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

Maria Karbon, Johannes Böhm, Bruno Meurers, Michael Schindelegger, David Salstein, Harald Schuh

Research Group Advanced Geodesy ,Vienna University of Technology, Vienna, Austria

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**

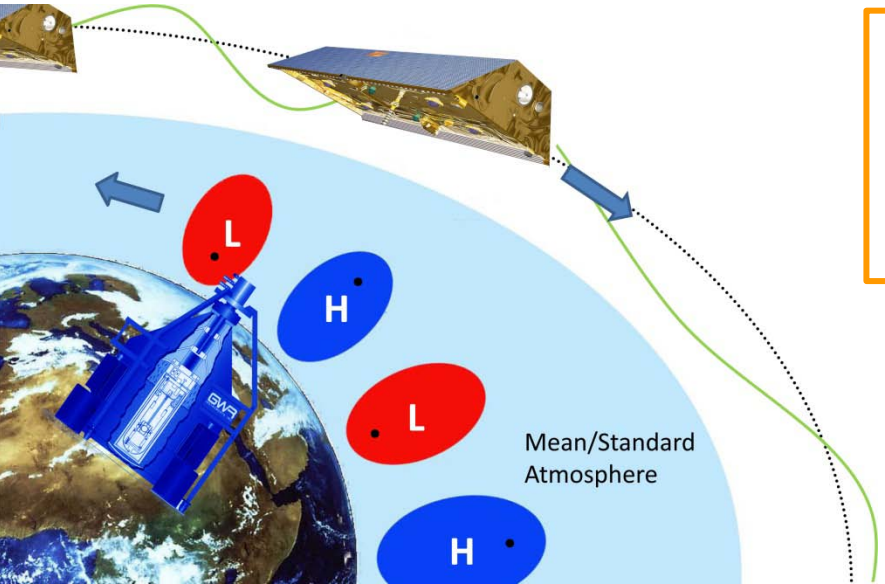
Based on a common data stream from the ECMWF, four atmospheric prime quantities are determined in a consistent way:

- Atmospheric Pressure Loading Corrections **APL**
- Atmospheric Angular Momentum Functions **AAM**
- Atmospheric Gravity Corrections **AGC**
- Atmospheric Delays

Atmospheric Gravity Corrections using NWM

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?

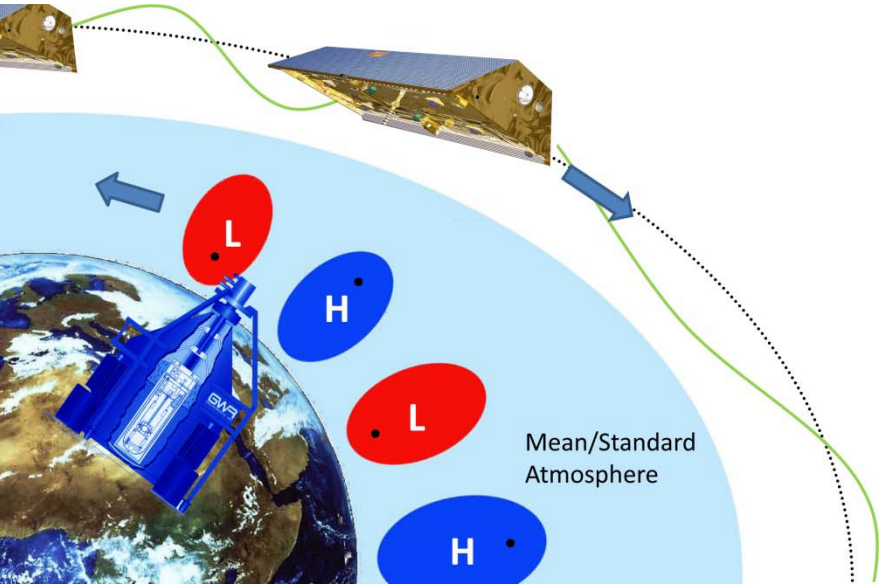
Atmospheric Gravity Corrections for satellite missions

Modelling the atmosphere's potential:

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

$$\begin{Bmatrix}\Delta C_{nm}\\ \Delta S_{nm}\end{Bmatrix} = \frac{1}{(2n+1)Ma}\iiint_{Earth} r^{n} P_{nm}(\cos\theta)\begin{Bmatrix}\cos m\lambda\\ \sin m\lambda\end{Bmatrix} dM$$

where $dM = \rho r^{2} dr \sin\theta d\theta d\lambda$



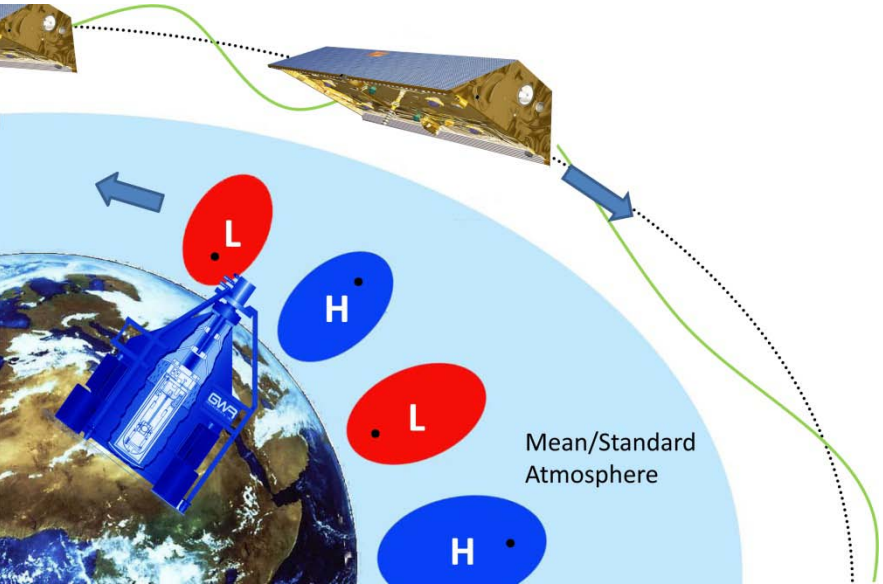
Thin Layer → **Vertical integration**

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

$$\begin{Bmatrix} \Delta C_{nm} \\ \Delta S_{nm} \end{Bmatrix} = -\frac{1}{(2n+1)Ma^{n+2}g_0} \iint_{Earth} \left(\left[\int_{Ps}^{0} r^{n+4} dp \right] - p_{VI} \right) P_{nm}(\cos\theta) \begin{Bmatrix} \cos m\lambda \\ \sin m\lambda \end{Bmatrix} \sin\theta d\theta d\lambda$$

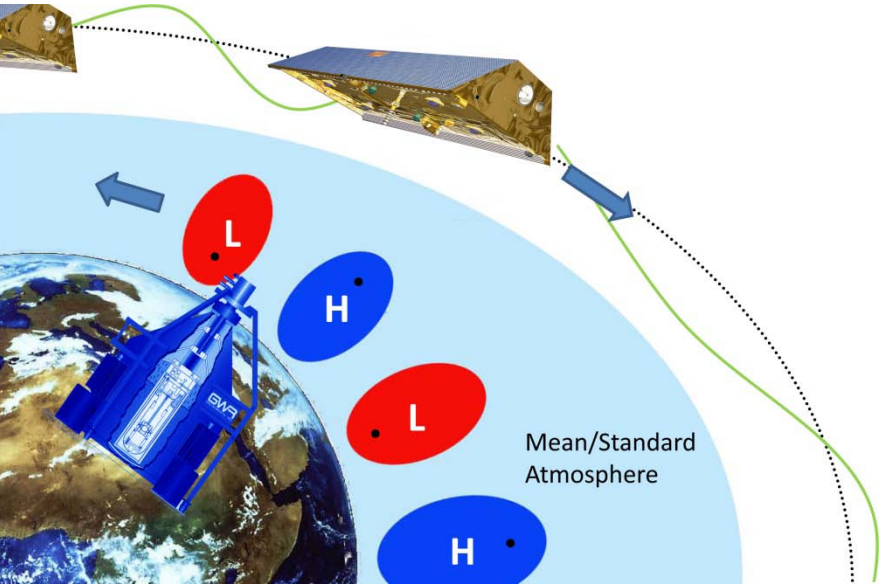


AGC for satellite missions AND ground based measurements

Vertical integration:

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

$$\begin{Bmatrix} \Delta C_{nm} \\ \Delta S_{nm} \end{Bmatrix} = -\frac{1}{(2n+1)Ma^{n+2}g_0} \iint_{Earth} \left(\left[\int_{Ps}^{0} r^{n+4} dp \right] - p_{VI} \right) P_{nm}(\cos\theta) \begin{Bmatrix} \cos m\lambda \\ \sin m\lambda \end{Bmatrix} \sin\theta d\theta d\lambda$$



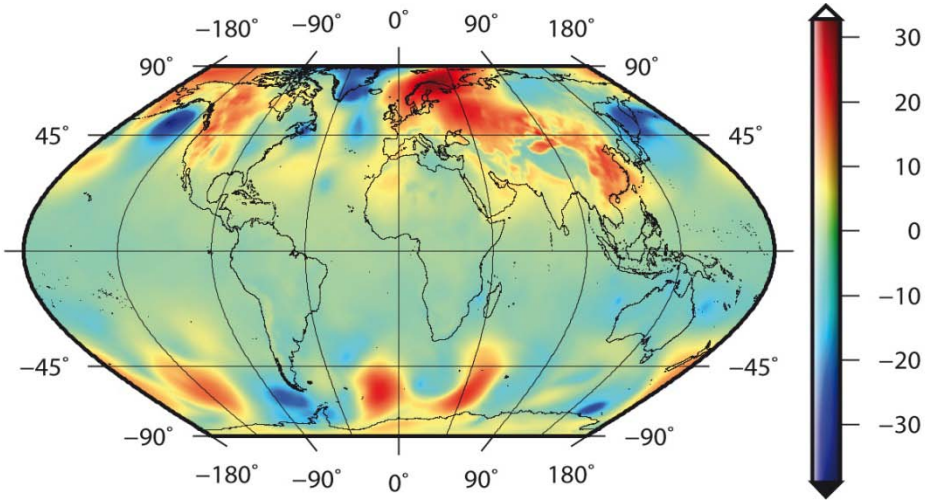
From spherical harmonic coefficients to gravity anomaly :

$$\Delta g(r) = \frac{GM}{r^2} \left\{ \sum_{n=2}^{\infty} (n-2) \left(\frac{a}{r} \right)^n \sum_{m=0}^{n} \overline{P_{nm}} \cos\theta \left(\Delta C_{nm} \cos m\lambda + \Delta S_{nm} \sin m\lambda \right) \right\}$$

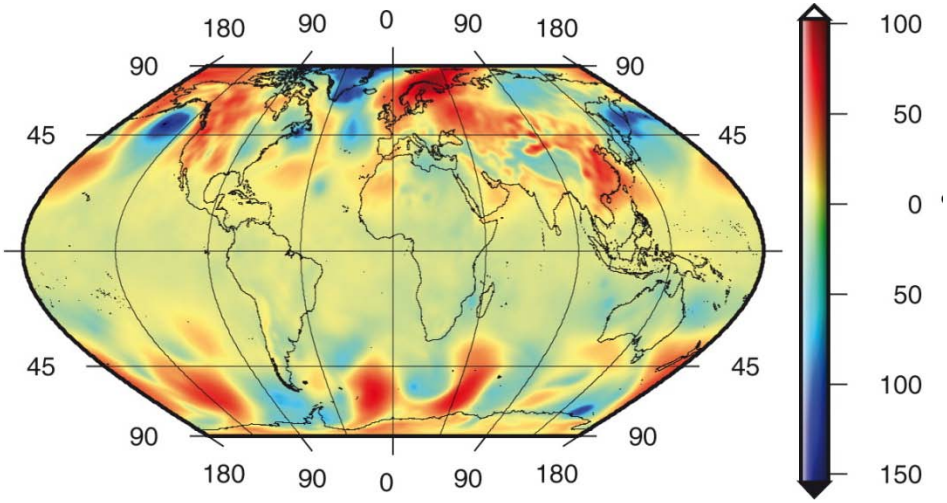
AGC for satellite missions AND ground based measurements

How does it look like?

- Pressure variation 01.01.2008-00 UTC in hPa
- Corresponding gravity anomaly in nm s^{-2}



Pressure [hPa]



Δg [nm s^{-2}]

Atmospheric Gravity Corrections using NWM

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/

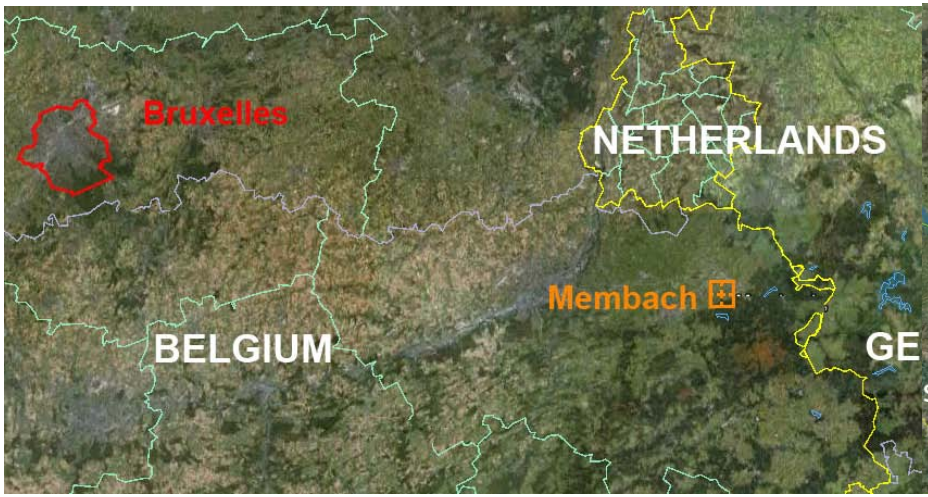
Evaluation and comparison

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)

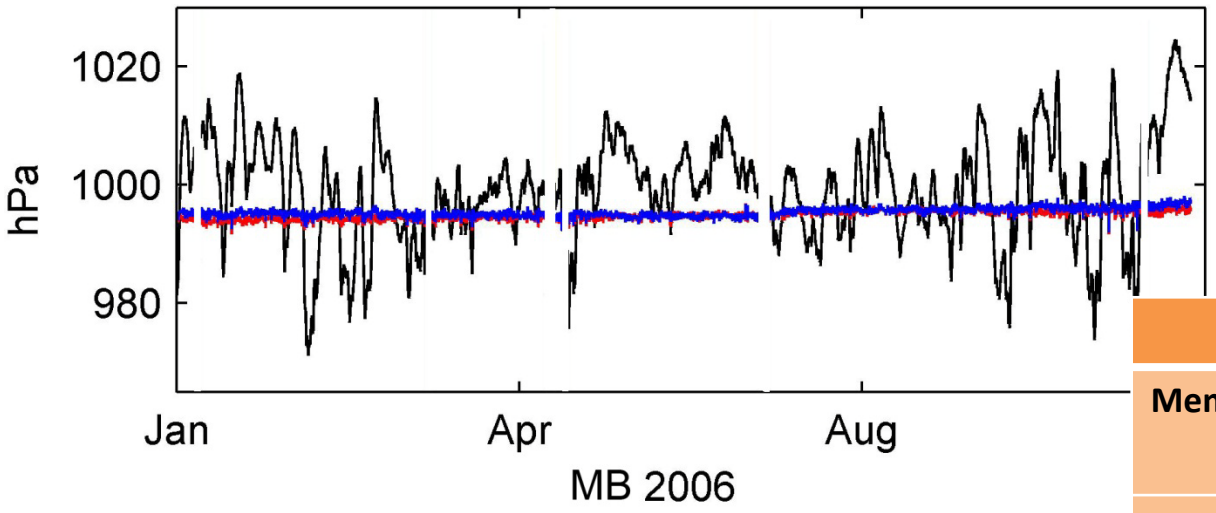
$$GN(\psi) = -\frac{G}{g_0 a^2} \sum_{n=0}^{+\infty} n P_n(\cos\psi)$$

$$\Delta g = \iint_{Earth} GN(\psi) * \left(p_{s\_actual} - p_{s\_ref}\right) dS$$

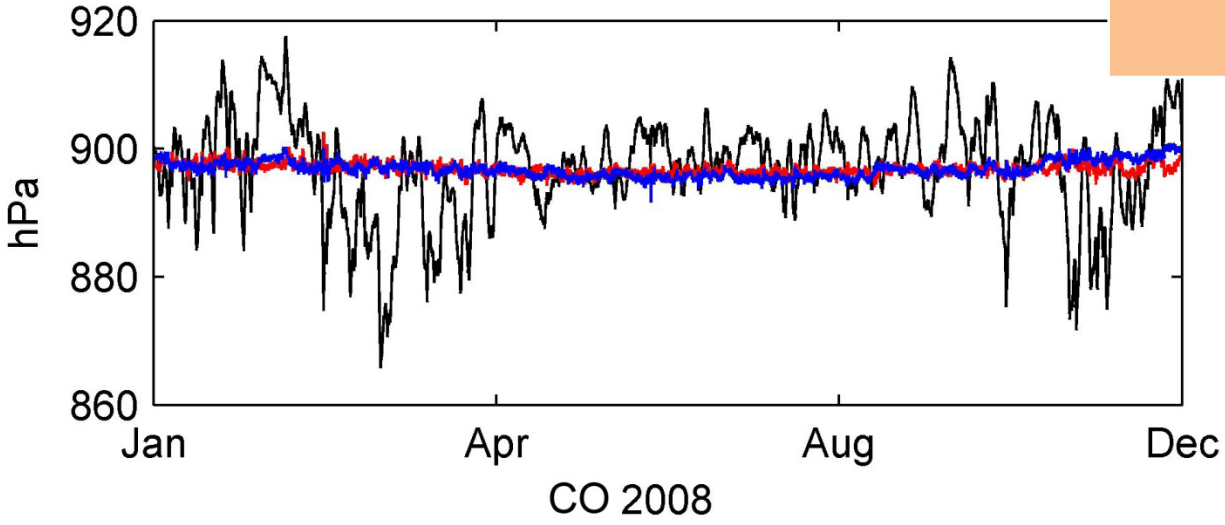
3. **Atmacs**: Atmospheric attraction computation service (Klügel et al.2009, Wettzell) using 6h-weather data from DWD, interpolated linearly to hourly steps
4. Solution by **ZAMG** (B. Meurers) using interpolated ATMACS values and a local pressure correction

Evaluation and comparison

Surface pressure variation:



MB 2006

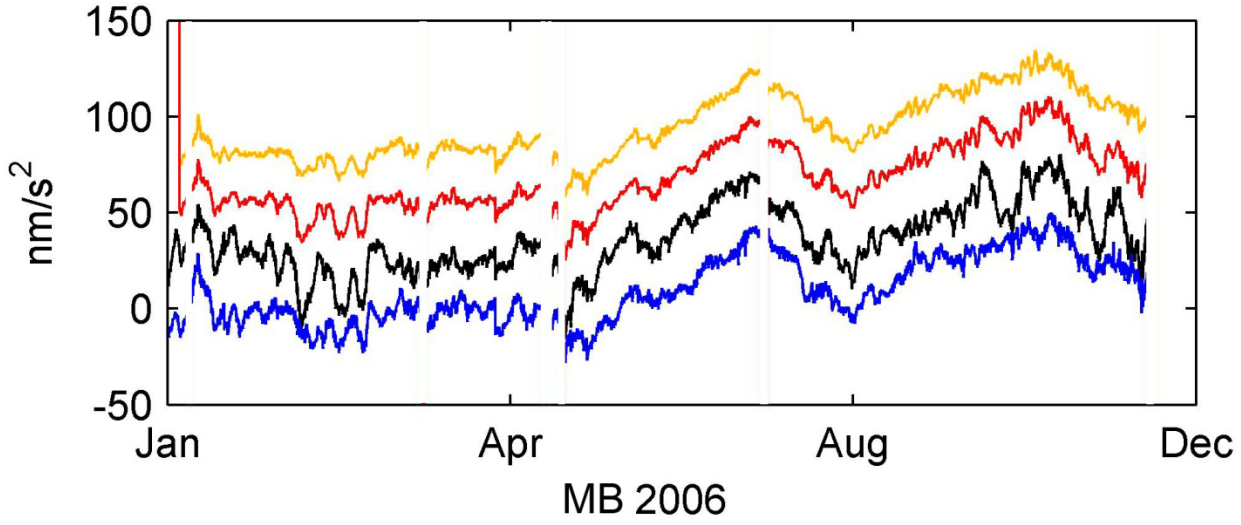


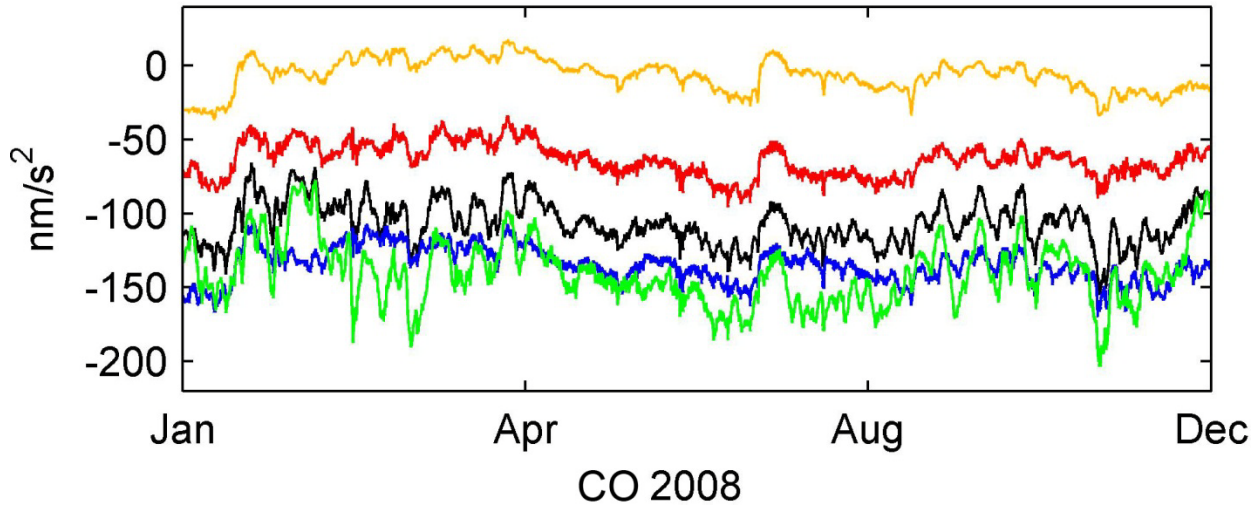
CO 2008

		m.d.	σ
Membach	**DWD**	5.8	0.7
	ECMWF	5.3	0.7
Conrad	**DWD**	9.3	1.3
	ECMWF	9.1	0.97

Evaluation and comparison

Residuals after atmospheric correction:

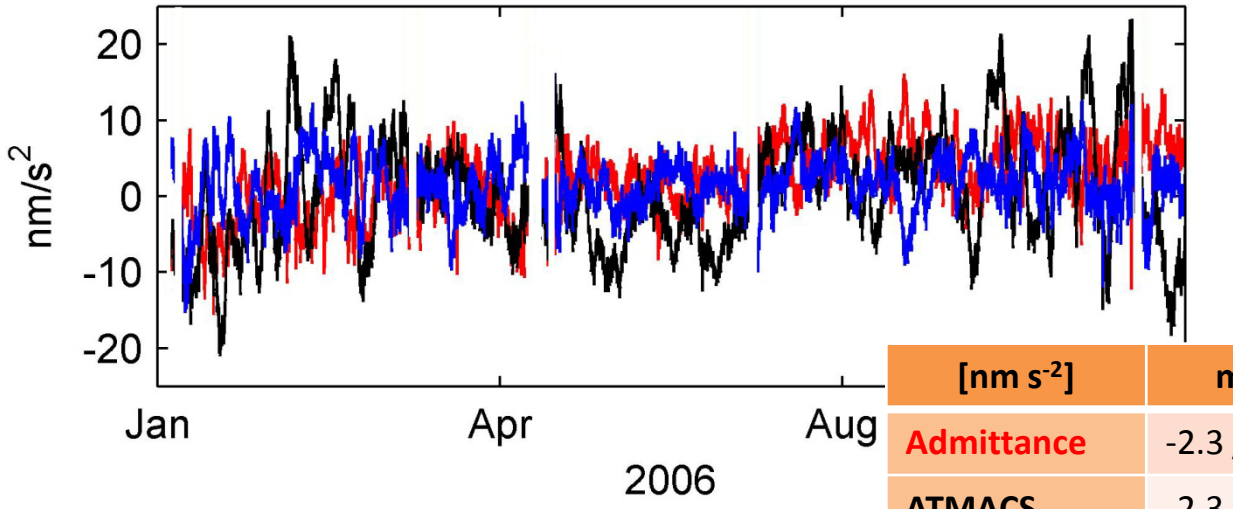


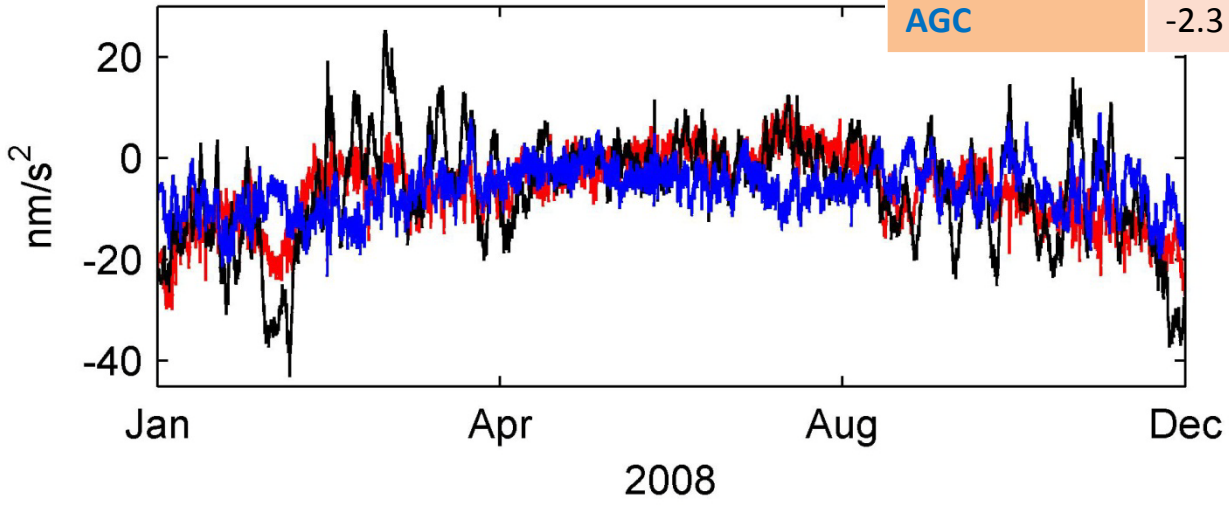


Zamg
Admittance
ATMACS
AGC
Green‘s F.

Evaluation and comparison

Differences of residuals with respect to ZAMG-solution:





[nm s^{-2}]	m.d.	σ	ρ
Admittance	-2.3 / -6.2	3.54 / 7.21	0.96 / 0.79
ATMACS	-2.3 / -6.2	6.17 / 10.56	0.91 / 0.69
AGC	-2.3 / -6.2	3.25 / 4.81	0.98 / 0.92

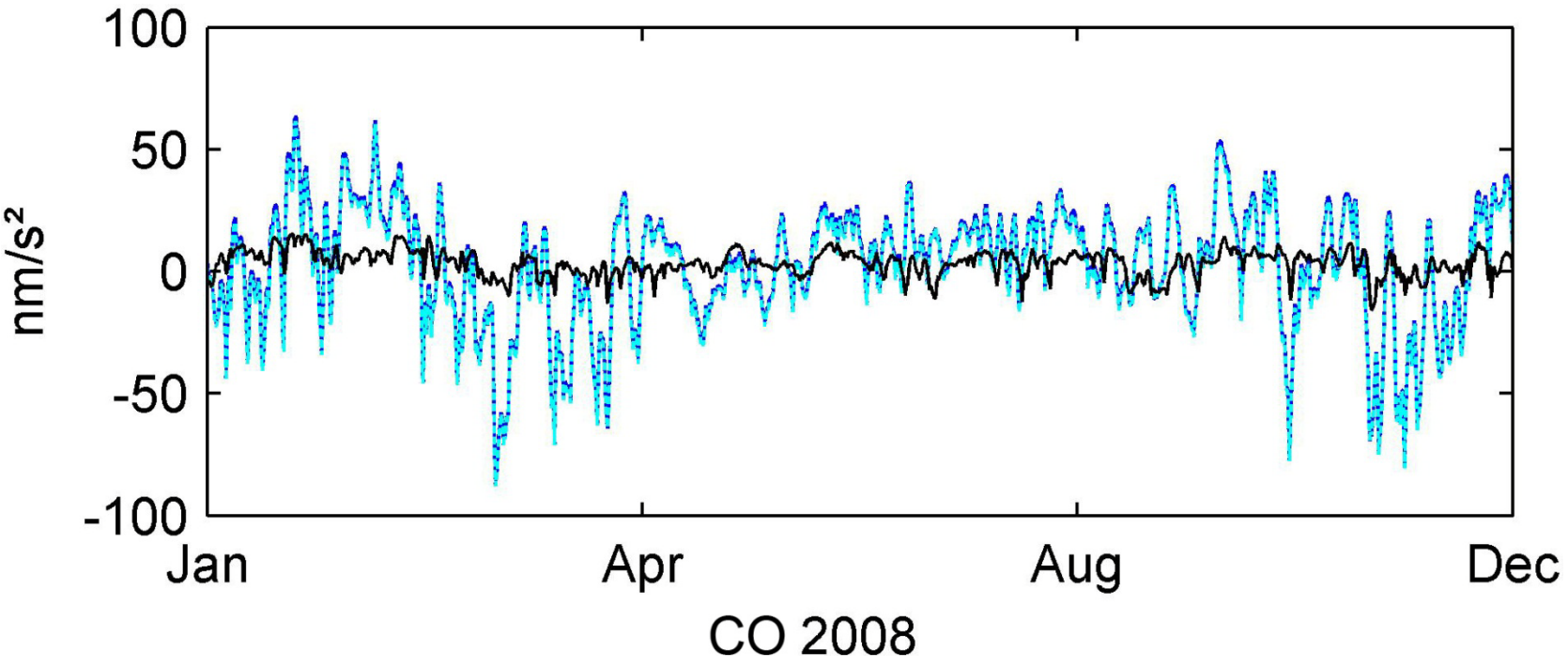
Evaluation and comparison

Impact of vertical structure in the AGC-approach for Δg:

- Vertical integration
- Thin Layer
- Difference x 10

Mean deviation = 1.3 nms^{-2}

Std. deviation = 0.5 nms^{-2}



Summary and outlook

Summary:

- **A**tmospheric **G**ravity **C**oefficients
  - … are applicable for ground based gravity measurements
  - … reach similar precicion 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!

FWF

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