Achievements of GNSS4SWEC Working Group 1: Advanced GNSS Processing Techniques

EMS2016-705

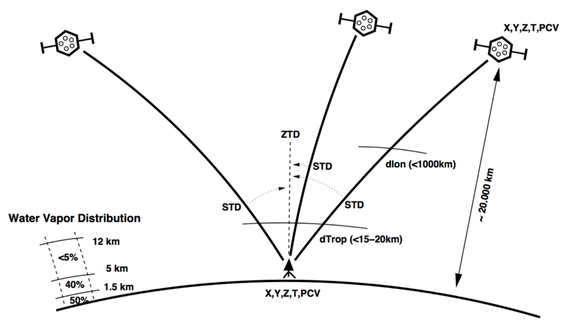
Jan Douša (1), Galina Dick (2), Michal Kačmařík (3), Pavel Václavovic (1), Eric Pottiaux (4), Florian Zus (2), Hugues Brenot (5), Gregor Möller (6), Fabian Hinterberger (6), Rosa Pacione (7), Andrea Stuerze (8), Kryštof Eben (9), Norman Teferle (10), Wenwu Ding (10), Laurent Morel (11), Jan Kaplon (12), Pawel Hordyniec (12) and Witold Rohm (12)

(1) Geodetic Observatory Pecny, RIGTC, Zdiby, Czech Republic (JAN.DOUSA@PECNY.CZ), (2) Helmholtz-Zentrum Potsdam Deutsches GeoForschungsZentrum GFZ, Potsdam, German, (3) Technical University of Ostrava, Czech Republic, (4) Royal Observatory of Belgium, Brussels, Belgium, (5) Belgian Institute for Space Aeronomy, Brussels, Belgium, (6) Vienna University of Technology, Austria, (7) E-GEOS, s.p.a. & ASI, Matera, Italy, (8) Bundesamt für Kartographie und Geodäsie, Frankfurt am Main, Germany, (9) Institute of Computer Science of the Czech Academy of Sciences, Prague, Czech Republic, (10) University of Luxembourg, Luxembourg, (11) GeF Laboratory, ESGT – CNAM, Le Mans, France, (12) Institute of Geodesy and Geoinformatics, Wroclaw University of Environmental and Life Sciences, Wroclaw, Poland

GNSS-Meteorology: Concept

Ground-based GNSS tropospheric products for meteorology:

- Focus on optimal estimating tropospheric parameters from permanent GNSS stations
- Near real-time data analysis exploiting well-known satellite and receiver positions
- Use of precise carrier-phase observations, models, etc..



GNSS model (carrier-phase observations):

$$L_{rec}^{sat} = \sigma_{rec}^{sat} + c\cdot\delta_{rec} - c\cdot\delta^{sat} + \lambda\cdot N_{rec}^{sat} + \Delta_{ion} + \Delta_{tro} + \varepsilon$$

Tropo model: Symmetric part Asymmetric part

$$\Delta_{tro} = STD = mf_H\cdot ZHD + mf_W\cdot ZWD + mf_G\left[G_N\cos(A) + G_E\sin(A)\right]$$

WG1 main objectives

The main WG1 goals are defined in four domains:

A. **Coordinating of development advanced tropospheric products** in support of weather forecasting (ultra-fast products, asymmetry monitoring, tomography, multi-constellation processing)

B. **Exploiting numerical weather data** in precise GNSS positioning (mapping functions, a priori ZHD modeling, tropospheric gradients, tropospheric models for real-time positioning, parameter conversions)

C. **GNSS data reprocessing and assessment of involved models** (to provide consistent tropospheric products for climatology)

D. **Stimulating transfer of knowledge,** tools and data exchange in support of new analysis centres and new networks setup

Sub-WG1: 10 specific activities and leaders appointed.
WG1 members: 73 members / 25 countries / 4 non-EU partners.

New ACs/networks

***Goal:** Support transfer of knowledge, data exchange for improving coverage of tropospheric products in Europe*

New ACs

- SGO – Satellite Geodetic Observatory, Penc, Hungary (Bernese)
- KTU – Karadeniz Technical University in Trabzon, Turkey (TropNET)
- AUT – Aristotle University in Thessaloniki, Greece (TropNET)
- BEU – Bulent Ecevit University in Zonguldak, Turkey (TropNET)
- IMO – Icelandic Meteorological Office (TropNET)
- *MUT – Military university of Technology, Warsaw, Poland (TropNET)*
- *SUG – Sophia University, Bulgaria (Uni Luxembourg)*
- New global ACs: GFZ, ROB

Support by:

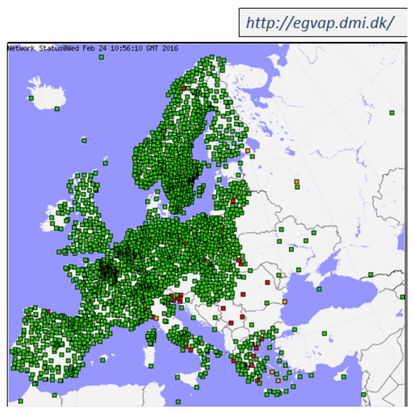
- *Uni Luxembourg – support to Bulgaria (post-processing campaign)*
- *GOP - TropNET processing package for Bernese sw*
  … including NRT monitoring & offline evaluations in GOP-TropDB

TropNET info: http://www.pecny.cz/ (Trop-NET)

New data/networks for E-GVAP

- Italy(+), Hungary, Greece, Lithuania, Latvia, Slovakia, Turkey, Iceland
  + expected: Turkey(+), Greece(+), Austria, Denmark, …
  + re-vitalised: Norway, Sweden, Finland, Poland

http://egvap.dmi.dk/

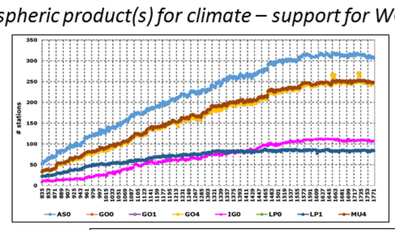


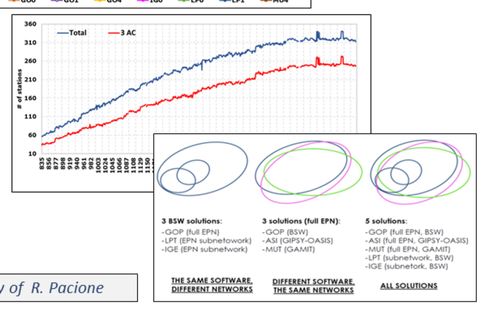
GNSS Reprocessing products

***Goal:** Prepare state-of-the-art homogeneous tropospheric product(s) for climate – support for WG3*

EUREF Repro2: 1996-2014

- ACs process full EUREF Permanent Network
  - ASI /e-GEOS (Gipsy/Oasis)
  - GOP – Geodetic Observatory Pecny (Bernese V52)
  - MUT – Military University of Technology (GAMIT)
- ACs contributes with EPN subnetworks
  - LPT – Swisstopo (Bernese V52)
  - IGN – Instituto Geografico National (Bernese V52)
- EUREF combined solution
  - ASI/E-GEOS – EUREF Tropospheric Product Coordinator





Courtesy of R. Pacione

GRUAN:

- GFZ – GeoForshungsZentrum Potsdam
- ASI/e-GEOS

Benchmark Campaign

***Goal:** Design a common data set for advanced GNSS products and strategy developments, their evaluation and inter-comparisons*

Preparation phase: design & data collection

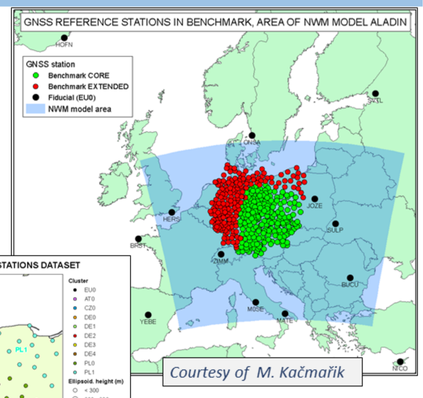
May-June 2013 - floods of Danube/Moldau/Elbe rivers
GNSS: ~500 stations (AT, CZ, DE, PL)
SYNOP: ~200 stations (AT, CZ, DE, PL)
NWM: regional (Aladin-CZ), global (ERA-Interim, NCEP GFS)
RS OBS: E-GVAP + two high-resolution (CZ)
WVR: Potsdam, Lindenberg (DE)
RADAR images: Brdy, Skalka (CZ)

Reference products

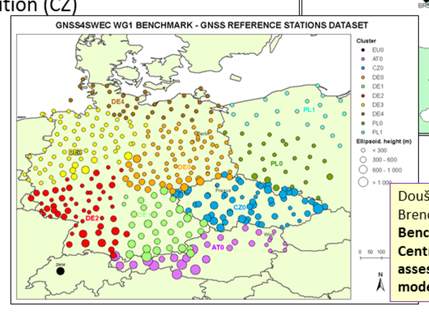
GNSS: Bernese (GOP), EPOS (GFZ)
NWM: G-Nut/Shu (GOP), DNS (GFZ)

User phase

contributions, evaluations
feedbacks, interpretations



Courtesy of M. Kačmařík



Douša J, Dick G, Kačmařík M, Brožková R, Zus F, Brenot H, Stoycheva A, Möller G, Kaplon: **Benchmark campaign and case study episode in Central Europe for development and assessment of advanced GNSS tropospheric models and products**, *Atmosph Meas Tech, 2016*

Troposphere asymmetry monitoring - gradients

***Goal:** develop and assess advance products for tropospheric asymmetry monitoring*

Courtesy of J.Douša

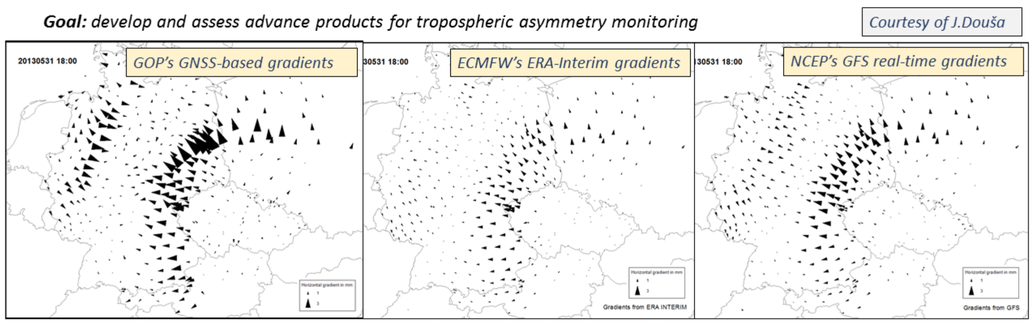


Figure: May 31, 2013 (Benchmark) – estimates of tropospheric gradients from GNSS & NWM

Advanced tropo-products: horizontal tropospheric gradients & slant delays

- Development of NRT/RT high-resolution gradients
- Development of NRT/RT slant delay retrievals including definition for new Tro-SINEX format standards
- Derivation of 1st and 2nd order troposphere gradients from NWM
- Inter-comparison of gradients and slant delays from GNSS, NWM and WVR

Validation of Slant Total Delays (STD)

***Goal:** find the best technique for GNSS STDs estimation, evaluate influence of post-fit residuals on STDs*

Benchmark data set, 10 GNSS reference stations (GOPE, KIBG, LDB0, LDB2, POTM, POTS, SAAL, WTZR, WTZS, WTZZ), 56 days

GNSS STD solutions

Name	Institution	Strategy	Software	GNSS	Elev. cut-off	Mapping function	ZTD/gradients interval	ZD post-fit residuals
CNAM	ESGT CNAM	DD	GAMIT	GPS	3 °	VMF1	1h / 1h	NO
GFZ	GFZ Potsdam	PPP	EPOS 8	GPS	7 °	GMF	15min / 1h	YES
GOP_F	GO Pecný	PPP	G-Nut/Tefnut	GPS	7 °	GMF	2.5min / 2.5min	YES
GOP_S	GO Pecný	PPP	G-Nut/Tefnut	GPS	7 °	GMF	2.5min / 2.5min	YES
ROB_G	ROB	DD	Bernese 5.2	GPS+GLO	3 °	GMF	15min / 1h	YES
ROB_V	ROB	DD	Bernese 5.2	GPS+GLO	3 °	VMF1	15min / 1h	YES
TUO_R	TU Ostrava	DD	Bernese 5.2	GPS+GLO	3 °	VMF1	1h / 3h	NO
TUO_G	TU Ostrava	DD	Bernese 5.2	GPS	3 °	VMF1	1h / 3h	NO
TUW_3	TU Vienna	PPP	NAPEOS	GPS+GLO	3 °	GMF	30min / 1h	YES
TUW_7	TU Vienna	PPP	NAPEOS	GPS+GLO	7 °	GMF	30min / 1h	YES
WUE	Wroclaw UES	PPP	Bernese 5.2	GPS	3 °	VMF1	5min / 1h	YES

NWM-based STD solutions

Name	Institution	NWM	Grid resolution
ALA/BIRA	BIRA	ALADIN-CZ	4.7 km
ALA/WUELS	Wroclaw UES	ALADIN-CZ	4.7 km
ERA/GFZ	GFZ Potsdam	ECMWF ERA-Interim	1 deg
GFS/GFZ	GFZ Potsdam	NCEP GFS	1 deg

WVR STD solution

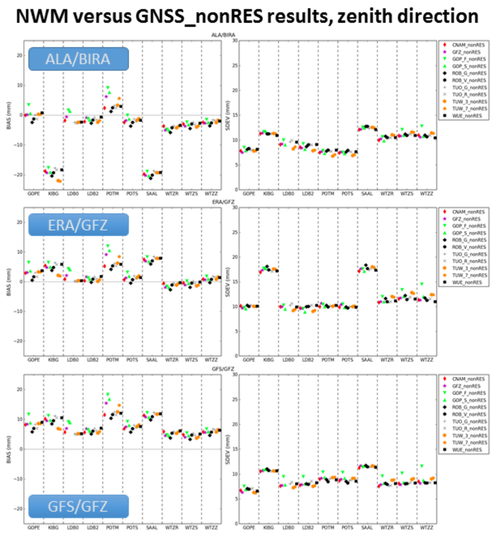
Name	Institution	Collocated GNSS stations
WVR	GFZ Potsdam	POTM, POTS

Impact of different configurations

Compared solutions	Remarks on solution differences	Bias [mm]	SDEV [mm]
TUW_3 – TUW_7	*elevation angle cut-off:* 3° vs. 7°	+0.46 ± 0.69	**0.98 ± 0.45**
ROB_G – ROB_V	*mapping function:* GMF vs. VMF1	**+1.20 ± 0.20**	**1.91 ± 0.27**
TUO_G – TUO_R	*GNSS observations:* GPS vs. GPS+GLO	+0.66 ± 0.37	**2.01 ± 0.47**
ROB_V – TUO_R	*ZTD/gradient resolution:* 15min/1h vs. 1h/3h	-0.19 ± 0.34	**3.10 ± 0.40**
GOP_F – GOP_S	*processing strategy:* Kalman filter vs. backward smoothing	-0.60 ± 0.55	**4.81 ± 0.79**

Validation of GNSS slant total delays – vs. NWM/WVR

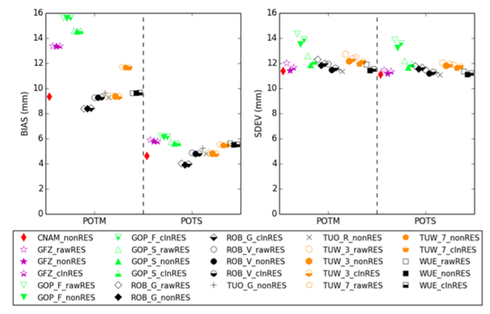
NWM versus GNSS_nonRES results, zenith direction



NWM versus GNSS results, zenith direction
SDEV values in mm, median of all GNSS solutions

Solution	NWM – GNSS_nonRES		NWM – GNSS_clnRES		NWM – GNSS_rawRES	
Elevation	7-15 °	> 15 °	7-15 °	> 15 °	7-15 °	> 15 °
ALA/BIRA	9,52	10,60	10,09	11,10	10,18	11,52
ERA/GFZ	10,65	11,60	11,25	11,99	11,23	12,40
GFS/GFZ	8,81	8,80	9,03	9,36	9,21	9,72

WVR versus GNSS results, zenith direction



Real-Time products - Demonstration Campaign

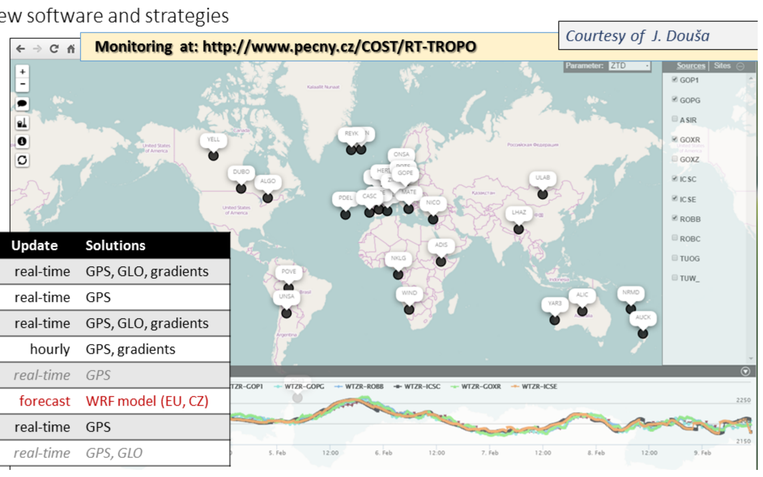
***Goal:** Develop and assess ultra-fast and real-time tropospheric products for NWP nowcasting*

- Use of IGS Real-Time Service global products for PPP (GNSS satellite orbits & clocks)
- Developing and assessing new software and strategies

RT Demo campaign

Scope: Europe (15) + Globe (17)
Start: April 1, 2015
Status: 2 March, 2016
Software: 6+1 types
Contributions: 7+1 ACs

Courtesy of J. Douša



AC	Software	Start	Update	Solutions
GOP	G-Nut/Tefnut	9.4. 2015	real-time	GPS, GLO, gradients
TUW	TUW software	15.4. 2015	real-time	GPS
ROB	G-Nut/Tefnut	23.4. 2015	real-time	GPS, GLO, gradients
ASI	Gipsy-Oasis	5.5. 2015	hourly	GPS, gradients
UL	*(PPP-wizard)*	*15.6. 2015*	*real-time*	*GPS*
ICS	G-Nut/Shu (GOP)	12.7.2015	forecast	WRF model (EU, CZ)
TUO	RTKLib	5.11.2015	real-time	GPS
BKG	*BNC*	*1.3.2016*	*real-time*	*GPS, GLO*

Real-Time monitoring – result analysis (accuracy)

Statistics over selected IGS/EUREF stations and all solutions since the beginning of RT-Demo (2015/Mar – 2016/Jun) *… not all stations provided by all ACs*

w.r.t. **EUREF**

w.r.t. **IGS**

Several ACs achieved stable and robust solution over time and stations satisfying RT requirements

One solution (ICS) consists of ZTD derived from NWM forecasts (6-12h)