Determination of a Gravity Field Model from one Month of CHAMP Satellite Data using Accelerations

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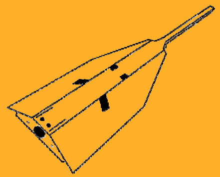

Motivation

The gravity field of the earth forms the basis of many different fields of research interest. The knowledge of the varying gravity values leads to a better geoscientific and atmospheric understanding of our planet. The earth is regarded as a dynamic system which characteristics are influenced over time. With the introduction of low earth orbiting satellite missions, new and advanced methods to estimate the gravity field of the earth have become possible. The aim of this project is the computation of a gravity field model based on CHAMP state vectors observed over a period of one month (July 2002).

Structure of Approach

Two different CHAMP data sets are utilised here, reduced dynamic and kinematic. The following figure 1 describes the approach which has been chosen.

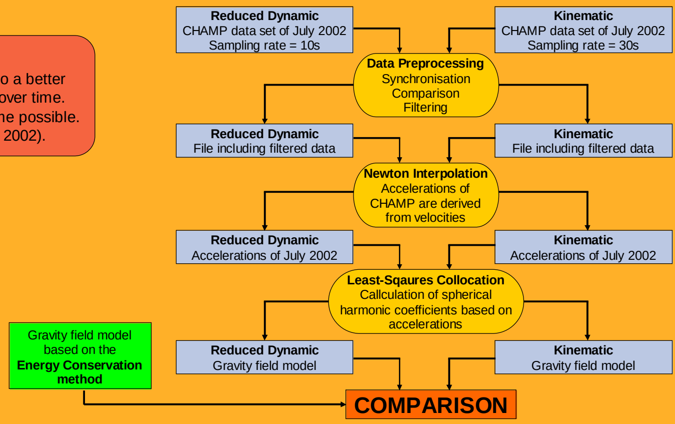

figure 1

Data Preprocessing

The idea is to compare two different data sets (kinematic and reduced dynamic) against each other in order to detect errors and inconsistencies within the data more easily.

For that reason two synchronised data files, based on reduced dynamic and kinematic observations, have been derived. The time interval is 30s except for several gaps where no reduced dynamic data are available. Kinematic observations and their corresponding reduced dynamic observations are deleted in case of disturbing influences on the kinematic data due to GPS discontinuities and edge effects.

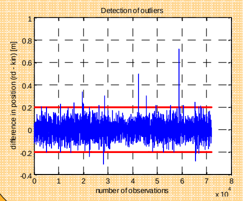

figure 2

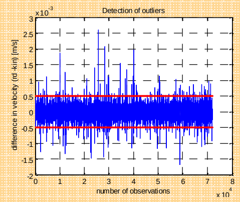

figure 3

Most of the differences in the magnitude of the position vectors, kinematic subtracted from reduced dynamic, are in the range of ±0.2m (figure 2). Differences in the velocity range between ±0.5mm/s (figure 3). Data which lie outside these borders are declared outliers and deleted. This reduces each data file by 0.7%.

Newton Interpolation

A seven-point Newton Interpolation approximates the point-wise velocities into a continuous function. This function is shown by the polynomial in equation 1 where equidistant observations are required [1].

$$\mathbf{V}(t)=\mathbf{V}_0+\sum_{i=1}^{n}\boldsymbol{\Delta}_{1/2}^{1}=\mathbf{V}_0+\binom{s}{1}\boldsymbol{\Delta}_{1/2}^{1}+\binom{s}{2}\boldsymbol{\Delta}_{1}^{2}+\binom{s}{3}\boldsymbol{\Delta}_{3/2}^{3}+\ldots+\binom{s}{n}\boldsymbol{\Delta}_{n/2}^{n} \qquad [1]$$

with $\boldsymbol{\Delta}_{n/2}^{n}=\sum_{i=0}^{n}(-1)^{n+1}\binom{n}{i}\mathbf{V}_i$ and $s=\frac{t}{\Delta t}=3$

The first derivative of this polynomial delivers the accelerations of the CHAMP satellite.

Least-Squares Collocation

The spherical harmonic coefficients c_{ij} and s_{ij} (equation 2 [2]) are computed using Least-Squares Collocation. The anomalous potential T in an arbitrary point P is thereby approximated by the observations *obs* and their covariances *cov*. In this case the observations are gravity disturbances which are derived from the above accelerations.

$$\frac{GM}{a}\begin{Bmatrix}c_{ij}\\ s_{ij}\end{Bmatrix}=\frac{1}{4\pi}\iint_{\varphi=-\frac{\pi}{2},\lambda=0}\overline{P}_{ij}\left(\sin(\varphi_p)\right)T(P)\begin{Bmatrix}\cos(j\lambda_P)\\ \sin(j\lambda_P)\end{Bmatrix}\cos(\varphi_P)\,d\lambda d\varphi \quad \begin{matrix}\text{if } j\geq 0\\ \text{if } j<0\end{matrix} \qquad [2]$$

The errors E of the spherical harmonic coefficients can be estimated by equation 3 with C_0 being the autocovariances of the coefficients and *cov(i,j)* being the normal-equation matrix.

$$\mathbf{E}^2=\mathbf{C}_0-\left\{\mathrm{cov}\left(\frac{GM}{a}c_{ij},obs_k\right)\right\}^T\{\mathrm{cov}(i,j)\}^{-1}\left\{\mathrm{cov}\left(\frac{GM}{a}c_{ij},obs_k\right)\right\} \qquad [3]$$

Only one-third of the filtered data have been used during collocation in order to reduce the system of normal equations. This leads to a distribution of observations as shown in figure 4.

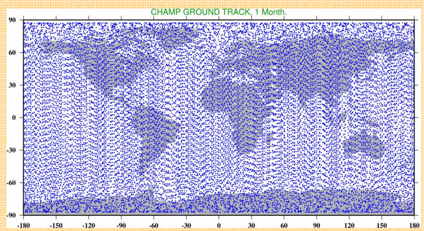

figure 4

Results

Figure 5: The reduced dynamic accelerations (red) show smaller differences in comparison to EGM96 than the kinematic accelerations (blue). The standard deviations are 0.3mgal and 1mgal respectively.

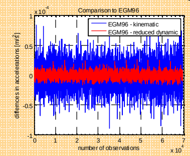

figure 5

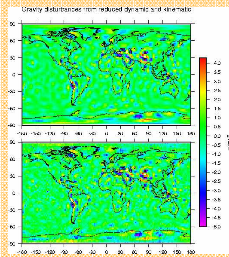

figure 6

Figure 6: Relative high differences between reduced dynamic and kinematic gravity disturbances and those based on EGM96 can be found at Antarctica, the Andes and the Himalayas where access is difficult.

Kinematic differences are in general slightly higher than reduced dynamic differences.

Figure 7: Up to degree 24, EGM96 has been removed from all data. Standard deviations of coefficient differences in red (reduced dynamic – EGM96) are smaller than those in blue (kinematic – EGM96). The standard deviations of coefficient differences using the energy conservation method (black) are also derived from the reduced dynamic observations. Up to degree 60, all graphs are lower than the standard deviation of the EGM96 coefficients (green).

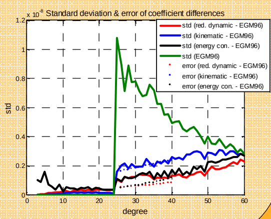

figure 7

Conclusion

1) A gravity field model has been computed by utilising Newton Interpolation and Least-Squares Collocation. This model is consistent to EGM96 at least up to degree and order 60.

2) The gravity field model shows an improvement to the energy conservation method and to EGM96 in areas where access is difficult.

3) The kinematic data are more influenced by noise than the reduced dynamic data. However, it is reasonable to use both data sets during data preprocessing in order to detect outliers.

[1] Austen and Reubelt: Spatial gravity field analysis using semi-continuous ephemerides of low-orbiting GPS-tracked satellites of type CHAMP, GRACE and GOCE, Thesis, Institute of Geodesy, University of Stuttgart, http://www.uni-stuttgart.de/gi/education/diplomarbeiten/austen+reubelt.pdf, 2000.

[2] Tscherning: Computation of spherical harmonic coefficients and their error estimates using Least-Squares Collocation, Journal of Geodesy, 75, 12-18, 2001.