Development towards inter-technique tropospheric parameter comparisons and their exploitation

J. Douša¹, S. Byram², G. Győri¹, O. Böhm¹, C. Hackman², F. Zus³

¹ Geodetic Observatory Pecný, RIGTC, Czech Republic
² U.S. Naval Observatory, U.S.A.
³ GFZ German Research Center for Geosciences, Germany

(jan.dousa@pecny.cz)

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Motivations & Goals

Tropospheric parameters from space geodetic techniques are side products along with estimating geodetic parameters of main interest.

However, various approximations still needed for tropospheric modeling:

- Separating hydrostatic/wet parts: \( \text{TDO} = \text{ZHD} + \text{ZWD} \)
- Mapping to the zenith: \( \text{STD}(\text{ele}) = m_f h \text{ZHD} + m_f w \text{ZWD} \)
- Asymmetry modeling: \( \text{STD}(\text{ele, azi}) = \text{STD}(\text{ele}) + m_f g (G_N \cos A + G_E \sin A) \)

Motivations – complementary benefits for:

- **Geodesy:** assessments of tropospheric approximations as well as other models
- **Geodesy:** exploitation of external tropospheric parameters for positioning
- **Meteorology:** assimilation of \( \text{ZTDs/STDs/grads} \) into numerical weather models
- **Climatology:** monitoring of long-term trends in integrated water vapor

Goals:

- Intra-technique comparisons (GNSS or other space geodetic techniques)
- Inter-technique comparisons (independent evaluations)
- Additional functionalities – QC, conversions, TS analyses, archive, user support
IGS TropoWG and GOP-TropDB development

Database optimizations

... to deal with billions of records, various sources and data types, ...

Data domain (basic design)
Individual tables designed for specific data sources (different content), for example:

- tGNSS
- tVLBI
- tDORIS
- tRAOBS
- tWVR
- tNWM
- tSYNOP
- ...

Time domain (partitioning)
Table partitioning (on a yearly basis)
Maintained by triggers (automated)
Inherited features (single interface)
Keep reasonable size for physical tables

SQL commands (analysis)
Optimizing command sequences, priorities, sampling, ...
Very specific SQL domain

Extensive data processing (vs. running costs)
Optimized data batches for DB insert function (to minimize running costs)
C/C++, perl outside DB or as embedded DB functions
e.g. radiosonde, Numerical Weather Models
### Data filling, pre-processing, format issues

**Extract-Transform-Load (ETL) input procedures**

- to decode (and pre-process) various input data formats
- to prepare and execute SQL command (INSERT / UPDATE)

### Input filter (decoders) - Decoding format (data source) - Insert SQL function - Remarks - Data type

<table>
<thead>
<tr>
<th>Input filter (decoders)</th>
<th>Decoding format (data source)</th>
<th>Insert SQL function</th>
<th>Remarks</th>
<th>Data type</th>
</tr>
</thead>
<tbody>
<tr>
<td>tro-snx-gnss2DB.pl</td>
<td>Tropo-SINEX</td>
<td>fnInsertGNSS</td>
<td>ZTDs from IGS/EUREF products</td>
<td>space geodetic technique</td>
</tr>
<tr>
<td>tro-snx-ivs2DB.pl</td>
<td>Tropo-SINEX (IVS)</td>
<td>fnInsertVLBI</td>
<td>ZTDs from IVS combined products</td>
<td>space geodetic technique</td>
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<tr>
<td>tro-snx-ids2DB.pl</td>
<td>Tropo-SINEX (GOP)</td>
<td>fnInsertDORIS</td>
<td>ZTDs from GOP tropospheric solutions</td>
<td>space geodetic technique</td>
</tr>
<tr>
<td>rt-flt2DB.pl</td>
<td>G-Nut/Tefnut output</td>
<td>fnInsertGNSS</td>
<td>ZTDs from GOP real-time analysis</td>
<td>space geodetic technique</td>
</tr>
<tr>
<td>cost-trp2DB.pl</td>
<td>COST 716 format</td>
<td>fnInsertGNSS</td>
<td>ZTDs from E-GVAP</td>
<td>in situ meteorological observations</td>
</tr>
<tr>
<td>met-rnx2DB.pl</td>
<td>Meteo RINEX</td>
<td>fnInsertINSIT</td>
<td>In situ meteorological data (GNSS)</td>
<td>in situ meteorological observations</td>
</tr>
<tr>
<td>cost-met2DB.pl</td>
<td>COST Met format</td>
<td>fnInsertSYNOP</td>
<td>COST 716 meteorological data</td>
<td>in situ meteorological observations</td>
</tr>
<tr>
<td>wvr2DB.pl</td>
<td>Radiometrics</td>
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<td>Radiometer data</td>
<td>NWM products</td>
</tr>
<tr>
<td>raobs2DB.pl</td>
<td>BADC old/new format</td>
<td>fnInsertRAOBS</td>
<td>BADC radiosonde integrated data</td>
<td>NWM products</td>
</tr>
<tr>
<td>raobs2DB.pl</td>
<td>EGVAP format</td>
<td>fnInsertRAOBS</td>
<td>EGVAP radiosonde integrated data</td>
<td>NWM products</td>
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<tr>
<td>raobs2DB.pl</td>
<td>IGRA format</td>
<td>fnInsertRAOBS</td>
<td>IGRA radiosonde integrated data</td>
<td>NWM products</td>
</tr>
<tr>
<td>cost-trp2DB.pl</td>
<td>COST 716 format</td>
<td>fnInsertNWM</td>
<td>ZTDs from NWM</td>
<td>NWM products</td>
</tr>
<tr>
<td>nwm-shu2DB.pl</td>
<td>G-Nut/Shu (ECMWF,NCEP)</td>
<td>fnInsertNWM</td>
<td>NWM integrated data and decay params</td>
<td>NWM products</td>
</tr>
<tr>
<td>nwm-dns2DB.pl</td>
<td>DNS (ECMWF,NCEP)</td>
<td>fnInsertNWM</td>
<td>NWM integrated data, gradients</td>
<td>NWM products</td>
</tr>
<tr>
<td>gpt2DB.pl</td>
<td>GPT2 model</td>
<td>fnInsertGPT2</td>
<td>Global Pressure and Temperature</td>
<td>Auxiliary models</td>
</tr>
<tr>
<td>geoid2DB.pl</td>
<td>EGM2008 model</td>
<td>fnInsertGEOID</td>
<td>EGM2008 geoid grid</td>
<td>Auxiliary models</td>
</tr>
<tr>
<td>surf2DB.pl</td>
<td>ETOPO1 model</td>
<td>fnInsertSURF</td>
<td>ETOPO1 global relief grid</td>
<td>Auxiliary models</td>
</tr>
</tbody>
</table>

Many formats! Official Tro-SINEX could help.
NEW: Numerical Weather Model field data processing

... to provide background data information for DB functionality ...

G-Nut/Shu - developed at GOP for NWM data processing
- Calculate 2D tropospheric correction model or site-specific parameters time-series for DB
- Assess scenarios for vertical approximations, parameter calculations (ZWD, T_m) and others

DNS - Direct Numerical Simulation - developed at GFZ (F. Zus)
- Highly efficient tool for thousands of NWM ray-traces in a second (a single standard CPU)
- NWM-derived mapping function coefficients & horizontal gradients

ERA-Interim (in GOP-TropDB)
- Currently: 1990 – 2013 and continuously extended
- Full period processed in 1°x 1° grid for surface & vertical reduction parameters
- Auxiliary background model for GOP-TropDB - tropospheric ties, converting factors, ...

.... considering to include other NWMs (in E-GVAP and GNSS4SWEC projects)
- Site-specific extractions only (e.g. for IGS/IVS/IDS/EUREF site locations)
- Global and regional high-resolution models and predictions
  - Assessment of NWM quality in support of GNSS processing and real-time positioning
  - Providing a feedback for the NWM providers when compared w.r.t. GNSS products as reference
New tropospheric correction model for positioning

... default model for flexible support of GOP-TropDB functionality ...

- Enhanced ZWD vertical approximation → applied now in the GOP-TropDB
- Improved ZWD physical model of Askne and Nordius (1987)
- Requires to assess various NWM models as a potential input for GNSS real-time positioning

Douša, Eliaš, Václavovic - Tropospheric correction model in support of Precise Point Positioning
PS12 – Real-time Service - Poster Session

Douša and Eliaš (2014)
An improved model for tropospheric wet delay, GRL 41

Global ERA-Interim data (2005-06-05:00)
Tropospheric ties – new ZWD vertical reduction

... approximations for correcting altitude differences in ZTD comparisons ...

\( \Delta ZHD \) (Teke et al., 2011)

\[ \Delta ZHD = \frac{0.0022768(p - p_0)}{1 - 0.00266 \cdot \cos(2\varphi) - 0.028 \cdot 10^{-6} h_0} \]

\( \Delta ZWD \) (Gyori and Dousa, 2014)

Vertical decay parameter \( \beta, \gamma \) estimated from ERA-Interim background data set

\[ \Delta ZWD = ZWD_0 \left[ \left( 1 - \frac{\beta (h - h_0)}{T_0} \right)^{(\gamma + 1) R_d} - 1 \right] \]

**ZWD vertical reduction assessment via global ERA-Interim NWM data**

ZWD vertically approximated at different altitudes compared to integrated ZWDs

<table>
<thead>
<tr>
<th>Height</th>
<th>0-1 km</th>
<th>1-2 km</th>
<th>2-3 km</th>
<th>3-4 km</th>
<th>4-5 km</th>
<th>5-6 km</th>
<th>6-7 km</th>
<th>7-8 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNB3 orig</td>
<td>11.4</td>
<td>20.7</td>
<td>20.2</td>
<td>19.9</td>
<td>15.3</td>
<td>13.2</td>
<td>10.4</td>
<td>7.9</td>
</tr>
<tr>
<td>New f(P)</td>
<td>8.2</td>
<td>7.4</td>
<td>5.5</td>
<td>6.5</td>
<td>5.6</td>
<td>5.6</td>
<td>5.0</td>
<td>3.7</td>
</tr>
<tr>
<td>New f(H)</td>
<td>8.3</td>
<td>7.4</td>
<td>5.5</td>
<td>6.5</td>
<td>5.7</td>
<td>5.6</td>
<td>5.0</td>
<td>3.7</td>
</tr>
</tbody>
</table>

*Table shows r.m.s. of ZWD differences [mm] at various altitudes*

*Dousa J, Elias M (2014), An improved model for tropospheric wet delay, GRL 41*
Results of NCEP’s GFS model (global scope)

Zus et al. (2014) The rapid and precise computation of GPS slant delays and mapping factors utilizing a numerical weather model, Radio Science, 49(3) 207-216
Gradients from ERA-Interim model (in Europe)

... assessment of enhanced NWM data exploitation in positioning ...

Zus et al (2014) The information content of GPS slant tropospheric delays @ Tropo Poster session
ERA-Interim long-term evaluation

... total statistics of ZTD from ERA-Interim compared to IGS (top) and EUREF (bottom)
ERA-Interim long-term evaluation

... monthly statistics of ZTD from ERA-Interim compared to IGS (top) and EUREF (bottom)

Estimated

Interpolated
GOP DORIS tropospheric parameters compared to IGS finals:

... revealed ZTD of 3 IDS stations significantly biased: AREQ, CHPI, SANT

→ South Atlantic Anomaly identified affecting Spot 5 satellite

Zenith Total Delay: DORIS (Spot-5) x GPS (IGSPPP)

GOP DORIS tropospheric solutions by P. Štěpánek (GOP)

IVS long-term evaluation (preliminary)

... statistics of ZTD from VLBI compared to IGS (top) and EUREF (bottom)

**Note:** To compare rigorously, we require to update input format and meta data availability

*IVS combined solutions by R. Heinkelman (GFZ)*
Individual IGS AC tropo-product comparison

... assessment of processing strategy

**CODE Repro2** ZTD results: **COD × COF**
period 1994-2013
which is more close to external data?

1. Very small differences in midnight
2. Assessment by radiosonde shows:
   positive results for **COD** (blue)
   positive results for **COF** (yellow/red)
Developing and other potential services

Web-based interface to the GOP-TropDB (in development)
- shared effort between USNO & GOP
- interactive meta data inventory & visualization
- comparison results & statistics visualization (static)
- combination/multi-plots of various raw data outputs (dynamic)
- extraction for raw data, differences, auxiliary parameters

Potential custom comparisons ... (or via GOP-TropDB dissemination)
- user specific data upload
- comparisons/visualizations of user-defined stations & time span
Considering data/functions dissemination

... specific development towards PUBLIC vs. USER area

→ various dissemination scenarios for user support
  • via login account at GOP (or USNO) or through web-interface
  • via a regular DB source update and public data dumps
  • (via database replication, web service etc.)

Initial interest in two projects:
  – GOP/USNO bilateral project in support of IGS TropoWG
  – GNSS4SWEC project for meteorology/climatology applications
Summary and outlook

Current work

- Focus on the background functionality development
  - New tropospheric ties
  - Sw tools for NWM data processing
  - Background data from ECMWF’s ERA-Interim (1990-present)
  - Structure in support of extended goals (public/data, web-interfaces etc.)
- Preliminary functionality testing & visualization
  - Rough comparison results (assess the potential)
  - Static visualization (via time-series, geographical maps, total statistics, ...)

Outlook

- Focus on the foreground user-friendly interfaces
  - Web-interfaces with on request functions
  - DB data extractions
  - Dissemination functions etc.
- Focus on detailed results of individual comparison, data sources
  - New data sources (NWM, RAOBS, ...)
  - Additional parameters (meteo, gradients, slants)