Global Near Real-Time, Multi-GNSS and Ultra-Fast Troposphere Estimation at Geodetic Observatory Pecný

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Outline

- Introduction
- Global hourly near – real-time ZTD estimates
- Assessment of multi-GNSS ZTD estimates
- Ultra-fast/real-time estimates of ZTD
- Summary
Ground-based GPS-meteorology

- 15 Institutions, 7 ACs, > 200 GPS sites

TOUGH (2003-2006): "Targeting Optimal Use of GPS Humidity Measurements in Meteorology"
- 15 Institutions, 12 ACs, > 400 GPS sites

E-GVAP I (2006 - 2009), E-GVAP II (2010-2012)
"The EUMETNET GPS Water Vapor Programme"
- 13 Institutions, 12 ACs, > 1600 GPS sites

COST Action (pre-proposal) – March 31, 2012
"Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate (GNSS4SWEC)"
- interested 37 institutions from 25 countries
- See poster by Jones at al.
Near real-time ZTD solutions by GOP

**Processing requirements:**
- hourly GNSS data and precise IGS ultra/rapid orbits

**GOP processing features:**
- Bernese GPS software v.5.0
- Process starts every hour at HH:20
- 4 hourly data batches and normal equations (NEQ)
- ZTD based on last 12 hours from NEQ combination
- Coordinates based on 28 days from NEQ combination

**GOP ZTD characteristics:**
- ZTD product (HH:00 – HH:59) - linear trend model
  (piece-wise linear function)
- ZTD product filtering:
  - min 4 hours in NRT ZTD solution
  - min 2 days in NRT CRD solution

**ZTD solutions (E-GVAP):**
- Regional/national (GPS)
- Regional/national (GNSS)
- Global (GPS)

Data collection
- GPS global 130 sites ≈ 7min
- GPS Europe 80 sites ≈ 4min
- GNSS Europe 100 sites ≈ 5min
GNSS regional network processed in GOP

Sites processed by GOP AC [GPS–meteo]
GOP NRT ZTD long-term comparison

Time-series of monthly ZTD comparisons [GOP-NRT GPS/GNSS regional - EUR-repro1]

Time-series of monthly ZTD comparisons [GOP-NRT GPS/GNSS regional - raobs/BADC]
GOP global hourly updated ZTD product
Getting official routine global ZTD solution

October 1, 2010 – started routine solution (testing status)
Evaluation 10 months with 80 global stations (IGS/EUREF repro1, radiosonde)
September 10, 2011 – switched to operational mode (UK MetOffice request)

Fig left - hourly files @ GOP DC → global solution started at HH:40
Fig right - a global network extension (80->170), but up to 20% no data
Global GOP ZTD – example time-series
ZTD time-series for European/global stations

Time-series of weekly ZTD comparisons [GOP NRT global - EUR-repro1]

Time-series of weekly ZTD comparisons [GOP NRT global - IGS-repro1]

GOP official / reconfigured with 170 sites

JPL → USNO
GOP near real-time ZTD products

GOP_GLOB x IGS/REP1 [ZTD Bias]
GOP near real-time ZTD products
# Global NRT ZTD vs. radiosondes

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<th>GPS station</th>
<th>Radiosonde number</th>
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**GOP global hourly ZTD (2010-2012)**

**ZTD NRT global product w.r.t.:**
- IGS post-processing ZTD product
- UK Met Office global NWP model

Clear quality latitude dependence to NWP model (usually NWP more dry and quality higher close to equator)
GOP multi-GNSS evaluation and new NRT ZTD product
ZTD - GPS, GLONASS, multi-GNSS (2009)

GNSS Zenith Total Delay [NRT: -6 hours]

GLONASS x GPS Zenith Total Delays [stations]

StdDev

Bias
Stand-alone GPS vs. GLONASS - offline
(all EPN multi-GNSS stations, I05 vs. I08 models)

- Processing of all EPN multi-GNSS stations over 2 months (around 1631)
- The GPS data contributes to ZTD product here about the factor of 2/3
- IGS08 PCO+PCV model shows better agreement of GPS with GLONASS
Operational NRT multi-GNSS GOP ZTD

- Multi-GNSS ZTD started after GPS week 1632 (IGS08 PCV+PCO models)
- Using the same strategy as GPS official contribution to E-GVAP, but more frequently exploit robustness of GOP NRT solution than stand-alone GPS
- Testing unofficial IGV (GPS+GLONASS) ultra-rapid orbits
- With exception of June/July (leap second), running continuously
- Compared with GPS (official) shows slightly better Sdev and Bias

Time-series of weekly ZTD comparisons [GOP-NRT GPS/GNSS - PP_EURREP1]

![Graph showing time-series of weekly ZTD comparisons]
GOP ultra-fast/real-time ZTD product development
G-Nut software library (in-house solution)

- C++, object-oriented, multi-threaded, multi-platform (linux, windows)
- G-Nut library developments (open-source) + applications
- Support filter and LSQ processing (using real-time stream and data-files)
- Support multi-GNSS (GPS, GLONASS, Galileo,..)
- Flexible core library and data/product containers for extension in future
- Sequence of targets:
  - Real-time, offline PPP in static & kinematic modes
  - Troposphere estimation in quasi real-time for severe weather monitoring
  - Precise satellite clock estimations (PPP support)
  - Products for PPP ambiguity resolution (in Europe), augmentation,....
  - ....

For more details see the poster by Václavovic, Douša and Györi (P07-09)
G-Nut software package

**http://www.pecny.cz/** (GNSS, software) ... looks here for updates ...

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**Data, models, products self-contained classes and their containers**

The main virtual base `gdata` class (dark grey background) represents any data, model or product classes either as self-contained data/product elements or their containers. This class provides a common mutex, `glog` pointer for common and multi-threaded logging and data type or group identification, which is later defined in each derived class.

Self-contained data/products elements (pink background) provides independent data such as e.g. all observation for a single station, satellite navigation message, RTCM position corrections, polynomials of precise ephemerides valid over a specific time, etc.

The containers (green background) are usually apply maps defined in a way to easily find the relevant self-contained element (pink background). In some classes (e.g. `gallnav`, `gallprec`) the cache is implemented to speed up the searching procedure, which is always done through an internal (find) function returning a pointer to specific data/product element.
Forward filter ZTD estimated with IGS precise orbits and clock during 44 days (April-May 2012), example for GOPE and AREQ sites, April-10, 2012
Simulated real-time ZTD (RTCM)

Forward filter ZTD estimation in simulated real-time with IGS01 corrections during 44 days (April-May 2012), example for GOPE and AREQ, April-10, 2012
Kinematic real-time solution (RTCM)

Forward filter for ZTD with estimating kinematic coordinates, IGS01 corrections during 44 days (April-May 2012), example for GOPE and ONSA, April-10, 2012
Statistic for ZTD based on two software

44-days statistics (April-May) from BNC2.6 and gNut-Geb w.r.t IGS/EUR repro1

ZTD comparison : gNut-GBE x BNC [RT] x EUR repro1

ZTD comparison : gNut-GBE x BNC [RT] x IGS repro1
CRD and ZTD dependence on RTCM age

Impact of 10-70s delays of RTCM corrections on troposphere and coordinates

Dependency of ZTD estimates on RTCM correction delay

Dependency of coordinate estimates on RTCM correction delay
Summary

- Routine ZTD processing routinely operated at GOP since 2001 - evaluated using EUREF, IGS reference products as well as radiosondes.

- First global hourly ZTD solution developed and evaluated over one year (2010-2011) and, on request, officially accepted in Sept 2011 in E-GVAP. The global product was evaluated with IGS, EUREF ZTD products, global NWP model (UK MetOffice) and radiosondes.

- Multi-GNSS hourly ZTD solution developed, GLONASS and GPS stand-alone products tested and after GPS week 1631 (with adoption of IGS08 models providing much better consistency btw GPS and GLONASS PCV+PCO) routinely provided based on IGU + IGV orbits.

- New core software library under development (G-Nut) and application for real-time or ultra-fast (sub-hourly) ZTD solutions based on IGS RTPP products and using PPP technique. First results were demonstrated.

- Most of the product monitoring can be found at [http://www.pecny.cz](http://www.pecny.cz)
Thank for your attention!

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ITRF2008 solution and ITRF2008 densification

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