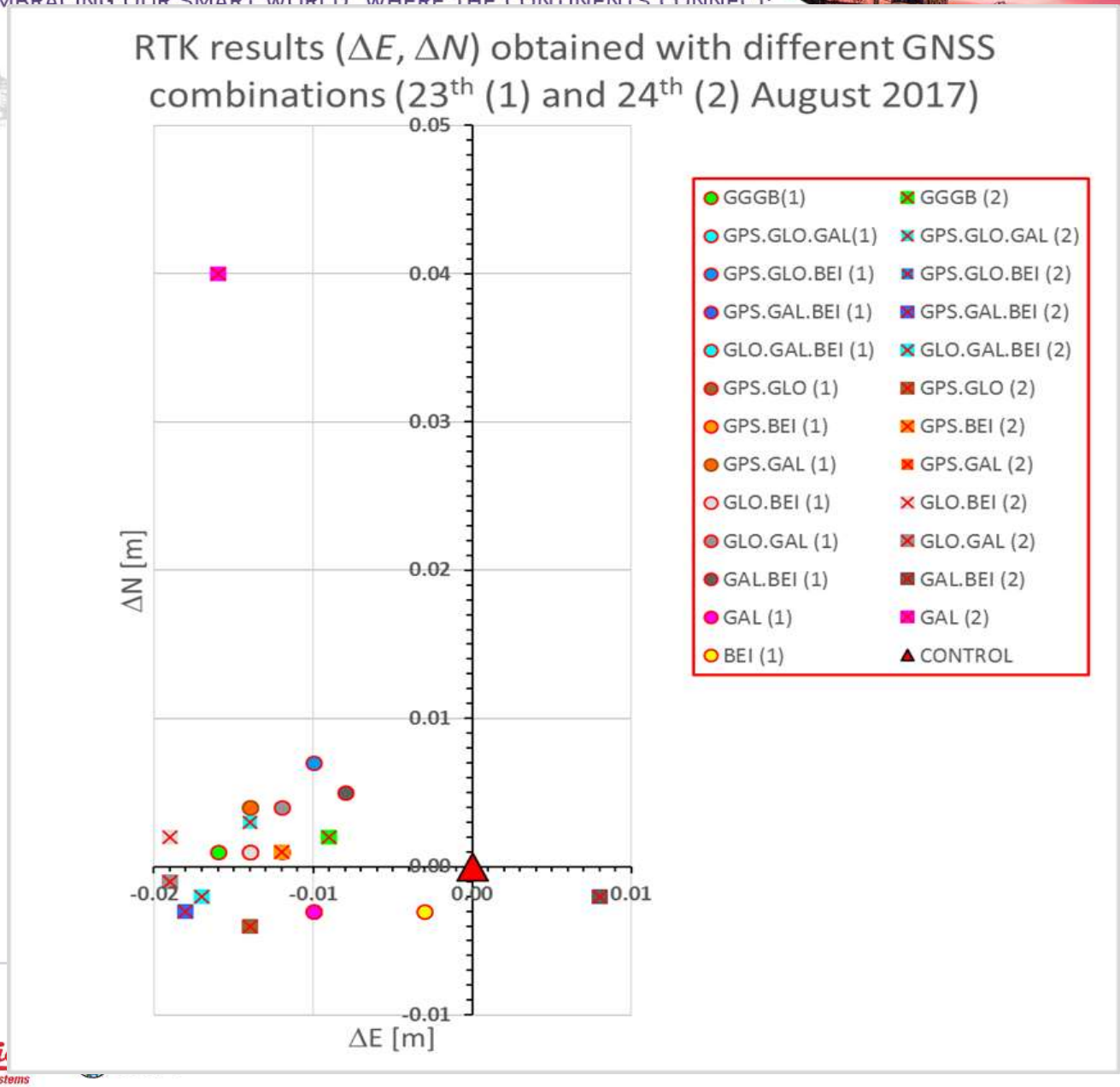
- Photos of the FC-5000 display showing RTK positiong results were captured simulating the recording of three consecutive epochs

RTK measurement results:

- The photos were systematically named and stored, taking care about GNSS constellation combination
- Ellipsoidal coordinates along with the PDOP, HRMS, VRMS were typed in Excell spreadsheet
- The most vulnerable step → special attention was paid including multiple checks
- (φ, λ, h) → Magnet Office Tools → (E, N, h)
- Accuracy and Precision estimation enabled

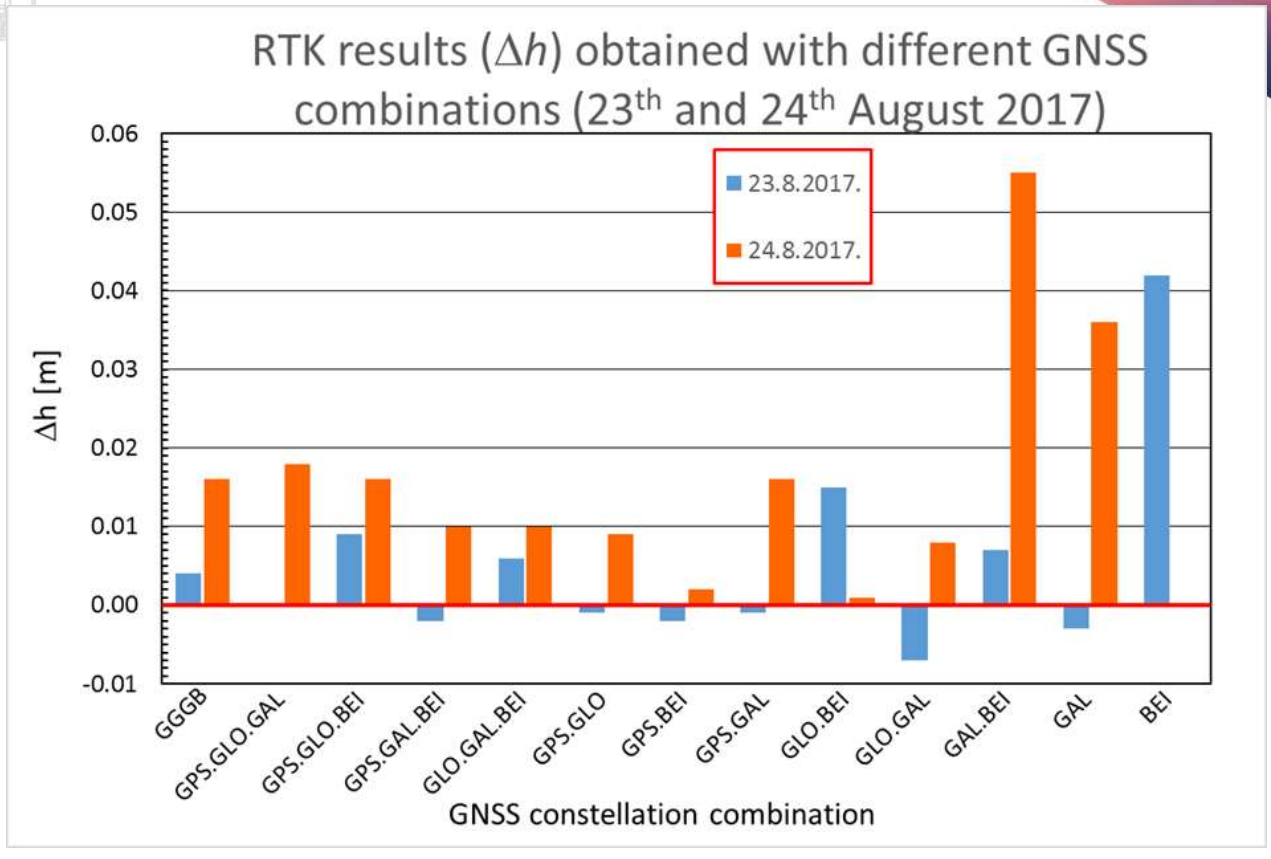
RTK accuracy estimation (2D):

- Static observations (B, S2)
- Δ = Measured – Reference
- August 23th 2017 (all combination provided a FIXED solution)
  (2D): 4 to 16 mm (AVE 13 mm)
- August 24th 2017 (BEI only combination with Autonomuous solution)
  (2D): 8 to 43 mm (AVE 17 mm)



RTK accuracy estimation (h):

- Static observations (B, S2)
- Δ = Measured – Reference
- August 23th 2017 (all combination provided a FIXED solution)
  (h): -7 mm to 42 mm (RMS 13 mm)
- August 24th 2017 (BEI only combination with Autonomuous solution)
  (h): 1 mm to 55 mm (RMS 22 mm)



RTK precision estimation (23th vs 24th August):

- Each GNSS constellation combination results are compared among two consecutive days of observation
- 2D: 0 to 43 mm (RMS 14 mm)
  largest differences obtained from GAL only (43 mm) and GAL.BEI combination (17 mm)
- Δh: -14 mm to +48 mm (RMS: 21 mm)
  largest differences obtained from GAL.BEI (48 mm) and GAL only (39 mm)
- CONCLUSION: combinations including at least on fully operational GNSS (GPS or GLONASS) can provide consecutive results within 2 cm

CONCLUSIONS:

- Single base RTK results obtained with 13 GNSS constellation combinations
- Individual and joint combinations consisting of observation data of systems under construction (Galileo and BeiDou)
- Exclusion of GPS observations from RTK solution (enabling individual solutions) has been carried out by TRU SW running on field controller
- Planning tool has pointed out optimal time windows allowing individual (GAL, BEI) solutions
- For reliable RTK positioning results (2 cm (2D) & (h)) the usage of at least one fully operationational GNSS is needed
- Results obtained with few constellations (3 or 4) haven’t shown a significant improvement in terms of accuracy and precision.

REMARK:

- This paper has been compiled from the students' publication rewarded with the Dean's Awards of the Faculty of Geodesy for the academic year 2016/2017.

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