Gross-Errors Detection in the Shipborne Gravity Data Set for Africa

Hussein Abd-Elmotaal
Atef Makhloof

Minia University, Faculty of Engineering, Minia 61111, Egypt
abdelmotaal@lycos.com

Abstract

In the frame-work of the African Geoid Project, a huge set of about 1.2 millions of shipborne gravity data points were collected. The shipborne data are collected in routes which intersect each others and merge together at the oceans surrounding the African continent. A scheme of gross-error detection within the shipborne gravity data set has been established employing the least-squares prediction blunder detection-removal technique to compute an estimation of the gravity anomalies at the data points without using the data values. The process works in such a way that it eliminates the blunders having a difference between the estimated and measured gravity anomalies more than three times the standard deviation of the whole data set. Hence, the process is repeated iteratively and re-computes the estimated values till the standard deviation of the differences becomes smaller than 1 mgal. Blunders of about 11% have been eliminated from the shipborne data set for Africa by the proposed technique.

Key words: gross-errors detection, shipborne, Africa, least-squares prediction.

1. Introduction

Data validation may include statistical tests to validate the reliability of the reconciled values, by checking whether gross-errors exist in the set of measured or observed values. These tests can be for example (Narasimhan and Jordache, 1999; Nyrnes el al. 2005)

- the chi square test (global test).
- the individual test.

If no gross-errors exist in the set of measured or observed values, then each penalty term in the objective function is a random variable that is normally distributed with mean equals to 0 and variance equals to 1.

The detection of possible gross-errors using the differences between observed values and values estimated using Least-Squares Collocation LSC technique has been successfully applied on a number of data types (cf. Tscherning, 1991 a, 1991 b; El-Tokhey and Abd-Elmotaal, 1996; Albertella et al., 2000). In this investigation, the least-square prediction detection-removal technique has been applied to remove the blunders from the shipborne gravity data set of Africa.

2. Mathematical Model

In this investigation, the least-squares prediction technique is used. Before estimating the gravity anomalies at the data points, the duplicated points were eliminated from the data set. This situation happens as results of sailing different ships on the same point from different routes.

The gravity anomaly at every point is computed from the neighbourhood points using the least-squares prediction technique excluding the gravity anomaly at the computational point. The number of the considered points in the neighbourhood of the computational point has been taken between 10 to 15 points. This number proved to be practically sufficient (Kraiger, 1988; Abd-Elmotaal and El-Tokhey, 1997).

The expression of the least-squares prediction is given by (Moritz, 1980; Tscherning 2002; Fashir and Kadir 1998):

$$\Delta g_p = \left(C(p,p_1) \quad C(p,p_2) \quad \ldots\ldots\ldots \quad C(p,p_n) \right) \begin{pmatrix} C(p_1,p_1) & C(p_1,p_2) & \ldots & C(p_1,p_n) \\ C(p_2,p_1) & \ldots & \ldots & C(p_2,p_n) \\ & \ldots. & \ldots. & \\ C(p_n,p_1) & \ldots.. & \ldots. & C(p_n,p_n) \end{pmatrix}^{-1} \begin{pmatrix} \Delta g_{p_1} \\ \Delta g_{p_2} \\ . \\ \Delta g_{p_n} \end{pmatrix} \tag{1}$$

where $C(p,p_1)$ stands for the covariance function between the estimated point and the running surrounding points and $C(p_i,p_j)$ is the covariance function between the running surrounding points.

The generalized covariance model of Hirvonen has been tested in the current investigation, which is given by (Moritz 1980, p. 179):

$$C(p_i,p_j) = C(s) = \frac{C_0}{(1+A^2 s^2)^p} \tag{2}$$

where s is the distances between the pair of points under consideration and the parameter A is given by (Abd-Elmotaal, 1992):

$$A = \frac{1}{\xi}\left(2^{\frac{1}{p}} - 1 \right)^{\frac{1}{2}} \tag{3}$$

with the empirically determined variance C_0 and correlation length ξ. The parameter p depends on the type of gravity anomalies. An impractical value of p = 0.25 has been used (ibid., 1992).

It is found from Eq. (2) that the covariance function depends on the inverse square distance and after studying the shipborne gravity anomalies, the inverse matrix in Eq. (1) is severely ill conditioned. Therefore, a local covariance function represented by an analytical function is applied in the current study as (Fashir et. al., 1998, eq.3):

$$C(p_i, p_j) = C(s) = C_0\left(1+\frac{s}{R}\right)^{-1} \tag{4}$$

where R stands for the means earth's radius. After estimating the gravity anomalies using the least-squares prediction technique, described above, at all data points, the difference between the estimated and measured values are computed. The points having differences greater than three times the standard deviation are removed. This step is repeated iteratively, defining the least-squares blunder detection-removal technique, till the standard deviation of the differences becomes smaller than 1 mgal (Fig.2).

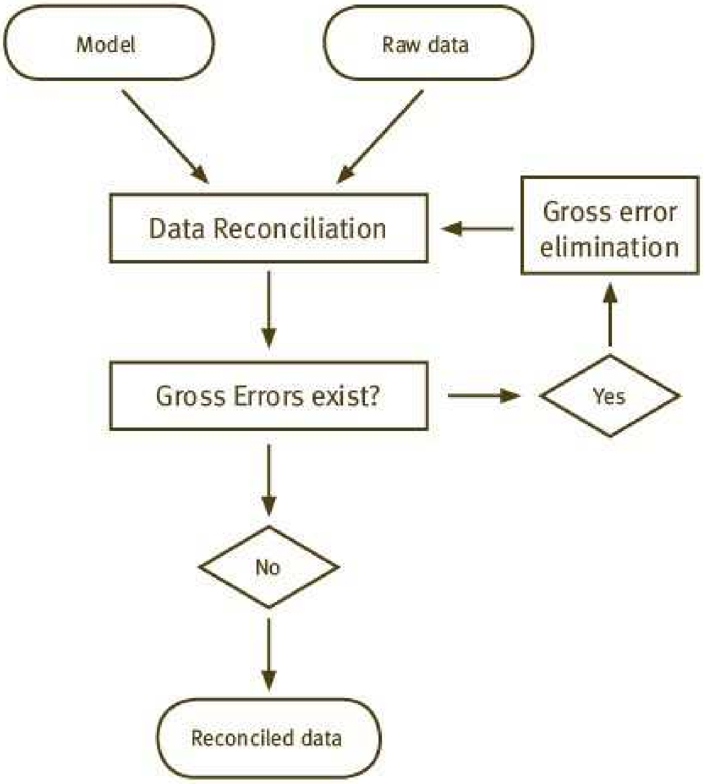

Fig. 1: Gross error detection-removal process.

3. Shipborne Free-air Gravity Anomalies Data

The National Geophysical Data Center (NGDC) Marine Trackline Geophysics database provides access to bathymetry and gravity data collected during marine cruises from 1939 to present. The coverage is worldwide. Data sources include both US and non-US oceanographic institutions, universities, and governmental agencies.

Data are distributed online via an interactive ArcGIS map viewer. Searches by geographic area, year of cruise, institution, platform, cruise, date or parameter are available. Downloads can be customized to area, parameter and format. The observations were stored in different format, in terms of different (horizontal and gravity) datums. Due to instrumental errors (drift, cross-coupling off-levelling), navigational errors, and other errors, significant inconsistency exist between different cruises. No attempt had been made by the data provider to ensure consistency among individual cruises.

The distribution of the available shipborne free-air anomalies for Africa is shown in Fig. 2. It shows that the data distribution is uneven. Some large gaps, especially at the Atlantic and Indian oceans, exist. The total number of the available shipborne gravity anomaly data points for the current investigation is 1233381 points for a larger window ($-42^\circ \le \phi \le 44^\circ$; $-22^\circ \le \lambda \le 62^\circ$) than the African data window ($-40^\circ \le \phi \le 42^\circ$; $-20^\circ \le \lambda \le 60^\circ$). These 2-degrees margins from all side were imported to minimize the window effect in the interpolation process used in the current investigation. The measured shipbone free-air anomalies range between -996 mgal and 998 mgal with an average of about -4.6 mgal and a standard deviation of 58.53 mgal.

Outliers exist in this data set as, e.g., at some points, the free-air anomalies attain the level of 900 mgal or higher. These outliers concentrate mainly in Oman Gulf and Persian Gulf near Oman and United Arab Emirates coasts. These outliers have been initially detected by comparing the shipborne gravity anomalies with those derived from the EGM2008 and Eigen-6C2 global geopotential models. However, the blunders diction-removal technique is explained in detail in the next section.

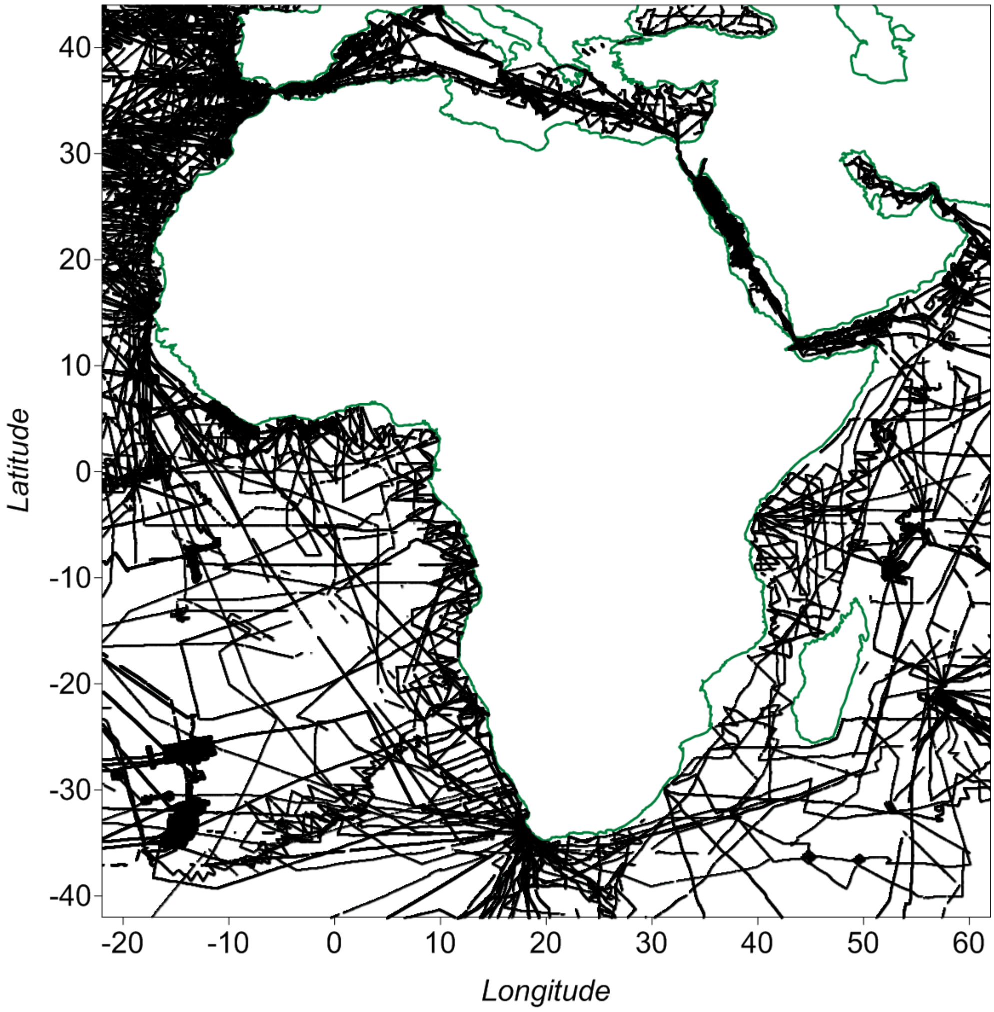

Fig. 2: Distribution of the shipborne gravity anomaly data set.

4. Numerical Analysis

A number of about 2000 duplicated points have been found in the data set and have then been removed. The gravity anomalies at the data points were calculated using the EGM2008 and the Eigen-6C2 global geopotential models. The differences between the measured gravity anomalies and the synthesized gravity anomalies from these geopotential models have been calculated. The points having differences larger than 50 mgal in magnitude have been removed from the data set. The value of the 50 mgal is based on practical experience (Denker and Roland, 2005; Featherstone, 2009). A number of about 3000 points have been eliminated from the data set using that process.

Then, the least-squares prediction technique has been applied for the remaining points. The generalized Hirvonen covariance model has been tested for each point. It has been found that the covariance matrix for some cases is ill-conditioned. Then, the covariance function in Eq. (4) has been applied instead in this investigation. The differences between the measured and predicted shipbone free-air anomalies range between -1182.90 mgal and 951.85 mgal with an average of about zero and a standard deviation of 10.25 mgal. These results were for the first iteration step. The points having differences greater than three times the standard deviation have been removed. Then, the least-squares prediction detection-removal technique has been applied for the remaining points. This step has been repeated iteratively six times till the standard deviation became smaller than 1 mgal. This process eliminates a number of 141517 points as blunders. This represents 11% of the total data set.

Figure 3 shows the blunder-free shipborne gravity anomalies. These blunder-free gravity anomalies (1091896 points) range between –238.3 mgal and 364.8 mgal with an average of about -5.08 mgal and a standard deviation of 39.65 mgal. The white pattern in Fig. 3 indicates gravity anomalies less than 10 mgal in magnitude. Figure 3 shows that most of the highest gravity anomalies exist in the Mediterranean Sea. Figure 3 illustrates also that the current investigation ends up with a good free-air gravity anomaly data set for the African surroundings.

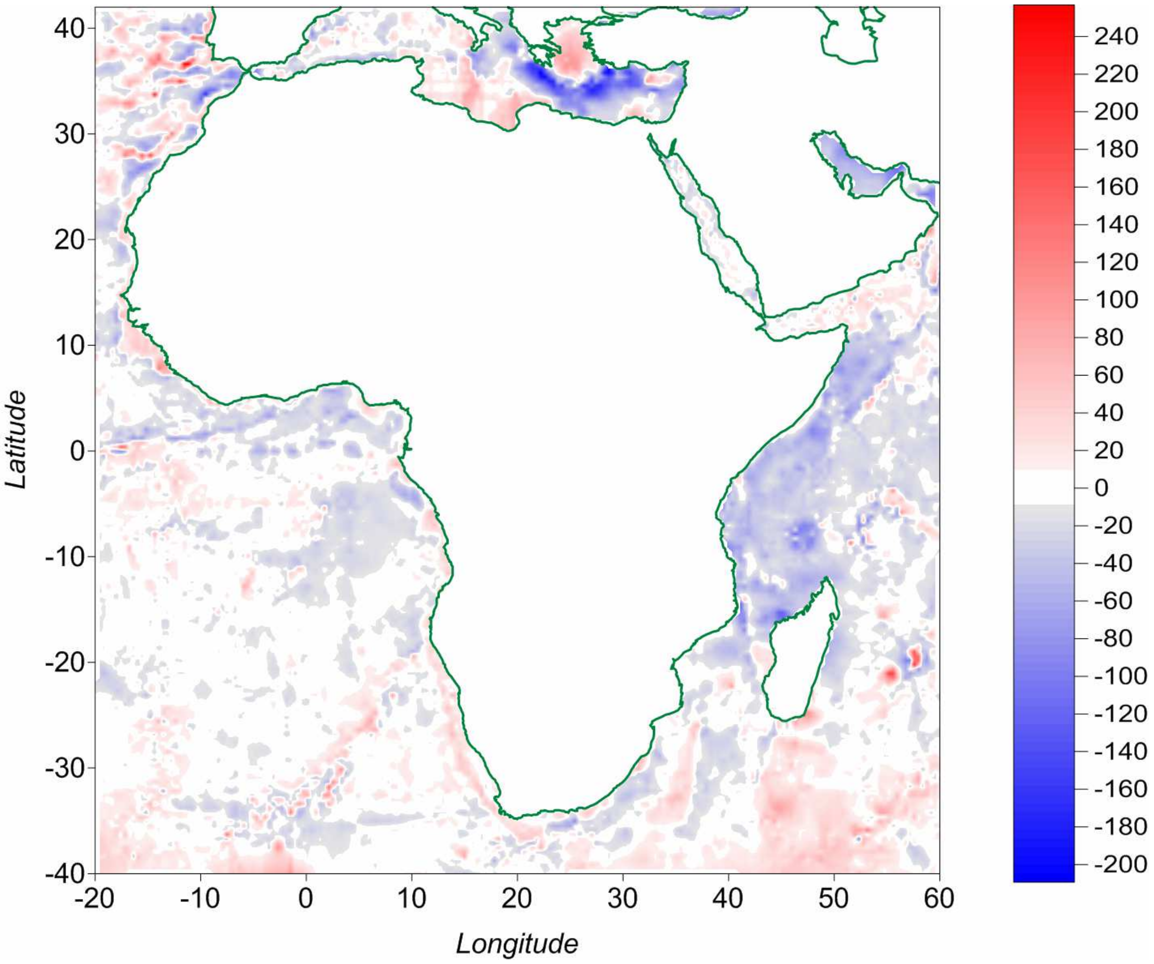

Fig. 3: Blunder-free Shipborne free-air gravity anomalies for Africa. Values are in mgal.

After the sixth iteration step, the differences between the measured blunder-free and predicted shipbone free-air anomalies range between -3.48 mgal and 3.48 mgal with an average of about zero and a standard deviation of only 0.93 mgal. Figure 4 shows the differences between the measured blunder-free and predicted shipborne gravity anomalies after the sixth iteration step. It shows that most differences are less than 1 mgal in magnitude (the white pattern). This illustrates the capability of the proposed technique to eliminate the gross-errors from the shipborne gravity anomaly data set.

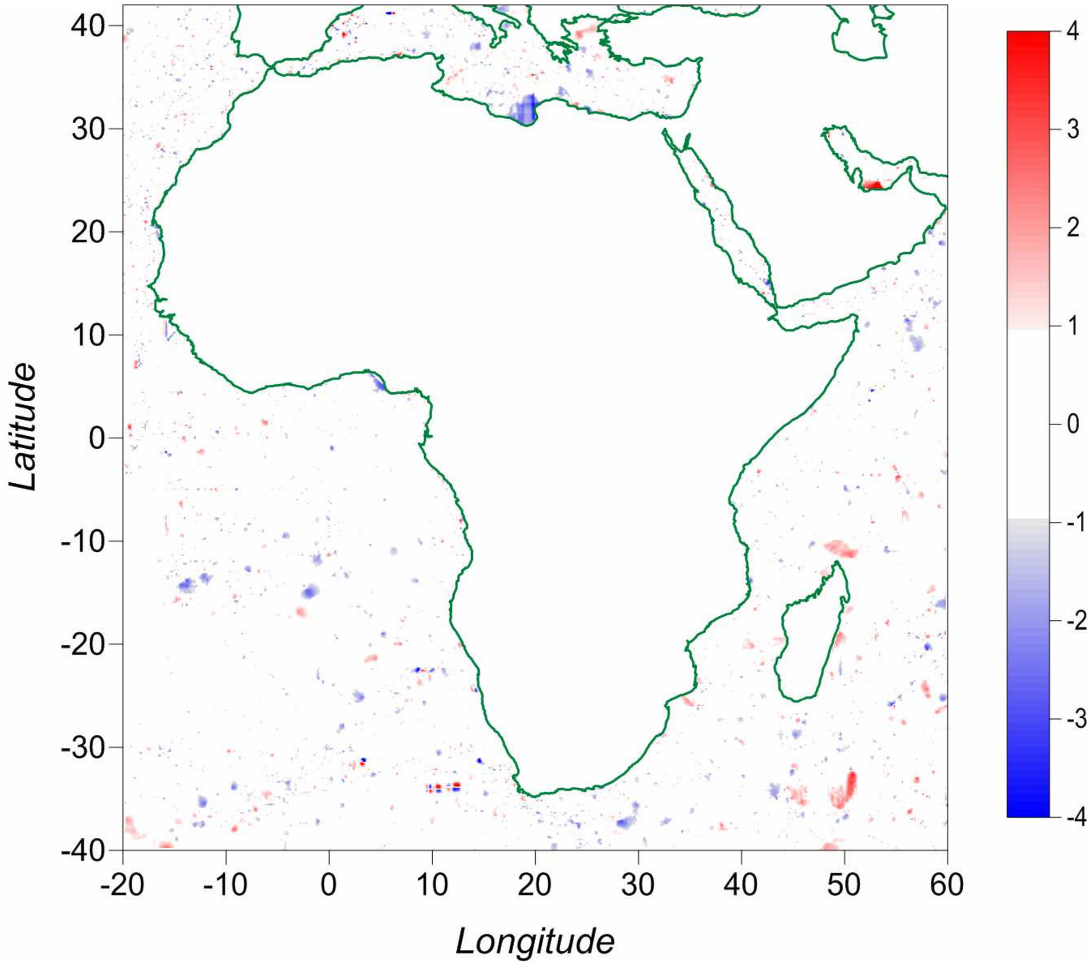

Fig. 4: Differences between the measured and predicted shipborne free-air anomalies for Africa after the sixth iteration step. Values are in mgal.

5. Conclusion

A shipborne free-air gravity anomaly database has been downloaded from NGDC's Marine Trackline Geophysics database, towards the determination of a detailed precise geoid model for Africa. The methodology employed is a two-steps procedure, i.e., a visual inspection test (removing the duplicated points) followed by a least-squares prediction blunder detection-removal iterative scheme. Both tests are highly objective, since in the former, holes and spikes not so deep or steep respectively can be either removed as blunders or remain in the database. In the latter, the removal of a measurement as erroneous depends solely on the selection of the data error (±50 mgal in our case). As far as the visual inspection test is concerned, only measurements that could be clearly distinguished as blunders were removed, considering that any remaining erroneous measurements will be removed during the least-squares prediction detection-removal technique. The least-squares prediction blunder detection-removal technique has been iteratively applied till the standard deviation of the differences between the shipborne measured and predicted gravity anomalies became smaller than 1 mgal. A total number of 141517 points have been removed as blunders. The proposed technique in this investigation proved to be capable to get rid of the possible blunders in the shipborne data set for Africa. A reasonably good free-air gravity anomaly database for the oceans surrounding Africa has been made available as an output of the current investigation.

Acknowledgements This project was supported financially by the Science and Technology Development Fund (STDF), Egypt, Grant No. 366.

6. References

Abd-Elmotaal, H. (1992): Statistical Behaviour of the Free-air, Bouguer and Isostatic Anomalies in Austria. Bulletien Geodésique, Vol. 66, No. 4, 325–335, DOI: 10.1007/BF00807417.

Abd-Elmotaal, H. and El-Tokhey, M. (1997): Detection of Gross-Errors in the Gravity Net in Egypt. Survey Review, Vol. 34, No. 266, 223–228.

Albertella, A., Migliaccio, F., Sansò, F. and Tscherning, C.C. (2000): Scientific Data Production Quality Assessment using Local Space-Wise Preprocessing. Sünkel, H. (ed.) **From** Eötvös to mGal, Final Report., 313–329.

Denker, H. and Roland, M. (2005): Compilation and Evaluation of a Consistent Marine Gravity Data Set Surrounding Europe. International Association of Geodesy Symposia, Vol. 128, 248–253.

El-Tokhey, M. and Abd-Elmotaal, H. (1996): Discovering the Blunders in the Egyptian Gravity Networks Using Least-Squares Collocation. Scientific Bulletin, Ain Shams University, Faculty of Engineering, Vol. 31, No. 1, Part 1, 62–71.

Featherstone, W.E. (2009): Only use Ship-Track Gravity Data with Caution: A Case-Study around Australia. Australian Journal of Earth Sciences, Vol. 56, No. 2, 191–195.

Fashir, H.H., Kadir A.A. (1998): Gravity Prediction from Anomaly Degree Variances. Buletin Geoinformasi, Vol. 2, No.2, 230–240.

Kraiger, G. (1988): Influence of the Curvature Parameter on Least Squares Prediction. Manuscripta Geodaetica, Vol 13, No. 1, 164–171.

Moritz, H. (1980): Advanced Physical Geodesy. Wichmann, Kartsruhe.

Tscherning, C.C. (1991 a): A Strategy for Gross-Error Detection in Satellite Altimeter Data Applied in the Baltic-Sea Area for Enhanced Geoid and Gravity Determination. International Association of Geodesy Symposia, Vol. 106, 95–107, DOI: 10.1007/978-1-4612-3104-2_12.

Tscherning, C.C. (1991 b): The Use of Optimal Estimation for Gross-Error Detection in Databases of Spatially Correlated Data. Bulletin d'Information - Bureau Gravimétrique International, Vol. 68, 79–89.

Tscherning, C.C. (2002): Datum-shift, Error-Estimation and Gross-Error Detection when using Least-Squares Collocation for Geoid Determination. Lecture notes, IGeS Geoid School, Thessaloniki, 2002.

Nyrnes E., Torkildsen, T., Nahavandchi, H. (2005): Detection of Gross-errors in Wellbore Directional Surveying for Petroleum Production with emphasis on Reliability Analyses. Kart og Plan 2005, Vol. 65, No. 2, 98–116.

Narasimhan, S., Jordache, C. (1999): Data Reconciliation and Gross Error Detection, Gulf Professional Publishing.