Comparison of High Precision Geoid Models in Switzerland

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Abstract. The recently released national geoid model CHGeo2004 of Switzerland was determined by combining gravity, vertical deflections and GPS/leveling. Its accuracy is in the order of 2-3 cm as could be verified by comparison with independent data. Besides of the standard models (topography and global geopotential model), a simple 3D density model of the Earth's crust has been introduced for the reduction of the observations. The method for the calculation was basically least squares collocation with a slight modification in the way that the parameters of the covariance function have been chosen to minimize the resulting residuals between the astrogeodetic, the gravimetric and the GPS/leveling geoid model.

Although CHGeo2004 is the result of a combination of different data sets, also the individual pure astrogeodetic, gravimetric and GPS/leveling solutions have been calculated. This gave us the opportunity to investigate the systematic discrepancies. With a pure astrogeodetic solution, we obtained a global accuracy of about 6 cm with some larger systematic differences to the combined solution of up to 20 cm. The deflections of the vertical are the most sensitive data set with respect to the variation of the covariance model. Gravity and GPS/leveling are less sensitive to changing the covariance function. Nevertheless, especially GPS/leveling shows rather large differences to the solutions of the other data sets in some areas.

The official geoid model that has been released to the surveyor community is strongly based on GPS/leveling, since their principal use of the geoid model is GPS height determination, which should be in agreement with leveling.

Keywords: Local geoid determination, Switzerland, combined geoid

1 Introduction

The main goal of the calculation of a new geoid model for Switzerland was to set up a consistent height system where the orthometric heights out of leveling (and gravity) are compatible with the heights out of GPS and the geoid model. Since today almost all height determinations with lower accuracy demands are performed by GPS measurements, a geoid model giving the same results as leveling was the principal request of the surveyors. This request implies, that GPS/leveling data had to be introduced into the geoid calculation with a rather high weighting.

2 The data set for CHGeo2004

In the last few years there have been efforts to cover the country with very precise GPS/leveling stations. So, many GPS stations have been connected to the first order leveling network and many leveling benchmarks have been observed by GPS in sessions of at least 24 hours. Today we can use about 200 GPS/leveling measurements for the geoid computation.

Another improvement of the data set for the new geoid computation was the densification of the already rather dense network of astrogeodetic stations. In regions with known problems in the existing geoid model CHGeo98, additional deflections of the vertical have been determined with the digital zenith cameras of the ETH Zurich (Müller et al. 2004) and of the TU Hanover (Hirt et al. 2004). In just 1 month about 60 stations could be observed with accuracy in the order of 0.1 arc seconds.

On the contrary to the geoid calculation of CHGeo98, where gravity was only used to model the difference between geoid and quasigeoid (downward continuation), gravity data has been introduced directly as observations in the determination of CHGeo2004. The more than 30'000 gravity values have been gridded with a resolution of 5 km.

This gives us the data set shown in fig. 1 with about 2200 gridded gravity values, about 700 deflections of the vertical and about 200 GPS/leveling observations. Another set of 270 'artificial' GPS/leveling observations has been introduced in the regions in neighboring countries where we had no or only few data. There, we introduced the height anomalies of the European quasigeoid model EGG97 (Denker et al., 1997) directly as observations just to avoid the drifting away of our solution in these areas. The weighting of these observations was chosen in a way that they reproduce the exact values of EGG97 on the introduced grid points themselves but also that they have no influence on the solution inside Switzerland. This can be reached by improving artificially the distance between these stations and the 'real' observations in the least squares collocation approach.

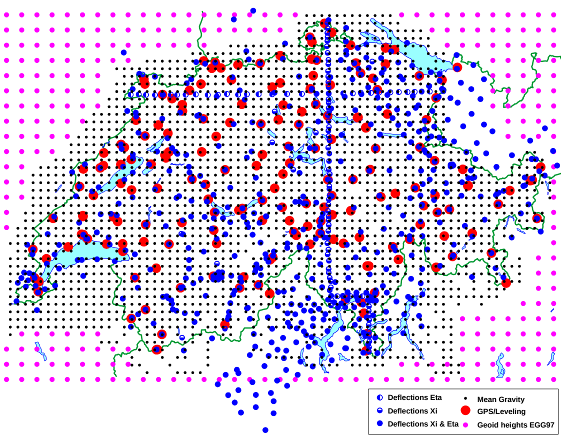

Fig. 1: Dataset for the determination of CHGeo2004

3 Mass models and reduction of data

The reduction of the observations has been performed in a first approach with the standard method by using a global geopotential model (EGM96) and a digital terrain model (RTC). As digital terrain model we used our national 25 meter DTM and outside of its area we used SRTM3 data. The full resolution of the DTM is only used in an area of about 150 meters around each data point. Further away we use re-sampled models with a resolution of 50, 500 and 10000 meters.

As further models we introduced a rather rough density model of the Earth's crust into the calculation. This model mainly includes a Moho model, a model of the Ivrea body, sediments of rivers, water masses of lakes and the ice thickness of large glaciers. Since a part of the effect of most of these models is already included in the global model, only the remaining part may be used for the reduction. In our calculations, we used the difference between the influence at station height and the influence at sea level for the reduction. This reproduces exactly the differences between normal heights and orthometric heights as we use them in our national leveling network LHN95 (Marti et al. 2001). Therefore, it also does not matter if we introduce normal heights or orthometric heights for the GPS/leveling observations in the geoid determination. If we apply the correct reduction, we obtain exactly the same results for the geoid and the quasigeoid, if we also apply a small correction to the GPS/Leveling data and the deflections of the vertical in the form of the product of the residual gravity and station height.

4 Calculation of the geoid

The residual field of all observations has been interpolated by least squares collocation with the 3rd order Markov model as the covariance function. Several tests by varying the parameters of the model and by changing the weights of the individual data sets have been performed, which mainly showed that the most sensitive data set with respect to the variation of the model parameters are the deflections of the vertical, whereas gravity and GPS/Leveling are not so much affected by changing the model. The definitive parameters have been chosen in a way that the residuals on GPS/Leveling become minimal for a pure astrogeodetic / gravimetric solution, which is a slight modification of the concept of least squares collocation.

For the official solution of CHGeo2004, a combination of all three data sets (GPS/leveling, gravity and deflections of the vertical) has been used, but GPS/Leveling data got a very high weighting, so that these observations got practically no residuals. This is the solution that guarantees the consistency in the height system and therefore, is preferred by the surveyor community but certainly it hides some problems of the GPS/leveling data set.

The restore from the co-geoid to the geoid and to the quasigeoid is simply done by adding the formerly removed effects of the mass models and the global model. Figures 2 and 3 show this step in the case of the geoid and in case of the quasigeoid, where we see the contribution of each part. Figure 4 shows the calculated geoid CHGeo2004.

The differences to the former geoid model CHGeo98 (fig. 5) are mainly caused by the strong weighting of GPS/Leveling in CHGeo2004 in some areas and - outside of Switzerland - by the use of data in areas which were not covered in the calculation of CHGeo98. The recently measured deflections of the vertical had only a minor influence and the introduction of gravity data had only an important effect in remote alpine areas which are not covered by astrogeodetic measurements or GPS/leveling.

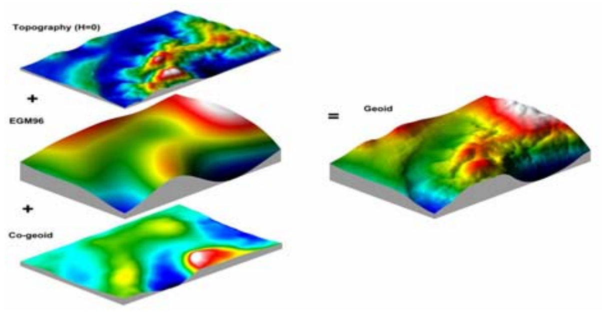

Fig. 2: Restore step of the geoid

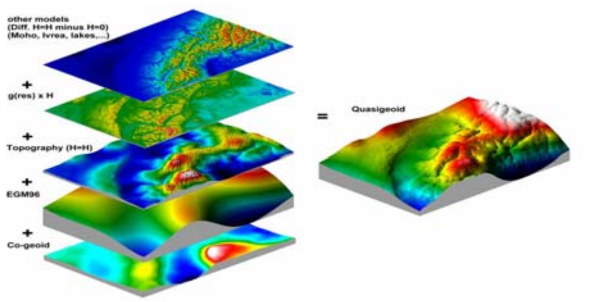

Fig. 3: Restore step of the quasigeoid

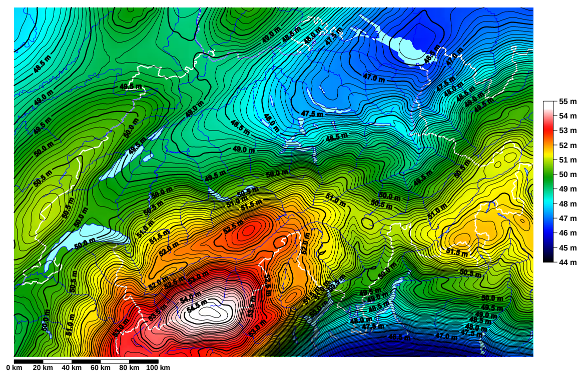

Fig. 4: Swiss Geoid model CHGeo2004

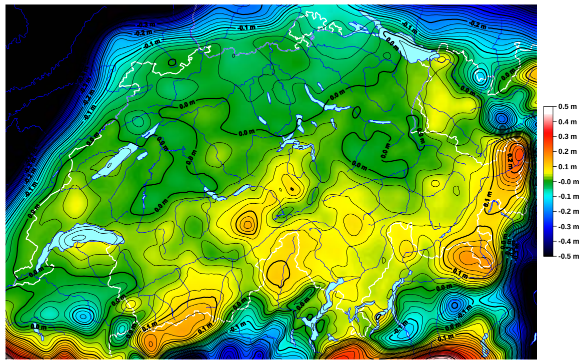

Fig. 5: Differences CHGeo2004 minus CHGeo98

The quasigeoid has basically been calculated for compatibility reasons with European projects such as UELN, EVRS (Ihde et al. 2001) or the European Gravity and Geoid Project EGGP (Denker et al. 2004). The differences between geoid and quasigeoid are in general smaller than 10 cm but they can-reach amounts of up to 60 cm in mountainous regions. These differences are shown in fig. 6.

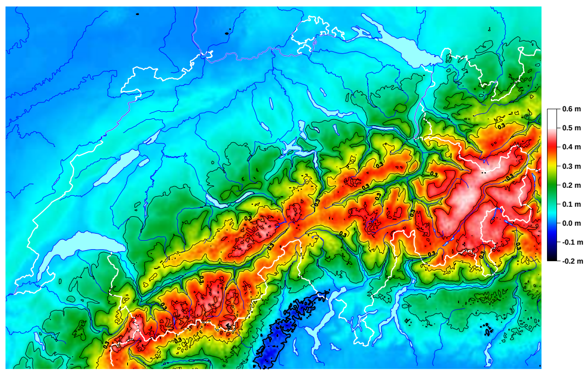

Fig. 6: Differences of geoid and quasigeoid

5 Comparison of solutions

The official solution of CHGeo2004 is a combined solution of GPS/leveling, gravity and deflections of the vertical with a very high weighting of the GPS/leveling observations. This gives the surveyors a geoid model they can use for height determination with GPS. Besides of this official model, several other solutions have been computed. The variations include the parameters of the covariance model and mainly the weighting of the observations. The next figures show a selection of these calculations and the differences of the results to the official combined solution.

One test was to compute a geoid model out of GPS/leveling data alone (fig. 7). This solution shows a rather good agreement with the combined solution in areas where GPS/leveling data is available. In regions without sufficient data coverage, the differences become very large and reach up to 60 cm in the southern areas, mainly in the region of the Ivrea body. Another test with only half of all available GPS/Leveling points showed almost the same result. The differences to the solution with all GPS/leveling were everywhere smaller than 2 cm.

A pure astrogeodetic solution (fig.8) is very sensitive to the parameters of the covariance function. Depending on these parameters we get a variation of the result in the order of 10 cm. In the east of the country we get differences of more than 20 cm compared to the combined solution. This indicates a discrepancy between the deflections of the vertical and GPS/leveling in this region. An explanation for this discrepancy could not be found yet. This area is well covered by astrogeodetic data and by GPS/Leveling points. Also the Austrian leveling data are in agreement with our leveling results. But as we see in fig. 8, in most parts of the country the differences to the combined solution are smaller than 5 cm. The mean GPS/leveling residuals of the astrogeodetic solution are about 6 cm.

Also a pure gravimetric solution (fig. 9) shows a very good agreement with the combined solution in most parts of the country - even better than the astrogeodetic solution. Only at the borders towards Italy there are larger differences of up to 20 cm. In these areas the gravimetric data coverage is rather poor and especially the effect of the Ivrea body is clearly visible. In the east of the country the gravimetric solution shows about the same tendency as the astrogeodetic solution.

A combined solution of astrogeodetic and gravimetric observations without GPS/leveling (fig. 10) is very close to the official resolution except for the region in the east, where GPS/leveling does not fit to the other observation types and in some remote areas at the borders where we have GPS/leveling stations. This solution is also very close to the pure astrogeodetic solution except in some areas of a very good coverage with gravity data and poor coverage with deflections of the vertical.

In fig. 11 is displayed the difference between the gravimetric and the astrogeodetic solution. The characteristics show once again the already mentioned problems in the East and the difficulties in the region of the Ivrea body and in the Southern Alps where the gravity coverage is rather poor.

As a summary can be said that for more than 90% of the country all the tested solutions are in agreement in the order of 2-3 cm. This is especially the case in the flatter areas in the north and west but also in most regions of the central Alps. The main problems of the geoid determination in Switzerland are found in the mountainous areas in the East and in the South towards the borders with Italy. One special case is the Ivrea zone, where we have larger differences of more than 20 cm between the different solutions.

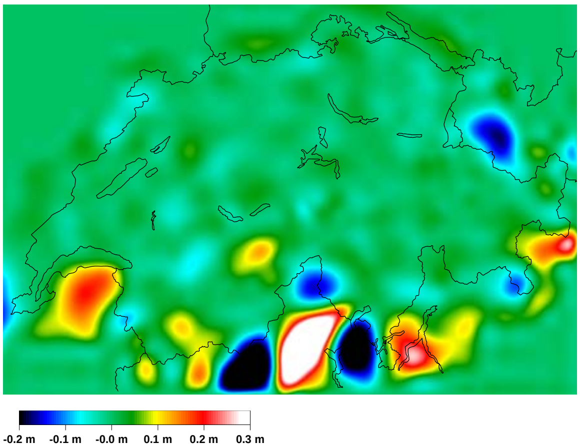

Fig. 7: CHGeo2004 minus GPS/leveling solution

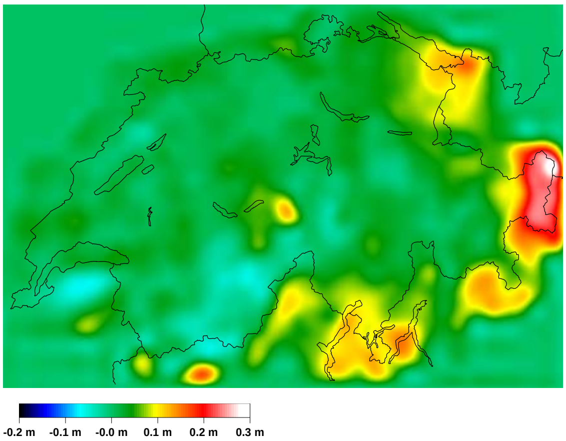

Fig. 8: CHGeo2004 minus astrogeodetic solution

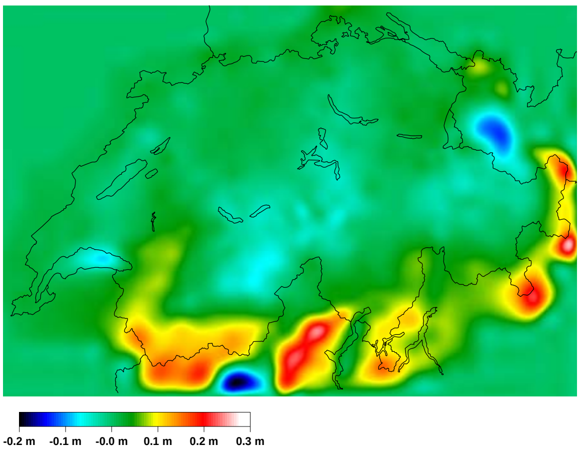

Fig. 9: CHGeo2004 minus gravimetric solution

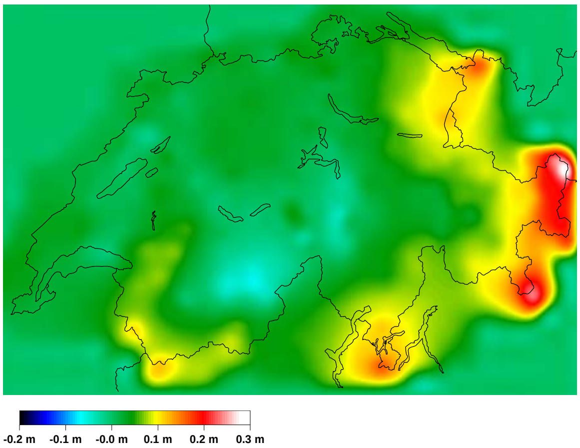

Fig. 10: CHGeo2004 minus gravimetric plus astrogeodetic solution

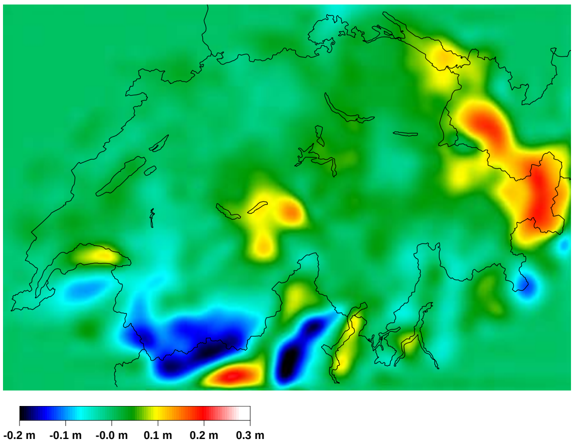

Fig. 11: gravimetric minus astrogeodetic solution

6 Conclusions

The geoid and quasigeoid model CHGeo2004 was calculated by the combination of all available data sets of gravity, deflections and GPS/leveling. For the reduction of the observations and for the downward continuation we used the geopotential model EGM96, a digital terrain model with a resolution of 25 meters and a simple density model of the Earth's crust. The method of computation was least squares collocation. The parameters of the covariance function have been chosen to minimize the GPS/leveling residuals in a pure astrogeodetic/gravimetric solution. The accuracy of the calculated model is in the order of 2-3 cm in most parts of the country. In some mountainous regions the accuracy may be in the order of 5 cm or even 10 cm.

The GPS/leveling data was introduced into the adjustment with a very strong weighting. This leads to a geoid model whose general form is fixed by these GPS/leveling measurements. Only in regions without leveling lines gravimetric and astrogeodetic measurements have a major influence. In the original plan it was foreseen to calculate a geoid model out of gravity and vertical deflections only. In this case, the GPS/leveling residuals would have been separated to the individual data sets in an additional adjustment as described in Marti (2001). But this lead to a solution which was very near to the combined solution which we finally chose. Therefore we rejected this more complicated way.

The comparison of different individual solutions of pure GPS/leveling, astrogeodetic and gravimetric geoid models showed that in most parts of the country they are in a very good agreement of better than 3 cm. Only in some mountainous regions in the South we get larger discrepancies of more than 20 cm. The main reasons for this are often local weaknesses of the data sets. But there are also other reasons such as the insufficient modeling of the Ivrea body. In the east of the country there also exists a discrepancy between GPS/leveling and the other data sets which could not be explained sufficiently until now. This area will be a major focus for gravity field investigations in the near future.

The calculation of the Swiss Geoid model CHGeo2004 was part of setting up a new consistent national height system that will be used from now on as the reference for all national geodetic work. The geoid model has been released to the surveyors and it is integrated in most geodetic GPS receivers and software sold in Switzerland. With this geoid model, it is possible to obtain orthometric and normal heights that are compatible with leveling better than 1 cm. Unfortunately, cadastral surveying will not change to this new modern height system and we will continue to have to deal with local height transformations (Marti, 2002).

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