Real-time Demonstration and Benchmark campaigns for developing advanced troposphere products

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IGS 2016, Sydney, 8.2 – 12.2
• Introduction

• Benchmark campaign
  • Design & data collection
  • Assessment of GNSS reference products and NWM-derived products
  • High-resolution gradient estimates, comparisons and animations
  • Study of impact of hydrometeors

• Real-Time Demonstration campaign
  • Design, contributions, monitoring
  • Assessment of RT products and smoothing strategy using the Benchmark campaign
  • Monitoring of real-time NWM corrections, dependence on forecast

• Summary
GNSS4SWEC Working Groups

**COST Action ES1206: GNSS for Severe Weather and Climate (GNSS4SWEC)**


→ 72 members
→ 26 EU+ countries
→ 4 non-EU partners
→ 10 specific activities

**WG1**

**Advanced GNSS processing techniques (AGNSS)**

Chair: **Dr Jan Dousa**, GOP (jan.dousa@pecny.cz)
Co-chair: **Dr Galina Dick**, GFZ (galina.dick@gfz-potsdam.de)

**WG2**

**GNSS for severe weather monitoring (GNSS4SW)**

Chair: **Dr Siebren de Haan**, KNMI (siebren.de.haan@knmi.nl)
Co-chair: **Dr Eric Pottiaux**, ROB (eric.pottiaux@oma.be)

**WG3**

**GNSS for climate monitoring (GNSS4C)**

Chair: **Dr Olivier Bock**, IGN (olivier.bock@ign.fr)
Co-chair: **Dr Rosa Pacione**, ASI (rosa.pacione@e-geos.it)
• Coordinating the development of advanced troposphere products in support of weather forecasting: ultra-fast production, asymmetry monitoring, tomography reconstruction, high-resolution products, multi-constellation processing

• Exploiting numerical weather model data in precise GNSS positioning and navigation
  generating synthetic troposphere parameters or observations
  evaluating NWM-derived troposphere corrections for real-time applications
  assessing troposphere mapping functions, impact of using mapping factors
  separating hydrostatic and non-hydrostatic parts in final and (near) real-time solutions

• GNSS data reprocessing to provide consistent troposphere products for climate research in Europe

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

→ 10 sub-WG setup with focus on specific topics
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)
RAOBS: 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

## GNSS reference products

Bernese + DD (GOP) – ZTDs (1h), GRD(6h)
EPOS-8 + PPP (GFZ) – ZTDs (15min), GRD(1h)

## NWM-derived parameters

G-Nut/Shu (GOP): ZWD + ZHD + T/Tm + vert. corrections
DNS (GFZ): ZWD + ZHD + GRAD + MF

<table>
<thead>
<tr>
<th>NWM source (software)</th>
<th>Grid Resolution</th>
<th>Analysis [hour]</th>
<th>Forecast [hour]</th>
<th>GNSS source (software)</th>
<th>Pairs #</th>
<th>Excl #</th>
<th>Bias [mm]</th>
<th>Sdev [mm]</th>
<th>RMS [mm]</th>
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<tbody>
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<td>ERA-Interim (Shu)</td>
<td>1 deg</td>
<td>6</td>
<td>0</td>
<td>GOP (Bernese)</td>
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<td>2</td>
<td>+0.0</td>
<td>9.6</td>
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<td>20</td>
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<tr>
<td>ALADIN (Shu)</td>
<td>4.7 km</td>
<td>6</td>
<td>0,1,2,3,4,5</td>
<td>GFZ (EPOS-8)</td>
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<td>22</td>
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<th>NWM Source (software)</th>
<th>GNSS Source (software)</th>
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<th>Sdev [mm]</th>
<th>RMS [mm]</th>
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Benchmark - NWM assessment

May 1 – June 30, 2013 - GNSS4SWEC Benchmark

Aladin-CZ – GNSS (GOP)

ERA-Interim – GNSS (GOP)

GFS – GNSS (GOP)
24-hour Evolution of Troposphere Gradients
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

Figure: May 31, 2013 (Benchmark) – estimates of tropospheric gradients from GNSS & NWM
Hydrometeors (Solheim et al., 1999): 
→ liquid water, ice, snow, graupel

\[
ZTD = ZHD + ZWD + ZHMD
\]

\[
ZHD = 10^{-6} \int_{0}^{\infty} N_h \, dz = 10^{-6} k_1 R_d \int_{0}^{\infty} \rho_m \, dz
\]

\[
ZWD = 10^{-6} \int_{0}^{\infty} N_v \, dz = 10^{-6} \int_{0}^{\infty} \left( k_2' \frac{e}{T} + k_3 \frac{e}{T^2} \right) \, dz
\]

\[
ZHMD = 10^{-6} \int_{0}^{\infty} \left( N_{lw} + N_{ice} \right) \, dz = \int_{0}^{\infty} \left( 1.45 M_{lw} + 0.69 M_{ice} \right) \, dz
\]
Real-Time products - Demonstration Campaign

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

**RT Demo campaign**

**Scope:** Europe (15) + Globe (17)

**Start:** April 1, 2015

**Status:** 2 Feb, 2016

**Software:** 6+1 types

**Contributions:** 6+1 ACs

<table>
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<tr>
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<th>Software</th>
<th>Start</th>
<th>Update</th>
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<td>G-Nut/Tefnut</td>
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<td>real-time</td>
<td>GPS, GLO, gradients</td>
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Real-Time Campaign – Recent Evaluations

**Initial phase**
- Common settings
- Software development
- Strategy enhancement
- Parameter extension
- Stability improvement
- Format standardization
- Continuous monitoring
- Benchmark exploitation

**Final solution**
- For a limited interval
- Synchronized data inputs
- Product final evaluation
Impact of NWM forecast length

**NWM forecast**

**Provider:** Institute of Computer Science, Czech Republic

**Model:** WRF 3.6

**Domain:** EU

**Resolution:** 9×9 km

**Levels:** 38 vertical

**Software:** G-Nut/Shu (GOP)

**Assessment**

**Network:** All benchmark

**Period:** 14 days

---

**Predicted ZTD**

**Degradation:**

1-2 mm / 6 hours

<table>
<thead>
<tr>
<th>NWP domain</th>
<th>Forecast window</th>
<th>Bias [mm]</th>
<th>Sdev [mm]</th>
<th>RMS [mm]</th>
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<td>-0.51</td>
<td>12.91</td>
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</table>
• GOP’s PPP with G-Nut/Tefnut using IGS Final and IGS real-time orbits + clocks

<table>
<thead>
<tr>
<th>ZTD (PPP, different inputs)</th>
<th>GNSS reference product (various)</th>
<th>Pairs #</th>
<th>Bias [mm]</th>
<th>Sdev [mm]</th>
<th>RMS [mm]</th>
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<td>GOP final (Bernese/DD)</td>
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<td>+0.4</td>
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<td>+2.8</td>
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<table>
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<tr>
<th>GNSS PPP inputs</th>
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<th>East gradient</th>
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<td>154</td>
<td>-0.05</td>
<td>0.43</td>
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</table>
Real-Time Simulation – Kalman filter + smoother

- Final ZTDs: GOP’s Bernese (1h, network solution) and GFZ’s (15min, PPP)
- Simulated RT/NRT ZTDs (IGS01 from IGS RTS): GOP’s G-Nut/Tefnut software (5 min, PPP)
- NRT simulation (Kalman+smoother): different smoothing update: 15min, 1h, 2h, 4h, 24h
• PPP, G-Nut/Tefnut (GOP)
• IGS01 orbit & clocks
• Simulated near real-time
• Converged solutions
• High-resolution product

→ The precision of high-resolution ZTDs has been improved by smoother with delays up to 4 hours

→ Smoother hasn’t been able to improve accuracy of ZTD for sub-daily run
Summary

Troposphere gradients

- Extreme gradients observed in a dense network (up to 7mm)
- Significantly lower magnitudes of gradients observed in all NWPs
- In some situations varies significantly, new information for NWP nowcasting ...

Real-time development

- RT ZTDs using PPP and IGS RTS products in RT Demo campaign (6 contributions)
- StdDev 5-9 mm for stable solutions, Bias < 5mm (but still highly site-specific)
- Offline simulated ZTD estimates using IGS RTS and IGS Final products showed a mean degradation of 1 mm in StdDev and about 2 mm mean bias

NWM for external troposphere corrections

- Accuracy of NWMs is 8-12 mm
- ZTD mean accuracy degradation with longer prediction is 1-2 mm / 6 hours

Hydrometeors

- Non-negligible components in rare situations, may impact ZTDs up to 2 cm!
Acknowledgements

• IGS for data and variety of GNSS products and models (RTS, MGEX, Final, PCO/PCVs, ...)
• EUREF for reference frame GNSS stations
• EPOSA, SAPOS, ASG-EUPOS, CZEPOS, VESOG, GEONAS, Trimble for GNSS data
• ECMWF for global ERA-Interim re-analysis numerical weather model
• NCEP for Global Forecast System (GFS) numerical weather model
• CHMI for mesoscale Aladin-CZ numerical weather model

EU COST Action ES1206 for the financial support of this collaborative effort
Ministry of Education, Youth and Science of the Czech Republic for the financial support