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Global gravity field models from the GPS positions of CHAMP, GRACE and GOCE satellites

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The aim of our work is to generate Earth's gravity field models from the GPS positions of low Earth orbiters. We will present our inversion method and numerical results based on the real-world data of CHAMP, GRACE and GOCE satellites.

The presented inversion method is based on Newton's second law of motion, which relates the observed acceleration of the satellite with the forces acting on it. The vector of the observed acceleration is obtained through a numerical second-derivative filter applied to the time series of the kinematic positions. Forces other than those due to the geopotential are either modelled (lunisolar perturbations, tides) or provided by the onboard measurements (nongravitational perturbations). Then the observation equations are formulated using the gradient of the spherical harmonic expansion of the geopotential. From this linear system the harmonic coefficients are directly obtained. We do not use any a priori gravity field model.

Although the basic scheme of the acceleration approach is straightforward, the implementation details play a crucial role in obtaining reasonable results. The numerical derivative of noisy data (here the GPS positions) strongly amplifies the high frequency noise and creates autocorrelation in the observation errors. We successfully solve both of these problems by using the generalized least squares method, which defines a linear transformation of the observation equations. In the transformed variables the errors become uncorrelated, so the ordinary least squares estimation may be used to find the regression parameters with correct estimates of their uncertainties.

The digital filter of the second derivative is an approximation to the analytical operation. We will show how different the results might be depending on the particular choice of the parameters defining the filter.

Another problem is the correlation of the errors in the GPS positions. Here we use the tools from time series analysis. The systematic behaviour of the sample autocorrelation function and partial autocorrelation function of the residuals shows that their dependence structure might be represented by the autoregressive model. This indeed appears to be the case, upon applying the estimated autoregressive model, the residuals become uncorrelated and the geopotential harmonic coefficients improve by a factor of 2–3.

We applied the presented method to orbits of CHAMP and GRACE covering 7 years (2003–2009) and to two months of GOCE (Nov/Dec 2009). The obtained long-term static gravity field models are of similar or better quality compared to other published solutions. We also tried to extract the time variable gravity signal from the CHAMP and GRACE orbits. Based on the data covering several years, we obtained the average annual continental hydrology signal, where the main geographical areas with important hydrological variations are evident.