Evaluation of the Vienna APL corrections using reprocessed GNSS series

R. Dach\textsuperscript{1} and P. Steigenberger\textsuperscript{2}

\textsuperscript{1}Astronomical Institute, University of Bern
Sidlerstrasse 5, CH-3012 Bern

\textsuperscript{2}Institut für Astronomische und Physikalische Geodäsie, TU München

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CODE, Center for Orbit Determination in Europe, is one of the Analysis Centers of the IGS. CODE is formed as a joint venture of

- the Astronomical Institute of the University of Bern (AIUB),
- the Swiss Federal Office of Topography (swisstopo),
- the Bundesamt für Kartographie und Geodäsie (BKG), and
- the Institut für Astronomische und Physikalische Geodäsie of TU München (IAPG, TUM).
Recent CODE reprocessing effort done by P. Steigenberger at TU Munich:
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Time interval: January 1994 to May 2003  GPS–only solution
May 2003 – present  GPS+GLONASS solution
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- **Following the IERS 2010 conventions**
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- fully consistent with IGS08.ATX and IGS08.SNX
- following the IERS 2010 conventions
- based on existing screened observation files
- considering the CODE processing strategy from June 2011
  - ambiguity resolution for GLONASS according to the latest implementations at CODE
  - including a GPS/GLONASS antenna calibration bias
  - ...
The CODE reprocessing has included the Vienna APL model (Wijaya et al. 2011) with scaling factors allowing to
- validate the model from GNSS data,
- easily compute two consistent solutions with/without APL corrections.
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From all days in 2010 two days are selected
21. January: most active APL in all stations of the network
29. May: least active APL in all stations of the network
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From all days in 2010 two days are selected
21. January: most active APL in all stations of the network
29. May: least active APL in all stations of the network

For these two days all APL corrections are summed in the processing program for each station.¹

¹Cannot be re-computed after data processing, e.g., from SINEX level!!
APL and GNSS–derived coordinates

Mean APL corrections for each station extracted from Vienna model during data processing

vertical component

APL correction in mm

21. January 2010
APL and GNSS–derived coordinates

Coordinate difference between solutions applying/not applying APL corrections

Coordinate difference in mm

vertical component

21. January 2010
Mean APL corrections for each station extracted from Vienna model during data processing.

APL correction in mm

horizontal component

21. January 2010
APL and GNSS–derived coordinates

Coordinate difference between solutions applying/not applying APL corrections

Coordinate difference in mm

horizontal component

21. January 2010
Coordinate difference between solutions applying/not applying but correcting for APL effect

Coordinate difference in mm

21. January 2010
Residuals of a Helmert-transformation between solutions applying/not applying but correcting for APL effect

Coordinate difference in mm

21. January 2010
RMS of coordinate comparison
APL and GNSS–derived coordinates

RMS of coordinate comparison

- Difference of the solution without applying APL corrections...

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>$RMS_N$</td>
<td>$RMS_E$</td>
</tr>
<tr>
<td>1.1 mm</td>
<td>1.4 mm</td>
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</tbody>
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...with respect to the solution applying the APL corrections on observation level.
### RMS of coordinate comparison

- **Difference of the solution without applying APL corrections...**
  - 21. January 2010
  - 29. May 2010

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<tbody>
<tr>
<td>21. Jan.</td>
<td>1.1 mm</td>
<td>1.4 mm</td>
<td>5.3 mm</td>
<td>0.6 mm</td>
<td>0.4 mm</td>
<td>1.5 mm</td>
</tr>
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</table>

- **Difference of the solution without applying but correcting for the APL effect...**
  - 21. January 2010
  - 29. May 2010

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<tbody>
<tr>
<td>21. Jan.</td>
<td>1.8 mm</td>
<td>2.5 mm</td>
<td>1.7 mm</td>
<td>0.5 mm</td>
<td>0.4 mm</td>
<td>0.2 mm</td>
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...with respect to the solution applying the APL corrections on observation level.
### APL and GNSS–derived coordinates

#### RMS of coordinate comparison

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- **Residuals of a Helmert–transformation of the solution without applying but correcting for the APL effect...**

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...with respect to the solution applying the APL corrections on observation level.
Residuals of a Helmert–transformation between solutions applying/not applying but correcting for APL effect

Residual effect in %

21. January 2010
Residuals of a Helmert–transformation between solutions applying/not applying but correcting for APL effect
Differences between troposphere estimates from solutions applying/not applying APL corrections

![Graph showing differences between troposphere estimates from solutions applying/not applying APL corrections for stations ZIMM, WUHN, and YAR2. The x-axis represents time from 00:00 to 00:00, and the y-axis represents values in millimeters. The graph includes lines for red (difference of troposphere estimates) and green (APL effect). Units: mm. 21. January 2010]
Differences between troposphere estimates from solutions applying/not applying APL corrections

- ZIMM
- WUHN
- YAR2

units: mm
red: difference of troposphere estimates, green: APL effect

29. May 2010
RMS of Earth-fixed satellite positions

- Difference of the solution without applying APL corrections...

<table>
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<tr>
<td>$RMS_X$</td>
<td>5.2 mm</td>
<td>2.0 mm</td>
</tr>
<tr>
<td>$RMS_Y$</td>
<td>14.5 mm</td>
<td>2.1 mm</td>
</tr>
<tr>
<td>$RMS_Z$</td>
<td>13.9 mm</td>
<td>2.1 mm</td>
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RMS of Earth-fixed satellite positions

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...with respect to the solution applying the APL corrections on observation level.
Final Orbits (AC solutions compared to IGS Final)
How APL may mitigate into GNSS orbits?
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Conclusion: APL must be corrected on observation level because an unmodelled APL-effect mitigates in different parameters of the GNSS analysis.
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**Resulting requirements:**

1. High quality model is needed that corresponds to the quality of the state-of-the-art GNSS processing.

2. The model must consistently cover the time span from 1994 to present.

3. The model must be easily accessible by any user for any station (preferable grids).

4. The model is required at least for the final processing at the analysis centers (three days delay).
Petrov and Boy, 2004:

- Is already in use by other IAG services.
- Good experience with previous studies.
- Bases on NCEP final products — sometimes too late for the final processing.

Wijaya et al., 2011:

- Using the same source as the VMF-correction \( \rightarrow \) optimal consistency.
- Latency is not an issue because a version based on predicted pressure is available.
- A new model on the market: not well established yet.
Scaling factors for the Vienna APL model: vertical

Estimated scaling factors for the atmospheric loading model

Mean scaling factors over 15 years
Scaling factors for the Vienna APL model: vertical

Estimated scaling factors for the atmospheric loading model

Mean scaling factors over 15 years

![Histogram showing the distribution of scaling factors for the model over 15 years. The x-axis represents the scaling factor for the model, ranging from -1 to 3. The y-axis represents the number of stations, ranging from 0 to 50. The histogram shows a peak around a scaling factor of 1, with a wide distribution.]
Estimated scaling factors for the atmospheric loading model

Mean scaling factors over 15 years

RMS of the corrections over 15 years
Scaling factors for the Vienna APL model: vertical

Estimated scaling factors for the atmospheric loading model

Mean scaling factors over 15 years

Dev. from one, norm. with RMS
Scaling factors for the Vienna APL model: vertical

Estimated scaling factors for the atmospheric loading model
Deviation from one over 15 years, norm. with the RMS

Dev. from scaling factor one in mm

-3 -2 -1 0 1 2 3
Scaling factors for the Vienna APL model: north

Estimated scaling factors for the atmospheric loading model
Deviation from one over 15 years, norm. with the RMS

Dev. from scaling factor one in mm

AIUB
Scaling factors for the Vienna APL model: east

Estimated scaling factors for the atmospheric loading model
Deviation from one over 15 years, norm. with the RMS

Dev. from scaling factor one in mm
Station repeatability: vertical

Repeatability of the weekly solutions
Vienna APL modell considered

No atm. loading corrections
Corrections from model, obs. level
Corrections from model, scaling factor

Stations, sorted by magnitude of the pressure loading

Repeatability (up) in mm

Stations with an APL effect $\geq$ 3 mm RMS and at least 5 years of data are included.
Station repeatability: vertical

Repeatability of the weekly solutions
Vienna APL modell considered

Corrections from model, obs. level
Corrections from model, scaling factor
Reference: No atm. loading corrections

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Corrections from model, scaling factor

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Stations with an APL effect ≥3 mm RMS and at least 5 years of data are included.
Three consistent cumulative solutions over 15 years are available:

1. without applying APL corrections
2. applying Vienna APL corrections as they are
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RMS differences for all stations with at least 5 years:

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<th>velocities (mm/year)</th>
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</tr>
<tr>
<td>0.25</td>
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Cumulative solution: coordinates and velocities

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Summary

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  Products will made available to the community at the AIUB-ftp server if the process is finished including the final quality control.
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APL mitigates into divers parameters of the GNSS–analysis.
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- In this context the influence of correcting the APL–effect on GNSS–derived parameters has been investigated: APL mitigates into divers parameters of the GNSS–analysis.

- The number of potential candidates of APL models for an IGS–like processing is limited.

- Station coordinates and velocities from a long–term cumulative solution are not affected by correcting or not correcting for the APL–effect.
THANK YOU for your attention

Publications of the GNSS-research group: http://www.bernese.unibe.ch/publist