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CHAMP Gravity Field Models using Precise Orbits.

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Abstract: The German CHAlleging Minisatellite Payload (CHAMP) launched in July 2000 carries a GPS receiver and a three-axes accelerometer. From GPS measurements a precise orbit of the satellite for August 2001 has been determined by DEOS at TU Delft. With these orbits and pre-processed accelerometer data, two global gravity field models to degree and order 90, UCPH2003_02 and UCPH2003_03 have been determined using fast spherical collocation from values of the gravity potential determined considering energy conservation. The models differ with respect to the treatment of the frictional forces. In the "03" model the frictional energy was determined by integration of the product of the velocity and the along-track accelerometer component, while for the "02"-solution the scalar product of the velocity vector and the acceleration vector was used.

Evaluation of the solutions has been made by comparison with a global set of 0.5° mean gravity anomalies with error-estimates below 5 mgal and new Arctic gravity data. A comparison with EGM96, the EIGEN-2 solution and between the two models have also been made. The differences between the solutions are found not to be statistically significant.

Introduction.

An energy conservation method has been applied to calculate gravity potential values from CHAMP data measured in August 2001. This period was selected because the solar activity was rather uniform, and preliminary orbit data from the period have been analyzed in earlier studies, see Howe et al., 2002. The analysis suggested that the quality of the preliminary orbit was one of the main factors contributing to the error.

Meanwhile we have obtained 'Precise Orbit' data from Delft Institute of Earth Oriented Space Research (DEOS), which include position and velocity of the satellite, as well as accelerometer measurements. For the determination of the gravity potential at satellite altitude, the kinetic energy of the satellite may be computed, and the gravity potential is obtained when external forces have been taken into account, see e.g. Jekeli (1999).

The external forces are the tidal potential of the Sun, V_s, Moon, V_m, and the friction F. In UCPH2003_02 we have taken the complete acceleration vector into account when calculating friction. In UCPH2003_03 only the along-track component is considered. The rotation of the earth's potential in the inertial frame must also be taken into account. By subtracting the Earths normal potential, U and an integration constant E, we find the anomalous potential; V is the velocity, x, y, v_x, v_y are components of the state-vector and ω is the rotational velocity of the Earth.

$$T_{sat} = \tfrac{1}{2}v^2 - V_s - V_m - \omega(x v_y - y v_x) - F - U - E_0$$

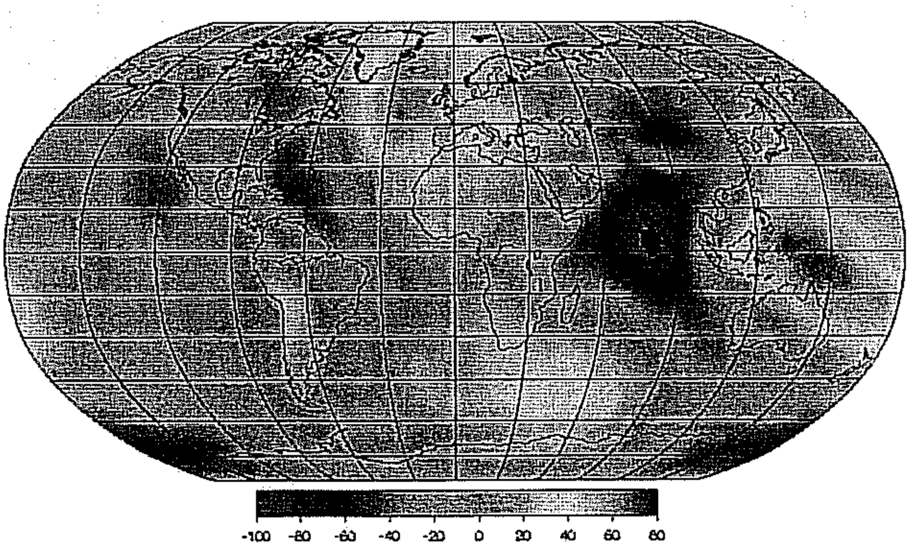

Figure 1:
UCPH2003_03
Geoid heights in metre

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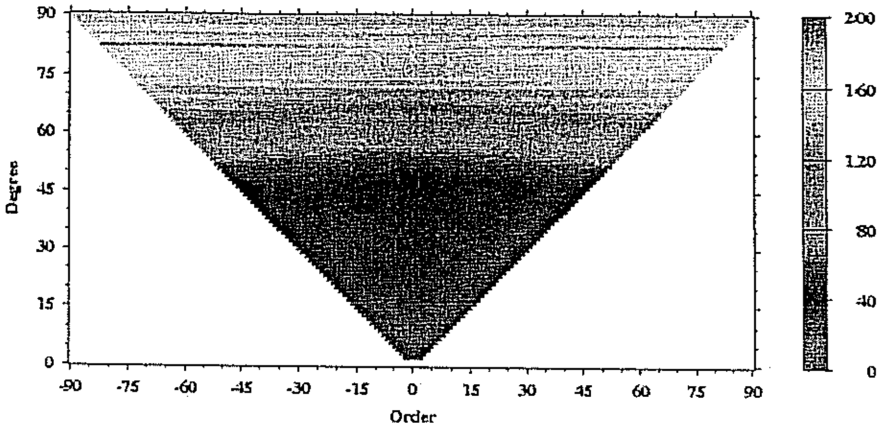
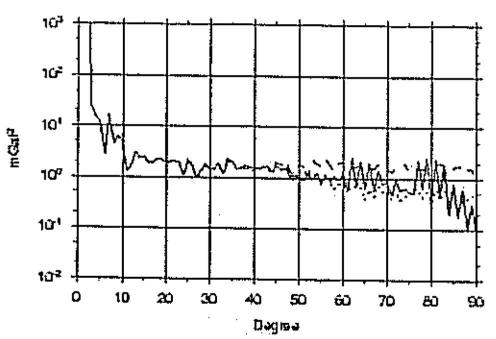


Figure 2: Error estimate for UCPH2003_03 coefficients. Scale is in units of 10^{-11}

Determination of spherical harmonic coefficients.

The method of least-squares collocation (LSC) may be used for the estimation of spherical harmonic coefficients, see e.g. Tscherning, 2001. The general use of the method requires the solution of a number of equations equal to the number of observations, here 90721. The solution of such a (full) system is just becoming feasible on a ordinary PC, but we decided to use the method of Fast Spherical collocation (Sansò and Tscherning, 2003). This method requires data located equidistantly on parallels, i.e. the data must be gridded in longitude. A grid with 0.5° spacing was determined using local LSC using the GRAVSOFT (Tscherning et al., 1994) program "geogrid". Initially the residual potential values were up-/downwards continued to a common height of 440 km above the ellipsoid using the gravity disturbance calculated from EGM multiplied with the distance. Furthermore the contribution due to EGM96 (Lemoine et al., 1998) to degree and order 24 was subtracted in order to make the data statistically more homogeneous.

The spherical harmonic coefficients and their associated errors were then determined by Fast Spherical Collocation using a uniform, uncorrelated noise of 0.5 m^2/s^2. EGM96 coefficients to degree and order 24 was then subsequently added to get a complete set of spherical harmonic coefficients.



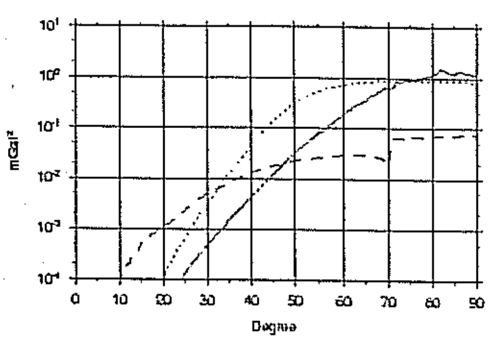


Figure 3: Degree variances (left) and error degree variances (right) for UCPH2003_03 (solid line), EGM96 (- - -) and EIGEN-2 (....).

to the gridding, which was done in large blocks with boundarys at 60° and -60° can be seen.

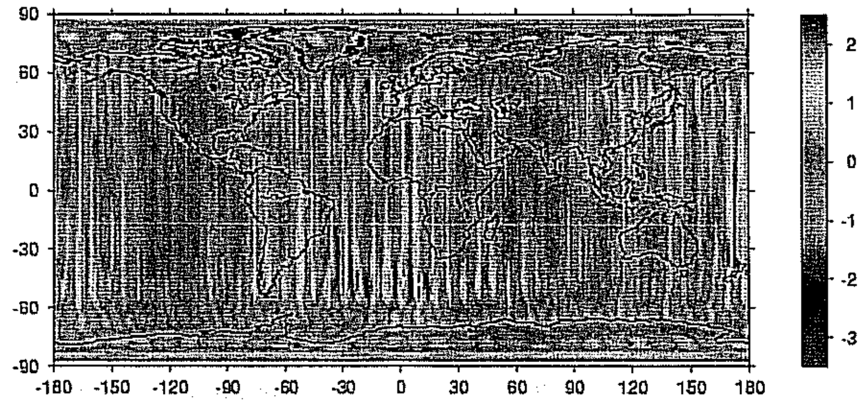


Figure 5: Differences between UCPH2003_02 and UCPH2003_03.

The mean difference between the two models is 0.2 cm and the standard deviation of the difference is 59.5 cm at zero level.

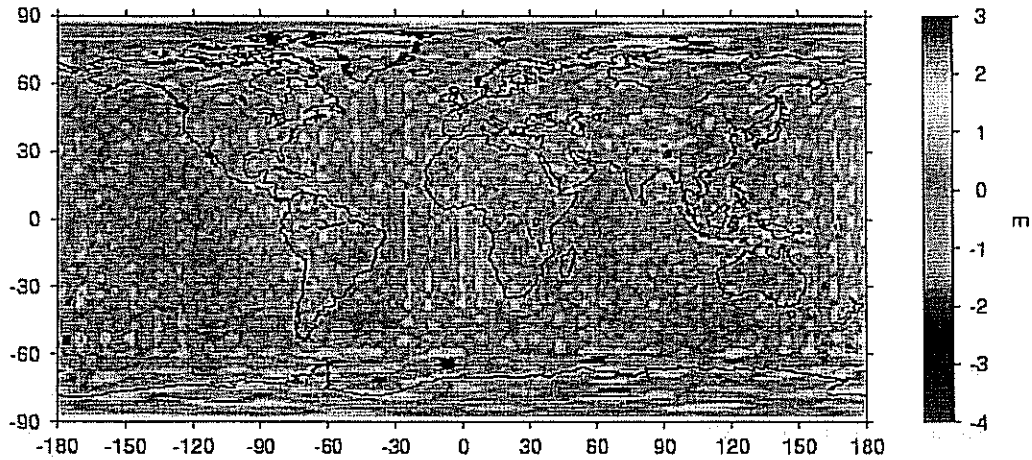


Figure 6: Differences between EIGEN-2 and UCPH2003_03.

The model UCPH2003_03 has also been compared to EIGEN-2 to degree 60. The difference between geoid heights computed from EIGEN-2 and UCPH2003_03 respectively are shown in figure 5. The mean difference between the two models is -0.46 cm and the standard deviation is 73.8 cm.

Since the accuracy of our model is 66 cm, the difference between the models is within the models accuracy.

It is therefore not possible to say that the models are significantly different.

Conclusion.

The CHAMP data from August 2001 have been used to produce 2 new gravity field models where we have taken advantage of DEOS orbit data. It seems however, that the data are still contaminated with considerable noise due to the still large solar activity in the selected period. Furthermore the uncertainty of scale-factors of the accelerometers and the noise in the attitude measurements reduced the precision of the calculation of the external forces. We hope (and expect) that data from later periods with lower solar activity will give better results. Furthermore, the gridding could be improved using general LSC and taking into account the along-track error-correlations.

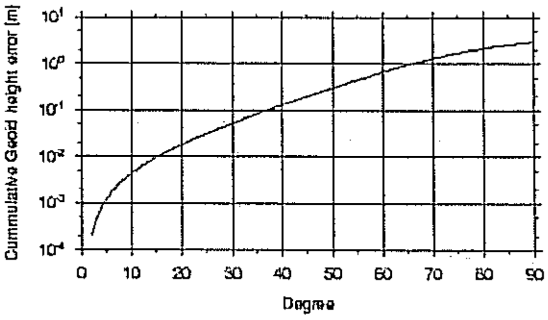


Figure 4: The accumulative geoid height error of our models.

Degree variances and error degree variances of our model are compared with EGM96 and EIGEN-2 (Reigber et al., 2003), see Figure 3.
It is seen by inspection of Figure 3 that above degree 60 there is no or little information left in UCPH2003_03 and EIGEN-2. Furthermore it is seen that below degree 40 UCPH2003_03 is expected to improve EGM96.

The accuracy of our models is seen in Figure 4. At degree 60 the accumulated geoid error is 66 cm.

Comparison with EGM96 gravity and with new Arctic gravity data.

In order to evaluate the models they have been compared to 0.5° mean gravity anomalies with error below 5 mgal used to determine the EGM96 coefficients and with new Arctic gravity data. The same comparison has been made for EIGEN-2 and EGM96. In all cases only the coefficients up to and inclusive degree 60 were used. The results are summarized in Table 1, for the mean gravity anomalies, from which we see that there are no significant difference between the solutions.

		UCPH 02.0.5		UCPH 03_02		UCPH 03_03		EIGEN -2		EGM 96	
Units: mgal	Obser-ved	Com-puted	Dif-erence	Com-puted	Dif-erence	Com-puted	Dif-erence	Com-puted	Dif-erence	Com-puted	Dif-erence
Mean.	-1.1	-0.6	-0.6	-0.7	-0.5	-0.6	-0.5	-0.7	-0.5	-0.7	-0.5
St.dev.	27.0	17.3	21.5	17.4	22.1	17.2	22.0	17.0	21.4	17.3	21.1
Max.	450.7	104.7	398.9	102.7	398.2	103.7	400.0	107.3	403.6	115.7	401.3
Min.	-300.3	-88.8	-268.2	-73.9	-292.4	-75.2	-286.9	-78.3	-277.5	-95.1	-266.5

Table 1. Comparison of 212675 mean gravity anomalies with error estimates below 5 mgal with EGM96, UCPH2002_02_0.5, (Howe et al., 2003) ,UCPH2003_02, UCPH2003_03, EIGEN-2 all to degree 60. Difference = difference between values calculated from the model and observed values..

The Arctic gravity data is a new data-set not used when determining EGM96, derived from airborne, surface and submarine data. A comparison for the whole arctic area showed no significant differences. However in some areas the solutions do not agree, and we selected the most pronounced area of disagreement bounded by latitudes 75°-78° N and longitudes 43° - 53° W (in Northwest Greenland). The comparison have again been made using only the coefficients to degree and order 60. It can be seen from Table 2 that our models fits better to the Arctic data than EIGEN-2 and EGM96.

Units: mgal	UCPH2003_02	UCPH2003_03	EIGEN-2	EGM96
Mean	-1.2	-0.9	-6.6	-4.6
St. Dev	13.6	13.8	15.8	17.8

Table 1: Comparison between Northwest Greenland gravity data and gravity values calculated from UCPH2003, EIGEN-2 and EGM96.

Evaluation of UCPH2003_02 and 03.

The models UCPH2003_02 and UCPH2003_03 have been compared to degree 90, see Figure 5. The only difference between the two models is (as already mentioned) that UCPH2003_02 is determined using the full acceleration vector and for UCPH2003_03 we only used the along-track component. For UCPH2003_03 we determined a scale factor for the along-track accelerometer for each day. Errors related to the tracks are clearly visible. Also some effect due

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The Gravity Fields: The spherical harmonic coefficients of the Gravity Field Models UCPH2003_02 and UCPH2003_03 are available at http://www.gfy.ku.dk/~eva/en/sagrada.php

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