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REFINED GEOID MODEL FOR THE UNITED ARAB EMIRATES

Sahrum Ses[1], Adel Khaleefa[2] and Rene Forsberg[3]
[1] UTM GNSS and Geodynamics Research Group, Universiti Teknologi Malaysia
[2] Military Survey Departments, GHQ of the United Arab Emirates
[3] National Space Institute, Technical University of Denmark
Email: sahrum@utm.my

ABSTRACT

A precise gravimetric geoid plays a role of tremendous importance in successful military operations. This work is aimed to determine the precise gravimetric geoid of the United Arab Emirates (UAE). In doing so, the GRAVSOFT package is used in computing the 1-D and 2-D FFT gravimetric geoids for the UAE between 23º N to 27º N and 52º E to 56º E. The new precise geoid has been computed and determined based on the GRS80 reference ellipsoid. The geometric geoid (N_{GPS}) at 157 GPS/Levelling stations has been used in evaluating the accuracy of the newly computed gravimetric geoid. Results show that GPS–derived ellipsoidal height of the selected GPS points with accuracy of ±3 cm. Further, the standard deviation of the difference between gravimetric geoid and geometric geoid indicates how well the fitting of the two surfaces. Meanwhile, the mean of the difference indicates how the two surfaces are vertically shifted with respect to the geometric geoids. In addition, the new gravimetric geoid heights that have been computed at 19 checking points (BMs) showing agreement with the corresponding geometric geoid heights at ±5cm level of accuracy. With additional gravity data over land and marine area of the UAE, the precision of the geoid would be improved for the future GPS/Levelling application.

Keywords: Geoid Model, Gravity, GPS/levelling, Geometric geoid, Global Positioning System (GPS).

1.0 INTRODUCTION

The geographical land gravity data coverage in United Arab Emirates (UAE) have a vital role for several sectors such as, Military Survey Department (MSD). In this context, the improvement of Global Positioning System (GPS) accuracy, provides better gravity coverage and precise geoid model. In fact, the orthometric height difference between two stations can be determined by subtracting the geoidal height difference from the ellipsoidal height difference which was measured by GPS. Further, geoidal height information are derived from the available global geopotential models which were used to fulfill this requirement. This procedure can give impact on the Military Survey Department (MSD) efforts in providing rapid means of accurate transformation of the height data through the proliferation of the uses and applications of the GPS. This is considered as further augment existing techniques which can provide similar services to the Armed Forces of UAE (Adel, 2007).

At present, GPS/Leveling can be used for most engineering applications. However, for high precision geodetic application and surveying purposes, the undulation must be determined with an accuracy of a few cm over a distance of 100 km. This is a challenge for providing the country with accurate geoid model. This paper presents basic investigations for the geoid determination in the UAE. Consequently, the main objective is to determine the first precise gravimetric geoid for the United Arab Emirates (UAE).

2.0 THEORETICAL BACKGROUND

The basic method of the gravimetric geoid computations will be spherical Fast Fourier Transform (FFT) with modified kernels on a dense 3´ (~ 5km) grid. The remove-restore technique is used to eliminate the terrain effects on land. The RTM (residual terrain model) reduction is used. The geoidal height *N* is split into three parts:

$$N = N_{EGM} + N_{RTM} + N_{res} \tag{1}$$

where

N_{EGM} is the geoidal height of the EGM global field.

N_{RTM} is the geoidal height generated by the Residual Terrain Model, RTM, i.e. the high-frequency part of the topography. This part is computed by prism integration.

N_{res} is the geoidal height residual, i.e. corresponding to the un-modeled part of the residual gravity field. This part of the field is computed by spherical FFT.

N_{res} is computed from Δg_{res} using Stoke's integration (Heiskanen and Moritz, 1967), extending in principle all around the earth:

$$N_{res} = \frac{R}{4\pi\gamma}\iint_{\sigma} \Delta g_{res}\,(S(\psi) + g_1)\,d\sigma \tag{2}$$

The function S is Stokes' function:

$$S(\psi) = \frac{1}{\sin(\frac{\psi}{2})} - 6\sin\frac{\psi}{2} + 1 - 5\cos\psi - 3\cos\psi\log(\sin\frac{\psi}{2} + \sin^2\frac{\psi}{2}) \tag{3}$$

Here Δg_{res} is the residual free-air anomaly, i.e. what is left in the gravity data after the contributions of the residual terrain effect Δg_{RTM} and the global field Δg_{EGM} are subtracted. The g_1 – term is the Molodensky term which can be neglected when terrain reductions are used (Schwarz et al., 1990).

To prevent the influence of local gravity data on the longest wavelengths (where spherical harmonic models are most accurate) we use modifications of the Stoke's kernel S (ψ). The technique is a modified Wong-Gore method, in which the modified kernel S_{mod} (ψ) has the following expression:

$$S_{\mathrm{mod}}(\psi) = S(\psi) - \sum_{n=2}^{N_2} \alpha(n)\frac{2n+1}{n-1} P_n \cos(\psi) \tag{4}$$

where the coefficients α(n) increase linearly from 0 to 1 between degrees N_1 and N_2:

$$\alpha(n)=\begin{cases} 1 & for \quad 2\leq n\leq N_1 \\ \dfrac{N_2-n}{N_2-N_1} & for \quad N_1\leq n\leq N_2 \text{ , } n=2,\ldots,N \\ 0 & for \quad N_2\leq n \end{cases} \tag{5}$$

The coefficients N_1 and N_2 are in principle to be determined by trial and error or experience, and represent a trade-off between when use to satellite fields fully (for $n < N_1$) and when to use local gravity data fully ($n > N_2$). GPS-levelling data are typically used in the optimization of N_1 and N_2.

The residual gravity term are transformed into the residual geoid by multi-band spherical FFT (Forsberg and Sideris, 1993), which provides a virtually exact implementation of Stokes formula on a sphere. The geoid is obtained by a number of band-wise operations of form:

$$N_{res} = S\ (\Delta\varphi,\Delta\lambda) * [\Delta g_{res}(\varphi,\lambda)\sin\varphi] = F^{-1}[F(S)F(\Delta g_{res}\sin\varphi)] \tag{6}$$

where F is the 2-dimensional Fourier transform:

$$F(\Delta g) = \iint \Delta g(x,y) e^{-i(k_x x + k_y y)} dxdy \tag{7}$$

and k_x and k_y the wavenumbers. 100% zero padding is typically to be used. For general details of the FFT methods. The spherical FFT method is implemented in SPFOUR. The outcome of the remove-restore technique is a gravimetric geoid, referring to a global datum, to adapt the geoid to fit the local vertical datum, and to minimize possible long-wavelength geoid errors, a fitting of the geoid to GPS control is needed as the final geoid determination step. The software package GRAVSOFT (Tscherning et al., 1992) was used in this study.

3.0 DATA

Between April 17th and June 15th 2003, Military Survey Department (MSD) and Fugro Ground Geophysics (FGG) have jointly conducted GPS-positioned detail gravity surveys for the entire UAE. The survey, bounded by 21° to 27°N and 50° to 58°E, which was covered the entire land area of UAE and number of islands in the Arabian Gulf. A total of nine new absolute gravity stations were established throughout the UAE forming gravity base network to provide control for the detail gravity survey. Three existing absolute gravity stations located at Dubai Municipality were used to provide datum for the gravity base network. Altogether the gravity base network comprises of twelve absolute gravity stations. The land gravity surveys were conducted on a nominal grid of about 5 x 5 km grid including number of stations that are located on islands in the Gulf. Almost all the measurements were done by helicopter (Bell Jetranger) except for down town areas where land vehicles were used. Distribution of the new land gravity data is shown in **Figure 1**.

The absolute gravity measurement was carried out using a Micro-G Solutions A-10 gravimeter. The quoted accuracy of the A-10 is 10 µGal (0.01 mGals) and the repeated base lines ties between absolute gravity stations that forming the gravity base network are within standard deviation of ±0.3 mGal. Land gravity data were acquired using Scintrex CG-3 and CG-3M gravimeters with the quoted reading accuracy of ±0.1mGal. An accuracy of ±0.2 mGal is assigned for the reduced free-air gravity anomaly data.

A total of 2,797 new relative gravity points have been measured during the campaign with accuracy of about 0.02mGal. However, the following gravity data files have been compiled and used for the geoid computation:

i. new land gravity data from Fugro/MSD (2797 points),
ii. land gravity data from Dubai Municipality (639 points),
iii. land gravity data from Bureau Gravimetric International (BGI) (137 points),
iv. land gravity data from old survey (747 points),
v. marine shipboard gravity data from oil companies (Mobil, GGECO and OB) (4777 points),
vi. marine shipboard data from BGI (3694 points), and
vii. satellite altimetry derived marine gravity (KMS02) (1274 points).

The new gravity data set were the most reliable data for the geoid computation in term of quality and coverage. These gravity anomalies were computed in GRS80 with accuracy ±0.2mGal. The new data set were expanded to overlap with gravity data set for UAE. These data were acquired by a German contractor in 2001 for Dubai Municipality, which are also tied to the absolute gravity stations located in Dubai, UAE. Further, gravity data set accuracy of Dubai is ±0.2 mGal.

A survey of land gravity of 1947 to 1956 for 25,240 data points is also available in digital format. However, only 747 points of these old data set were covered Saudi Arabian border that were used for geoid computation. However, there is no documentation regarding quality of these dataset. Marine gravity data were used in this study which are involved the combination of GECO (1980 survey) and Mobil (1981-1982 survey) shipborne gravity data. Marine gravity data from other sources were provided by BGI covering larger part of UAE coastal waters. The BGI data also sparsely were covered coastal zone of southern Iran (**Figure 1**). Satellite altimetry derived marine gravity anomalies were estimated by inverse-FFT model known as the KMS02 using ERS, GEOSAT and TOPEX missions data. The data were selected and thinned to an 11 km grid resolution. After comparison with altimetry derived gravity anomalies, the existing marine gravity data were less accurate with standard deviation of ±5 mGal. In the case of the Arabian Gulf, where UAE marine region is a part of it, KMS02 data set solution represents smooth gravity field. In order to determine the UAE gravimetric geoid, it is necessary to choose the geopotential model that is best fitting with UAE geographical zone.

The existing GGMs are used in comparing their corresponding values with gravity and GPS/leveling geometric geoid undulation data. Accuracy of the geometric geoid at trigonometric stations depend on the accuracy of GPS which was derived ellipsoidal height (standard deviation = ±2 cm) and trigonometrically derived orthometric height (standard deviation = ±0.7 m). EGM96 and PGM2000A global geopotential models provided the best fit with the geometric geoid height at trigonometric stations with standard deviation of ±0.67 m.

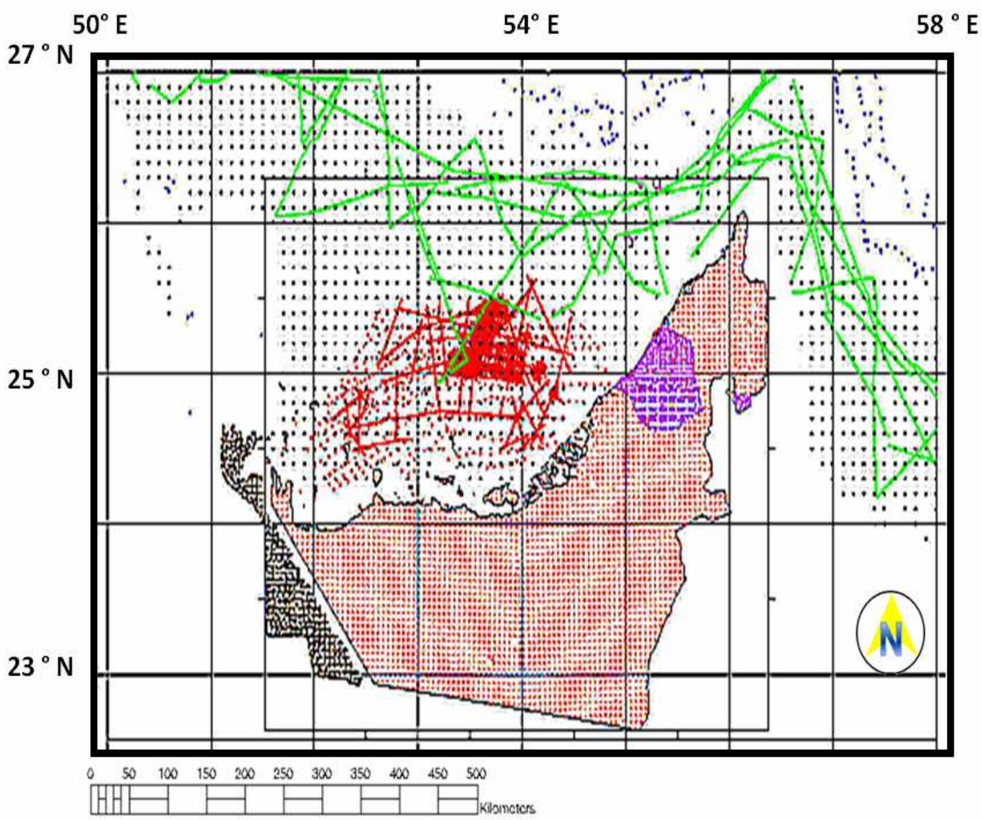

Figure 1. Distribution of gravity data over land and marine area of UAE

Comparison between gravity anomalies which were computed from various geopotential models and land gravity anomalies has been carried out. The observed gravity anomalies are accurate to ±0.2mGal. Result indicates that PGM2000A and shows the best agreement with the observed anomalies with standard deviation of ±20.90mGal. Therefore, the EGM96 and PGM2000A geopotential models performed well in recovering geoid undulation and gravity anomalies in the UAE. However, due to its consistency, PGM2000A model was selected to recover long wave length geoid information in UAE.

4.0 COMPUTATION AND RESULTS

A precise gravimetric geoid undulation of the UAE is being computed following Remove-Compute-Restore (RCR) techniques. The long wavelength reference field of the geopotential model and the medium wavelength topographic effects were removed from the observed gravity anomalies. Stokes' integration is subsequently used to convert the residual gravity anomalies into residual geoid undulation. The final gravimetric geoid undulation signal of the UAE was reconstructed by restoring the reference field and topographic contributions.

The following are the general steps that have been developed for the FFT geoid computation strategy:

1. Computation of geopotential geoid and residual gravity anomalies for the best-fit GGM model to remove the long wavelength effect.

2. Computation of mean and reference digital elevation height models to be used in computing terrain correction and terrain corrected gravity anomalies (to remove the medium wave length effects).

3. Applying (adding) atmospheric correction (±0.78 m) to the reduced gravity data for reducing gravitational attraction of the atmosphere.

4. Griddling of the residual gravity data for FFT technique computation input.

5. Computation of residual geoid from residual gravity data using FFT technique.

6. Computation of terrain effects by 2-D FFT using DTM with zero padding (100%).

7. Restoration (Adding) of computed terrain effect.

8. Restoration (adding) of reference geoid computed in (1) to get final gravimetric Co-Geiod/Geoid.

9. Computation of indirect effect to be applied (if significant) in final gravimetric geoid for the UAE.

The FFT technique requires regular geographic grid of gravity anomalies. The 2-DFFT and 1-DFFT computation techniques are used to accommodate spherical FFT approximation. The SPFOUR program of GRAVSOFT was used in computing the 1-D and 2-D FFT gravimetric geoids for the UAE. The input data used is the gridded residual gravity anomaly at 1.5' spacing. Specific Stokes' modifications degree band was selected and used in the computation of the 1-D and 2-DFFT residual geoid. Hundred percent (100%) zero padding was applied to fill up (pad) the empty outer boundary areas with dummy values (zeros) to avoid the edge discontinuity problem and cyclic convolution.

The computed 2-DFFT residual geoid is shown in **Figure 2**. The 2-DEFT residual has maximum value of 2.95 m over the mountainous region which are located in northeast of UAE. Terrain correction should be applied to the gravity data when centimeters level geoid of accuracy is required. The largest terrain effect can be seen mainly in the northeast of the UAE where the correlation of terrain with topography is noticeable. The computed 1-DFFT residual geoid is shown in **Figure 3**. The 1-D FFT residual geoid has maximum value of 2.53 m in northeast of UAE due to the topography effects. In fact, complicated topography features are dominated in UAE due to the existence of Oman Mountain, faults, fractures and high capacity of dune covers (Adel, 2007). These results are acquired due to the standard procedures which are used for data analysis. According to Schwarz et al. (1990) the modification of FFT algorithm for geoid computation can provide accurate geoid mapping. Further, 2-DFFT can produce accurate terrain map for mountains area. This study agrees with the study of Schwarz et al. (1990).

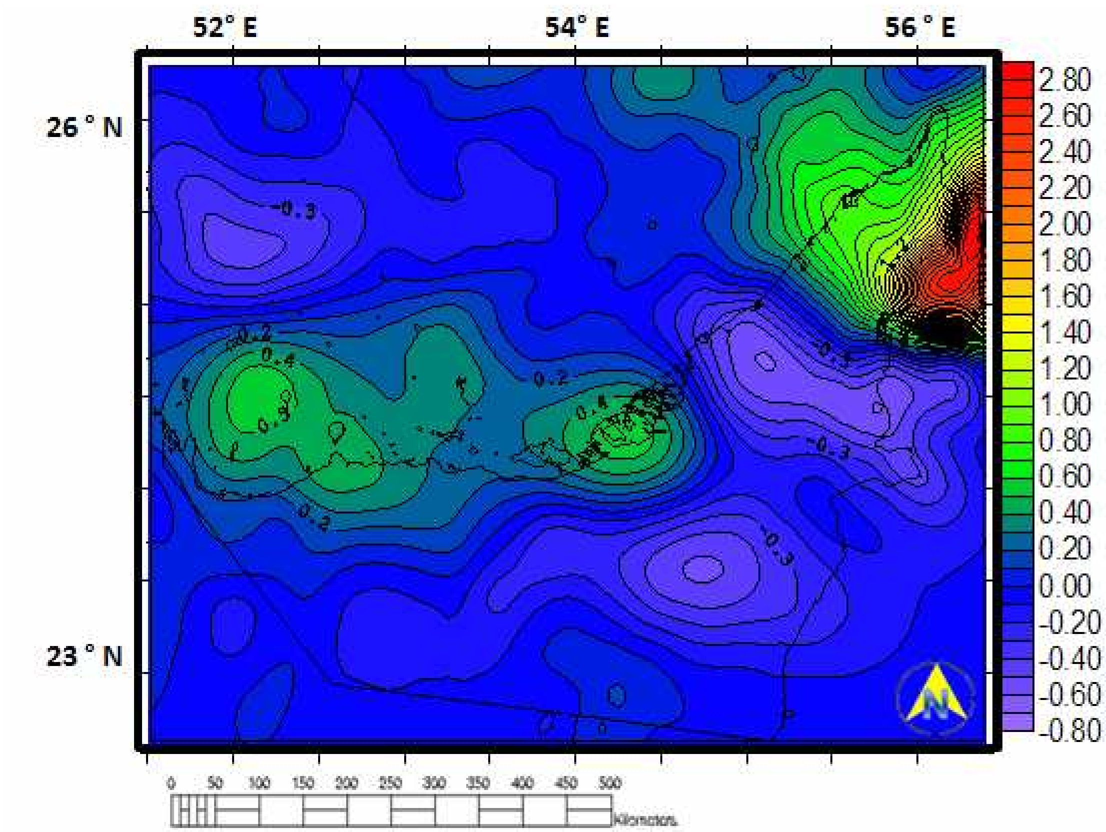

Figure 2. Residual geoid effects from spherical 2-D FFT (unit in m)

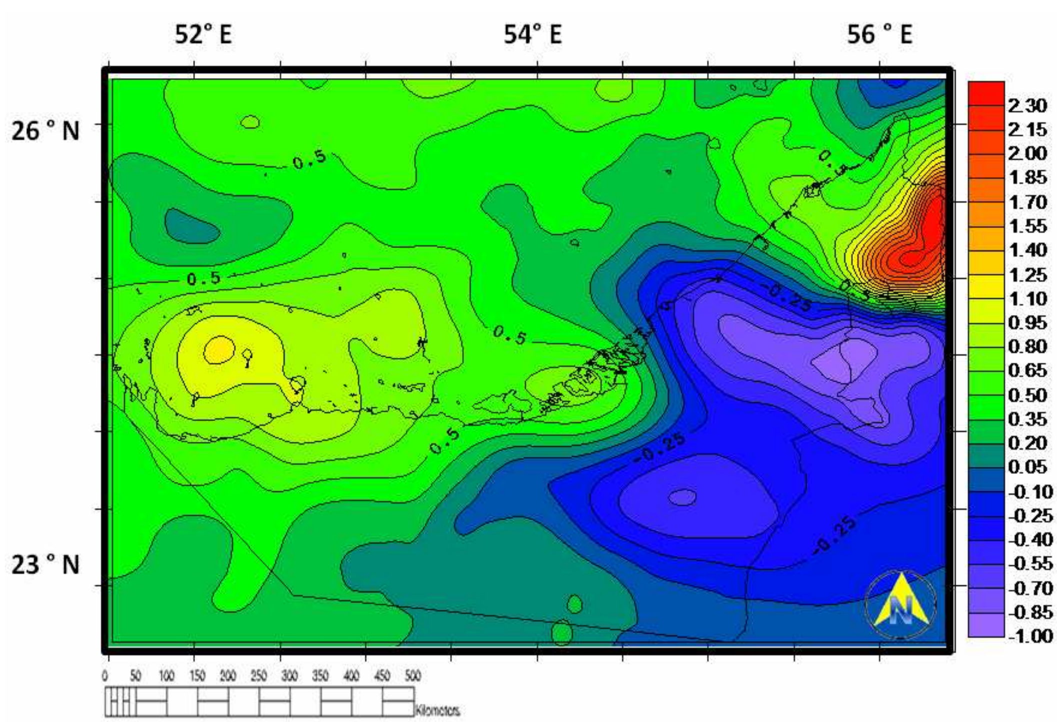

Figure 3. Residual geoid effects from spherical 1-D FFT (unit in m)

The difference between residual geoid effects from spherical 2-D FFT and 1-D FFT computations over the land area of UAE is shown in **Figure 4**. The magnitude of the difference is increasing from -0.3m to 0.5m in the east-west sector.

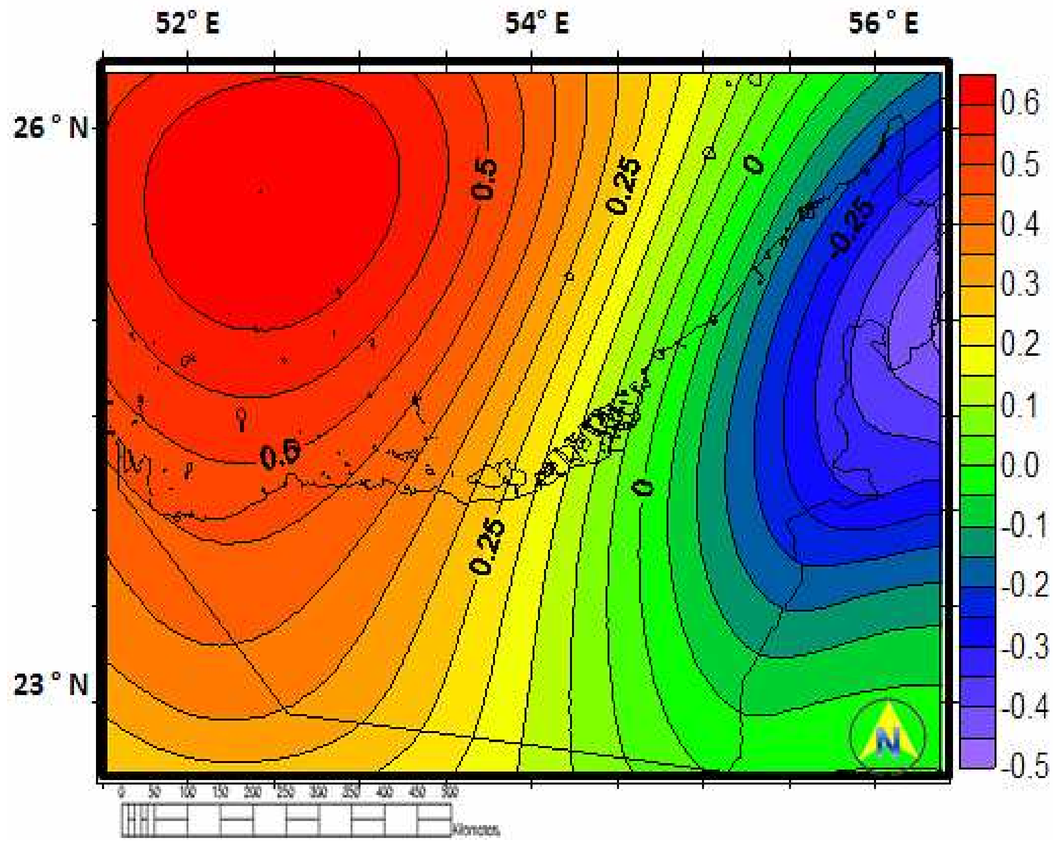

Figure 4. Difference between 1-D and 2-D FFT residual geoids (C.I. = 0.05 m)

The total gravimetric geoid computed by FFT technique is shown in **Figure 5**. Generally, the geoid has minimum and maximum values of –34 m and –24 m, respectively. The lowest geoid is found to be in the coastal areas of northeast Abu Dhabi and Dubai, UAE. Elsewhere, the geoid is very gentle over the fairly flat region of the UAE.

Smooth negative geoid undulation over most of the flat land area of UAE is being observed particularly in the central part of the country. A rather steep geoid undulation is being observed over the mountainous area located in the eastern part of the country. The geoidal slope of 10 m over a distance of less than 50 km is found over the mountainous area of varying height up to 3,000 m. A gradual slope of 3 m over the entire marine area of the UAE is found with increasing geoid height in north-west direction. The geoid over coastal waters of UAE is smooth due to sparse shipborne gravity data tracks and 5 km grid altimetry derived anomalies. The geometric geoid (N_{GPS}) at 157 GPS/Leveling stations is used in evaluating the accuracy of the newly computed gravimetric geoid. It is anticipated that the GPS–derived ellipsoidal height of the selected GPS points is given at the accuracy of ±3 cm, while the accuracy of their related leveling heights is ±3 cm. Therefore, the corresponding accuracy for the geometric geoid heights is better than ±3 cm.

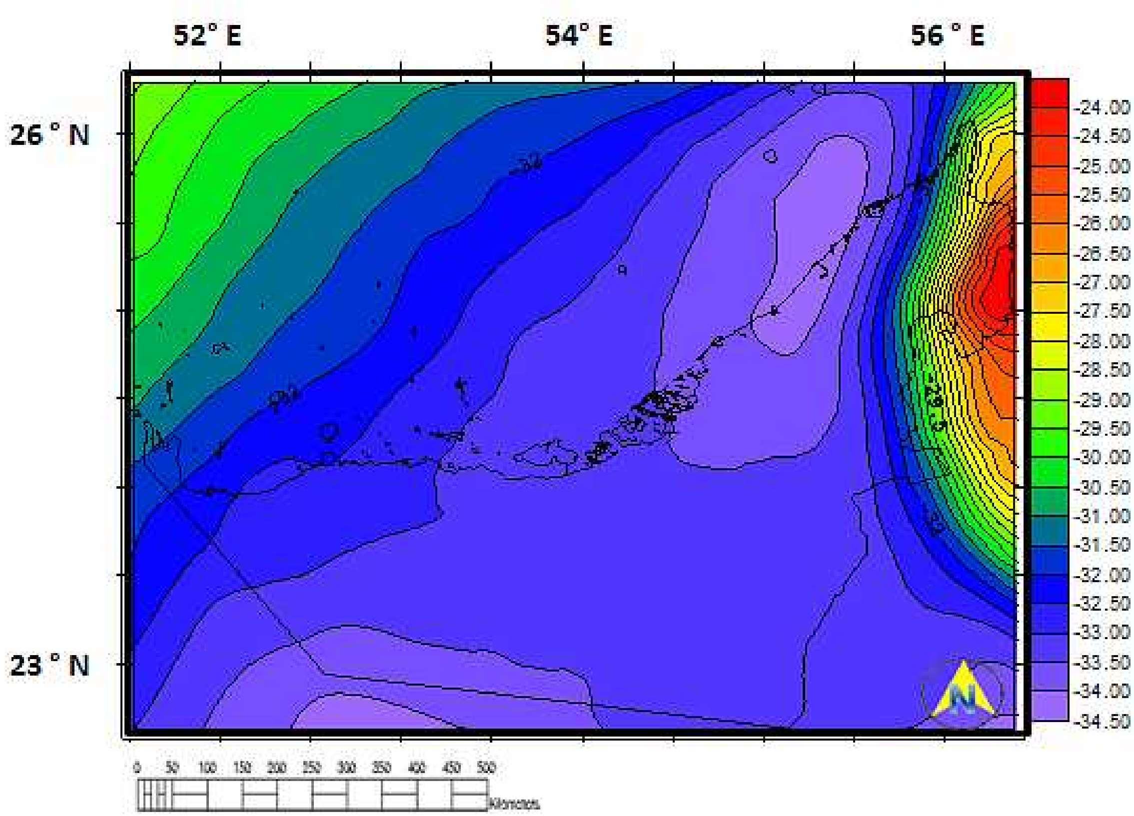

Figure 5. FFT gravimetric geoid (C.I. = 0.5 m)

The standard deviation of the differences between gravimetric geoid and geometric geoid (N_{GRAV} - N_{GPS}) shows how good the fitting of the two surfaces. Meanwhile, the mean of the difference indicates how the two surfaces are vertically shifted with respect to the geometric geoids. Comparison results suggest that the two geoid surfaces are better than ±17 cm. The new gravimetric geoid heights that were computed at 19 checking points (BMs) showing agreement with the corresponding geometric geoid heights at ±5 cm level of accuracy.

5.0 CONCLUSION

The objective to determine the first precise gravimetric geoid for the United Arab Emirates (UAE) was achieved. The geoid was computed using FFT technique. In carrying out the task, substantial gravity data for the entire country were gathered through land gravity measurement and compilation of the existing marine and land gravity anomalies. Detailed analysis on the computed gravimetric geoid was provided by comparing with GPS/Leveling derived geoid height at selected points in UAE. Finally, accuracy of the geoid was estimated and its potential for GPS/Leveling application was evaluated.

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AUTHORS

Dr. Sahrum Ses is a professor of geomatic engineering and the Dean at the Faculty of Geoinformation Science & Engineering, Universiti Teknologi Malaysia (UTM). He holds B.Surveying degree from UTM, M.Phil degree from University of Newcastle upon Tyne, England and a PhD in Geodetic Surveying from University of South Australia. His research interests lie in the areas of satellite surveying application and geoid modelling. He has authored over 60 articles in both international and national journals, conference proceedings, and workshop in the field of GPS surveying application to cadastral surveying, local precise gravimetric geoid modeling, satellite altimetry for marine application and high precision GPS measurement for geodetic engineering application.

Picture Not Available

Dr. Adel Alshamsi is the Head of Geodetic Section at the Military Survey Department, United Arab Emirates (UAE). He holds B.Sc in Surveying degree from North East London University, England, and a PhD in Geomatic Engineering from Universiti Teknologi Malaysia (UTM). His research interests lie in the areas of satellite surveying for geodetic application, geoid modelling and hydrographic surveying. He has authored a numbers of articles in journals, conference proceedings, and workshop in field of GPS application to geodetic surveying, local precise gravimetric geoid modeling, and GPS/levelling for engineering application.

Rene Forsberg is a scientist and currently the Head of the Geodynamics Department, National Space Institute, Technical University of Denmark (DTU). His research interests lie in the broad field of geodynamics, physical geodesy and seismology. His research and development focus on activities in physical geodesy, GPS/INS, static and kinematic gravimetry, among many other things. He has regularly authored articles in international refereed journals, conference proceedings, and workshop in his field of research interests.