# Comparison of Superconducting Gravimeter and CHAMP Satellite Derived Temporal Gravity Variations

Jürgen Neumeyer[1], Peter Schwintzer[1], Franz Barthelmes[1], Olaf Dierks[1],
Yuichi Imanishi[2], Corinna Kroner[3], Bruno Meurers[4], He-Ping Sun[5], and
Heikki Virtanen[6]

[1] GeoForschungsZentrum Potsdam, Dept. Geodesy and Remote Sensing, Germany
(neum@gfz-potsdam.de)
[2] Ocean Research Institute Tokyo, Japan
[3] Institute of Geosciences, FSU Jena, Germany
[4] Institute of Meteorology and Geophysics, University of Vienna, Austria
[5] Institute of Geodesy and Geophysics Wuhan, China
[6] Finnish Geodetic Institute Masala, Finland

**Summary.** The operational Superconducting Gravimeter (SG) network can play an important role for validation of satellite-derived temporal gravity field variations. A comparison shows a quite good agreement between SG and CHAMP results within their estimated error bars. It could be proved that the SG-derived temporal gravity variations are representative for a large area within the µgal accuracy, if the local gravity effects are removed.. The long-periodic tidal waves are well determined by ground measurements, therefore they can be applied as a reference for validation. For further validation, field SG measurements should be carried out in representative areas with large gravity variations (e.g. Amazon area).

**Key words:** gravity field, CHAMP, Superconducting Gravimeter, gravity variation

## 1 Introduction

One objective of the new-generation satellite gravity missions CHAMP and GRACE is the recovery of temporal Earth gravity field variations. For the CHAMP mission the gravity resolution is about 1 µgal at a half wavelength spatial resolution of $\lambda/2 = 5000$ km with a temporal resolution of 1 month. For the GRACE mission a largely increased resolution is expected.

Of fundamental interest is the combination of satellite-based and surface gravity measurements. Because CHAMP's temporal resolution ranges from 1 month to years, surface gravity measurements must have a long-term stability, which only Superconducting Gravimeters (SG) fulfil.

On the Earth surface high-precision gravity measurements are carried out with Superconducting Gravimeters forming the SG network of the Global Geodynamic Project (GGP). These measurements have a gravity resolution in ngal range and a linear drift of some µgal per year.

When we compare satellite-derived with ground-measured gravity variations, we must ensure to the best knowledge that after preprocessing and reduction of known gravity effects both data sets represent the same sources of gravitation and spatial resolution. Therefore all local gravity effects must be removed from the ground measurements.

## 2 CHAMP recovery of temporal gravity field variations

The CHAMP data processing is performed with an extended EIGEN-2 Earth gravity field model [Reigber et al. 2003]. The input data for this model are:

- CHAMP-GPS satellite-to-satellite tracking and accelerometer data,
- Satellite Laser Ranging data of Lageos-1, and -2, Starlette and Stella.

Normal equation systems were generated to compute the EIGEN-2CHAMP+4SLR solution for:

- Spherical harmonic coefficients of the gravitational potential complete to degree/order 120,
- Coefficients up to degree/order 4 at 30d (monthly) intervals.

The time related gravity reduction for the CHAMP gravity field solution is performed for the following effects:

- Atmospheric pressure (direct attraction and loading term): 6-hourly data (ECMWF) are used to model temporal variations in the gravitational potential.
- Ocean tides and ocean loading: The FES 2000 ocean model is applied for semidiurnal to long-periodic constituents.
- Pole tide: The IERS polar motion series are used.
- Earth tides according to the IERS conventions [McCarthy 2000].

From the resulting 12 sets of spherical harmonic coefficients of degree 2 through 4 ($\lambda/2$ = 5000 km) monthly gravity variations have been calculated for the selected SG positions in a time span from Dec. 2000 to Dec. 2001 with an estimated standard deviation of 1 μgal.

## 3 Superconducting Gravimeter derived gravity variations

The SG gravity data are reduced for the same gravity effects as the CHAMP solution. Additionally local and instrumental effects are removed.

In a first step the raw SG gravity data are corrected for spikes and offsets. Then the linear instrumental drift is removed These preprocessed data are reduced for the following gravity effects:

- Atmospheric pressure: By using the local air pressure a single admittance coefficient is calculated, which is used for reduction of the air-pressure-induced gravity effect (attraction and loading term),
- Ocean loading calculated with the FES 95 model [Francis & Mazzega 1990],
- Pole tide calculated with IERS polar motion series and a gravimetric factor of 1.16 [Torge 1989],

- Earth tides calculated with analysed tidal parameters based on the Wahr-Dehant Earth tide model [Wenzel 1996],
- Local groundwater-level-induced gravity effect: By using water table measurements a single admittance coefficient is determined for reduction of this effect [Neumeyer et al. 1999].

After these gravity reductions we got the SG gravity variations. For comparing with CHAMP, monthly means of the gravity variations were calculated.

## 4 Comparison results

The present SG network comprises 20 stations in operation. Here, six SG stations have been selected: Sutherland / South Africa ($\phi$ =-32.381 deg, $\lambda$=20.811 deg, h=1791 m), Vienna / Austria ($\phi$=48.25 deg, $\lambda$=16.358 deg, h=192 m), Moxa / Germany ($\phi$=50.645 deg, $\lambda$=11.616 deg, h=455 m), Metsahovi / Finland ($\phi$=60.217 deg, $\lambda$=24.396 deg, h=56 m), Wuhan / China ($\phi$=30.516 deg, $\lambda$=114.49 deg, h=80 m), Matsushiro / Japan ($\phi$=36.543 deg, $\lambda$=138.207 deg, h=406 m).

For the time period from Dec. 2001 to Dec. 2002 the gravity data of these sites were processed according to the above processing procedure. For comparison monthly averages of the gravity variations are used. The assigned CHAMP values are taken from the monthly global gravity field solutions for the coordinates of the selected SG sites. Gravity variations due to Earth and ocean tides, pole tide and atmosphere are reduced in both SG and CHAMP derived series, the remaining time variable effects should be due to continental large scale hydrology.

Figure 1 shows the comparison result. Each station is represented by one box with two graphs. The upper part displays the SG measured gravity variations (grey) and the monthly averages (black). The lower part shows the CHAMP derived gravity variations (black) and again the monthly averages of the SG gravity variations (grey). For a the better visualisation the curves are created about their mean values.

The comparison shows a reasonable agreement in the trend behaviour of the gravity variations for all stations: For the stations with large variations (Metsahovi, Wuhan and Matsushiro) the CHAMP solution follows quite well the SG result too. Concluding we note a significant result of the comparison. The CHAMP and the SG are measuring approximately the same gravity variations within their estimated error bars. The GRACE result with an expected improved spatial and temporal resolution will further improve the significance of the comparison.

On the other hand the result proves that the Superconducting Gravimeter derived gravity variations, although being point measurements, are representative for a large area within the µgal accuracy. Neighbouring stations show coherent signals [Crossley & Hinderer 2002]. This is shown on two examples:

1. The sites Moxa and Vienna which are 435 km apart show nearly the same gravity variability. In particular there is also a good agreement in time periods smaller than 1 month (Figure 2).

2. The distance between Wuhan and Matsushiro is about 2300 km. The gravity

variations also show a similar behaviour concerning the longer period variations.

The large scale validity of SG derived gravity variations requires the reduction of local gravity effects from the SG series. Therefore, beside precise air pressure measurements water table, soil moisture, rainfall, snow loading etc. measurements should be carried out at SG sites. For comparison purposes those SG sites are only useful to be employed, where local gravity effects can be well monitored and modelled.

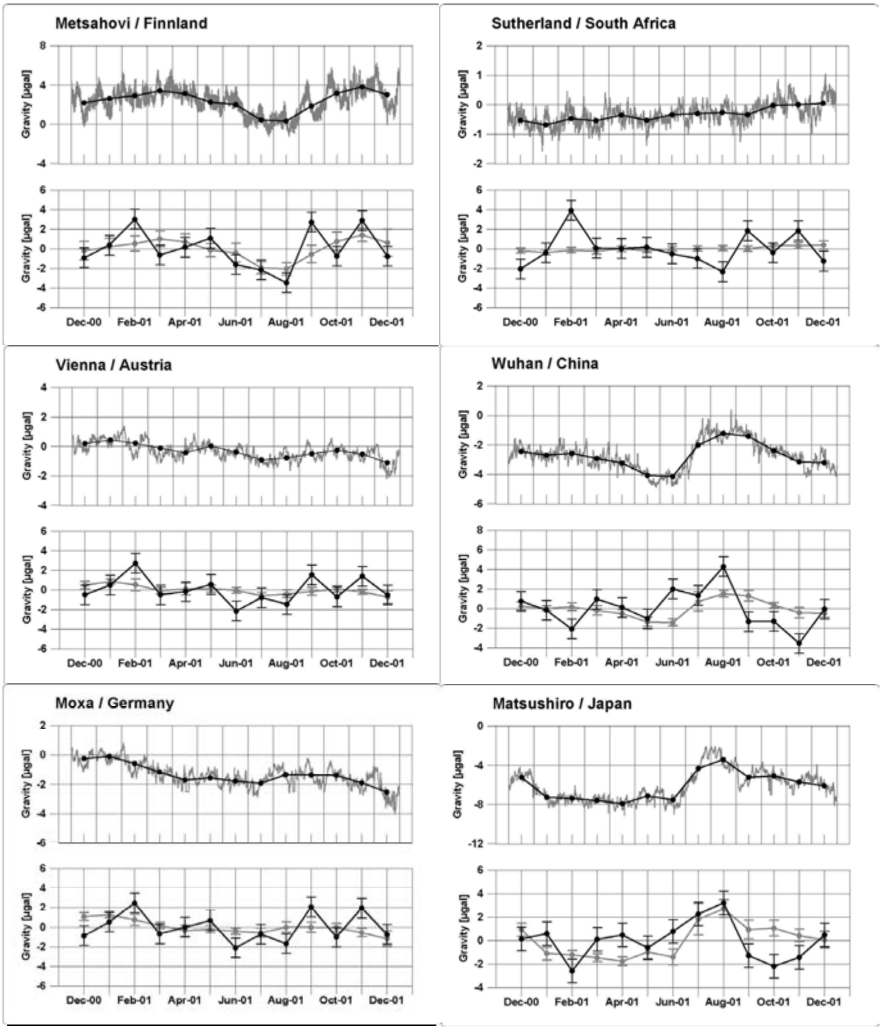

**Fig. 1.** Gravity variations at Superconducting Gravimeter sites:
Upper panel per box: - SG gravity variations (grey)
- SG monthly mean of gravity variations (black)
Lower panel per box: - CHAMP monthly gravity field solution (black)
- SG monthly mean of gravity variations (grey)

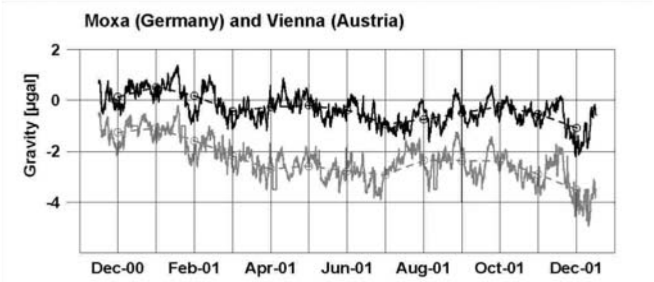

**Fig. 2.** SG gravity variation of Vienna (black) and Moxa (grey).

For further validation of satellite-based gravity variations, especially for GRACE, additional surface gravity measurements with Field Superconducting Gravimeters should be carried out in areas with large gravity variations and negligible local gravity effects considering the spatial resolution of the satellite measurements, for instance in the Amazon area where seasonal gravity changes can be observed in the order of some 10 µgal.

## 5 Long-periodic Earth tides as reference

For Earth tidal-forces-induced gravity variations the relation between satellite and surface gravity variation measurements can be expressed in a first approximation by the body Love numbers h and k and the gravimetric factor δ. On the Earth surface the gravimeter is measuring beside the gravitational attraction (mass) the gravity effect due to elastic deformation (vertical surface shift) and the deformation potential (mass redistribution due to the vertical surface shift).

The gravimetric factor is a function of the Love numbers h and k. For the spherical harmonic expansion degree l = 2 we have

$$\delta 2 = 1 + h2 - 3/2 \cdot k2 \qquad (1)$$

With the nominal Love numbers *h2* = 0.614 for elastic deformation and *k2* = 0.302 for deformation potential. The gravimetric factor is δ2= 1.16.

The satellite is not sensitive to the vertical surface shift. Therefore h2 = 0 and the gravimetric factor for the satellite measurements can be expressed by

$$\delta 2_S = 1 - 3/2 \cdot k2 \qquad (2)$$

With *k2* = 0.302 one obtains $\delta 2_S$ = 0.547. The ratio between $\delta 2_S$ and δ2 is rδ = 0.471. Accordingly the gravity signal from the satellite should be smaller than the gravimeter signal by this factor rδ. This assumption is valid for the tidal-forces-induced gravity variations. Therefore the SG gravity data have been reduced by the factor Rδ for the CHAMP comparison of tidal waves.

The long periodic tidal waves STA (period = 121.75 days), SSA (period = 182.62 days) and SA (period = 365.63 days) are well determined by ground measurements. They have the same source for SG and CHAMP temporal gravity field variations. Therefore they can be applied as reference for validation. For non-tidal

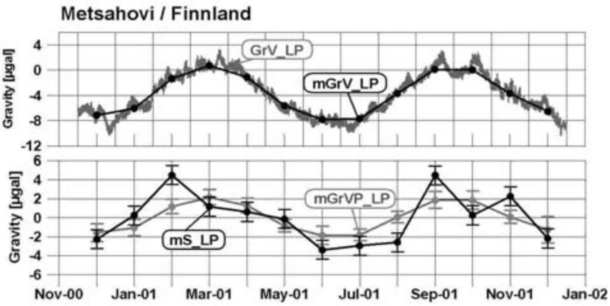

**Fig. 3.** Gravity variations for Metsahovi station including Earth tidal STA, SSA and SA.

forces induced elastic deformation the load Love numbers must be applied.

Figure 3 shows an example of Metsahovi station. For this purpose the SG data have been processed according to the above processing procedure but without reduction of the long-periodic tidal waves STA, SSA and SA (GrV_LP). From this data set monthly averages (mGrV_LP) are calculated. For comparing with CHAMP the mass and deformation potential terms must be considered. Therefore the monthly averages are divided by the factor rδ (mGrVP_LP). The station Metsahovi has been selected for this simulation because it has the largest long-periodic tidal amplitudes of the six selected SG stations.

Additionally the long-periodic gravity part caused by the tidal waves STA, SSA and SA is added to the CHAMP result (mS_LP). This simulation shows that for further evaluation studies the well resolved long-periodic Earth tides can be used as reference for comparison. Then, in the corresponding satellite based (monthly) gravity solution these tidal constituents shall not be reduced.

## References

Crossley D, Hinderer J (2002) GGP Ground Truth for Satellite Missions. Marees Terrestres Bulletin d'Informations, Bruxelles *136*: 10,735-10,742.

Francis O, Mazzega P (1990) Global charts of ocean tides loading effects. J Geophys Res *95(C7)*: 11411-11424.

McCarthy DD (2000) IERS conventions 2000, International Earth Rotation Service.

Neumeyer J, Barthelmes F, Wolf D (1999) Estimates of environmental effects in Superconducting Gravimeter data. Marees Terrestres d'Informations, Bruxelles *131*: 10,153-10,159.

Reigber Ch, Schwintzer P, Neumayer K-H, Barthelmes F, König R, Förste Ch, Balmino G, Biancale R, Lemoine J-M, Loyer S, Bruinsma S, Perosanz F, Fayard T (2003) The CHAMP-only Earth Gravity Field Model EIGEN-2. Adv Space Res *31(8)*: 1883-1888.

Torge W (1989) Gravimetry. de Gruyter, Berlin, New York.

Wenzel H-G (1996) Earth tide data processing package ETERNA 3.3. Marees Terrestres Bulletin d'Informations, Bruxelles *124*: 9425-9439.