GEOCENTER MOTIONS DERIVED BY DIFFERENT SATELLITE METHODS

Horst Montag, Anhalt University of Applied Sciences, Dessau, Germany

ABSTRACT

The gravitational center of the Earth, the geocenter, plays a crucial role as the origin of the terrestrial reference system, and it is also an important parameter for geodynamic investigations. Therefore, it should be determined and monitored with highest accuracy. This can be done by satellite methods using the geocenter as the dynamical origin.
Current accuracies of measurements and modelling allow the study of temporal variations of the geocenter. Comparisons were performed for different solutions based on Satellite Laser Ranging (SLR), Global Positioning System (GPS) and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) data. Although the potential of the methods treated is different to prove the motion of the geocenter the results demonstrate significant variations of all three Cartesian components, mainly seasonal effects. The amplitudes are in the order of several millimeters; the phases show partly large differences. Conclusions for further activities are drawn based on these comparisons.

INTRODUCTION

The geocenter realized by the coordinates of the tracking network on the solid Earth, is used as the origin of the Terrestrial Reference System (TRF). For the geodesy this geocentric coordinate system plays a crucial role as the absolute system. Therefore, it should be determined and monitored with highest accuracy.
Physically, the geocenter is defined as the center of the mass distribution of the entire Earth interior, the oceans, and the atmosphere; it is the dynamic origin of satellite motion. Caused by a great variety of inner and outer forces on the Earth system this center of mass is changing. Setting equal zero the degree one Stokes coefficients of the Earth's gravity field the motion of the geocenter is equal to the translation of the origin of the used TRF, that means the relative motion of the gravitational center of the Earth with respect to the tracking network.

Current accuracies of the different methods allow to investigate the temporal variations of the geocenter. With reference to the more detailed paper delivered to the Fall 1997 AGU Meeting (Montag, 1997) this brief report is intended to evaluate the significance of the observed phenomena on the basis of the comparison of the results of different satellite geodesy solutions.

COMPARISON OF THE DIFFERENT SOLUTIONS

Based on the data of the last years (time span between 3 and 5 years) the geocenter solutions used consist of the following:
- three solutions using Satellite Laser Ranging (SLR) data to the satellites Lageos 1 and 2 (Montag et al., 1996; Eanes, 1997; Pavlis, E., 1997),
- one SLR solution with Topex-Poseidon (T.-P.) satellite (Cheng, 1997),

- three GPS data solutions (Montag et al., 1996; Zhu, 1997; Heflin, 1997) and
- one solution using DORIS data on SPOT2, SPOT3 and Topex-Poseidon satellites (Bouille and Cazenave, 1997).

Different software packages were used for the different analyses. The model parameters generally conform to the IERS conventions (McCarthy et al., 1996), but several exceptions refer to the Earth gravity field, the tidal parameters and others. Also, the kind of parameters and the parameter estimation procedure differ between the different solutions. Here the Lageos solutions have advantages because of the smaller orbital perturbations. In the case of GPS, e.g., the estimation of the solar radiation (once per revolution, as velocity impulse or others) or the kind of phase ambiguities solutions can have essential influences although the solution of both effects have been lately steadily improved.
Generally, the different solutions are more or less sensitive to the model parameters and the estimation procedure. This may cause systematic errors which are always difficult to estimate. Therefore, the redundancy of different methods is important.The best procedure is to combine the different solutions in a proper way.

The comparisons have shown that the precision of the obtained components of the geocenter motions (scatter about their respective means) is generally significantly better for x and y (about or less than 5 mm) than for the z component, which is partly more than 10 mm. But there are several deviations. In the case of the GPS solutions the scattering is much higher. The Topex-Poseidon solution (SLR) show a different behavior. Here the z- component is more smoothed than x and y; for x and y the precision is in the same order as for the other solutions.
In their general course, the variations of the three Cartesian geocentric parameters are interpreted as geocenter motions. They show a different behavior, as for the amplitude as concerning the phases. The solutions based on Lageos vary between about +10 mm and -10 mm for x and y; z reaches amplitudes of more than 20 mm. The GPS solutions show partly much higher amplitudes, especially again for z. Similar big variations show the differences of the weekly station coordinates solutions of the seven IGS Analysis Centers (CODE, EMR, ESA, GFZ, JPL, NGS, SIO) with respect to ITRF94 performed by JPL, MIT and NCL (30 weekly results in 1997/98, Kouba, 1997). This confirms the relatively large sensitivity of the modelling procedure (which is partly different in the mentioned Analysis Centers) to the GPS data. The geocenter variations based on DORIS data and Topex-Poseidon analyses amount about or less than 20 mm (between ±10 mm) for all thre components.

DETERMINATION OF THE ANNUAL AND SEMIANNUAL GEOCENTER VARIATIONS

The results of the Fourier power spectra analyses for the time series of the geocenter variations show an annual period for all components and all solutions. The derived periods amount to between 220^d and 380^d. This is mainly caused by the seasonal mass redistributions, but other phenomena, e.g. longer and long-term climate oscillations or long-periodic tides and nutation effects, have some influence too.
A semiannual period seems to be significant also but it was not found in all series (partly GPS and T.-P.). The derived period lengths vary between 120^d and 210^d.
Additionally, several other periods were found, but not the same in all series and partly not very significant. Mainly, they are situated in the region of a fortnight (only higher resolved GPS solution) and of two to four months. Some series indicate periods of about two years too. For investigating the shorter periods one needs a higher resolution, and for longer periods the time series should be prolonged.

For the annual and semiannual variations of the geocenter the amplitudes and phases (referred to 1994.0) were determined. Generally, the amplitudes of the annual period are bigger by a factor of 2 to 3 than the semiannual effects, but the differences between the single solutions are relatively high. Especially the GPS solutions delivered unrealistic results in some cases. The derived precision indicate uncertainties up to several mm for the amplitudes; for the phases the errors can reach very large amounts depending on the amplitude and the method. These precisions plus estimated values for systematic effects were used to calculate the weights of the different solutions. The weights for a single solution and component vary between 1 and 8. Because of unrealstic results, a single GPS solution was not included in further averaging (weight 0). Thus the contribution of the Lageos solutions amounts more than 50%, those of Topex-Poseidon plus Doris about 30%, and that of GPS about 20%.

Using these weights the overall means were computed and are shown in Table 1. Both the x- and y- component have an amplitude for the annual period of about 3 mm, but a phase difference of about 100°. The errors (weighted r.m.s.) are in the order of ±1mm and ±20°, respectively. The annual amplitude for z is 4.5 mm with an uncertainty of ±1.7 mm. The bigger amplitude for z may be caused by the dominance of seasonal mass redistributions between the northern and southern hemisphere. The higher errors (amplitude and phase) are, as for the investigation of other phenomena, at least partly related to the geometry of the tracking station network. The phase for z amounts 87° and is situated nearly in the middle between those of the x- and the y-component.

The amplitudes of the semiannual periods are about half of the annual amplitudes in the case of x and y; for z the difference is even bigger. Again the phases are different for all three components.

Table 1: Summary of Annual and Semiannual Geocenter Motion (weighted means)

Compo-nent	Annual		Semiannual	
	Amplitude [mm]	Phase [°]	Amplitude [mm]	Phase [°]
1	2	3	4	5
x	**2.9** ± 1.0	**32** ± 18	**1.4** ± 0.3	**190** ± 30
y	**3.7** ± 1.3	**146** ± 18	**2.0** ± 1.2	**273** ± 26
z	**4.5** ± 1.7	**87** ± 22	**1.0** ± 0.6	**74** ± 27

The phase differences reflect the difference of the effect of the mass redistributions in time and space. Recent investigations about the influence of atmosphere, ocean and groundwater (Dong et al., 1997) have shown similar amplitudes. That means the amplitudes of Table 1 can be, in general, quite well explained by these phenomena. But this is not the case for the phases; here a fairly good correlation can only be seen between the ground water effect (the biggest influence) and the z-component of the annual variation.

CONCLUSIONS

The comparison of the above solutions for the investigation of geocenter variations based on different data and different software systems has shown that this effect is real. Although the potential of the applied methods for the evidence of the geocenter behavior is different, common signals demonstrate the components of the geocenter variations. In future the proof of the geocenter motion has to be further improved by including more and prolonged observation series, and by using more expanded and sophisticated parameter sets. The SLR solutions with Lageos will continue to provide the basic elements of the determination of geocenter motions.

The most significant effects are the annual and semiannual geocenter variations caused by the different seasonal mass redistributions in the Earth system (air pressure, ocean circulations, ground water, snow etc.) superimposed by other phenomena (longer periodic climate oscillations, tides, nutation; convections, core-mantle interactions and other mass motions in the Earth interior). Thus the observed time series of geocenter variations can be used to constrain geophysical models. Therefore, the inter-disciplinary investigation of the geocenter motion and its correlation with the different geodynamic phenomena will become more and more important for future analyses.

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