„Optimal Sampling Rate and Session Duration for Centimeter-Level Rapid-Static Positioning within EUPOS Network”

P. Wielgosz[1], L.W. Baran[1], D.A, Grejner-Brzezinska[2], I. Kashani[2]

1 - University of Warmia and Mazury in Olsztyn, Poland
2 – The Ohio State University, USA

8th Bilateral Geodetic Meeting Poland-Italy
Wrocław, 22-24 June 2006

Research Objectives

- **Develop and evaluate state-of-the-art *methodology* and *algorithms* for rapid-static technique suitable for ASG/*EUPOS network***
- Study the observational *session duration* required for cm-level accuracy
- Study the optimal data *sampling rate*
- Investigate the required accuracy of the *ionospheric corrections*
- Evaluate *ambiguity resolution* success rate, speed and reliability
- Evaluate the *rover position* quality

ASG/EUPOS network

- I trust all important details concerning ASG/EUPOS network were presented by my distinguish predecessor, professor Janusz Śledziński, in the first session
- Summarizing:
  - ~15 Central and East European countries involved
  - ~**86 stations** to be established in **Poland** by the end of 2007
  - **average distance** between the reference stations **~70 km**
  - it means the **user** receiver may be located **no further** than **~40 km** from the nearest station

Methodology - Functional Model (DD)

$$\lambda_1 \Phi_{1,ij}^{kl} - \rho_{ij}^{kl} - (\alpha_i^k T_i - \alpha_i^l T_i - \alpha_j^k T_j + \alpha_j^l T_j) + I_{ij}^{kl} - \lambda_1 N_{1,ij}^{kl} = 0$$

$$\lambda_2 \Phi_{2,ij}^{kl} - \rho_{ij}^{kl} - (\alpha_i^k T_i - \alpha_i^l T_i - \alpha_j^k T_j + \alpha_j^l T_j) + I_{ij}^{kl} (\upsilon_1^2 / \upsilon_2^2) - \lambda_2 N_{2,ij}^{kl} = 0$$

$$P_{1,ij}^{kl} - \rho_{ij}^{kl} - (\alpha_i^k T_i - \alpha_i^l T_i - \alpha_j^k T_j + \alpha_j^l T_j) - I_{ij}^{kl} = 0$$

$$P_{2,ij}^{kl} - \rho_{ij}^{kl} - (\alpha_i^k T_i - \alpha_i^l T_i - \alpha_j^k T_j + \alpha_j^l T_j) - I_{ij}^{kl} (\upsilon_1^2 / \upsilon_2^2) = 0$$

k, l - satellite indexes

i, j - station indexes

$\Phi_{n,ij}^{kl}$, $P_{n,ij}^{kl}$ - DD phase and code observation on frequency n

ρ_{ij}^{kl} - DD geometric distance

$T_{i,j}$ - tropospheric total zenith delay (TZD)

α_i^k - troposphere mapping function

I_{ij}^{kl} - DD ionospheric delay

υ_1, υ_2 - GPS frequencies on L1 and L2

λ_1, λ_2 - GPS frequency wavelengths on L1 and L2

$N_{1,ij}^{kl}$, $N_{2,ij}^{kl}$ - carrier phase ambiguities

Methodology - Adjustment Model

Sequential Generalized Least Squares (GLS)

- All parameters in the mathematical model are considered *pseudo-observations* with a priori information ($\sigma = 0 \div \infty$)

$$F(L_F^b, L_X^b) = 0 \qquad B_F V_F + B_X V_X + W_F = 0$$

- Two characteristic groups of interest:

  L_F^b - *instantaneous* parameters (e.g., ionospheric delays)

  L_X^b - *accumulated* parameters (e.g., ambiguities)

- *Flexibility*, easy implementation of:
  - ✓ stochastic constraints
  - ✓ fixed constraints
  - ✓ weighted parameters

Methodology - Network Solution

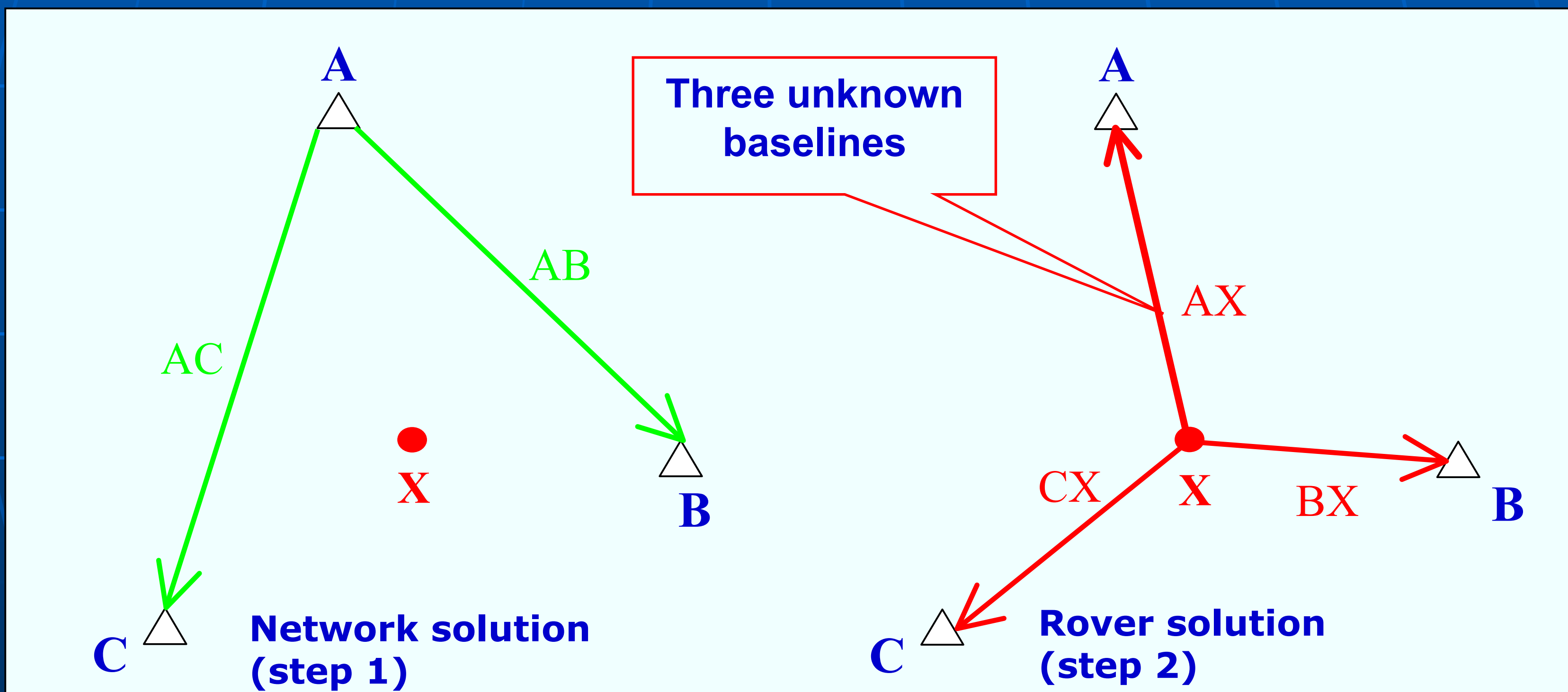
- **Network correction generation**
  - Precisely *known reference station* coordinates
  - Double-difference (DD) *ionospheric* delay estimation and *decomposition* to zero-difference (ZD)
  - *Tropospheric* total zenith delay (TZD) estimation
- **Ambiguity resolution (AR)**
  - Least square AMBiguity Decorrelation Algorithm (*LAMBDA*)
- **Validation**
  - *W-test:* minimum of 3 observational epochs (for 30-second sampling rate) and W-test > 4 required for validation
- **Unknowns**
  - DD *Ionospheric* delays, *Tropospheric* TZD per station, DD *ambiguities*

The network corrections are interpolated to the rover location

Methodology - Rover Solution

- **Rover solution**
  - Multi-baseline (network) solution
  - Utilizes information from the reference network solution – ionospheric and tropospheric delays
    - Atmospheric delays are interpolated to the user location
  - 1-2 iterations
  - 2nd iteration is applied when needed, using the float estimates and their associated stochastic characteristics from the 1st iteration as a priori information
- **Unknowns**
  - User coordinates and ambiguities
  - The DD ionospheric delays and TZD are constrained in the GLS adjustment (20 cm and 1-2 cm respectively)

Methodology - 2 step solution



Previous experiments

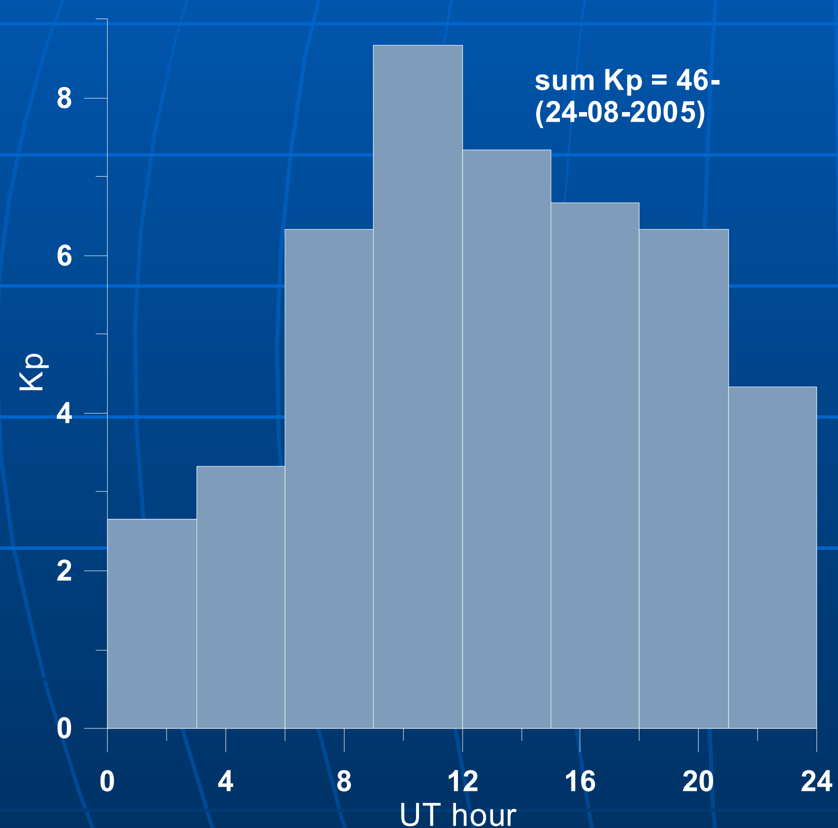
- Previous analyses showed that it is possible to obtain a centimeter-level horizontal position (±2 cm) from 20-minute long observational sessions over 60 km baselines when using the proposed methodology
- Application of commercial software provided decimeter-level position (±15 cm) in the same conditions

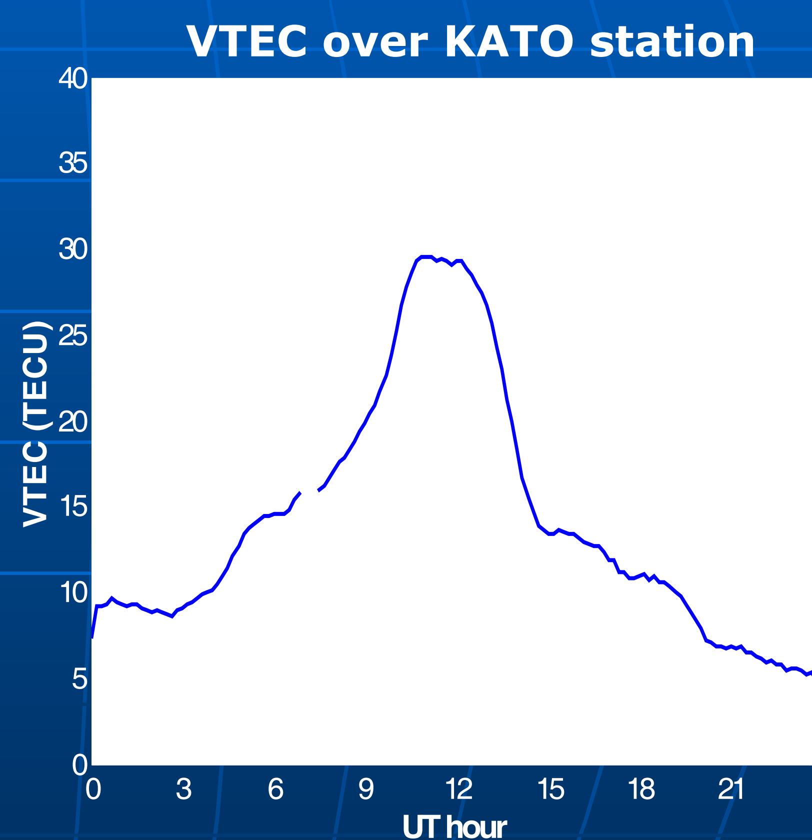
Experiment (I)

Map: www.asg-pl.pl

- GPS data from ASG-PL and EPN networks
- 24-hour data set collected on August 24,2005 with 5-second sampling rate
- KATO station selected as a simulated user receiver (rover)
- KATO data divided into 144 sessions, 10 minutes long each
- Each of 144 sessions was processed independently and resulting coordinates quality and repeatability were analyzed
- ” True” reference coordinates were derived using Bernese

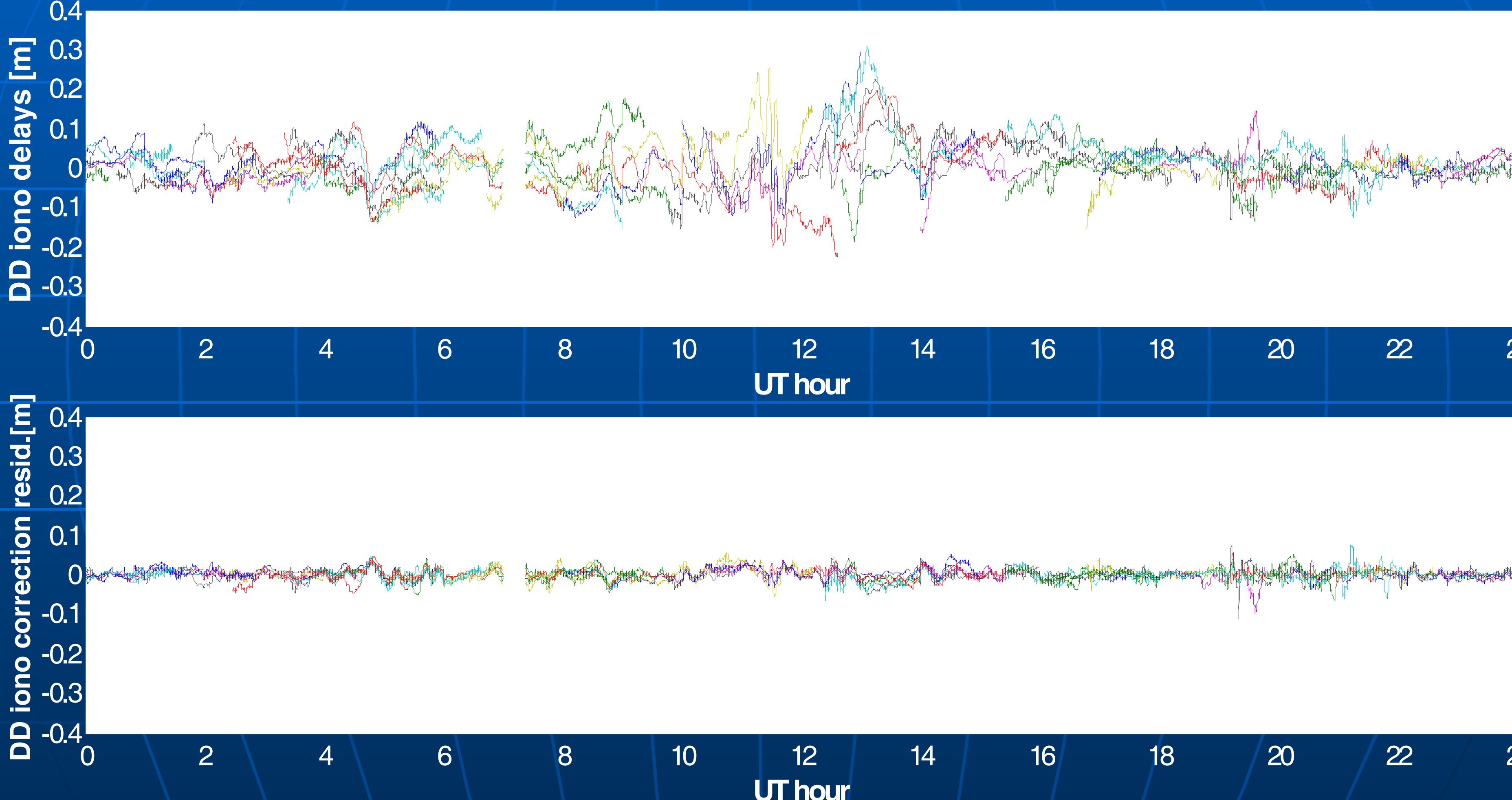
Experiment (II)





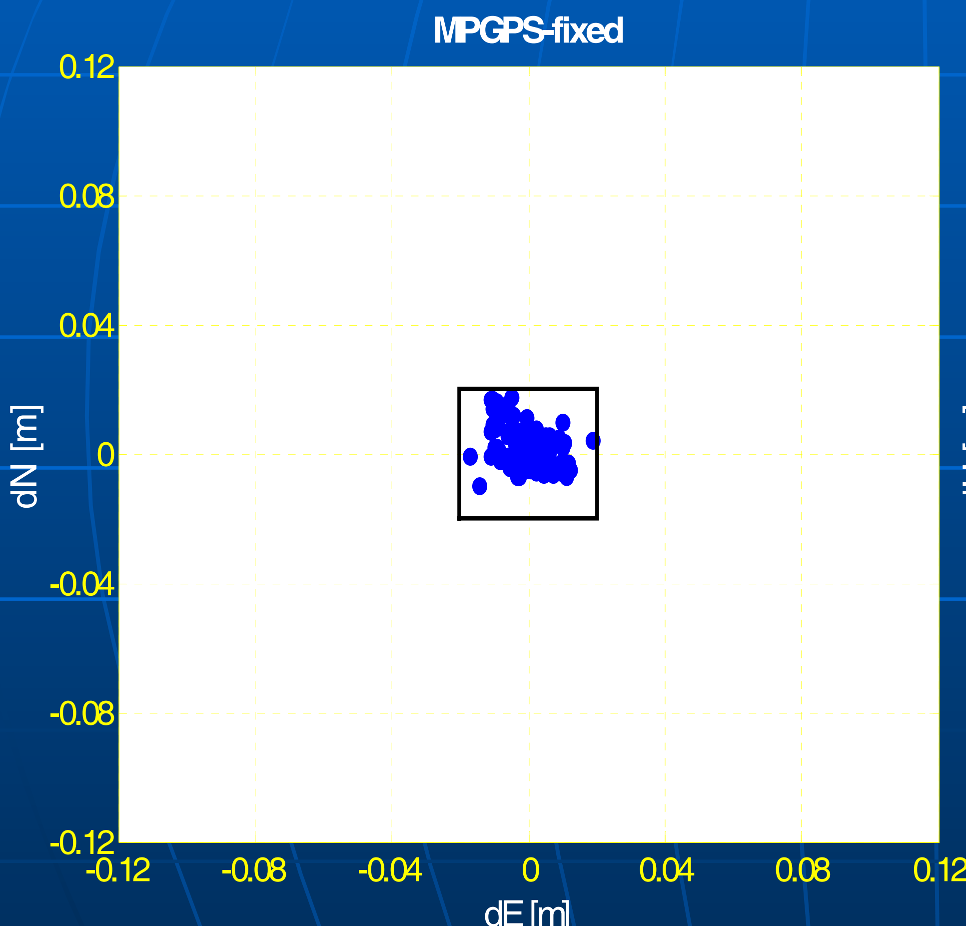
The state of the ionosphere on August 24, 2005

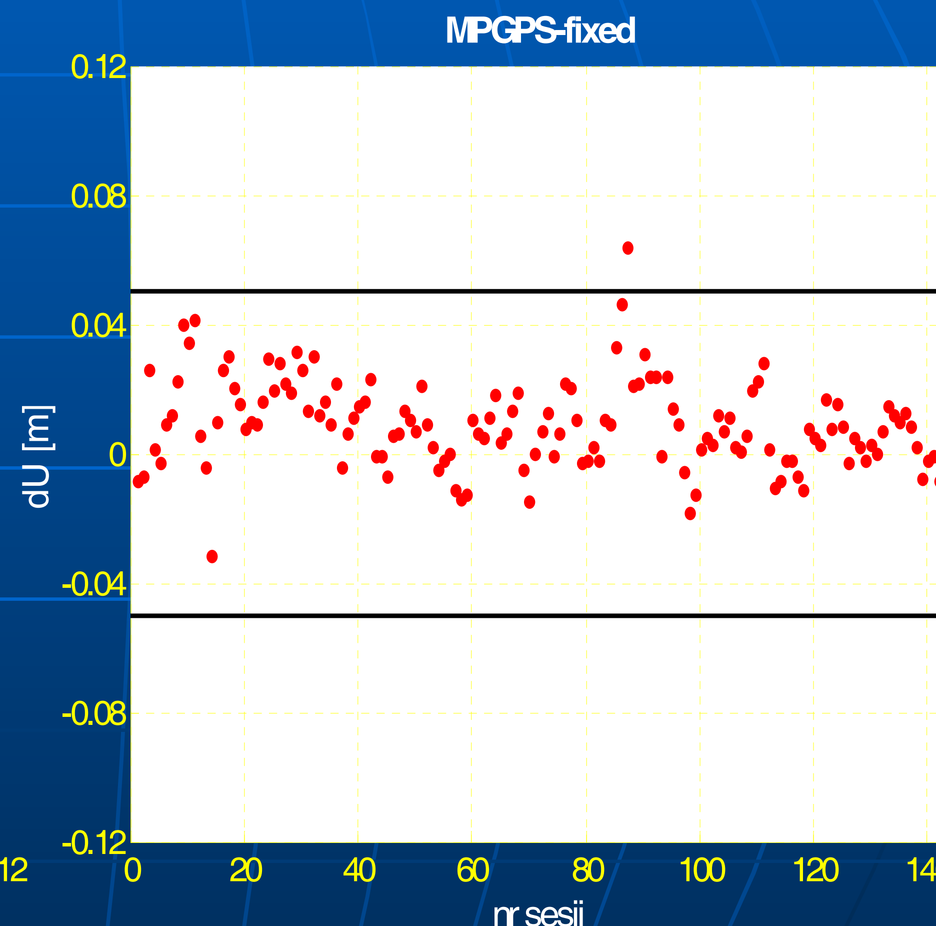
Experiment (III)



True DD ionospheric delays (top) and DD Ionospheric correction Quality/residuals (bottom), <u>KATO-LELO baseline – 64 km</u>

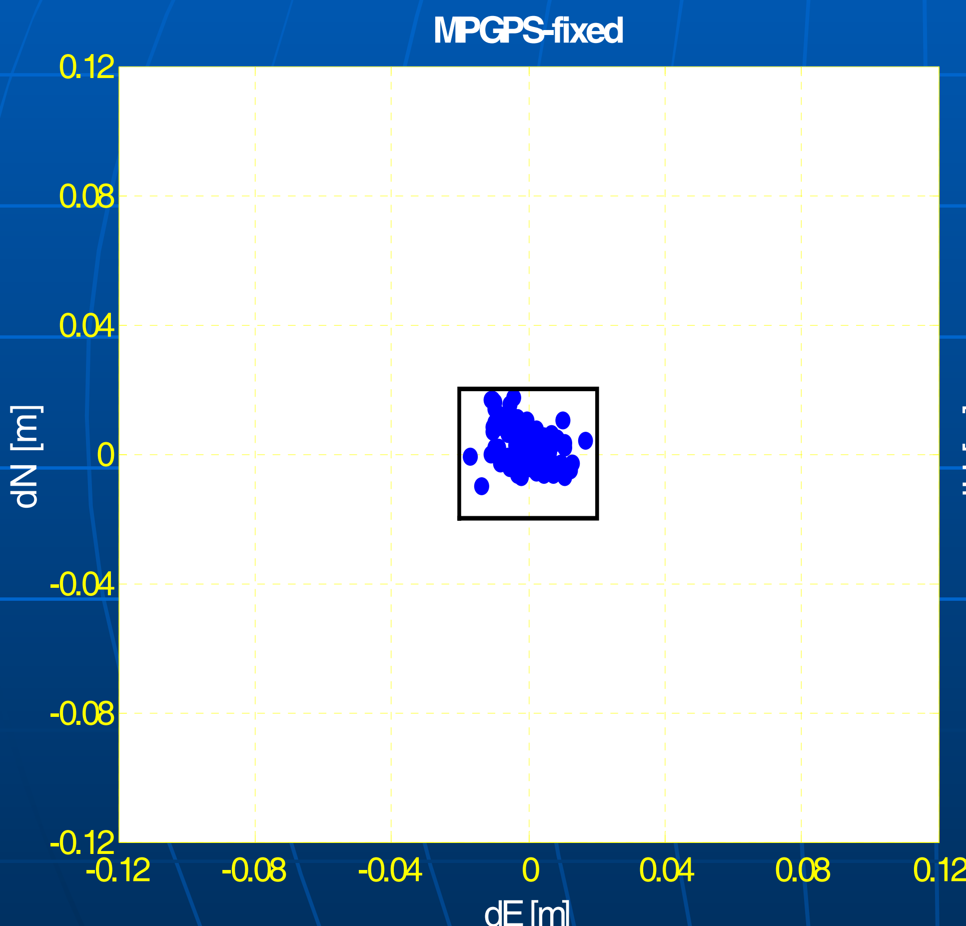
Experiment (IV)

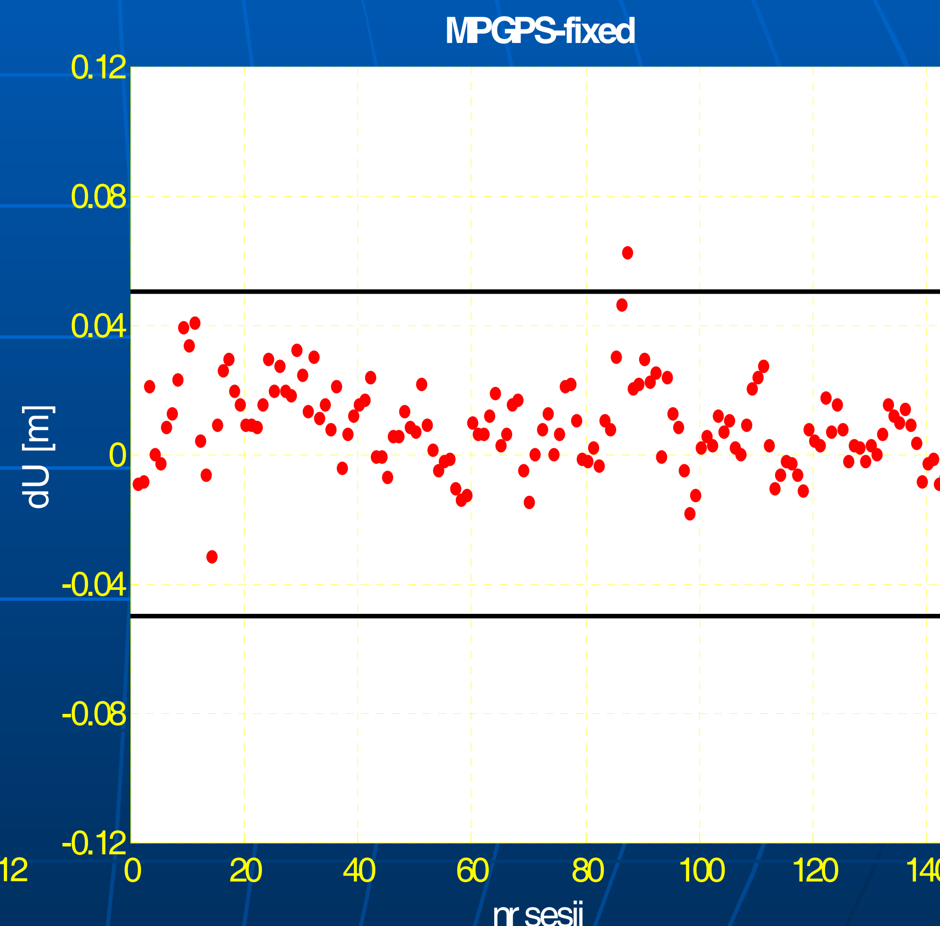




Position residuals, **<u>30-second</u>** sampling rate, 144 sessions, 10 minutes each

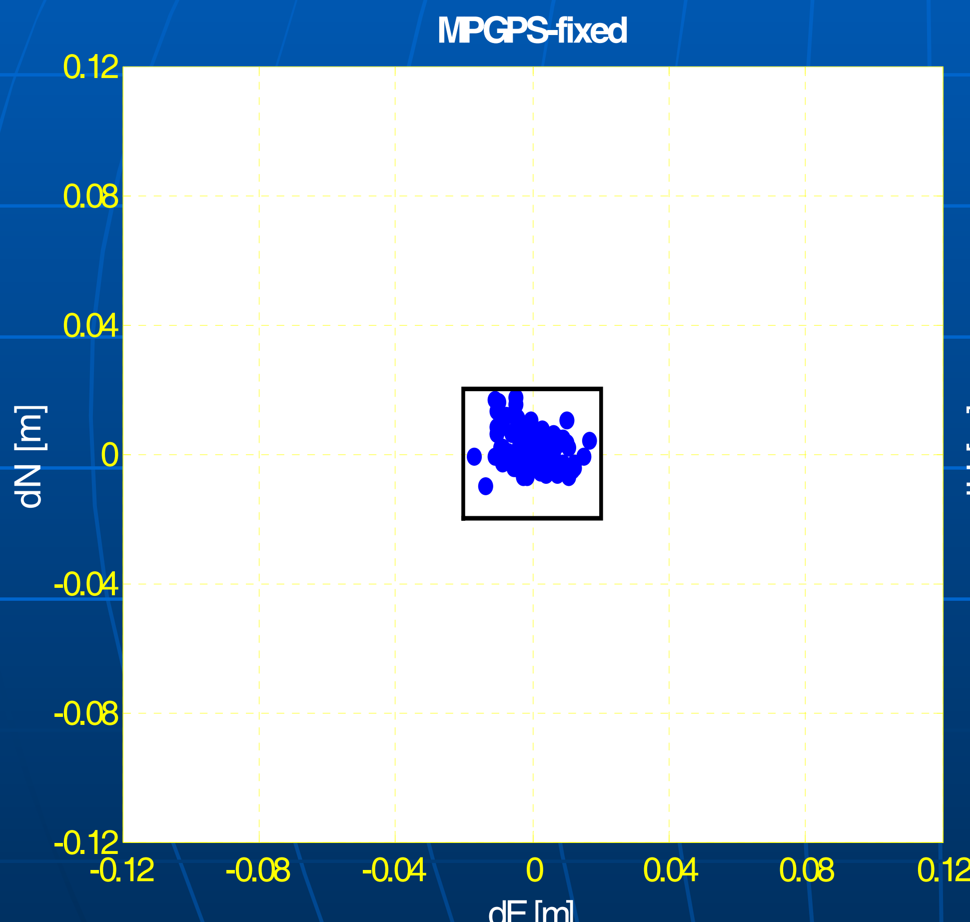
Experiment (V)

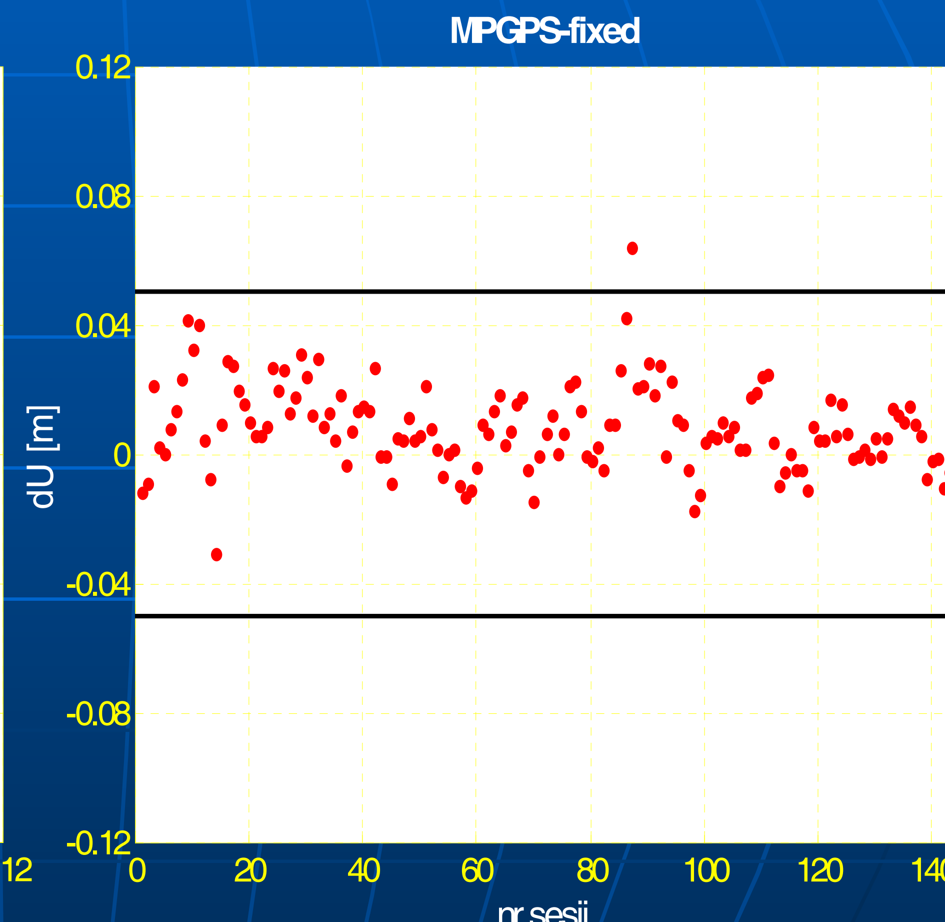




Position residuals, <u>**15-second**</u> sampling rate, 144 sessions, 10 minutes each

Experiment (VI)





Position residuals, **5-second** sampling rate, 144 sessions, 10 minutes each

Experiment (VII)

Position residuals, 144 sessions, 10 minutes each (sampling rates: 30, 15, 5 seconds)

	max dN [cm]	max dE [cm]	max dU [cm]	mean dN [cm]	mean dE [cm]	mean dU [cm]	std dN [cm]	std dN [cm]	std dU [cm]
30 sec	1.9	1.8	6.4	0.0	0.1	0.9	0.6	0.5	1.4
15 sec	1.6	1.8	6.3	0.0	0.1	0.9	0.6	0.5	1.4
5 sec	1.6	1.8	6.4	0.0	0.1	0.9	0.6	0.5	1.4

Experiment (VIII)

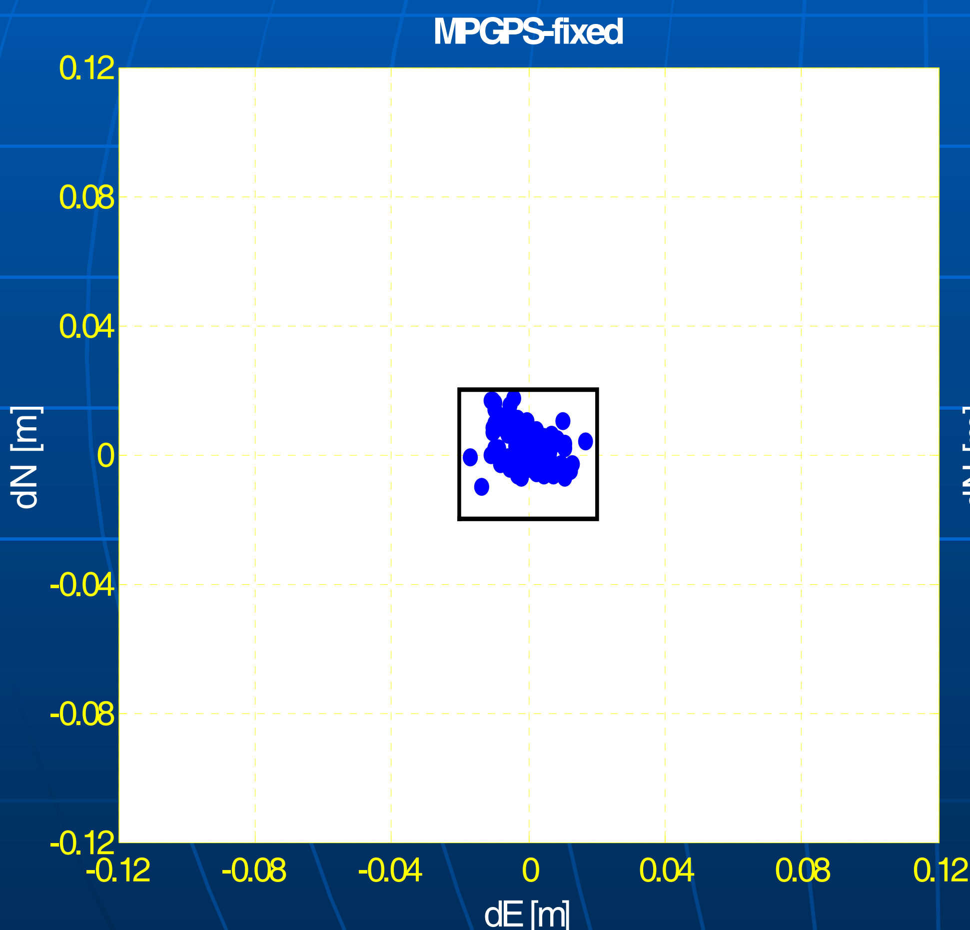
Session statistics

	Number of Sessions	Solved sessions	Not solved sessions*	Ambiguity validation failures	Time-to-fix
30 sec	144	141	3	0	3ep=90sec
15 sec	144	141	3	0	4ep=60sec
05 sec	144	141	3	0	6ep=30sec

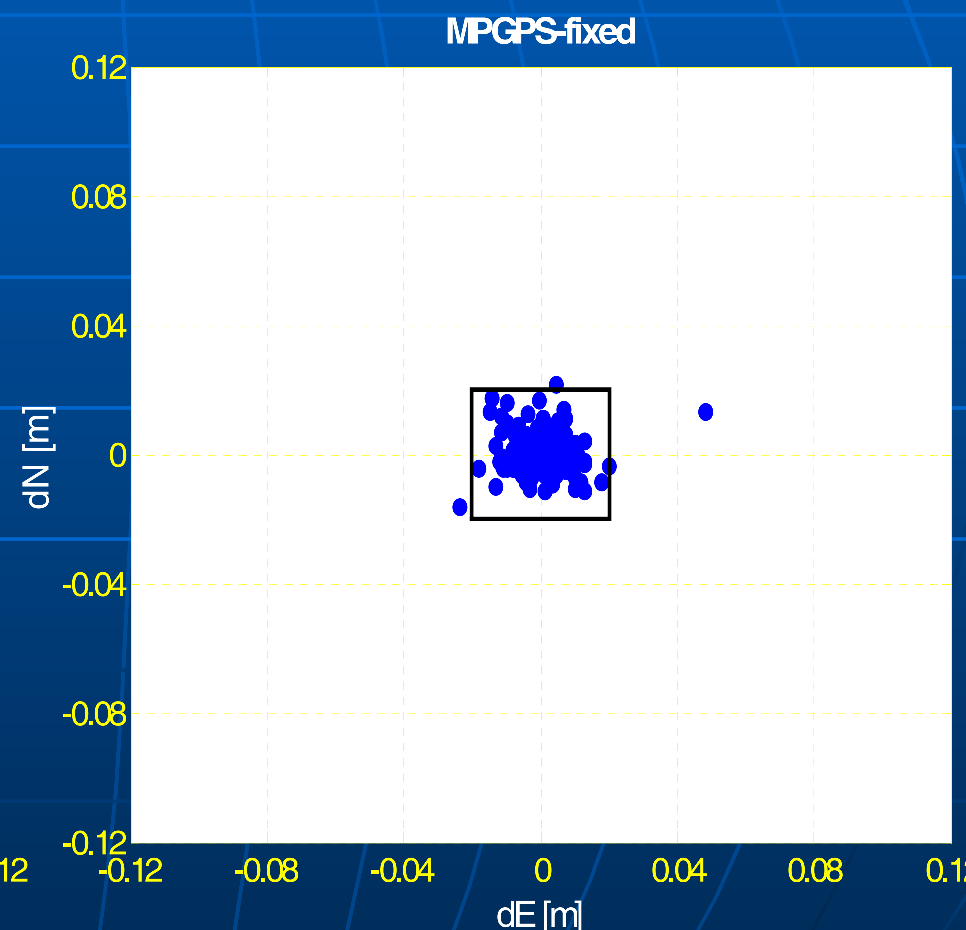
*07:00:00-07:22:36 gap in KATO data

Experiment (IX)

10-minute long sessions (40 ep)



1-minute long sessions (4 ep)



Position residuals, 1**5-second** sampling rate, 144 sessions

Experiment (X)

Position residuals, 144 sessions, sampling rate 15 seconds (10-, 3- and 1-minute long sessions)

	max dN [cm]	max dE [cm]	max dU [cm]	mean dN [cm]	mean dE [cm]	mean dU [cm]	std dN [cm]	std dN [cm]	std dU [cm]
10 minutes (40ep)	1.6	1.8	6.3	0.0	0.1	0.9	0.6	0.5	1.4
3 minutes (12ep)	3.6	2.2	7.4	0.0	0.1	1.0	0.8	0.6	1.6
1 minute (4ep)	4.8	2.2	10.0	0.0	0.1	1.0	0.9	0.6	1.8

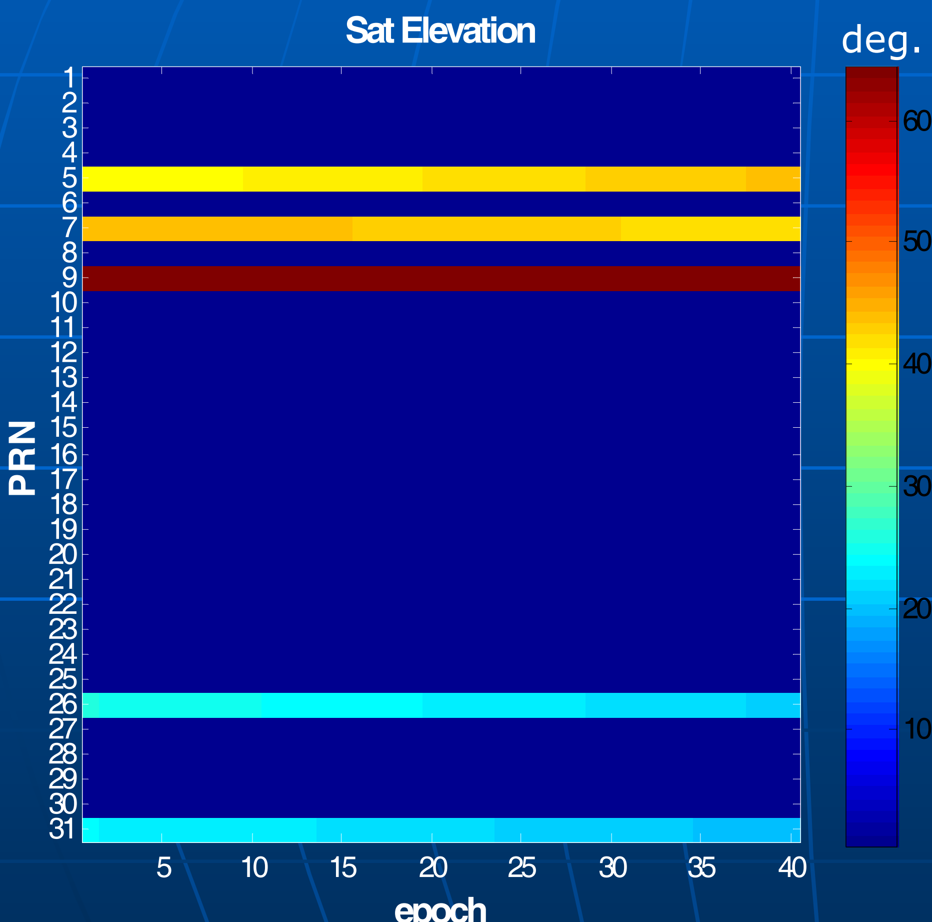
Experiment (XI)

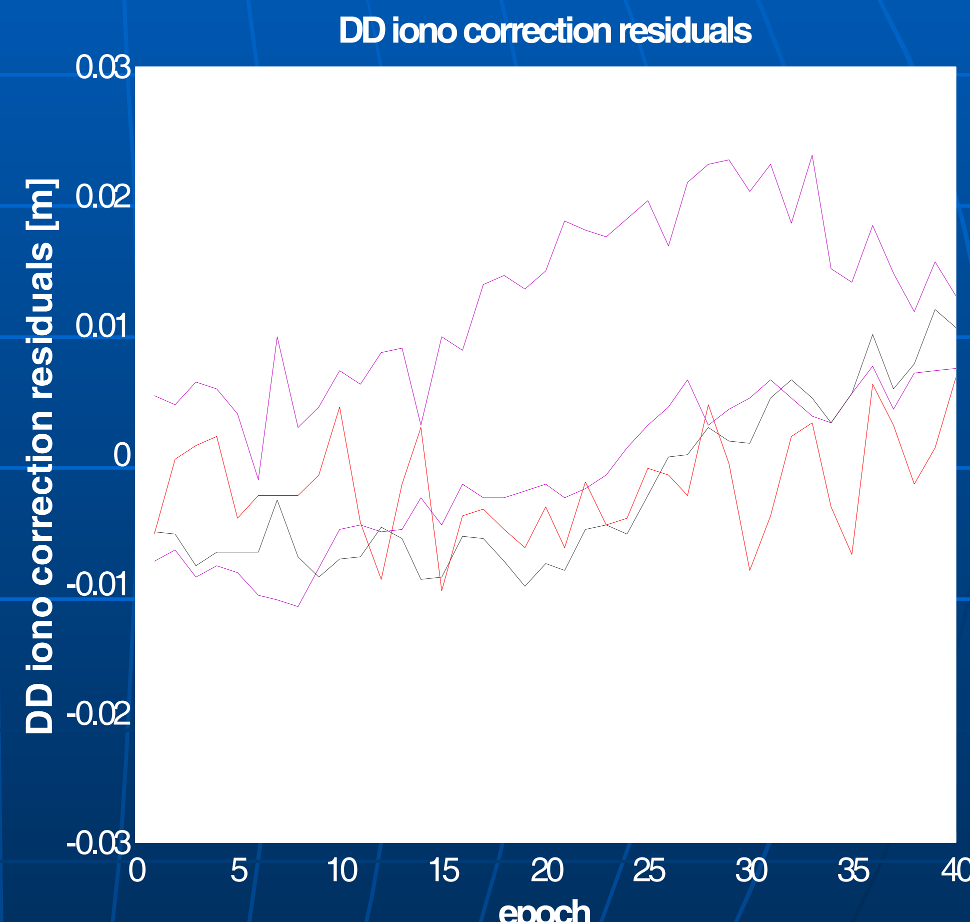
Session statistics

	Number of Sessions	Solved sessions	Not solved sessions*	Ambiguity validation failures	Time-to-fix
10 minutes (40ep)	144	141	3	0	4ep=60sec
3 minutes (12ep)	144	141	3	0	4ep=60sec
1 minute (4ep)	144	141	3	0	4ep=60sec

*07:00:00-07:22:36 gap in KATO data

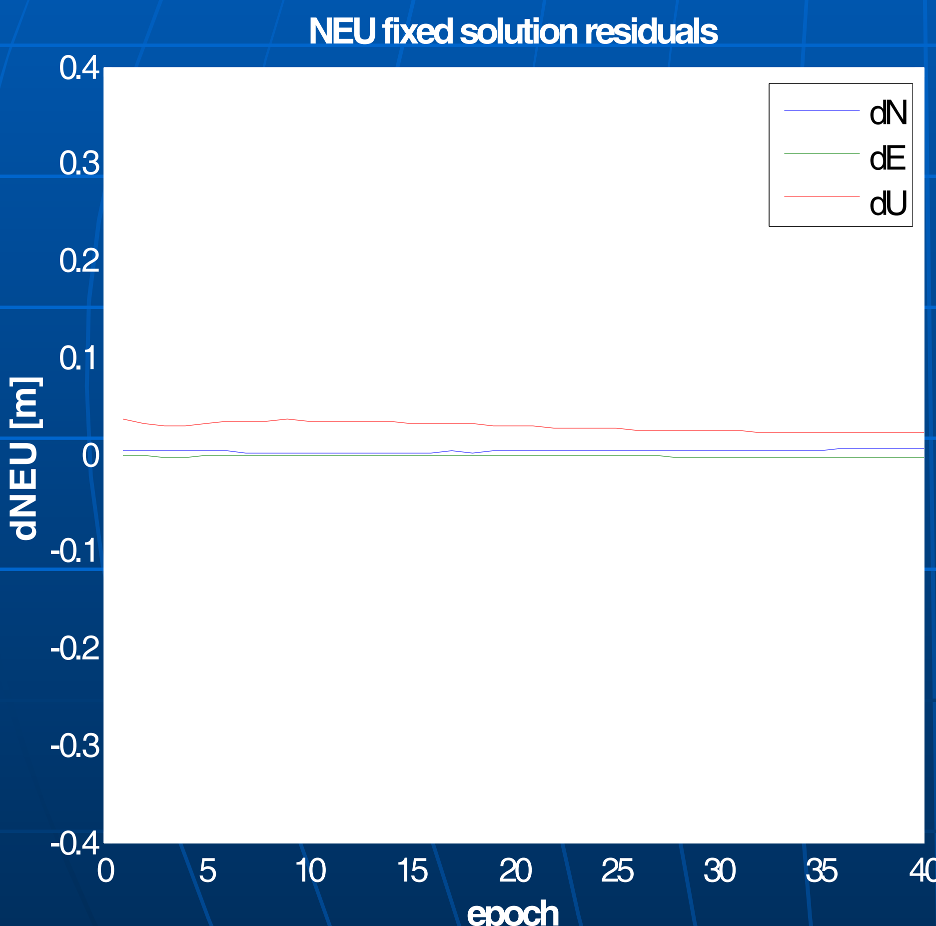
Experiment (XII)

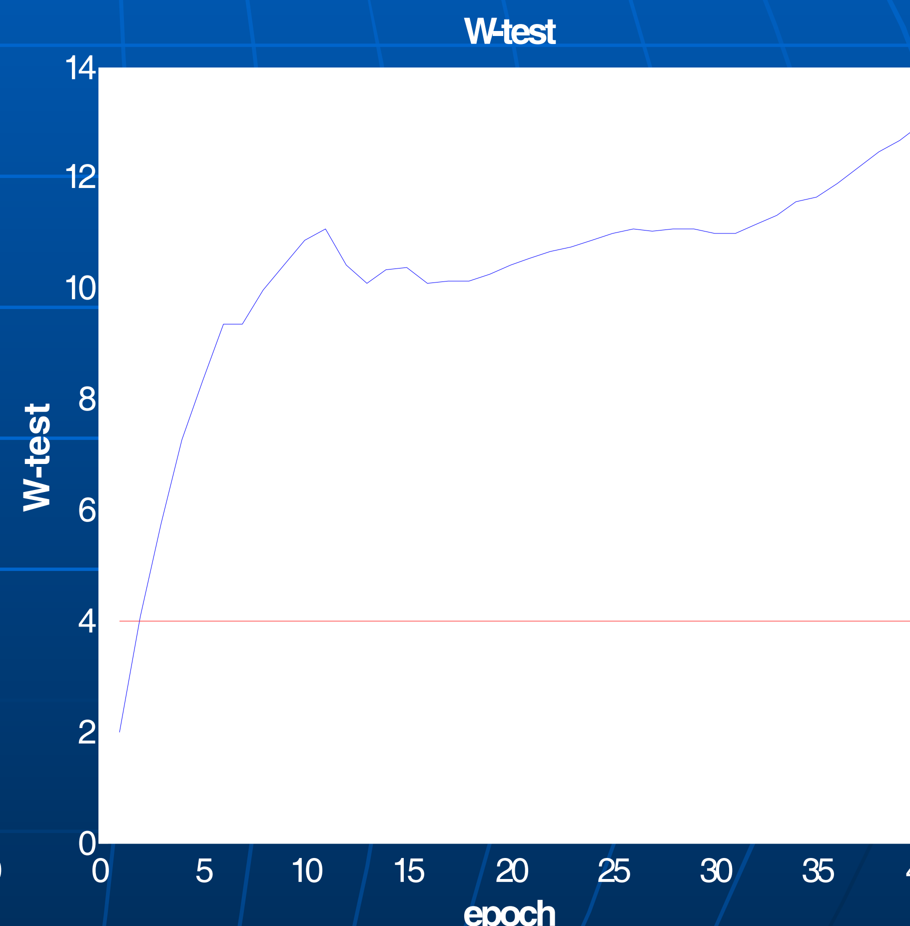




15:00-15:10 UT session

Experiment (XIII)





15:00-15:10 UT session

Conclusions

- Cm-level horizontal position accuracy can be achieved using short span (a few minutes) of double frequency GPS data within ASG/EUPOS network
- Data sampling rate lower that 30 seconds has negligible influence on the position quality (but has some influence on time-to-fix)
- When the ionospheric correction accuracy is better that ½ cycle of L1 signal, fixed solution is possible just after a few observational epochs only
- Application of the presented algorithm should reduce the measurement costs dramatically

Future Developments

- Test different network geometry (e.g., single-baseline solution, rover outside the network)
- Modify algorithms to handle single frequency data, GALILEO in the future
- Test on lover quality GPS data
- Apply the algorithms to kinematic positioning
- Feasibility study of instantaneous positioning