Atmospheric sensing by GNSS signal in GNSS&Meteo group investigations

P. Hordyniec, W. Rohm, J. Bosy, T. Hadaś, K. Sośnica, K. Wilgan, J. Kapłon, J. Sierny, K. Kaźmierski

Institute of Geodesy and Geoinformatics
Wroclaw University of Environmental and Life Sciences
Poland

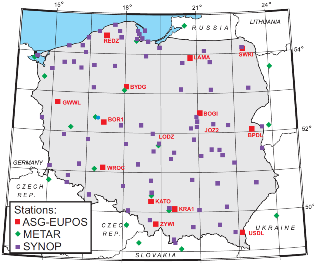
Observing Network

Meteo-stations:

15 EPN stations (Paroscientific Met4A)

75 SYNOP stations (Vaisala MAWS)

22 METAR stations



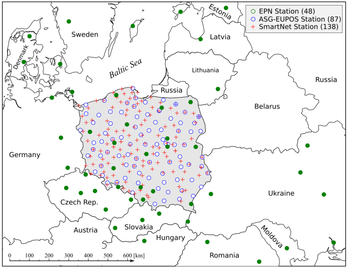
- P [*hPa*], T [^oC], RH [%]
- reports: 30' - 1h

WUELSNET Network:

- Poland

273 stations

40 km mean distance



- ZTD/STD, IWV
- data interval: 30' - 1h

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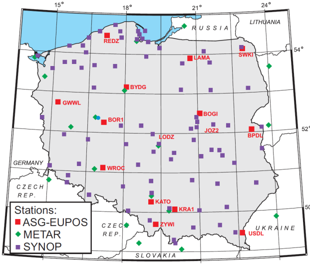

- P [*hPa*], T [^oC], RH [%]
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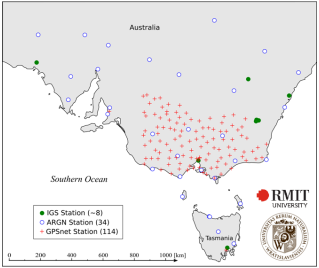
VICNET Network:

- Victoria, Australia

156 stations

70 km mean distance



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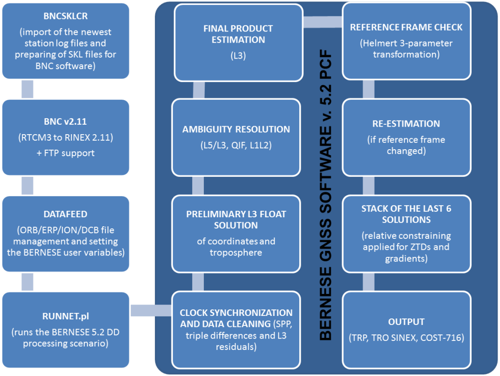
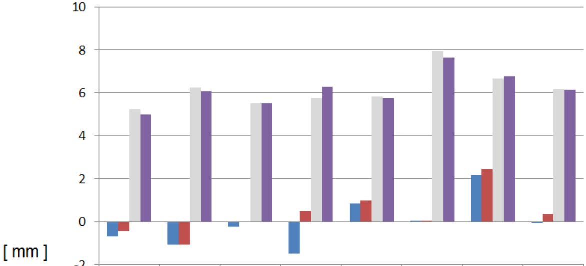
NRT ZTD



L5/L3 (code & phase) strategy	
Reference frame	ITRF2008 (for the epoch of measurements)
A priori ZTD model/mapping function	Saastamoinen/Dry GMF
Estimated ZTD model	Wet GMF
Ambiguity resolution	L5/L3, QIF, L1/L2

NRT ZTD

VICNET ZTD wrt IGS final ZTD (91 - 170 DOY 2015)



	CEDU	HOB2	MOBS	PARK	STR1	STR2	TID1	MEAN
bias FLOAT	-0,70	-1,08	-0,22	-1,48	0,85	0,03	2,16	-0,06
bias FIXED	-0,46	-1,07	-0,01	0,51	0,97	0,03	2,43	0,35
stddev FLOAT	5,21	6,23	5,53	5,76	5,82	7,94	6,64	6,16
stddev FIXED	5,00	6,08	5,52	6,27	5,75	7,62	6,78	6,14

IWV (GNSS and Meteo)

Integrated Water Vapor

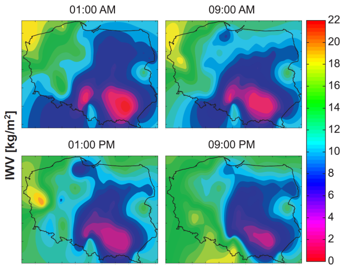
$$IWV = \frac{ZWD}{10^{-6} \cdot R_w} \left(k_2' + \frac{k_3}{T_m} \right)^{-1}$$

$$\begin{aligned} R_w &= 461.525 \pm 0.003 \; [J \cdot kg^{-1} \cdot K^{-1}] \\ k_2' &= 24 \pm 11 \; [K \cdot hPa^{-1}] \\ k_3 &= 3.75 \pm 0.03 \; [10^5 \cdot K^2 \cdot hPa^{-1}] \\ T_M &\approx 70.2 \pm 0.72 \cdot T_0 \end{aligned}$$

where R_w is universal constant for wet air, k_2' and k_3 are refractivity coefficients (Boudouris, 1963), T_0 is surface temperature, T_M is mean temperature

Available for both:

- WUELSNET (GNSS + meteo)
- VICNET (GNSS)

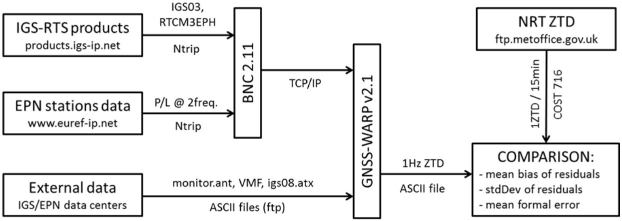


Reference: Bosy, J. et al. (2012). Near real-time estimation of water vapour in the troposphere using ground GNSS and the meteorological data, Ann. Geophys., 30, 1379-1391, DOI: 10.5194/angeo-30-1379-2012

GNSS WARP

GNSS Wroclaw Algorithms for Real-time Positioning

- designed for Precise Point Positioning (RT and PP)
- short-time forecasts of orbit corrections (up to 8 min/4 min for GPS/GLONASS)
- random-walk ZTD constrained by regional model



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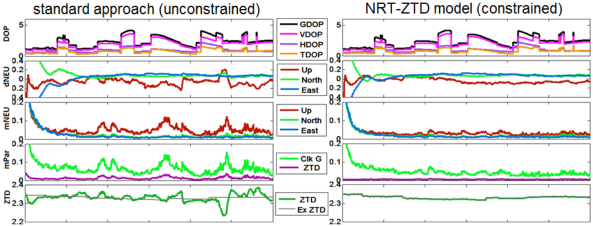

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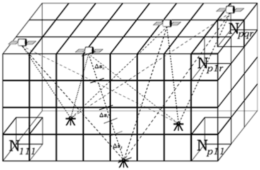
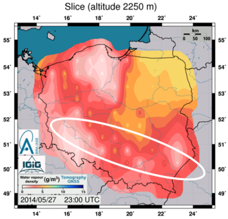
GNSS Tomography

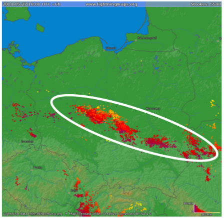
TOMO2

$$L_{atm}(\epsilon, \alpha) = STD = 10^{-6} \int Nds$$

- resolving vertical structure of severe weather
- 3D NRT model for area of Poland
- a way to derive wet refractivity
- Kalman filter for forward processing





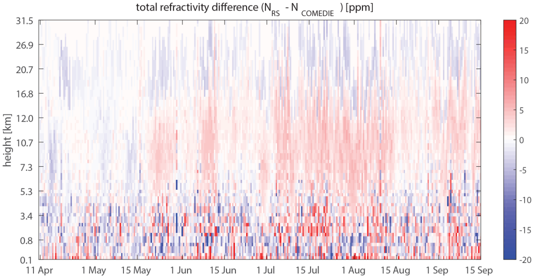


Reference: Rohm, W., and Bosy, J. (2011). The verification of GNSS tropospheric tomography model in a mountainous area. Advances in Space Research, 47(10), 1721-1730, DOI: 10.1016/j.asr.2010.04.017

COMEDIE Refractivity

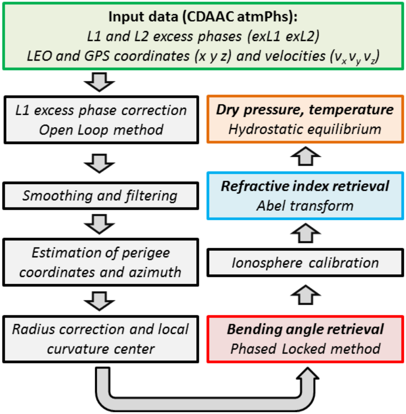
Collocation of Meteorological Data for Interpolation and Estimation of Tropospheric Pathdelays

- reconstruction of WRF refractivity profiles and GNSS data
- validation against radiosonde (04.2014 - 09.2014)

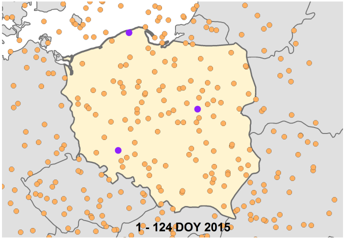


model	WRF	WRF/GNSS	GNSS
bias	0.22	0.48	1.53
std	2.70	3.31	9.43

GPS Radio Occultation

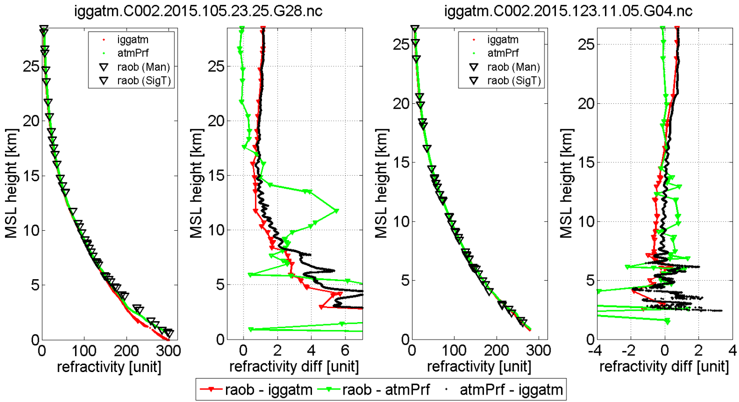


1. **NOAA/ESRL Radiosonde Records**
   - 3 Polish stations at 00/12 UTC
   - mandatory profiles (17 levels)
   - significant wrt T ($\approx$ 30)
   - $N = f\,(P,\ T,\ T_{dd})$



2. **collocated GPS-RO profiles**
   - 200 km distance mismatch
   - 1-hour window

GPS Radio Occultation

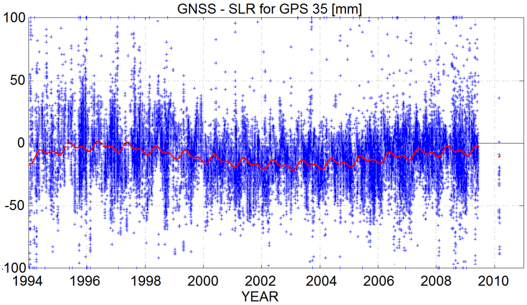


SLR

Satellite Laser Ranging

- insensitive to ionosphere
- verification of GNSS observations
- higher order ionospheric delays

- ionospheric activity:
  - high (2001 - 2005)
  - low (1995 - 1998, 2007 - 2009)



Reference: Sośnica, K., Thaller, D., Dach, R., Steigenberger, P., Beutler, G., Arnold, D., Jäggi, A. (2015). Satellite Laser Ranging to GPS and GLONASS. Journal of Geodesy 89(7), 725-743, DOI: 10.1007/s00190-015-0810-8

Current Projects

- National Science Centre PRELUDIUM: Improving methods of real-time GNSS satellite precise positioning, 2013 - 2015
- National Science Centre OPUS: Multi-GNSS real-time Precise Point Positioning, 2015 - 2018
- ESA Contract: Higher Order Ionospheric modelling campaigns for precise GNSS applications - HORION, 2014 - 2016
- National Grant TANGO: GNSS tomography as an important meteorological data source - results commercialization, 2015 - 2018
- National Science Centre PRELUDIUM: Prognostic troposphere model based on meteorological data, GNSS products and Numerical Weather Prediction models, 2015 - 2017
- National Science Centre SONATA: GNSS observations as a numerical weather prediction data source, a way forward to enhanced forecast quality, 2014 – 2017
- E-GVAP The EUMETNET EIG GNSS water vapour programme), 2012 -
- COST Action ES1206: Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate (GNSS4SWEC), 2013 - 2017

Future Plans

1. **Ray tracing in WRF model:**
   - slant delays
   - GPS RO excess phase and bending angle
2. **GNSS data assimilation:**
   - ZTD and STD
   - GPS RO bending angle
3. **Real time multi-GNSS:**
   - multi-GNSS algoritms development
   - real time PPP and STD estimation

Thank you for your attention

pawel.hordyniec@igig.up.wroc.pl

GNSS&Meteo Group:
www.igig.up.wroc.pl/igg/