Developments in Near-Real-Time Tropospheric Delay Estimations

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( http://pecny.asu.cas.cz/meteo/ )

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Processing Parameters

'EUREF' [from BKG] (13) : BOGO, BOR1, BRUS, GOPE, GRAA, HOFN, ONSA, PENC, PFAN, REYK, UPAD, WTZR, ZIMM

'IGS' [from CDDIS] (8) : KIRU, STJO, GODE, CRO1, KOUR, HRAO, SUTH, NSSP

Meteo : BOGO, BRUS, PENC, ZIMM, GRAA, (GOPE)

Processing strategies:

- Coordinates : heavily constrained
- Residual check : 20 mm
- Elev. cut-off : $15^\circ/8^\circ$ [cos(z)]
- Ambiguities : free/fix (QIF)
- TZD : per 20 minutes, all site [ABS: 1m / REL: 0.0025m]
- Apriori TZD : Saastamoinen
- Gradients : no/yes [1-2-6-12 / day]
- Orbits : CODE P2/IGR (2-daily arcs)
- Satellite exclusion : day-to-day consistency check [Total-RMS: 0.5m / 5m]
- Orbit improvements : Argument of Latitude (AoL) [0.01”]
  : AoL + 2 RPR [1.10e-8 m/s^2]
Aspects of Near-Real-Time Processing

A) Satellite selection/exclusion. Using 2-daily orbit arcs we check day-to-day consistency between daily ephemerides. Hence, we derive Total-RMS residual criterion for later satellite exclusion procedure (SEP). This strategy is preferred against the usage of predicted SP3 accuracy code. CODE P2 product are applied due to early availability before the noon (each new 2-daily arc is usually switched at every midday).

B) Periodical instabilities. Due to prevailing bad satellites in period 12-13 UTC (8-15 UTC) together with decreasing quality when forthcoming to the end of used arcs (large residuals), the periodical instability occurs each day. (There is any good solution up to now to avoid this problem!)

C) Partial orbit improvement. Estimating Argument of Latitude (AOL) for each satellite we tried to improve predicted orbits partially in along-track direction – the most uncertainty modelled component. Additionally the other variants uses 2 radiation pressure coefficients (direct D0 and Y-bias Y0) or along-track stochastic parameters.

D) 1H+24C vs. 4H processing. 1H+24C solution uses 1H-data processing together with the combination of the last 24 hours, while 4H variant always processes the last 4-hourly data independently. In the first case we extract last-hour values, in the second case already the 3rd-hour values. Hence, in both variants we can check the consistency in the results, in the 4H solution even one hour ahead. The 4H results have usually weakly lower stability (is more dependent on the quality of all used orbit arcs); it was also tested for ambiguity-fixed solution (but seems to be unsuccessful). The both variants spend approximately the same CPU time.
Aspects of Near-Real-Time Processing

(Continuation)

B) Post-processed variants. Different post-processed variants using IGS rapid orbits (IGR) were tested: the data cut-off angle (plus elevation dependent weighting – ELW), ambiguity-fixed solution, gradient estimations. It can be shown some systematic biases occur. Comparing above strategies: lowering cut-off angle to 8° (+ ELW) usually increases the ZTD values, as well as the introduction of additional gradient estimation to ZTD increases it, but ambiguity-fixed solution decreases it.

F) PWV accuracy. We estimated the accuracy of all the variants of our processing (NRT and post-processed) by comparing GPS derived PWV to radiosonde data stemming from nearby stations. Unfortunately, for some stations (ZIMM, BOGO, BRUS) the biases cannot be still evaluated due to the missing informations of mutual localization of the radiosondes and GPS sites. The result comparisons are evaluated and sorted considering the ZTD formal RMS from the estimation.

C) Extent of GPS network. Including the IGS sites from other continents we enlarged the processed GPS network. The estimation of absolute ZTD values (no site constrained) continued even in the period of last 14 days when CODE center was unreachable (Aug 21 – ???). At this time, the network consisted only of European hourly GPS sites available at BKG. For both periods the PWV results are compared separately to check the stability and biases stemming partially from the different extent of the network.
A1) CODE P2: Predicted vs. Rapid Orbit Differences

For each satellite (SATELLITE 1, SATELLITE 2, ..., SATELLITE 24), the graphs show the differences in orbit parameters over time. The differences are plotted against time, with the x-axis representing dates and times (e.g., 24 May 12:00, 25 May 12:00). The y-axis represents the orbital differences in meters, with a range from -1.0 to 1.0 meters.

Key: Red lines indicate Radial residuals, black lines show Along Track residuals, and gray lines denote Out of Plane residuals. The orbit differences are noted for the period from 1999 Jun 01 to 1999 Jun 06, with each satellite's orbital parameters compared to a reference model.
A2) Impact of Satellite Selection: ZTD Plot (GOPE)

no Satell-Excl vs. Satellite-Excl.
B1) Periodical Instability: ZTD Plot (PFAN)
B2) Periodical Instability: ZTD Plot

Daily satellite availability – problematic periods marked (12-13 UTC)
C1) Partial Orbit Improvements: ZTD Plot (PFAN)

No orbit improv. vs. AoL+2-RPR orbit improv. (offic. solution)

![Graph showing ZTD plot with different orbit improvement scenarios.](image)
C2) Partial Orbit Improvements: ZTD Plot (WTZR)

AoL-est. vs. AoL+2-Stoch-est.

Total zenith tropospheric delay [meters]

Apriori model
EL (4H) Arg. of Lat. (AoL) sol.
EL (4H) AoL + 2 Stoch. sol.
RA (24H) reference sol.

plotted: Sep 06, 1999 (13:19)

RMS [mm]

D1) 24C/1H vs. 4H (NRT processing) : ZTD Plot (BRUS)

The graph shows the comparison of total zenith tropospheric delay (ZTD) for 24C/1H and 4H data with NRT processing. The graph includes the BRUS model, 4H (ER) solution, 24C (CR) solution, and a reference 24H (RA) solution. The data is plotted from August 31 to September 4, 1999 (12:46) with a focus on the RMS values in millimeters. The graph indicates variability in the ZTD values over the period, with significant drops and rises.
E1) Post-Processing Strategies: PWV Plot

![PWV Plot](image)

- RD (6410) - PWV
- RA (5410) - PWV
- RFCS.PWV

Plot dates: Sep 02, 1991 (14:56)

![PWV Residuals Plot](image)

- actual PWV residuals - RH
- actual PWV residuals - RA
- GFAD + actual PWV residuals - RG
- abs_txx + GFAD + actual PWV residuals - RX

Plot dates: Sep 02, 1991 (14:56)
## F1) PWV accuracy: Post-processed variants (GOPE)

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<tr>
<th>24H SOL</th>
<th>ZTD-RMS [mm]</th>
<th>nobs #</th>
<th>PWV-bias [mm]</th>
<th>PWV-sig [mm]</th>
<th>Remarks</th>
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G1) GPS Network Extent

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Summary

Specific NRT processing strategy:

- effective combination of satellite selection/exclusion procedure together with partial orbit improvement was proved as a significant contribution

Final GOP results: (http://pecny.asu.cas.cz/meteo/)

- our best NRT variant – CR (24C/1H): Arg. of Lat. + 2-RPR using 2-daily orbits and day-to-day Total-RMS < 0.5m exclusion criterion – shows significantly improved stability of the NRT results
- post-processed variant – RX (24H): 8° elev-cut-off + ambig.-fixed + 2 gradients/day – shows the smallest bias in comparison to PWV from radiosondes

Future investigations:

- orbit improvement studies (NRT upgraded orbits?)
- empirical study of orbit error impact for tropospheric estimates
- systematic bias study (gradients, ambig.-fixed in NRT?)
- GPS network density and extent (and distribution of processing)
- effective time interval for tropospheric corrections
- NRT ionospheric model estimates
- study of 'low-cost' one-frequency GPS apparatus usage ... etc.