High precision combined geoid determination in Switzerland

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Abstract. The actual geoid and quasigeoid model of Switzerland CHGEO98 was determined in 1998 by combining gravimetric, astrogeodetic and GPS/levelling data. For the reduction of the observations a 25 m DTM, a simple density model and a model of the crust-mantle boundary were used. Since no global geopotential model was introduced, a rather large trend remained in the residuals, which caused several problems in combining the various data sets and in the step of downward continuation. The accuracy of CHGEO98 is said to be in the order of 3 to 5 cm over the whole country and the GPS/levelling residuals are in the order of ±8 cm with a rather smooth behaviour.

The goal of the new geoid determination CHGeo2004 is to reach an accuracy of 1 cm over the whole country and to reduce the GPS/levelling residuals to the order of the precision of the GPS and levelling height determination. The main source of new gravity field information are mainly thousands of recently collected gravity measurements but also some very accurate deflections of the vertical, the determination of additional GPS/levelling stations and new density models. The introduction of a global geopotential model eliminates the large trends in the residuals of the previous geoid determination but raises some new problems in the treatment of the density models. Especially the handling of intra-crustal anomalies, such as the Ivrea body, demands new approaches in the concept of residual 'terrain' corrections.

Keywords: Local geoid determination, Switzerland, mass models, density, combined geoid

1 Introduction

The actual national geoid model CHGeo98 (fig. 1), which is a combined solution of gravity, astrogeodetic measurements and GPS/levelling has an accuracy in the order of a few cm. But despite of this accuracy, the newer GPS/levelling measurements show systematic discrepancies in the order of 7 to 20 cm in some regions. Therefore, a new effort was made to collect existing data and to fill some gaps with new measurements.

This presentation shows the data sets, the used mass models for the reduction of the data, the general methods of computation and some first results.

2 The Geoid model CHGeo98

CHGeo98 has been determined using about 600 deflections of the vertical (fig. 3), about 3500 gravity measurements and about 70 GPS/levelling stations. The raw observations have been reduced by the influence of mass models such as topography, Moho, Ivrea body, sediments of large rivers, water of lakes, ice of glaciers and several local density anomalies.

The residual gravity field (co-geoid) was then calculated by least squares collocation. The geoid as well as the quasigeoid has been generated by adding the effects of the mass models that have been eliminated before the collocation process. Both solutions are supposed to have an accuracy of about 3 cm in the flatter areas and of about 5 cm in mountainous regions as could also be verified by comparison to the independent European Gravimetric geoid EGG97. Despite of this high accuracy, residuals of several cm at the GPS/levelling stations remain. Therefore it was decided that the Swiss Geoid should be recomputed.

One major new data source for a new geoid solution is the currently available measurements. Whereas in CHGeo98 about 3500 gravity values have been used, there are now more than 40'000 values available (fig. 2) for the geoid computation, which corresponds to about 1 station per km^2. More important than the increase of the number of stations is that all the new data has been rigorously tested and is now available in a unique reference system without outliers. Additional information for the geoid determination is the recently measured deflections of the vertical (fig. 3) and many recent accurate GPS/levelling connections.

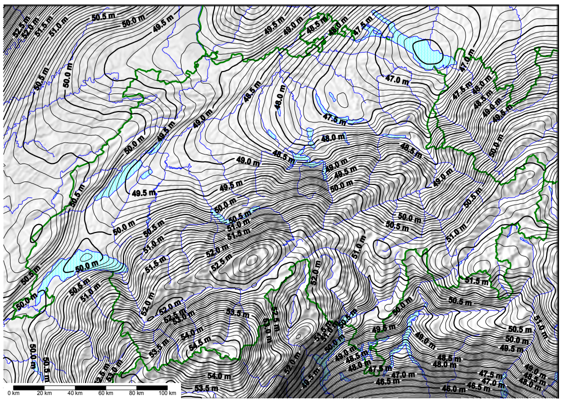

Fig. 1: area covered by DHM25 and the investigated area

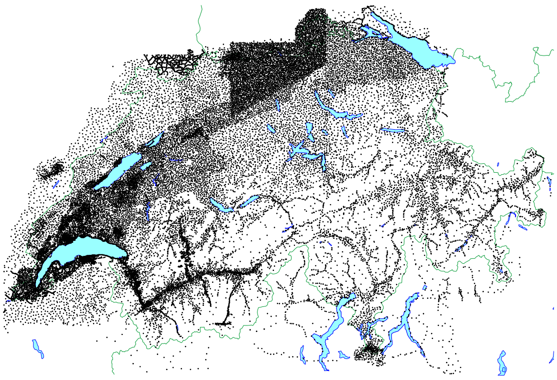

Fig. 2: available gravity data for the geoid determination

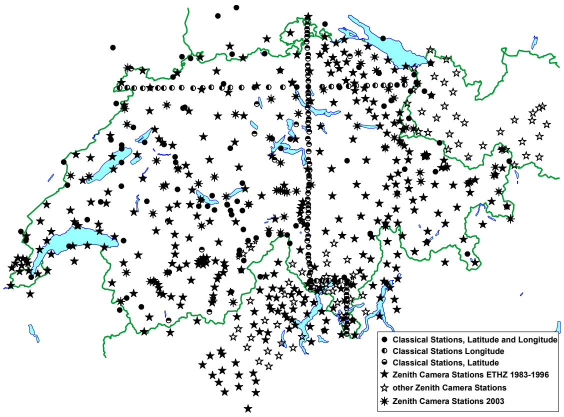

Fig. 3: available deflections of the vertical

3 Mass models and reduction of data

Other than in the geoid determination of 1998, for the actual calculations a global reference model has been introduced (EGM96, fig. 13). This has the advantage that we do not have to model anymore the density distribution of very deep structures (Moho and below). The largest part of their influence is included in the global model. It allows us also to restrict the digital terrain model to a smaller area of about 70 km around the country.

As a DTM we continue to use DHM25 with a resolution of 25 m. This model was only slightly modified since 1998 by introducing break faults and by re-digitizing the glacier surfaces. In the surrounding areas not covered by DHM25 we use now the SRTM3 data set. The full resolution of the DTM is only used in the close neighbourhood of the points. Further away we use re-sampled models with a resolution of 50, 500 and 10000 meters.

The topographic effect on gravity, vertical deflections and height anomalies is calculated by using mainly formulas for vertical prisms, but for the nearest topography formulas for irregular polyhedrons are used. The residual terrain correction (RTC) is calculated in a standard way by introducing a smoothed DTM.

Local density models have only been introduced in the most important cases such as water masses of large lakes, the ice coverage of glaciers or quaternary sediment fills in the main river valleys.

Other than in the geoid determination of 1998, a model of the crust mantle boundary (Moho) has not been introduced. Tests showed, that practically all the effect of this density discontinuity is 'seen' by the global model. This holds true also for the tertiary sediments of the Po plain, where only some near surface features have been modelled.

The RTC concept, as it is used in the standard geoid calculation, should in principle also be applied in the case of all other introduced density models: One part of the gravity effect is included in the global model and just the remaining high frequency part should be considered. But for most of the models this is not necessary: Either they cause practically only high frequency effects (sediments, glaciers and lakes) or only low frequency effects (Moho). The topography model is something in between and can be treated with the standard approach. Other models that have to be separated are large intra-crustal structures like the Ivrea body in Northern Italy and Southern Switzerland (fig. 6). This large density anomaly causes local, as well as regional effects (fig. 4 and 5). For the geoid determination this body is modelled by several polyhedrons of varying density. If a global gravity field model is introduced, the regional part of this structure has to be eliminated from the calculations. This step has not been performed yet rigorously and the effect of the Ivrea body remains in the calculated residual field, which disturbs significantly the homogeneity and the determination of a global harmonic covariance function in the collocation process. A way to avoid this problem would be to use a reference model with a higher resolution, as it will be available soon.

Figures 7 to 12 show the effect of reducing the observations by the geopotential model and topography. The remaining residuals are small and show a smooth behaviour. It is mainly the influence of the Ivrea body that remains in the residuals. In the reduced gravity data, the effect on reducing also this model (fig. 8) can be seen and also the remaining effect of the quaternary sediments of rivers is clearly visible.

Better than in the gravity data set, the systematic part of the residual field can be seen in the vertical deflections (fig. 11) and in the GPS/levelling height anomaly residuals (fig. 12).

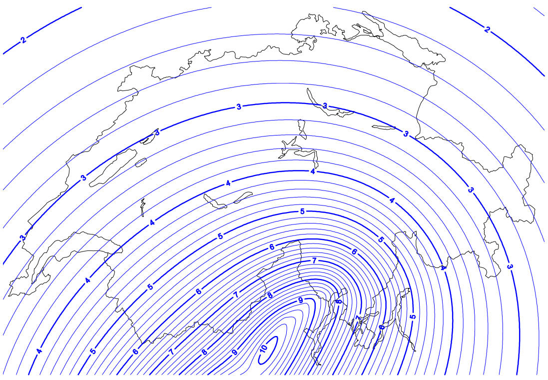

Fig. 4: Influence of the Ivrea body on height anomalies in [m]

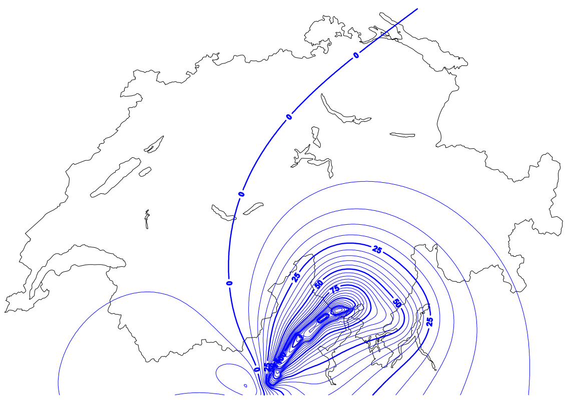

Fig. 5: Influence of the Ivrea body on gravity [mgal]

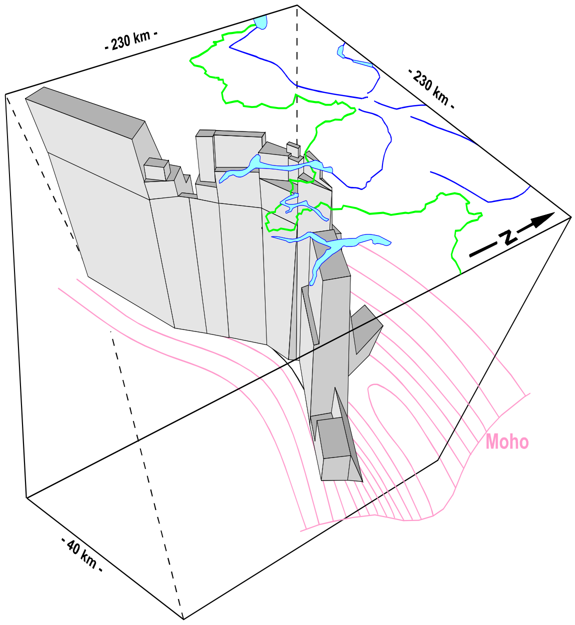

Fig. 6: 3D model of the Ivrea body

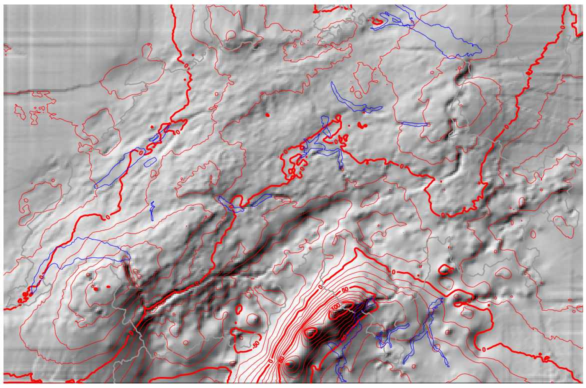

Fig. 7: gravity reduced for EGM96 and topography

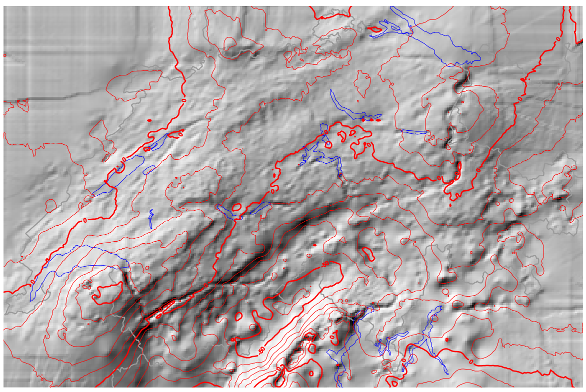

Fig. 8: gravity reduced for EGM96, topography and Ivrea body

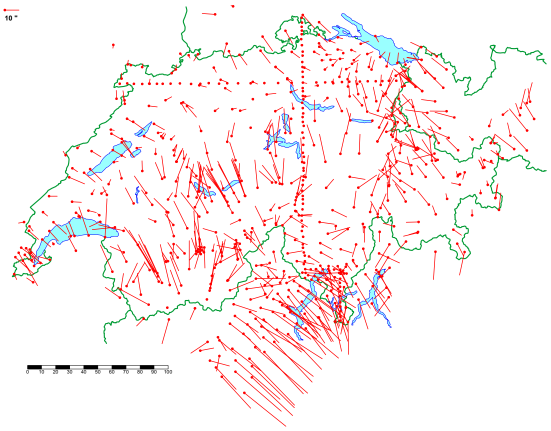

Fig. 9: measured vertical deflections

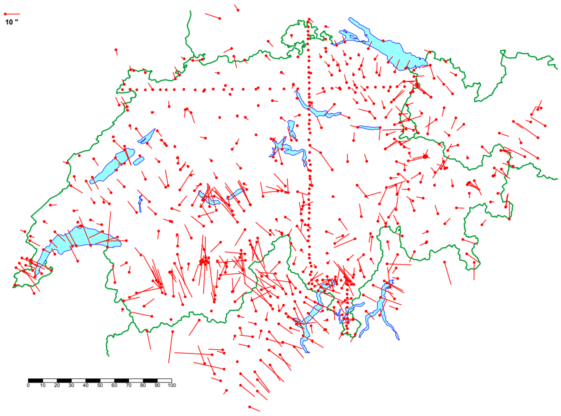

Fig. 10: Vertical deflections reduced for EGM96

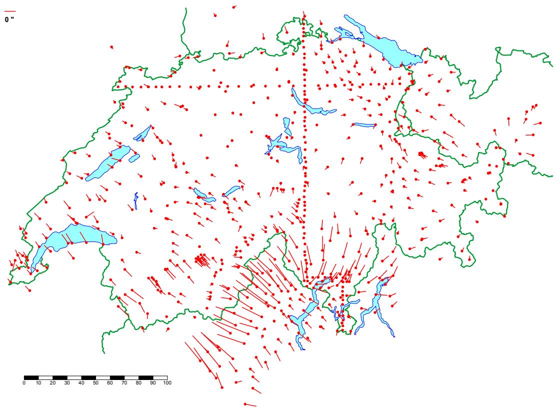

Fig. 11: Vertical deflections reduced for EGM96 and Topography

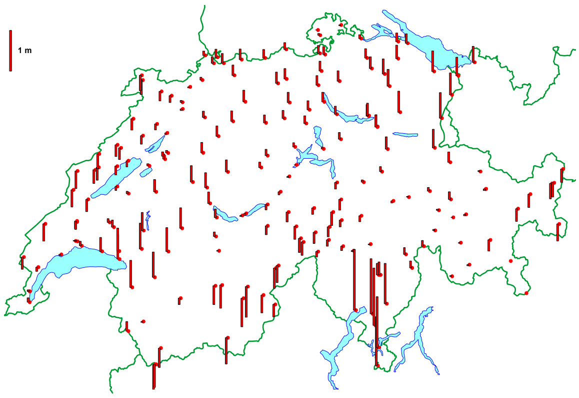

Fig. 12: GPS/Levelling height anomalies reduced for the effects of the global model (EGM96) and topography (RTC)

4 Preliminary geoid determination

The method we use to calculate the co-geoid is least squares collocation. The first step is to determine the empirical auto-covariances and cross-covariances for the individual data sets. Out of these empirical functions the two parameters of the 3rd order Markov covariance model are calculated by a least squares adjustment.

After the determination of the covariance model, we first calculate solutions for each data set separately. So we obtain a gravimetric, an astrogeodetic and a GPS/levelling solution. For deflections of the vertical and GPS/levelling the measured (and reduced) point values can be used directly in the collocation. For gravity it was necessary to reduce the amount of data by gridding them to a 2x2 km grid.

For each solution it was tested if the variation of the covariance parameters has a significant effect. For the gravity data this influence was rather small. For GPS/levelling it is obvious that in regions with no or bad data coverage the variation of the model caused rather large differences in the order of more than 15 cm. Also for the astrogeodetic solution the variation of the covariance model caused significant changes of the result. Another approach for the determination of the covariance parameters for the astrogeodetic solution was, to calculate them in a way that the GPS/levelling residuals become minimal (fig. 15). This solution was very near to the solution determined out of the empirical covariances.

It was interesting to see, that the astrogeodetic solution showed rather large differences depending on which measurements have been included in the adjustment: There is an indication that the older measurements show a systematic offset in many regions (fig. 14). Therefore, for the best astrogeodetic solution only measurements since 1980 has been used. There will be further tests to include also older data.

The gravimetric solution showed a very good agreement with the two other solutions in most of the regions. But there remain some systematic discrepancies mainly in the region of the Ivrea body. Since the mass model of the Ivrea body could not yet be handled sufficiently until now, this gravimetric solution is not presented yet.

The combined solution of vertical deflections and GPS/levelling (fig. 16) caused no severe problems. The data sets fit well together with no large systematic discrepancies.

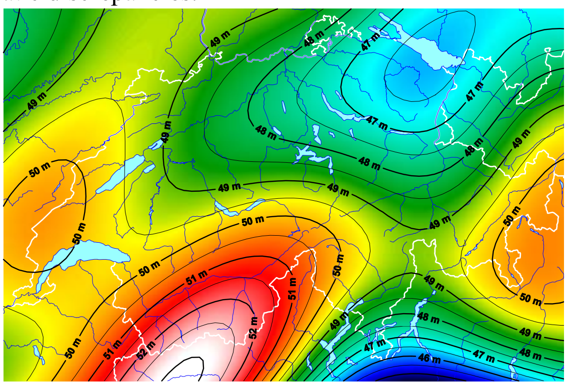

Fig. 13: The EGM96 reference model for the Swiss geoid determination

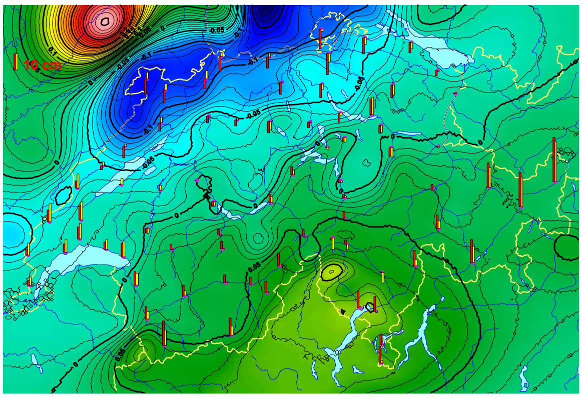
Fig. 14: GPS/levelling residuals of astrogeodetic solution of all available data since 1860 (in red) and of astrogeodetic solution where only data since 1980 are used for computation (in yellow). The residuals become smaller if we eliminate old measurements. This indicates problems in the reference frame of the old coordinates (star catalogue, pole coordinates or terrestrial reference system)

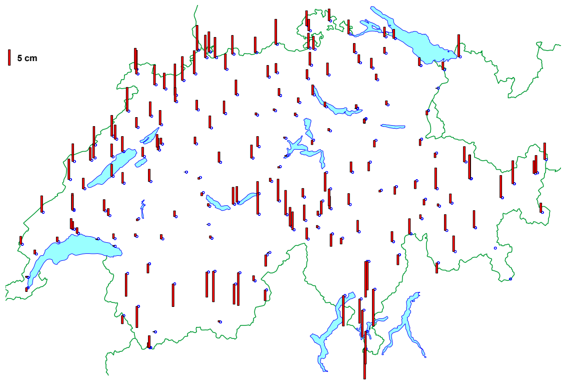

Fig. 15: GPS/levelling residuals of astrogeodetic solution

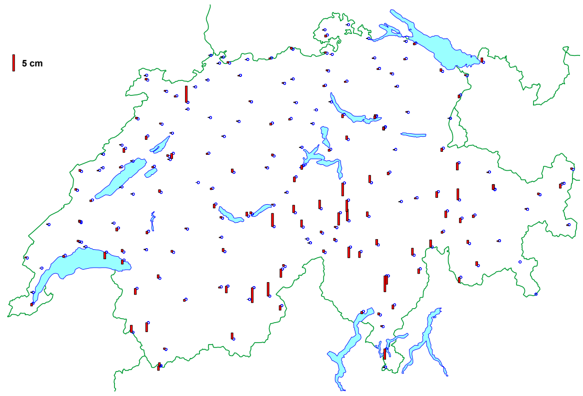

Fig. 16: GPS/levelling residuals of combined solution vertical deflections and GPS/levelling

5 Conclusions

The introduction of a global geopotential model helped in determining a local geoid by removing large trends which can not be considered in local mass models. An accurate reference model with a resolution of more than 360 would be very helpful for reducing the necessary efforts for modelling the local density anomalies as we see in the example of the Ivrea body.

The introduction of local density models for river basins and water masses of lakes helps to get a smoother residual field - especially for gravity data.

The calculation of a pure GPS/levelling geoid is problematic in mountainous areas. The reason is mainly that in many regions no levelling lines are measured. The resulting data gaps cause major problems in the collocation process. In such regions it is necessary to include gravimetric or astrogeodetic data.

A pure astrogeodetic geoid determination gives good results if the data is sufficiently dense and of high quality. Systematic errors in the astrogeodetic data disturb the result significantly.

Although only preliminary versions of the geoid have been computed, it can be said, that the differences between the gravimetric and the astrogeodetic solution are very small and in the order of a few cm only. The GPS/levelling data fit well in both solutions with a mean remaining residual of about 6 cm. This result depends slightly on the chosen parameters of the covariance function, especially in the astrogeodetic solution.

Some further modifications of the mass models and the covariance model parameters are necessary before a better gravimetric solution can be completed and presented.

If all the solutions of the three data sets fit sufficiently well together, a combined solution will be ready at the end of 2004.