Procedures for the unified european gravity base net (UEGN02) adjustment and experiences

G. Boedecker
Bavarian Academy of Sciences and Humanites/BEK[1]

Abstract: On the occasion of the IAG Scientific Assembly Budapest 2001 it was agreed to work on a unification of European gravity reference networks, also in continuation of some previous works. The adjustment model for absolute and relative gravity observations is quite straightforward. In the course of the realization it turned out, that the real challenge is to cope with the diversity of network structures, data peculiarities and different observation procedures. Although the percentage of data errors is small, the total number is significant. Because of the very diverse possible error mechanisms, it is not possible, to apply schematic decision rules. Rather, the observation information has to be made transparent. To this end, software was developed based on Matlab[2] with extensive use of graphical tools. The paper focuses on the processing aspects rather than the results for this ambitious project over 16 countries, 1700 stations and some 35000 observations.

Key words: gravity reference network, Matlab, network adjustment

1. Introduction

After the project had been started following the IAG Scientific Assembly Budapest 2001, a meeting was held of experts from interested countries, and some working procedures agreed on including data formats. Since then, the project was advanced, based on data submitted by 16 countries and evaluation by the cooperation of a small working group from different countries with O. Francis of ECS Luxembourg for the tidal reduction and the author responsible for the adjustment. A general report was presented at the GGSM meeting Porto 2004 *(Boedecker et al., 2004)*.

[1] Alfons-Goppel-Str. 11, 80539 München, Germany; e-mail: boe@bek.badw-muenchen.de
[2] Matlab®

In this paper, we shall focus on the real computation procedures, the practical problems encountered and the lessons learned. This may be interesting not only for other gravimetric works, but for other types of projects.

2. Method

The adjustment model has been presented and explained e.g. in *Boedecker et al. (2004)*. In short: Both types of terrestrial gravity observations, absolute observations and relative observations are combined in one model. The absolute observations provided by the respective field parties – including the tidal reduction applied – were immediately used for the adjustment. For the relative observations, the immediate readings at the instruments are converted to gravity units on the basis of a known calibration function. A tidal reduction has been applied on the basis of a homogeneous model for all of Europe by O. Francis of ECS Luxembourg. At stations with changing instruments heights above the reference benchmarks, a height reduction has been added.

The model for the resulting relative observation is based on a series of observations including all observations carried out with one gravimeter within one day. The parameters for such a series are the point gravity values observed, a bias and a linear drift term for each series, and an overall linear calibration parameter for all observations of each instrument involved. The weights of the absolute observations were taken from the information of the corresponding field parties, based on repeated observations. The weights of the relative observations were determined from an iterative weight estimation. In the weight estimation, one factor has been determined per series. For details see *Boedecker et al. (2004)*.

The total computation work was based on Matlab and hence also the error analysis and identification aids were programmed in Matlab. The design of the programme is guided by the characteristics of the task: There are now stations and absolute observations from 16 countries included. 11 countries provided relative observations. The total number of observations is some 35000. The problem includes some 1700 station gravity values and a total of 10000 parameters to be solved for. It is important to note the characteristics of the relative observations: They are read from 51 different gravity meters; some of them were given different names e.g. after a repair or instrument adjustment status change. In view of these numbers and the diversity of network structures, instrumental individuals, observation procedures in detail, it was clear that the software has to provide (i). fully automatic generation of observation matrix, and (ii.) tools to make problems transparent. One requirement was the homogeneous formatting of data files and – as far as possible – identical observation procedures. For this purpose, format descriptions were distributed.

For the least squares adjustment, the standard Matlab linear equation solver ("\") was used. This means, the solution reduces to $\mathbf{x} = \mathbf{A}\backslash\mathbf{I}$ for $\mathbf{x}$: parameter vector, $\mathbf{A}$: observation matrix and $\mathbf{I}$: observation vector with an initial weight vector $\mathbf{p}$. For including the weights, the method of homogenized observation equations was used. In view of the problem size, it is quite convenient to use the sparse matrix features of Matlab instead of the earlier alternative for similar problems, namely the prior reduction of series parameters, i.e. of bias and drift parameters. In normal runs, the inversion of the normal matrix is not necessary. Only for the occasional computation of parameter error estimates, the computation of the inverse is unavoidable. Because the inverse of 10.000×10.000 is not really a small thing for a normal PC, the (complete) inverse is computed by solving the linear equations row by row based on $\mathbf{N}^{-1} \times \mathbf{N} = \mathbf{I}$. Because the Matlab linear equation solver ("\") represents a whole strategy with various options depending on the stability of the matrix, this may take some time which cannot be predicted precisely. On the standard 3.2 GHz PC of the author, it usually takes around 5 to 30 minutes.

For initialising an adjustment run, the station data file names, the absolute observation file names and the relative observation file names are provided. The programme reads the data and performs various checks such as for duplicate station names at identical coordinates, allocates different names from different observation sets to unique names etc. etc.. The task is completely defined by the data files submitted: For all the stations appearing in the data files, a staton gravity is computed. Relative observation files consist of a seamless list of observations with the only requirement that consecutive observations are given in consecutive lines in the file in the proper order. The software then identifies the series according to the above rules. Also, it identifies the observation repetition numbers from all of the relative observations along all of the ties. This is not important for the adjustment, but for plotting and later error analysis. Boolean matrix operators of Matlab proved to be very efficient both in coding lines and in computation time. The identification of the parameter vector and the generation of the observation matrix **A** is fully automatic for any input files. The solution of the linear equation $\mathbf{x} = \mathbf{A}\backslash\mathbf{I}(\mathbf{p})$ is solved iterating **p** for the part of the relative observations; the weights for the absolute observations are kept constant. For this weight iteration, a sensible number of iterations is 4 to 6.

Subsequently, the residuals are determined. Some useful statistics are carried out and general information produced such as number of observations at stations, etc. etc. The residuals are analysed for suspected erroneous observations. The essence of this information is not only printed, but – more importantly – used for graphical presentation. By graphical user interface, it is possible to locate stations by name using a pulldown menu, to retrieve station data etc. This way, data problems become manageable.

3. Illustrations of adjustment procedures and results

In Fig. 1, first the total network had been plotted including stations, signatures for absolute observations, relative ties with observation repetition numbers, relative series with suspicious residuals and other details. The computation time starting from raw data input, solution with weight iteration, information compilation and plotting takes about 30 sec. (without inverse). After zooming, on left mouse click at a station site, the different stations with identical planar coordinates with their heights and names and maybe residuals are depicted. At right mouseclick, a pulldown menu opens for selecting a station to be located by name. The searched station is shown in a separate window (yellow frame upper left). The various zooms and special information requests may be mixed. This way and consulting the printout if necessary, the problem can be tackled.

The relative observation series weight iteration, see Fig. 2, shows the up- and downweighting which converges quite nicely.

Because the pure printing of station gravity values does not make sense, the residual histogram may serve as a proof that we have accomplished the network adjustment (Fig. 3).

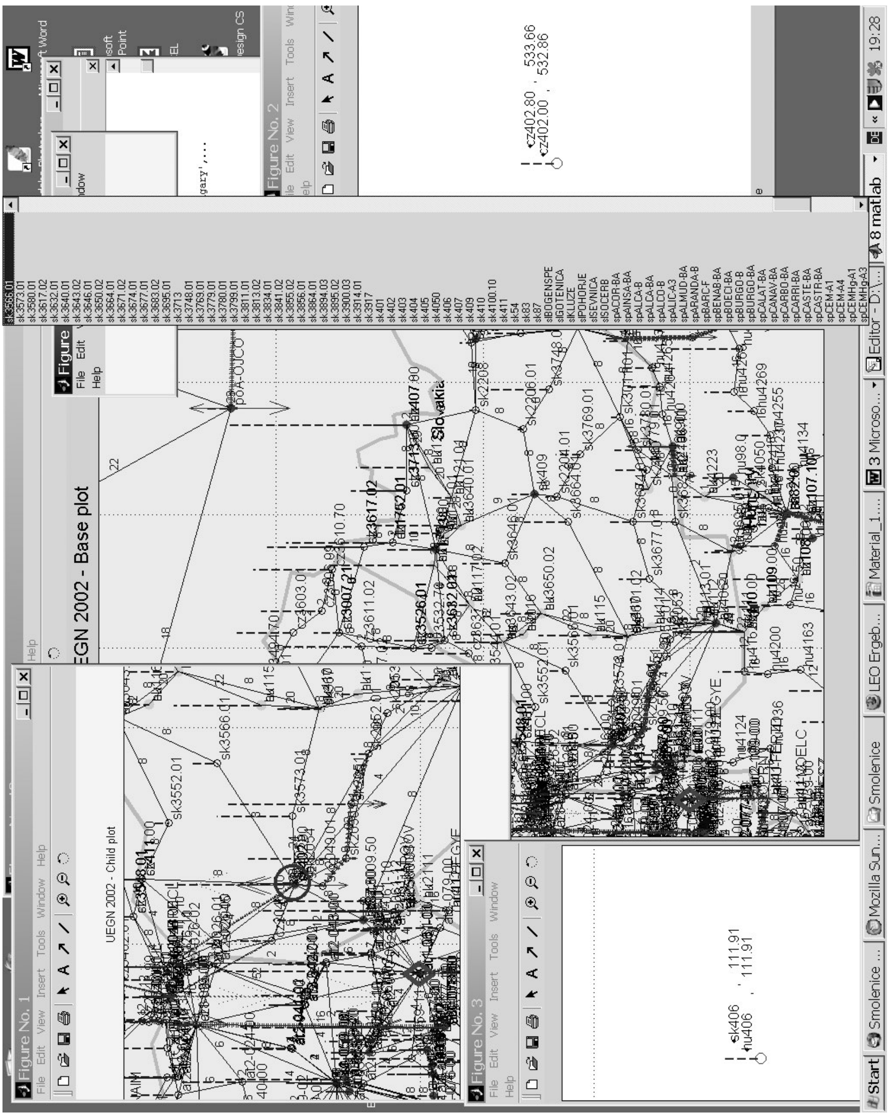

Fig. 1. Screen shot of interactive work on UEGN02. Further explanation c.f. text.

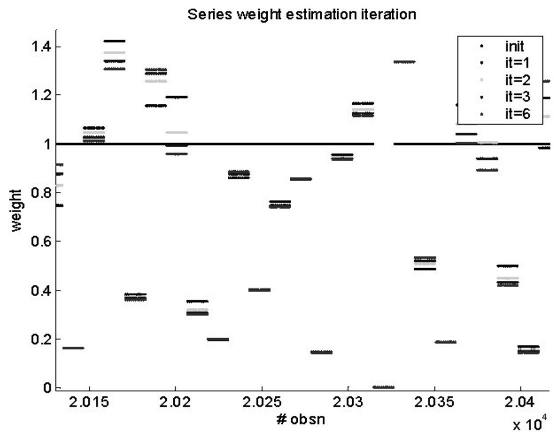

Fig. 2. Iterative weight estimation. For further explanation see text.

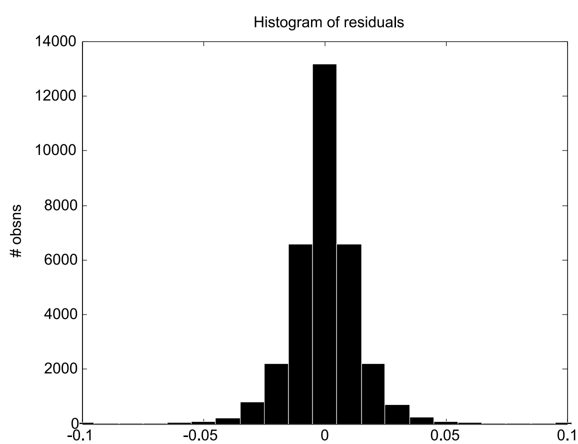

Fig. 3. Residual histogram.

If an outlier occurs, this would lead to a down-weighting of the whole series – which is not justified. For this reason, outliers may be marked in the observation data file or added to a special list. Often, outliers are caused by a station misidentification. Sometimes, this happens, when a field observation party carries out observations in another country and uses a (slightly) different naming convention. This may be cured by either modifications of the original observation file or by putting these station names to the above mentioned 'alias' file.

The handling of absolute data had to deal with different procedures: The original idea was to take the original absolute observation at height and to allocate this point its own identity. Relative observations connecting this (up) station to the ground floor marker (down) should be handled as any other relative network observation. Instead, often the original information was not available, because it was processed via the 'gradient' to deliver an absolute value for the ground marker only.

Another source of (small) errors is the fact, that the proof masses of different relative gravity meters are at different heights and the gradient at different locations is different. It was tried to minimize these effects, but some remain. This leads to the insight that the true gravity values at ground floor never will be known, because the proof mass always will be at some distance above and the gradient close to the ground may vary more than at some height. In principle, more detailed conventions may be agreed for these details. On the other hand, we have to accept that there are many small errors of different origin such as groundwater, atmosphere etc. etc. and hence the errors discussed in this section are in the general noise floor.

Because the relative gravity observations processed in this project are mainly observed without automatic recording but using a manual fieldbook, a considerable number of errors of very diverse nature may enter:

- irregular drift rates, e.g. because of big mountain height differences covered within a short time and maybe imperfections of the instruments; irregular drift rates because of other transportation stress,
- irregularities of the calibration function as e.g. circular errors,
- reading errors,
- time errors,
- station identification errors, particularly at identical planar coordinates but at different height levels,
- station designation errors, particularly when relative ties crossed borders and unambiguous name assignment was lacking,
- errors due to deviations from 'normal' state of station, e.g. groundwater, atmosphere.

Some of the above errors may be minimized further by very individual procedures. This was not possible for a network of this size. On the other hand, one should also be cautious with respect to over-parametrization of e.g. drift models.

Unlike other situations, there is no clear allocation of the magnitude of a suspected error to a particular cause. Also, the magnitude can vary from usual noise level to full mGal. For this reason, it is not possible to establish a clear scheme for error identification. Rather, if a likely error occurs, the situation has to be made transparent in order to enable the editor to analyse the situation and find a remedy applicable – or to eliminate the suspected observation.

4. Conclusions on the processing procedures and some experiences

- Handling such a heterogeneous network became feasible by using Matlab; particularly the various matrix manipulation tools, the sparse matrix feature and the Boolean operators were important, but also the graphical capabilities including the graphical user interference.
- It is hardly possible to design an automatic decision process on suspicious observations. Instead, it is most important, to make the details of the observation process manageable and transparent.
- This way, additional errors in the observation files could be found which obviously were not detected in the course of the previous national gravity reference network processing.
- Nevertheless, the size of the problem of such varied setting is at about the limit. Also, the response of some participating countries for data clarification retarded the completion of the project. It is now very close to the final computation run.
- In new similar projects, one should try to introduce more stringent guidelines and rules for all constituents: stations, absolute observations, relative observations etc. For a given dataset, this was naturally not possible.
- The past complaints of inhomogeneities of terrestrial data sets for downstream applications such as geoid should be counteracted: “Possible systematic error sources affecting terrestrial gravity data were studied . . . with

the largest components coming from inconsistencies in gravity and position reference systems." *(Roland and Denker, 2002).*

- An account of the project in general besides the processing and a publication of the gravity values will be given soon elsewhere.

References

Boedecker G., Francis O., Kenyeres A., 2004: Unified European Gravity Reference Network 2002 (UEGN02) – Status 2004. GGSM Coll. Porto. CD-Proceedings 2004.

Roland M., Denker H., 2002: Evaluation of Terrestrial Gravity Data by New Global Gravity Field Models. In: Tziavos I. N. (Ed.) Gravity and Geoid 2002 - 3rd Meeting of the International Gravity and Geoid Commission, Thessaloniki, Greece, 26.–30. August, 2002.