Local troposphere models based on numerical weather prediction for GNSS real-time precise positioning

Karina Wilgan, Tomasz Hadaś, Paweł Hordyniec, Jarosław Bosy, Witold Rohm

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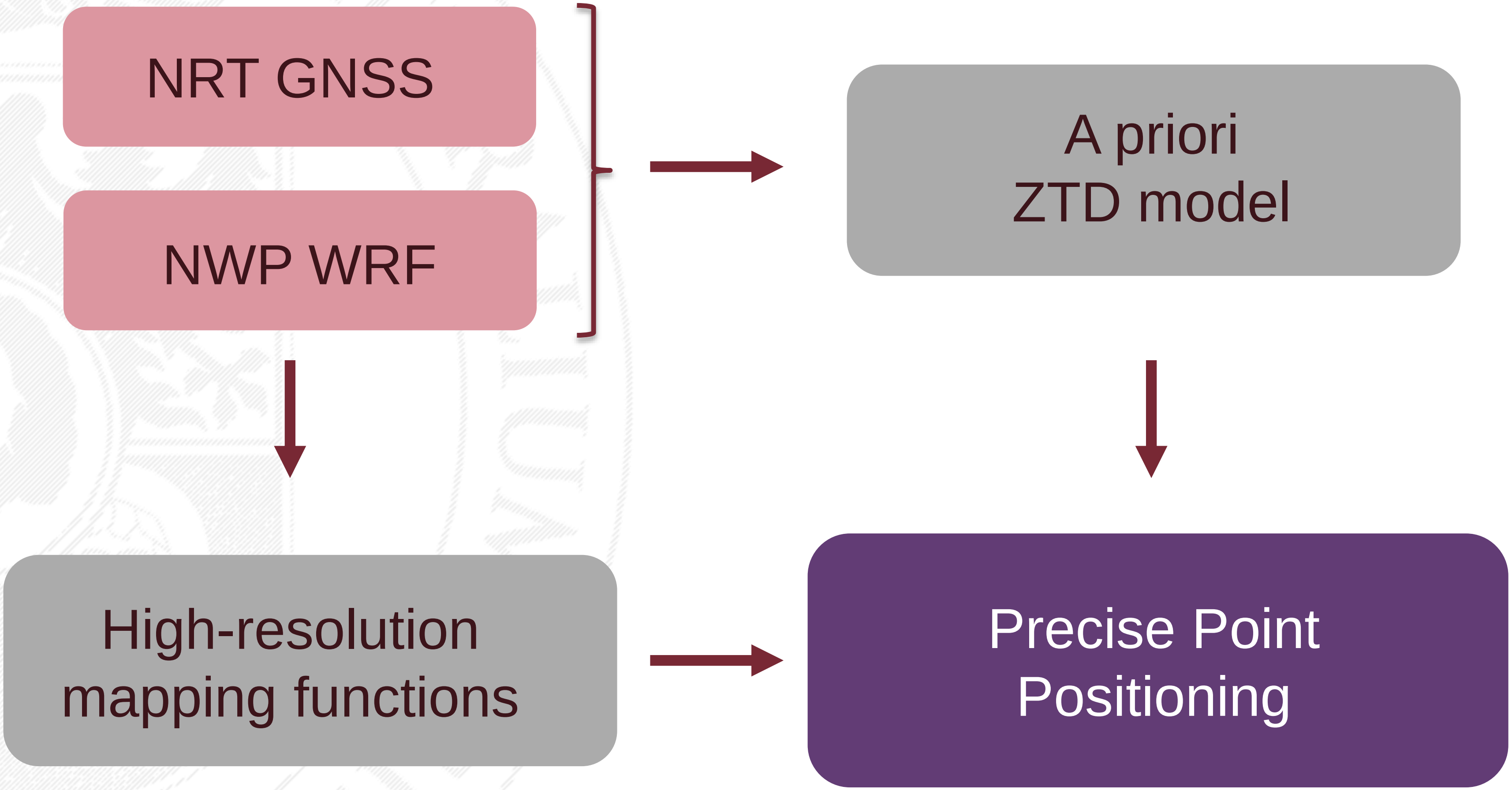
Motivation

- Troposphere is a major error source in precise positioning
- ZTD is highly correlated with the receiver height and receiver clock error
- This results in long convergence time of PPP solutions

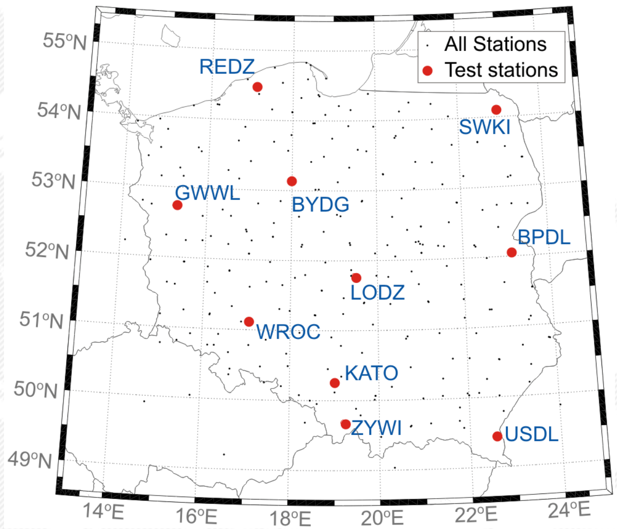
Introducing the high-resolution model of troposphere:

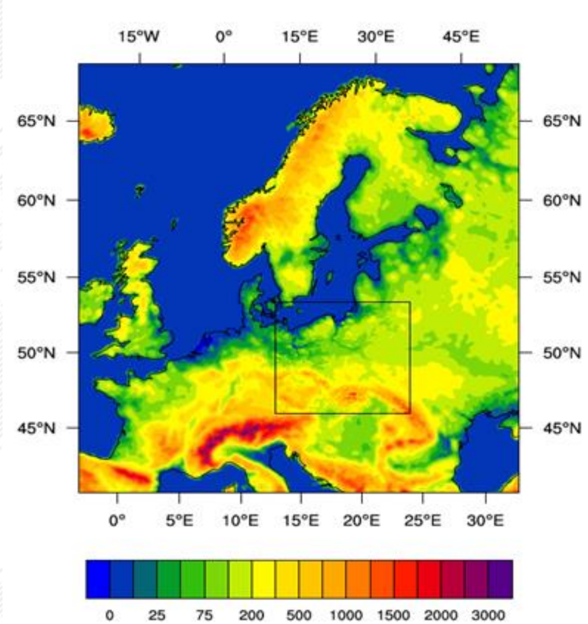
- Improving the postioning accuracy
- Shortening the convergence time

Methodology



Data





NRT GNSS

- near-real time
- 272 stations from Poland and adjacent area
- 10 test stations (EPN) excluded from building the model
- ZTD with 1-h resolution
- product of Bernese software v5.2
- double-differenced

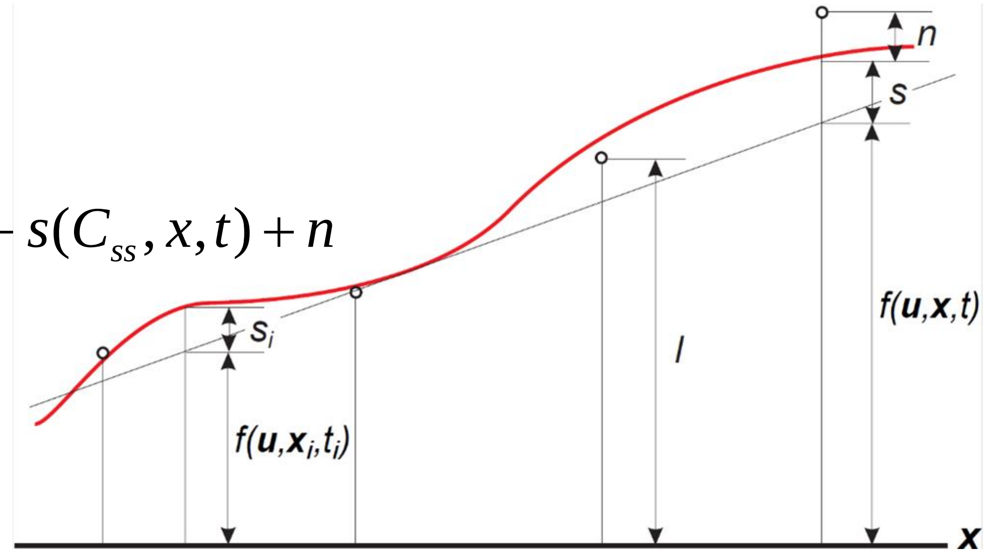
NWP WRF

- WRF – Weather Research & Forecasting
- 219x237 horizontal nodes
- 4x4 km^2 grid
- 47 vertical levels
- forecasts at 0:00, 6:00, 12:00, 18:00 UTC
- total refractivity (N) from p, T, e with 1-h resolution (coefficients Rüeger `best average'):

$$N_{tot} = k_1 \frac{p-e}{T} + k_2 \frac{e}{T} + k_3 \frac{e}{T^2}$$

A priori ZTD - methodology

$$l = f(u,x,t) + s(C_{ss},x,t) + n$$



Least-squares collocation using software **COMEDIE** developed at ETH Zürich

Zenith total delay (from NRT GNSS)

$$ZTD(x,y,z,t) = (ZTD_0 + a_{ZTD}(x-x_0) + b_{ZTD}(y-y_0) + c_{ZTD}(t-t_0)) \cdot e^{-\frac{z}{H_{ZTD}}}$$

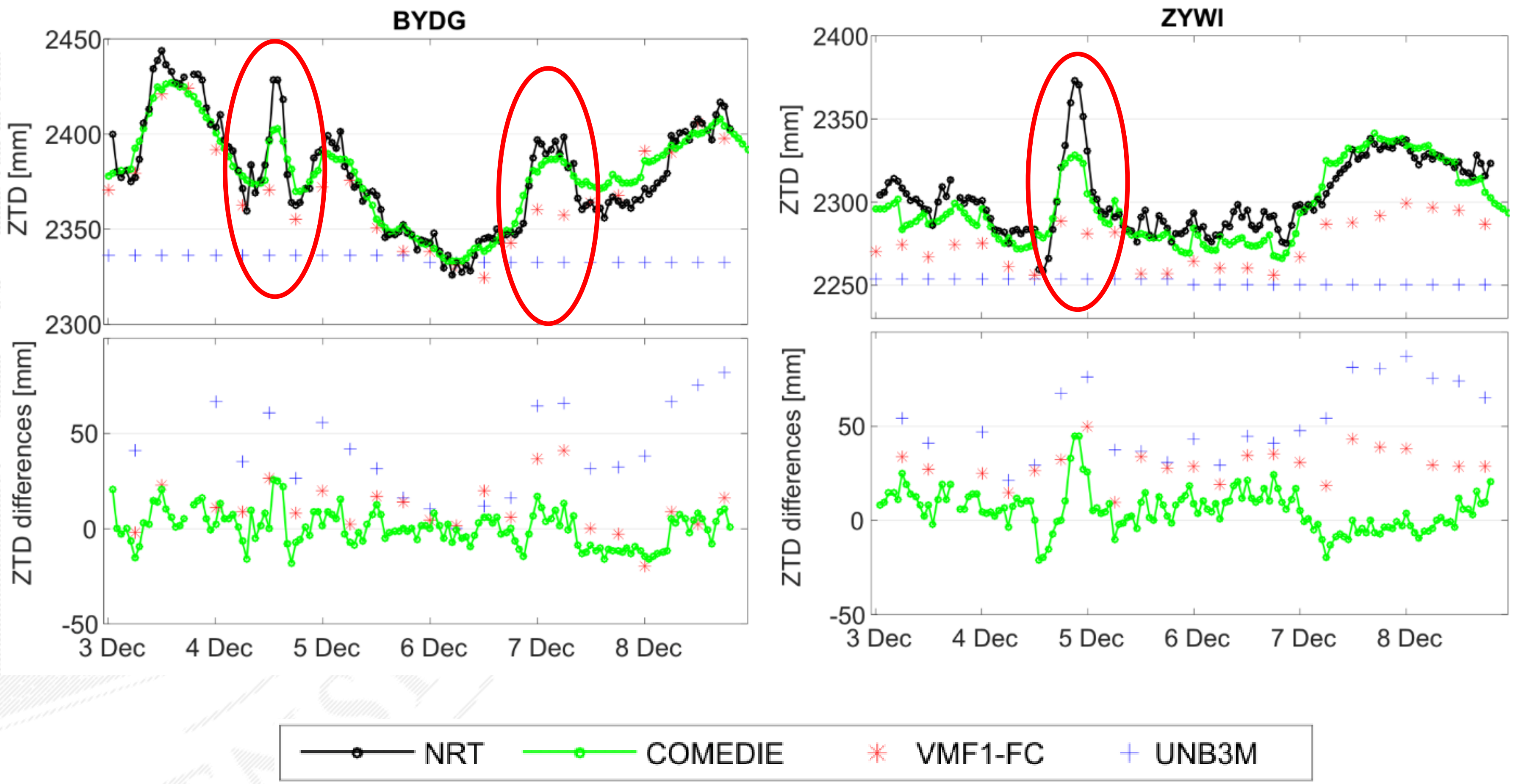
Total refractivity (from WRF)

$$N(x,y,z,t) = \frac{1}{H_{ZTD}}(ZTD_0 + a_{ZTD}(x-x_0) + b_{ZTD}(y-y_0) + c_{ZTD}(t-t_0)) \cdot e^{-\frac{z}{H_{ZTD}}}$$

More about a priori ZTD → Wilgan K, Hurter F, Geiger A, Rohm W, Bosy J (2016) *Tropospheric refractivity and zenith path delays from least-squares collocation of meteorological and GNSS data* J Geod (online)

A priori ZTD - results

Comparison of ZTDs obtained from 3 models (COMEDIE, VMF1-FC, UNB3m) w.r.t. NRT GNSS solution for two sample stations: BYDG and ZYWI; test period Dec 3-8, 2015



Mapping function WRFMF- methodology

- the methodology based on VMF `fast' approach
- hydrostatic b,c → from Isobaric Mapping Function:
  $b_h = 0.002905$
  $c_h = 0.0634 + 0.0014 \cdot \cos(2\varphi)$
- wet b,c → from Niell Mapping Function:
  $b_w = 0.00146$
  $c_w = 0.04391$

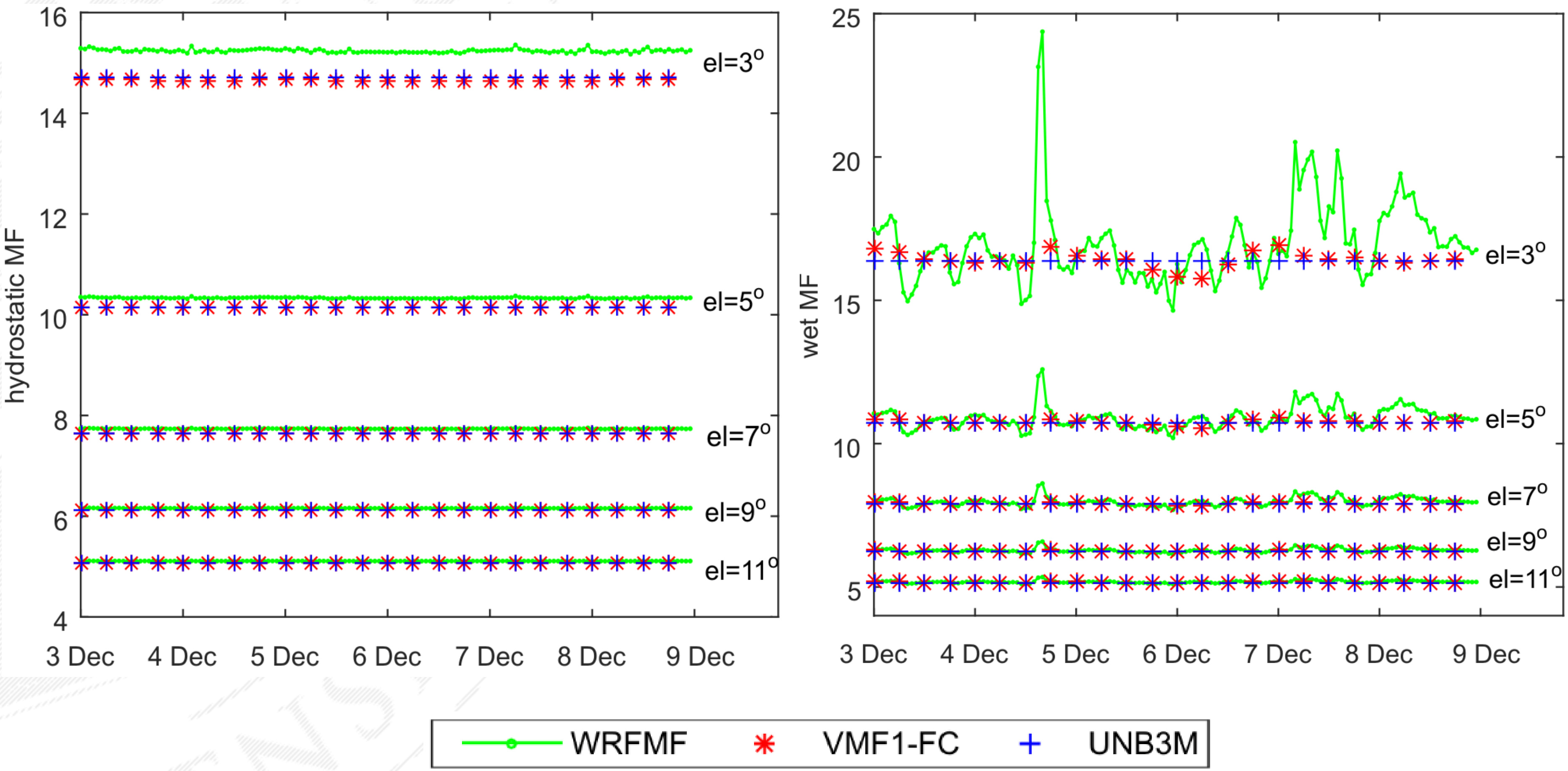
$$MF(el) = \frac{1 + \frac{a}{1 + \frac{b}{1 + c}}}{\sin(el) + \frac{a}{\sin(el) + \frac{b}{\sin(el) + c}}}$$

- ray-tracing through WRF for *el*=3.3° → *SHD/SWD, ZHD/ZWD* every 1-h
  $MF_h = (SHD + d_{geo})/ZHD$
  $MF_w = SWD/ZWD$
- a-coefficients from inverting the continued fraction → WRFMF

More about ray-tracing → poster Hordyniec et al., *Radio Occultation Toolbox (ROWUELS) - Recent Development in Raytracing Algorithms*

Mapping function WRFMF -results

Comparison of the hydrostatic and wet MFs from three models: WRFMF, VMF1-FC and UNB3m; station BYDG; cut-off angle in processing 5°



Application of high-resolution troposphere model

In-house developed Precise Point Positioning (PPP) software GNSS-WARP; simulated real-time mode

6 processing variants

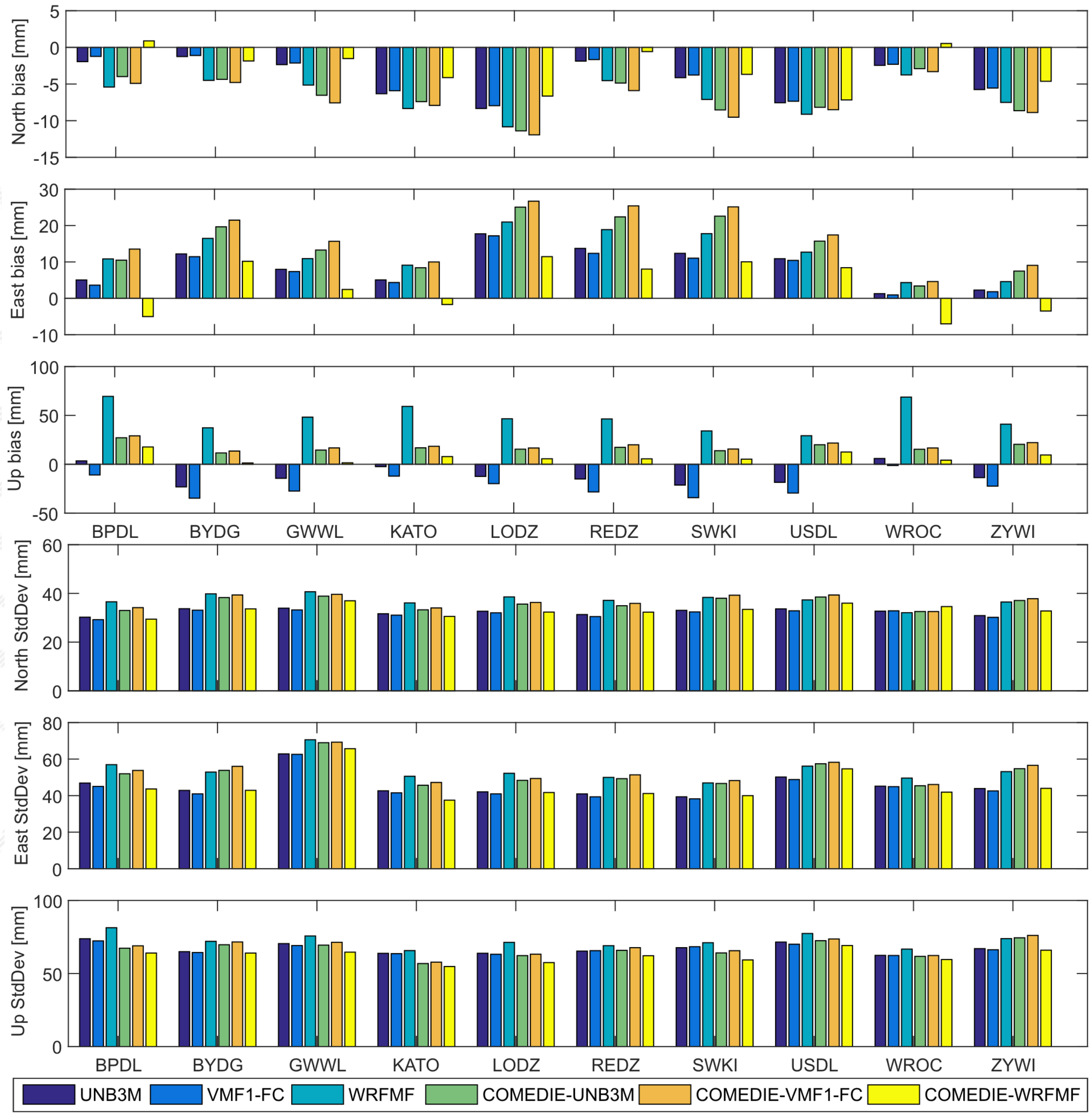
	Name	A priori ZTD	Constraining	MF
1.	UNB3m	UNB3m	None	UNB3m
2.	VMF1-FC	VMF1-FC	None	VMF1-FC
3.	WRFMF	WRF	None	WRFMF
4.	COMEDIE-UNB3m	COMEDIE	10 mm	UNB3m
5.	COMEDIE-VMF1-FC	COMEDIE	10 mm	VMF1-FC
6.	COMEDIE-WRFMF	COMEDIE	10 mm	WRFMF

More about the software → Hadas T (2015) *GNSS-Warp Software for Real-Time Precise Point Positioning*. Artificial Satellites, 50(2):59-76

Kinematic positioning

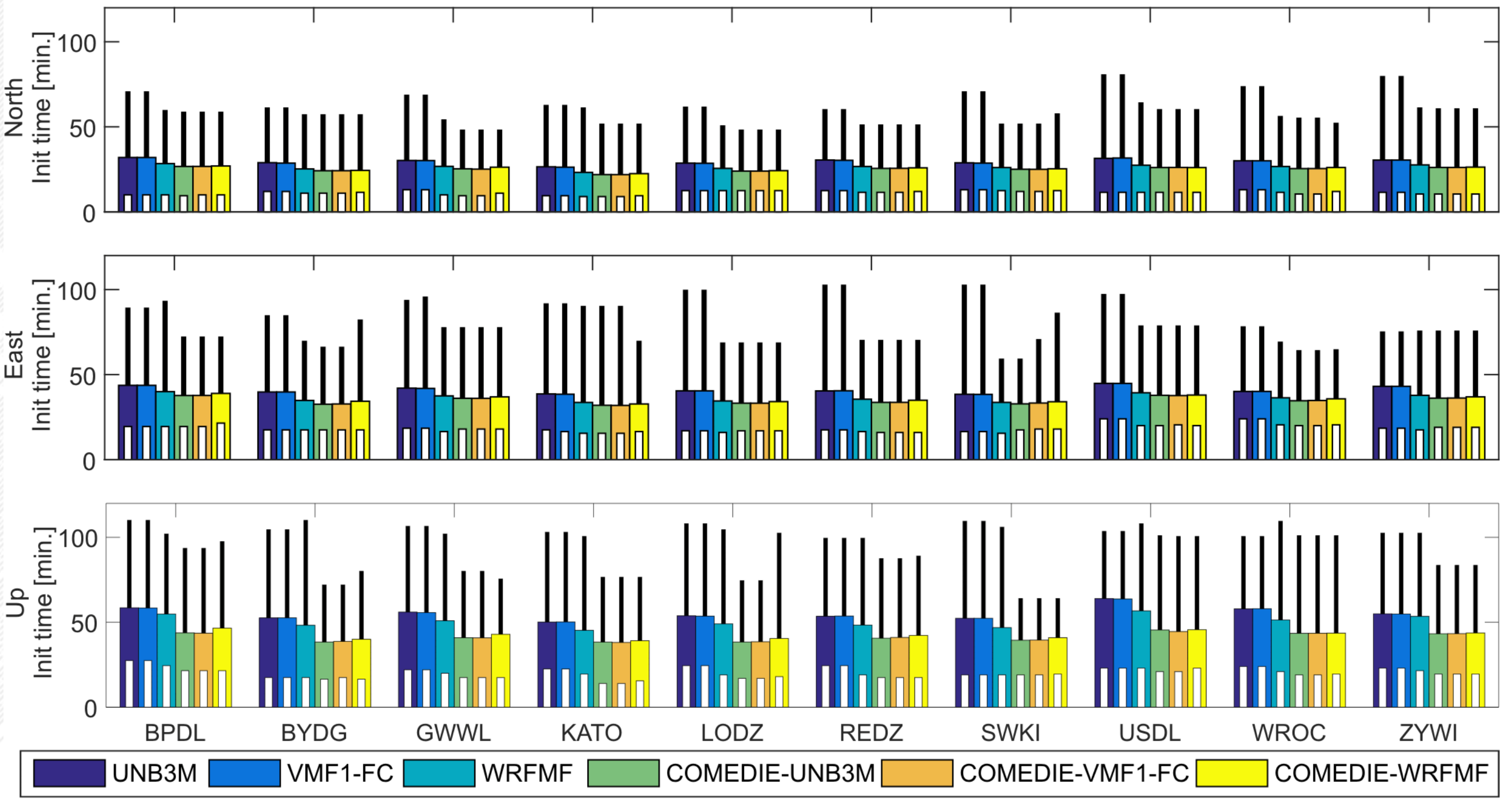
Mean biases and standard deviations of kinematic coordinate residuals (estimated - EPN official) for 10 Polish EPN stations, data period: Dec 3-8, 2015

Name	Up Bias [mm]	Up StdDev [mm]
UNB3m	-11.1	67.1
VMF1-FC	-22.1	66.5
WRFMF	48.0	72.4
COMEDIE-UNB3m	17.2	66.5
COMEDIE-VMF1-FC	19.1	67.8
COMEDIE-WRFMF	7.1	62.1



Convergence time (2-h reinitialized kinematic)

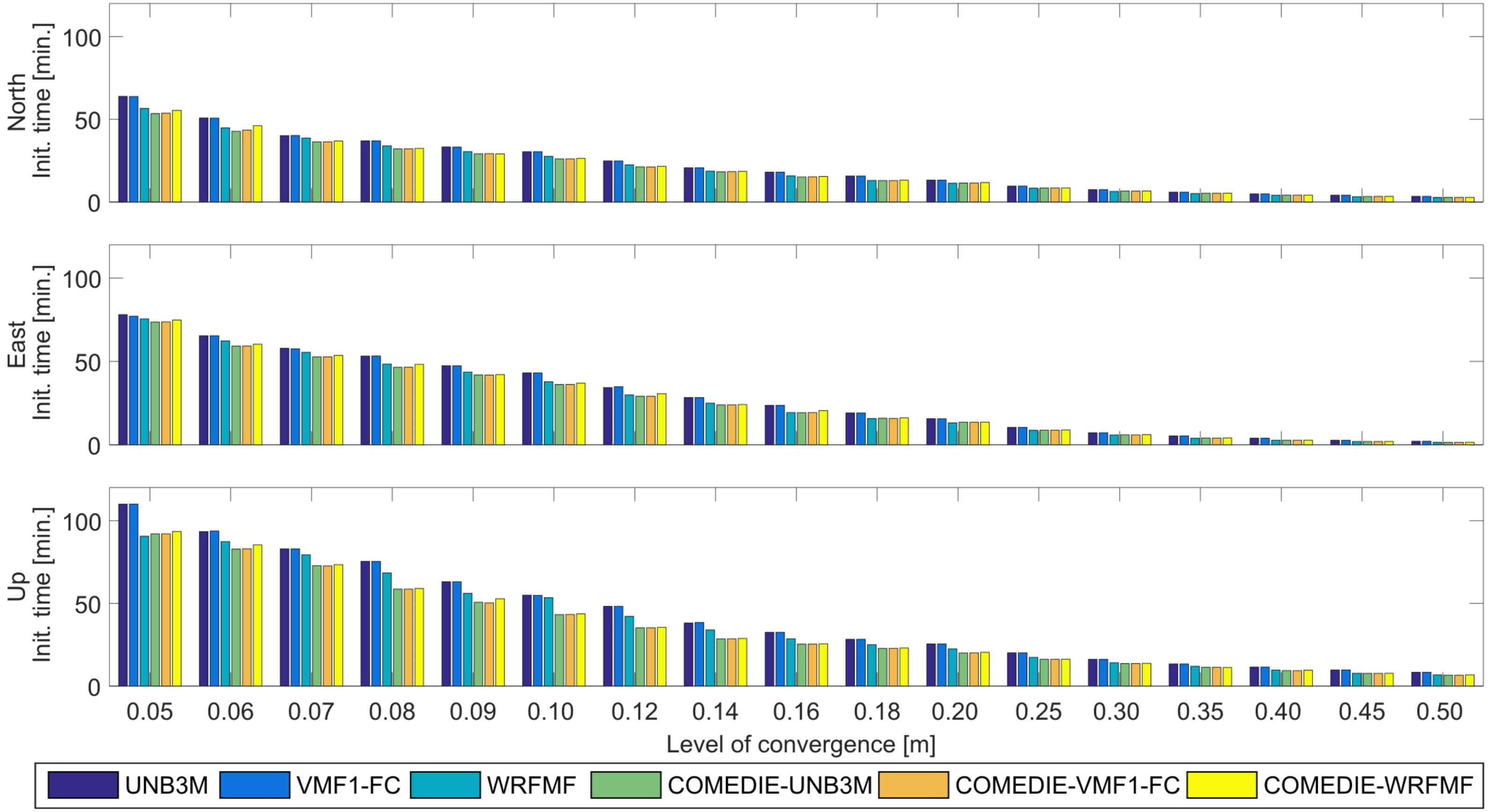
Initialization time for **10 cm** level of convergence (based on formal error) averaged from 10 Polish EPN stations; data period Dec 3-8, 2015; color bars denote the mean time, black bars the maximum time and white bars the minimum time required for the solution to converge



variant	North	East	Up
`standard'	30 min	41 min	55 min
COMEDIE	25 min	36 min	42 min

Convergence time

Mean initialization times for various levels of convergence averaged from 10 Polish EPN stations; data period: Dec 3-8, 2015



Summary

- PPP in 6 processing configurations (different combinations of a priori ZTD and MFs)

- 2 types of coordinates: continuous kinematic and reinitialized kinematic

- Kinematic positioning: COMEDIE-WRFMF has the smallest average biases (7.1 mm) and standard deviation (62.1 mm) for the Up component

- Convergence time (from 2-h reinitialized kinematic): using the ZTD from COMEDIE shortens the convergence time by 17% for North component, by 12% for East component and by 24% for Up component (for 10 cm convergence level)

WROCŁAW UNIVERSITY OF ENVIRONMENTAL AND LIFE SCIENCES

Thank you for your attention!

Questions?

karina.wilgan@igig.up.wroc.pl

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