Mitigation of unmodelled non–tidal atmospheric pressure loading into parameters of a global GNSS solution

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IGS workshop
23.–27. July 2012, Olsztyn, Poland
Motivation

• Atmospheric pressure loading (APL) can clearly be detected in space-geodetic solutions and needs to be corrected.

• With the global coverage of the tracking network and the continuous tracking capability, GNSS is in a comfortable situation among the space-geodetic techniques.

• In the frame of the series of Unified Analysis Workshops a discussion was initiated on how to correct for the APL effect:
  • correcting each individual observation
  • correcting station coordinates with the mean value
Outline

Motivation

Description of the experiment

APL and GNSS–derived coordinates

APL and GNSS–derived troposphere

APL and GNSS–orbits

Conclusion
Description of the experiment

- CODE reprocessing effort from 2011:
  - Time interval:
    - January 1996 to May 2003  GPS–only solution
    - May 2003 to December 2010  GPS+GLONASS solution
  - fully consistent with IGS08.ATX and IGS08.SNX
  - following the IERS 2010 conventions
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- 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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- 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.

- This dataset is used to support the “IERS Call for atm-load corrected solution”.

- We focus here on the solutions from the year 2010.
• Inland stations may have an effect up to a few cm, whereas coastal stations are almost not affected.

• \( \text{RMS}(\text{APL}) \): RMS of the APL effect over all stations for each day
• Inland stations may have an effect up to a few cm, whereas coastal stations are almost not affected.

• $\text{RMS}(\text{APL})$: RMS of the APL effect over all stations for each day

21. January: most pronounced APL for all stations of the network

01. July: moderate APL in all stations of the network

29. May: smallest APL in all stations of the network
Mean APL corrections for each station extracted from Vienna model during data processing.
APL and GNSS–derived coordinates

Coordinate difference between solutions applying/not applying APL corrections

vertical component

Coordinate difference in mm

21. January 2010
APL and GNSS-derived coordinates

Coordinate difference between solutions applying/not applying but correcting for APL effect

vertical component

Coordinate difference in mm

21. January 2010
APL and GNSS–derived coordinates

Residuals of a Helmert–transformation between solutions applying/not applying but correcting for APL effect

Coordinate difference in mm

vertical component

21. January 2010
APL and GNSS–derived coordinates

RMS of coordinate comparison
RMS of coordinate comparison

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

<table>
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<tr>
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<tbody>
<tr>
<td>RMS_N</td>
<td>1.1 mm</td>
<td>0.4 mm</td>
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<tr>
<td>RMS_E</td>
<td>1.4 mm</td>
<td>0.4 mm</td>
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<tr>
<td>RMS_U</td>
<td>5.3 mm</td>
<td>2.3 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

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

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... with respect to the solution applying the APL corrections on observation level.
Summary

• The station coordinates between the solution without applying but correcting after the processing for the APL effect agrees on the 0.1 mm RMS–level with the solution applying APL corrections on observation level.

• This includes differences of up to ±0.5 mm for individual stations even on days with a moderate magnitude of the APL effect.
Summary

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- Such a correction can be done on 1-day SINFEX level.
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- Such a correction can be done on 1-day SINEX level.

- But what about other GNSS-derived parameters that are not in the SINEX files?
Differences between troposphere estimates from solutions applying/not applying APL corrections

units: mm

red: difference of troposphere estimates, green: APL effect

21. January 2010
APL and GNSS–derived troposphere

Differences between troposphere estimates from solutions applying/not applying APL corrections

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

29. May 2010
Differences between troposphere estimates from solutions applying/not applying APL corrections versus APL correction

21. January 2010

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APL and GNSS–derived troposphere

Differences between troposphere estimates from solutions applying/not applying APL corrections versus APL correction

ABS of \( \Delta \)tropo in mm
21. January 2010

ABS of \( \Delta \)tropo in mm
27. January 2010
APL and GNSS–derived troposphere

Differences between troposphere estimates from solutions applying/not applying APL corrections versus APL correction

- ABS of ∆tropo in mm
  - 01. July 2010
  - 29. May 2010

Percentage of parameters

0 1 2 3 4 5
Summary

APL and GNSS–derived troposphere

ABS of $\Delta$tropo in mm

All days of 2010
Summary

APL and GNSS–derived troposphere

- Vertical APL corrections are correlated with a factor of $1/3$ with the estimated troposphere parameters.
Summary

APL and GNSS–derived troposphere

- Vertical APL corrections are correlated with a factor of $1/3$ with the estimated troposphere parameters.

- Only the variation of the APL effect during one day (processing batch length) is relevant — the influence exceeds 1 mm only in extremely rare cases.
APL and GNSS–orbits

RMS of Earth-fixed satellite positions

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

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<tr>
<td>$RMS_Y$</td>
<td>14.7 mm</td>
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... with respect to the solution applying the APL corrections on observation level.
APL and GNSS–orbits

RMS of Earth-fixed satellite positions

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<td>$RMS_Z$</td>
<td>13.9 mm</td>
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...with respect to the solution applying the APL corrections on observation level.
APL and GNSS–orbits

Differences in the satellite positions between solutions with and without correcting for APL

21. January 2010
Satellite R01 has only 1000 observations causing a very weakly determined orbit from a one-day solution.
APL and GNSS–orbits

Differences in the satellite positions between solutions with and without correcting for APL

Orbit difference in mm

23. December 2010
How APL may mitigate into GNSS orbits?
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APL and GNSS–orbits

Differences in the satellite positions between solutions with and without correcting for APL

<table>
<thead>
<tr>
<th>RMS in mm</th>
<th>Number of days</th>
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<tbody>
<tr>
<td>&gt;10 mm</td>
<td>25 days</td>
</tr>
<tr>
<td>&gt;7 mm</td>
<td>68 days</td>
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<tr>
<td>&gt;5 mm</td>
<td>153 days</td>
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considering all satellites
APL and GNSS–orbits

Differences in the satellite positions between solutions with and without correcting for APL

considering all satellites

RMS in mm

>10 mm: 25 days
> 7 mm: 68 days
> 5 mm: 153 days

classing all satellites except of that one with the biggest RMS of orbit differences

RMS in mm

>10 mm: 7 days
> 7 mm: 38 days
> 5 mm: 126 days
Summary

• Unmodeled APL–effect can mitigate into GNSS satellite orbits if a large area is affected by APL deformation.
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• Weakly observed satellites can easily be shifted by few centimeters (depending on the start and end point of their trajectory with respect to the deformed area).
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- Unmodeled APL–effect can mitigate into GNSS satellite orbits if a large area is affected by APL deformation.

- Weakly observed satellites can easily be shifted by few centimeters (depending on the start and end point of their trajectory with respect to the deformed area).

- For all other satellites the difference between applying APL or not may exceed 5 mm RMS over all satellites for a reasonable number of days.
Conclusion

• Correcting APL on observation level is the only approach without any compromises.
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• When applying mean APL corrections to station coordinates after the processing, the variation in time of the APL effect is absorbed by the troposphere parameters (one third of the effect — typically very small)
Conclusion

• Correcting APL on observation level is the only approach without any compromises.

• When applying mean APL corrections to station coordinates after the processing, the variation in time of the APL effect is absorbed by the troposphere parameters (one third of the effect — typically very small)

• An new realization of the geodetic datum is required after applying mean APL corrections to the station coordinates. This has to be done as long as all relevant parameters are accessible, e.g., in a software–internal normal equation. In case of SINEX the orbit parameters are missing, which may absorb a part of the unmodeled APL effect.
• ... 

• With such approach the station coordinates deviate from the consequent correction on observation level by 0.1 mm RMS; what typically includes differences for individual stations of up to 0.5 mm.
Conclusion

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Everybody has to decide by its own which level of compromises can be accepted to get the benefit of exchangeable APL models after the processing.
Final Remark

The results can also be interpreted as a general error mitigation study that act in the same way for comparable (unmodeled) effects in the GNSS analysis:

1. Atmospheric pressure loading
2. Ocean non–tidal loading
3. Hydrologically induced deformations
THANK YOU for your attention

Publications of the satellite geodesy research group:
http://www.bernese.unibe.ch/publist