Preliminary analysis of CHAMP state vector and accelerometer data for the recovery of the gravity potential

E. Howe and C. C. Tscherning

Department of Geophysics. Juliane Maries Vej 30, DK-2100 Copenhagen Ø, Denmark, e-mail: eva@gfy.ku.dk, cct@gfy.ku.dk

Abstract. From energy considerations the relationship in inertial space between the gravitational potential and the state vector of the satellite can be found. The state vector from the rapid science orbit of CHAMP has been used after the velocities have been converted to the inertial system.

The satellite loses kinetic energy due to external forces. We consider the tidal potential from the sun and the moon, energy dissipation and the explicit time variation of the gravitational potential in inertial space.

Data from two 4 day periods have been analysed. The GRS80 earth normal potential and a constant were subtracted in order to obtain potential differences. Using Bruns' theorem we calculated the height anomaly at the satellite position. The height anomalies were compared with values calculated from EGM96. The differences show a piecewise bias and trend. When correcting for a bias and trend in a one-day period the differences had a standard deviation of 0.14 m. Otherwise the differences were 0.5 and 1.4 m for the two periods, respectively. This show that the accelerometers have biases which may be identified and eliminated by comparing with a high degree and order gravity potential reference field.

Key words: Energy principle, height anomalies, accelerometer biases

1 Introduction

We will here use energy considerations to find the relationship in inertial space between the state vector of CHAMP and the gravitational potential. The CHAMP orbit is based on GPS and the gravity field model GRIM5-C1 using the reduced dynamics method to determine the position and the velocity (the state vector).

3 accelerometers are also onboard CHAMP. We have used the pre-processed accelerometer data in order to calculate the energy dissipation. In the pre-processing the accelerations have been re-sampled from 1 Hz to 0.1 Hz. However there are scale errors, biases and possibly drifts in the accelerometer, which we have to estimate. A comparison with external data has here been used to estimate the bias correction. No scale and drift errors were estimated.

The rapid science orbit state vector data ($x, y, z, v_{x,}, v_{y,}, v_{z,}$) and the pre-processed accelerometer data ($a_{x,}, a_{y,}, a_{z,}$) for two 4 day periods have been analysed. The two randomly chosen periods are May 18-21 2001 and August 18-21 2001.

2 Data analysis

The state vector velocities were converted to inertial velocities and the kinetic energy was calculated T=$\frac{1}{2} * v^2$. From this we have subtracted the potential of the sun V_{sun} and the moon V_{moon}, the rotation potential $\omega * (x * v_y - y * v_x)$ (Jekeli 1999), the frictional energy F, a constant E_0 and the GRS80 earth gravity normal potential U without centrifugal term. The height anomaly ζ was calculated by dividing the potential difference by normal gravity, g. The height anomaly can be expressed as

$$\zeta = (\tfrac{1}{2} * v^2 - V_{sun} - V_{moon} - \omega * (x * v_y - y * v_x) - F - E_0 - U) / g$$

The frictional energy F has been calculated in different ways, or put equal to zero. We calculated F as $\int |v| * a_y dt$ or as $\int \bar{v} \bullet \bar{a} dt$ where a_y is the along track acceleration and $\bar{a}$ is the acceleration vector. The first procedure for the calculation of the frictional energy requires alignment of $\bar{v}$ with the satellite. The quaternions which express the alignment had unfortunately large errors in the two 4 day periods.

The use of the frictional energy without any corrections to the accelerations does not give better results than setting it equal to zero. We therefore had to assume that the accelerometer had biases, scale factor errors and possibly drifts. The bias has been determined as a tilt of the height anomalies. The total bias correction is determined to be $-0.364*10^{-5}$ m/s^2 and $-0.352*10^{-5}$ m/s^2 for the two periods but it seems like a drift is present also. The scale factor is determined to be between 0.7 and 0.8. We have initially only subtracted a bias in the along track acceleration and a trend (given by the CHAMP data centre) in the radial acceleration.

The height anomaly was compared to values computed from EGM96 (Lemoine et al 1998), see Table 1. Note that applying the corrections for friction does not give a better fit to EGM96. If the full inner product is used the results become very erroneous.

Table 1 Comparisons between EGM96 and CHAMP height anomalies at satellite altitude. (m)

	Dif. May		
	With F=0	With $F = \int |v| * a_y dt$	With $F = \int \bar{v} \bullet \bar{a} dt$
Mean	0.23	0.23	0.14
Std. dev.	0.30	0.49	26.26

	Dif. August		
	With F=0	With $F = \int \lvert v \rvert * a_y dt$	With $F = \int \bar{v} \bullet \bar{a} dt$
Mean	0.40	0.40	0.31
Std. Dev.	1.37	1.39	26.01

The height anomalies for the two periods are shown on Figure 1, where we have not corrected for energy dissipation. It can be seen that both datasets gives a good picture of the geoid at satellite altitude.

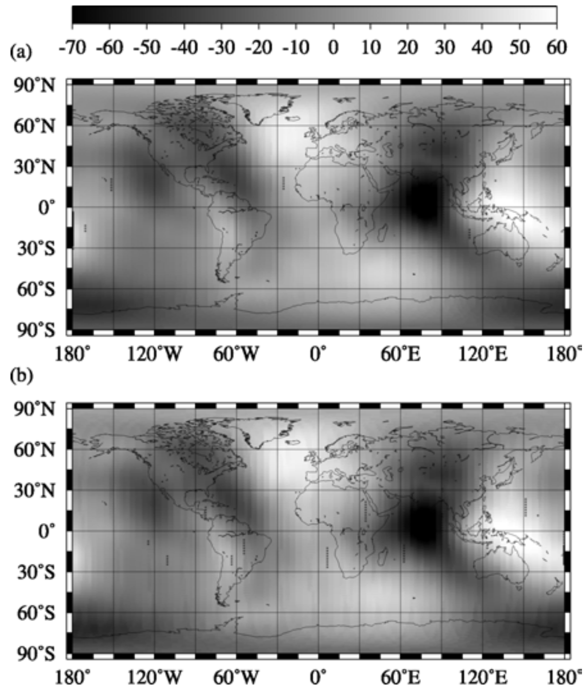

Fig. 1 a) is the height anomalies at satellite altitude for May 18-21 2001. b) is the height anomalies at satellite altitude for August 18-21 2001.

The differences between CHAMP height anomalies and values calculated from EGM96 are shown in Figure 2 together with $F = (\int \lvert v \rvert \bullet a_y dt) / g$. The difference and the correction seem both to be piecewise linear.

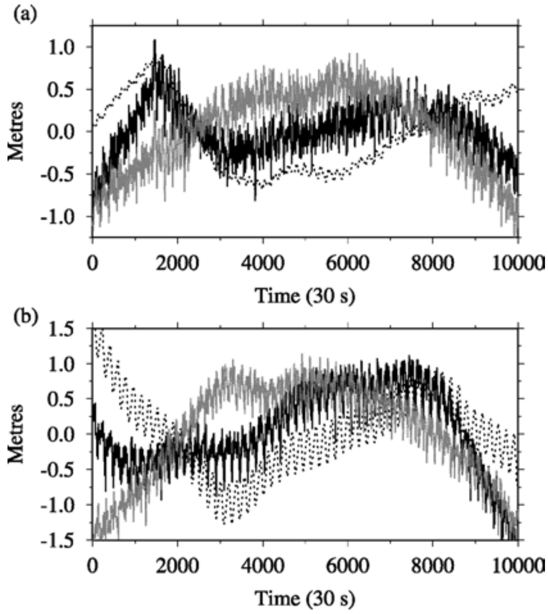

Fig. 2 a): The differences between CHAMP height anomalies from May 18-21 2001 and values calculated from EGM96 (black). The friction energy divided by gravity is plotted as dots. The grey curve is the difference between CHAMP height anomalies where the corrected acceleration is considered and values calculated from EGM96. b): As in a) for August 18-21 2001.

There is a large difference between the two periods. We found a simple explanation for this by analysing more closely the accelerometer data. The acceleration is supposed to be numerically largest when the satellite perigee is over the Equator. But this depends on atmosphere density, which changes from day to night. If the satellite is at its perigee at night, this compensates for the closeness to the Earth. This is what happens in the May period. The opposite happens in August, which leads to an amplification of the accelerations. The satellite is at perigee during the day. It shows that the day-night difference in atmosphere density is important. The bias and scale errors have a larger influence when the signal amplitude is larger.

We tried a further adjustment of the accelerations using a best fit to EGM96 for reduced periods when the differences had a linear behaviour. This gave an improved agreement of 0.14 m with EGM96 for the time period, see Figure 3.

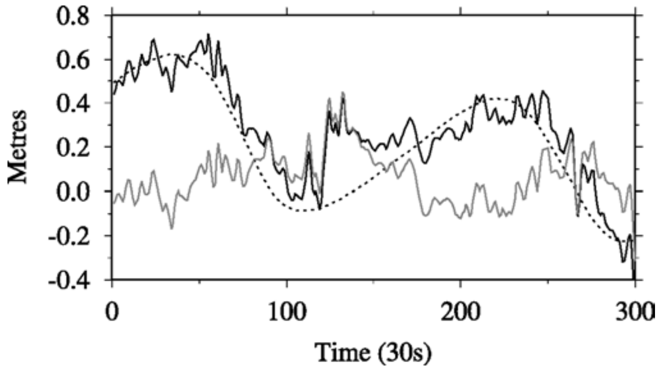

Fig. 3 The differences between CHAMP height anomalies and values calculated from EGM96 for approximately August 18 2001 (black). Only the first 300 measurements are plotted. The frictional energy divided by gravity is plotted as dots. The grey curve is the difference between CHAMP height anomalies where the corrected acceleration is considered and values calculated from EGM96. We see an agreement of 0.14 m with EGM96 for the time period. The spike of 0.4 m corresponds to the difference calculated in a point over a mountain range in Antarctica.

3 Conclusion

We have seen the importance of the relationship between atmosphere density and the accelerations, which can be used to correct the accelerations.

Furthermore the residuals have a piecewise linear trend originating from the frictional energy loss, which may be parameterised and determined by least-squares adjustment like when adjusting a gravity network. This may be an alternative procedure for correcting the observed accelerations. Another possibility is to use density values from an atmospheric model and disregard the very noisy acceleration and attitude data.

The first CHAMP gravity field model, EIGEN-1S gives a new possibility to correct the accelerations. We will use this to determine better estimates of the scale factor, the biases and the drifts.

Acknowledgement: Thanks to the CHAMP data centre for providing the data. Thanks to L. Stenseng for debugging the software. This paper is a contribution to the project SAGRADA sponsored by the Natural Science Council of Denmark.

References

Jekeli C (1999) The determination of gravitational potential differences from satellite-to-satellite tracking. Celestial Mechanics and Dynamical Astronomy, Vol. 75, pp. 85-101

Lemoine FG, SC Kenyon, JK Factor, RG Trimmer, NK Pavlis, DS Chinn, CM Cox, SM Klosko, SB Luthcke, MH Torrence, YM Wang, RG Williamson, EC Pavlis, RH Rapp, and TR Olson (1998) The Development of the Joint NASA GSFC and the National Imagery and Mapping Agency (NIMA) Geopotential Model EGM96. NASA/TP-1998-206861, Goddard Space Flight Center, Greenbelt, MD

Wessel P and WHF Smith (1998) New improved version of Generic Mapping Tools released. EOS Trans. American Geophysical Union, Vol. 79 (47), pp 579