Atmospheric correction for superconducting gravimeters
based on operational weather models

European Geosciences Union
General Assembly 2012

G4.1 Gravity field research - data acquisition - processing and - interpretation
26 April 2012, Vienna, Austria

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Atmospheric correction for superconducting gravimeters based on operational weather models

Outline:

1. Introduction of GGOS Atmosphere
2. Gravity corrections using NWM
3. Evaluation and comparison
4. Summary and outlook

http://ggosatm.hg.tuwien.ac.at/
GGOS Atmosphere

funded by the FWF, the Austrian Science Fund

Purpose: provide a detailed understanding of atmospheric involvement in geodesy, as noted in its three pillars: geometry, rotation, gravity field

Based on a common data stream from the ECMWF, four atmospheric prime quantities are determined in a consistent way:

- Atmospheric Pressure Loading Corrections (APL)
- Atmospheric Angular Momentum Functions (AAM)
- Atmospheric Gravity Corrections (AGC)
- Atmospheric Delays
Gravity field measurements reflect the **instantaneous** distribution of mass in the system Earth. Fluctuations on various time and space scales are **NOT** cancelled out by sufficient observation time, and therefore have to be **modelled**.

This is not only valid for **ground based** measurements but also for **satellite gravity missions**.

**Question:** Are the models developed for satellite gravity missions suitable to correct ground based measurements?
Atmospheric Gravity Corrections for satellite missions

Modelling the atmosphere’s potential:

\[
\Delta V = \frac{GM}{r} \sum_{n=0}^{\infty} \sum_{m=0}^{n} \left( \frac{a}{r} \right)^n P_{nm}(\cos \theta)(\Delta C_{nm} \cos m\lambda + \Delta S_{nm} \sin m\lambda)
\]

\[
\begin{align*}
\Delta C_{nm} &= \frac{1}{(2n+1)Ma_E} \iiint r^n P_{nm}(\cos \theta) \begin{bmatrix} \cos m\lambda \\ \sin m\lambda \end{bmatrix} dM \\
\Delta S_{nm} &= \frac{1}{(2n+1)Ma_E} \iiint r^n P_{nm}(\cos \theta) \begin{bmatrix} \cos m\lambda \\ \sin m\lambda \end{bmatrix} dM
\end{align*}
\]

where \( dM = \rho r^2 dr \sin \theta d\theta d\lambda \)

Thin Layer

Vertical integration
Atmospheric Gravity Corrections for satellite missions

Vertical integration:

- Gravity measurements are sensitive to the centre of mass of the atmospheric column → Vertical structure has to be taken into account

\[
\begin{align*}
\{\Delta C_{nm}\} &= -\frac{1}{(2n+1)Ma^{n+2}g_0} \int_{\text{Earth}} \left[ \int_{Ps}^{0} r^{n+4} dp \right] P_{nm}(\cos \theta) \left\{ \begin{array}{c}
\cos m\lambda \\
\sin m\lambda 
\end{array} \right\} \sin \theta d\theta d\lambda \\
\{\Delta S_{nm}\} &= \int_{\text{Earth}} \left[ \int_{Ps}^{0} r^{n+4} dp \right] P_{nm}(\cos \theta) \left\{ \begin{array}{c}
\cos m\lambda \\
\sin m\lambda 
\end{array} \right\} \sin \theta d\theta d\lambda
\end{align*}
\]
Vertical integration:

- Gravity measurements are sensitive to the centre of mass of the atmospheric column. Vertical structure has to be taken into account.

\[
\begin{align*}
\left\{ \Delta C_{nm} \right\} &= - \frac{1}{(2n+1)Ma^{n+2}} \int_{\text{Earth}} \left( \int_0^r r^{n+4} dp \right) \left( P_{nm}(\cos \theta) \begin{bmatrix} \cos m\lambda \\ \sin m\lambda \end{bmatrix} \right) \sin \theta d\theta d\lambda \\
\left\{ \Delta S_{nm} \right\} &= \text{Vertical structure has to be taken into account}
\end{align*}
\]

From spherical harmonic coefficients to gravity anomaly:

\[
\Delta g(r) = \frac{GM}{r^2} \left\{ \sum_{n=2}^{\infty} \left( \frac{a}{r} \right)^n \sum_{m=0}^{n} \overline{P_{nm}} \cos \theta \right. \\
&\quad \left. \left( \Delta C_{nm} \cos m\lambda + \Delta S_{nm} \sin m\lambda \right) \right\}
\]
AGC for satellite missions AND ground based measurements

How does it look like?

• Pressure variation 01.01.2008-00 UTC in hPa
• Corresponding gravity anomaly in nm s\(^{-2}\)
Atmospheric Gravity Field Coefficients featured by TU Vienna:

- Degree and order = 100
- ECMWF operational analysis and ERA40 pressure level fields
- 6-hourly, 1° x 1°
- ETOPO5 topography
- Thin layer (1980-now)
- Vertical integration (2000-now)
- Corresponding mean fields

http://ggosatm.hg.tuwien.ac.at/
Evaluation and comparison

Conrad Observatory

- Operated by ZAMG (Central Institute for Meteorology and Geodynamics)
- 50 km SW of Vienna at "Trafelberg“, 1000 m above sea level
- SG GWR-C025
- Hourly dataset covering 2008

Membach

- Operated by the Royal Observatory of Belgium
- about 150 km East of Bruxelles, 250 m above sea level
- SG GWR-C021
- Hourly dataset covering 2006, some
Evaluation and comparison

Comparisons are needed:

1. **Regression Coefficient** (-0.3 μGal / hPa)
2. **Green’s Functions** (Newtonian, 2D, 0.1° grid, 10° radius)

\[
GN(\psi) = -\frac{G}{g_0 a^2} \sum_{n=0}^{+\infty} nP_n(\cos \psi)
\]

\[
\Delta g = \iint_{Earth} GN(\psi) \ast (p_{s\_actual} - p_{s\_ref}) dS
\]

3. **Atmacs**: Atmospheric attraction computation service (Klügel et al. 2009, Wettzell) using 6h-weather data from DWD, interpolated linearly to hourly steps
4. Solution by **ZAMG** (B. Meurers) using interpolated ATMACS values and a local pressure correction
Surface pressure variation:

<table>
<thead>
<tr>
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<th>m.d.</th>
<th>σ</th>
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</thead>
<tbody>
<tr>
<td>Membach</td>
<td>DWD</td>
<td>5.8</td>
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<td>ECMWF</td>
<td>5.3</td>
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<tr>
<td>Conrad</td>
<td>DWD</td>
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</tr>
<tr>
<td></td>
<td>ECMWF</td>
<td>9.1</td>
</tr>
</tbody>
</table>
Evaluation and comparison

Residuals after atmospheric correction:

Zamg
Admittance
ATMACS
AGC
Green’s F.
Evaluation and comparison

Differences of residuals with respect to ZAMG-solution:

<table>
<thead>
<tr>
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<th>[nm s(^{-2})]</th>
<th>m.d.</th>
<th>σ</th>
<th>ρ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Admittance</td>
<td>-2.3 / -6.2</td>
<td>3.54 / 7.21</td>
<td>0.96 / 0.79</td>
<td></td>
</tr>
<tr>
<td>ATMACS</td>
<td>-2.3 / -6.2</td>
<td>6.17 / 10.56</td>
<td>0.91 / 0.69</td>
<td></td>
</tr>
<tr>
<td>AGC</td>
<td>-2.3 / -6.2</td>
<td>3.25 / 4.81</td>
<td>0.98 / 0.92</td>
<td></td>
</tr>
</tbody>
</table>
Evaluation and comparison

Impact of vertical structure in the AGC-approach for $\Delta g$:

- **Vertical integration**
  - Mean deviation = $1.3 \text{ nms}^{-2}$

- **Thin Layer**
  - Std. deviation = $0.5 \text{ nms}^{-2}$

- **Difference x 10**

![Graph showing variations in $\Delta g$ over time from January to December 2008]
Summary:

• Atmospheric Gravity Coefficients
  ... are applicable for ground based gravity measurements
  ... reach similar precision as established models
  ... are available on a global scale
  ... only small impact by vertical distribution of masses

Outlook:

• Including local model
• Incorporating indirect effect, i.e. loading
Thanks for your attention!

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