Improved Official Geoid Model for Israel, 2008

Hezi SARID, Hsein NASR-ALDIN and Dan SHARNI, Israel

Key words: geoid, undulation, EGM2008, WGS84, gravity anomaly

SUMMARY

The Survey of Israel (SOI) has 849 anchor-points, where "orthometric" and "ellipsoidal" heights are known [the quotation marks indicate low accuracy for these terms].
On this basis, a kriging process established the Israel Undulation Model (currently ILUM1.2), by purely mathematical interpolation.
A research project was funded by SOI - to improve this official (statutory) model by gravimetric interpolation (parts A+C+D+E). The method chosen is Remove/Restore (R/R), whereby all known contributions to the undulations are accounted for.
Data sources are: observed gravity in Israel, measured free-air anomalies over the seas (Med and Red), and Bouguer anomalies in neighboring areas. All data were converted to free-air anomalies on a 1-minute grid, on the WGS84 ellipsoid.
The global gravity model EGM2008 was utilized as a reference for the process – for both undulations and gravity anomalies.
A Stokes integration, to 2-degrees (beyond Israel borders) was performed.
The full process includes: remove model undulations, Stokes contributions (of residual anomalies, known minus model), and Indirect Effect, at anchor-points – to obtain residual undulations; interpolate to the grid; add back model and Stokes contributions, and Indirect Effect – to obtain grid undulation predictions; interpolate for any required location. The entire project is carried out in GIS environment.
Statistics for the various undulation fields are:

Official model ILUM1.2 – from 16.22 to 23.89, average 19.04 m;
Global model EGM2008 – from 16.41 to 24.46, average 19.03 m (bias removed);

A test vector, of 518 additional anchor-points (supposedly) not incorporated in the official model, was predicted with the complete R/R process. This procedure worked, with satisfactory results – but was inconclusive, as the points proved to be very close to the controls, if not identical with them.
Further tests were carried out on 3 difficult areas in the South – by removing 11/9/3 anchor-points, and then predicting them with the R/R process. The results were good: ±7/6/11 cm, for areas of 700/300/1,200 sq.km, respectively; probably better than the official model could predict.

The R/R process proved its validity and importance – in improving the official undulation model for Israel.

Another part of the research (part B) utilized the UNB Geoid Program suite – by applying a modifies Stokes-Helmert process to Israel data, extending to 7-degrees (beyond Israel borders). The results will be presented at the conference.

The new geoid thus obtained will be compared to the EGM2008 global model, and should constitute the basis for a new elevation network for Israel.

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1. INTRODUCTION

The Survey of Israel (SOI) funded an applied research project, to improve the official (statutory) geoid in Israel. This came as a continuation of the Israel Geoid Pilot, executed in the Haifa area, 1994-1999, by Haim Papo and Dan Sharni *[Papo and Sharni, 1994-1999]*.
The project consists of five parts – four of which deal with a Remove/Restore procedure, while one part utilizes a University of New Brunswick (UNB) Geoid Program suite.
The R/R procedure first removes all known contributions to the undulations in Israel (global gravimetric model, area gravity anomalies, local topography), then interpolates (to a desired location), and finally restores the known effects (at the desired location). The project sections are: [1] Resuscitation of the Pilot data and programs, [3] Expansion of data bases, [4] Proving areas in the South, [5] Application to the whole country.
The UNB Geoid Program suite was licensed to the SOI, after Dan Sharni participated in a workshop, in Fredericton. Part [2] of the project is the application of the program, using a Modified Stokes/Helmert integration, to establish the geoid in Israel.
The R/R procedure improved the existing IsraeL Undulation Model (ILUM1.2), while the UNB program computed, for the first time, the true geoid for Israel. The SOI should now switch from elevations-above-sea-level, to true orthometric elevations.

2. THE REMOVE/RESTORE PROCEDURE

2.1 Programs and data

The Pilot programs, mostly in FORTRAN, were resuscitated. New programs were written, to accommodate the requirements of the expanded project. The programs are written in MatLab and Excel, and extensive use is made of ArcView/ArcMap GIS procedures and tools.
The data for the Pilot in the Haifa area needed to be expanded, to cover 2-degrees (and 7-degrees) outside of Israel, for the R/R (and UNB) procedure.

2.1.1 Programs

The main program is written in MatLab, and it does everything required, with the aid of several service programs, in MatLab and Excel, as well as built-in GIS routines and tools in ArcView/ArcMap. They translate Old Israel (ICS/Cassini) location coordinates (of gravity points) to New Israel (ITM) coordinates; apply WGS84 gravity formula; compute Free-Air discrete gravity anomalies from gravity observations; fill "holes" in the data, average and grid the anomalies, into 1-minute cells (mostly with Kriging); convert between several grid sizes (50-m., 200-m., 2-km. 0.3-minutes or 2-minutes to 1-minute, etc.); convert from Bouguer anomalies to Free-Air anomalies (over the 2 lakes in Israel, as well as the 2 seas and land areas outside Israel); convert from anomalies at the surface (in the EGM2008 global model) to classical Free-Air anomalies; remove EGM2008 undulations from anchor-points (where SOI

has “observed” values); removes global model anomalies (EGM2008 reduced to Free-Air) from observed ones; perform Stokes integration on the residual anomalies (done in FORTRAN, from the Pilot); compute the Indirect Effect (on undulations); remove Stokes and Indirect Effect from the residual undulations; interpolate and predict (at desired locations, or on the grid); restore all effects; perform statistics, draw maps, etc. *[Heiskanen and Moritz, 1967; Sharni, 1998]*.
Some of the simple tools, employed to recognize/eliminate gross errors in gravity/location data, were: plotting locations, adjusting/plotting relation lines (Free-Air or Bouguer anomalies to heights), etc. See */Figure 1/*.

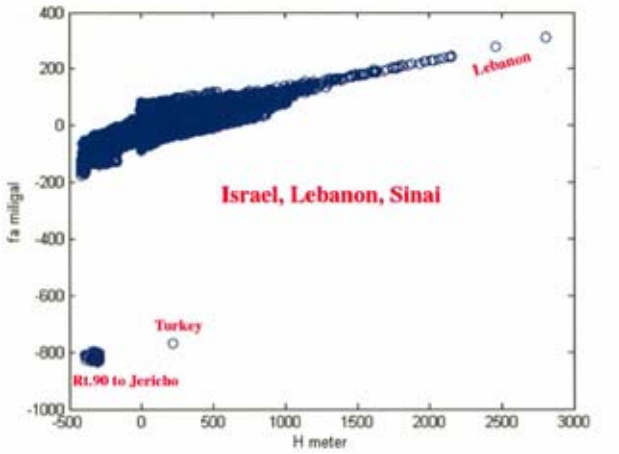

Figure 1: Discerning wrong data (gravity, location)

2.1.2 Data
The Pilot data (used for the Haifa area) needed to be expanded, to cover 2-degrees beyond Israel’s borders. Also the makeup of the data required modification – as the pilot utilized 3-minutes and 0.9-minute cells, whereas the current project uses 1-minute cells throughout.

2.2 Project data

All project programs and data are discussed at length in the reports to the SOI *[Sarid et al, 2008; Sarid et al, 2009]*.

2.2.1 Global Models
The Pilot used the Wenzel GPM’98B global model (which included some gravity anomalies from Israel). The model was resuscitated, and tested – but not applied for the project.
The NGA preliminary global model PGM2007A had been tested and utilized to some extent. However, the final NGA EGM2008 model is the reference global model for the project. Dr. Nikos Pavlis was kind enough to also provide the surface anomalies, on a 2-minute grid (covering 7-degrees outside Israel, applicable also for the UNB program).

2.2.2 Observed Free-Air anomalies for Israel - Land
The Geophysical Institute of Israel (GII) is the repository for gravity data in Israel (and adjacent land areas). GII was kind enough to provide all discrete data, some 57k points. The

data required much screening and conversions: from Old Israel (ICS/Cassini X-Y) coordinates to New Israel (ITM/WGS'84-2000 ϕ,λ) coordinates; from old Potsdam gravity values to IGSN'71 values; and then reduction to the geoid (with surveyed elevations, verified by the Israel GIS elevations), and subtraction of normal gravity at the WGS'84 ellipsoid; incorporation of the Atmospheric correction; removal of double points; corrections to wrong locations and gravity values, etc. [GII included Topographic Corrections – except close to, and outside, Israel's borders. Consequently, about one tenths of the points don't have good/any TC. This should be addressed – wherever we need to consider Bouguer anomalies]. See */Figure 2/.*

Figure 2: Observed Gravity for Israel

2.2.3 Free-Air anomalies for Israel – Water

We received Bouguer anomalies for the 2 lakes within Israel (Lake Kinneret, and the Dead Sea), courtesy of Dr. Michael Rybakov. They required coordinate transformations, reference to WGS'84 gravity, and conversion to Free-Air anomalies (utilizing bathymetry, courtesy of Dr. John Hall).

2.2.4 Free-Air anomalies outside Israel – Land

We received Bouguer anomalies for the land masses to 2-degrees beyond Israel's borders, again courtesy of Dr. Michael Rybakov. These required coordinate transformations, reference to WGS'84 normal gravity, and conversion to Free-Air anomalies (utilizing the global DTM, SRTM).

We also received NGA EGM2008 global model gravity anomalies (at the surface) from Dr. Nikos Pavlis – to 7-degrees beyond Israel's borders. These needed (negligible) conversion to classical Free-Air anomalies, and re-gridding (from 2-minutes to 1-minute). They serve as the reference for the UNB Geoid Program suite.

2.2.5 Free-Air anomalies outside Israel - Sea

Over the 2 seas in the area (the Med and the Red) there are Topex/Poseidon gravity data, requiring no reductions, only re-gridding.

2.2.6 Total Data

The total data sources are presented in */Figure 3/* - to 2-degrees beyond the borders (from the sources above); and in */Figure 4/* - to 7-degrees (from EGM2008).

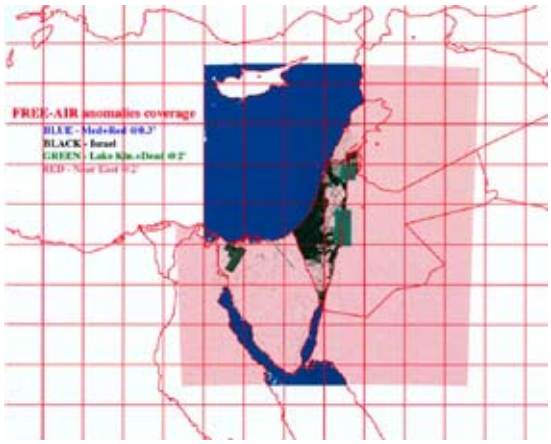

Figure 3: Anomalies Sources (2-degrees around Israel, various)

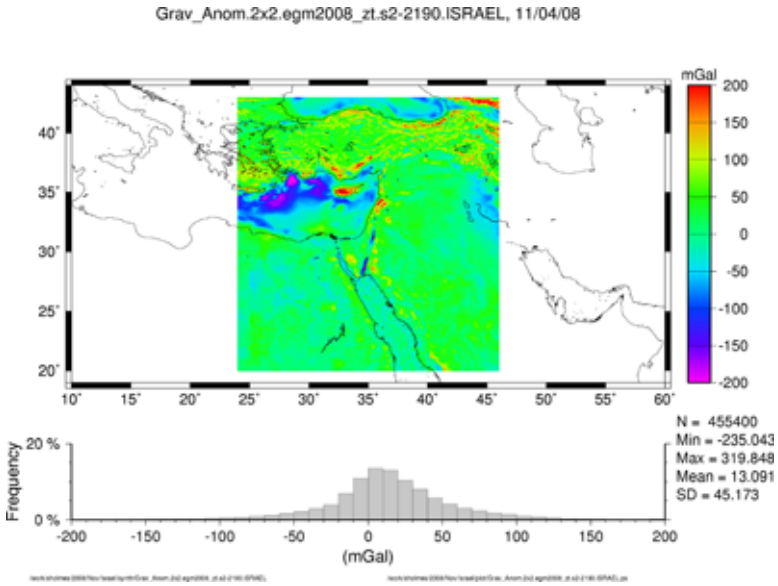

Figure 4: Anomalies Data (7-degrees around Israel, EGM2008)

2.3 Computations

The R/R process first transforms global model EGM2008-gravity anomalies, from the topography to the geoid, and removes them from the corresponding observed anomalies. [There residual anomalies should further be corrected by the Indirect Effect on anomalies – but were not, in our project, as the differential effects would not exceed 2 mgal].

The procedure then removes all known effects on ILUM1.2-undulations, at the anchor-points: global model EGM2008, Stokes integration to 2-degrees beyond the borders, and the Indirect Effect on undulations (above seal-level) – to obtain a residual undulation field. This is then

interpolated to the grid, or to any desired location – where the removed effects are now restored.
The residual undulation field is much smoother than the original undulation field, and its magnitude is much smaller. Therefore this gravimetric prediction is better than the purely mathematical (kriging) process utilized for ILUM1.2.

2.3.1 Verification

In order to verify our R/R process, 2 tests were conducted.
The first involved 518 points provided by SOI, (supposedly) not used as anchor-points for the official model (of 849). Our process indicated the following prediction accuracies (after removal of the points from the control field, then R/R prediction):

473 points – from -0.10 to +0.10, average 0.00 m, rms ±0.03 m;
500 points – from -0.20 to +0.20, average 0.00 m, rms ±0.04 m;
518 points – from -0.40 to +0.47, average 0.01 m, rms ±0.08 m.

On further investigation, it was found out that almost all the test points were actually located very close to – if they were not identical to – the control points. Thus our R/R process could not surpass the ILUM1.2 ”prediction", and is inconclusive.
We then investigated 3 very difficult test areas in the South. We chose critical areas, where the model geoid forms a saddle (11 points, area 1), a peak (9 points, area 2), and where data is scarce (3 points, area 3) */Figure 5/*. All these areas have ILUM1.2 accuracies of about 10 cm or worse */Figure 6/*.

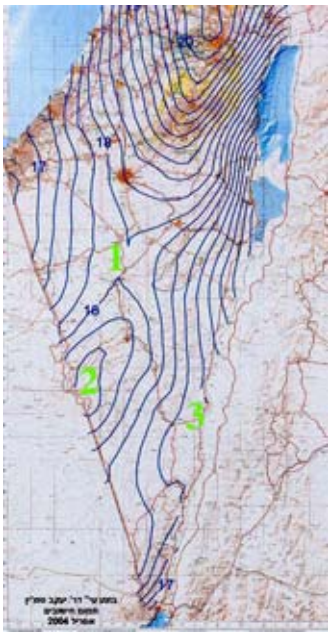

Figure 5: Test Areas

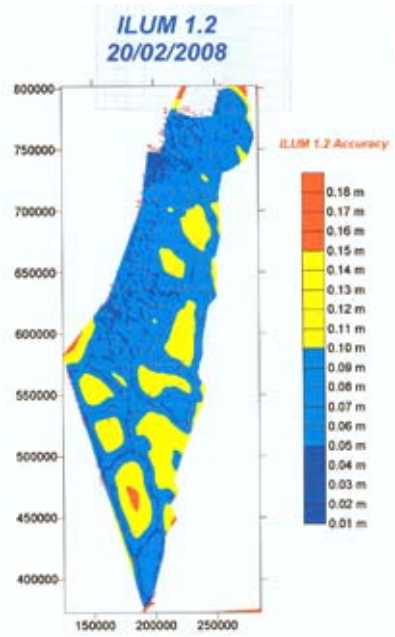

Figure 6: Official Model Accuracies

We, again, removed the test points (green) from the control points (blue), and predicted with our R/R procedure (with Stokes to 3 degrees, in this case). The results are shown in */Figure 7/* as cm-differences to the measured values (red).

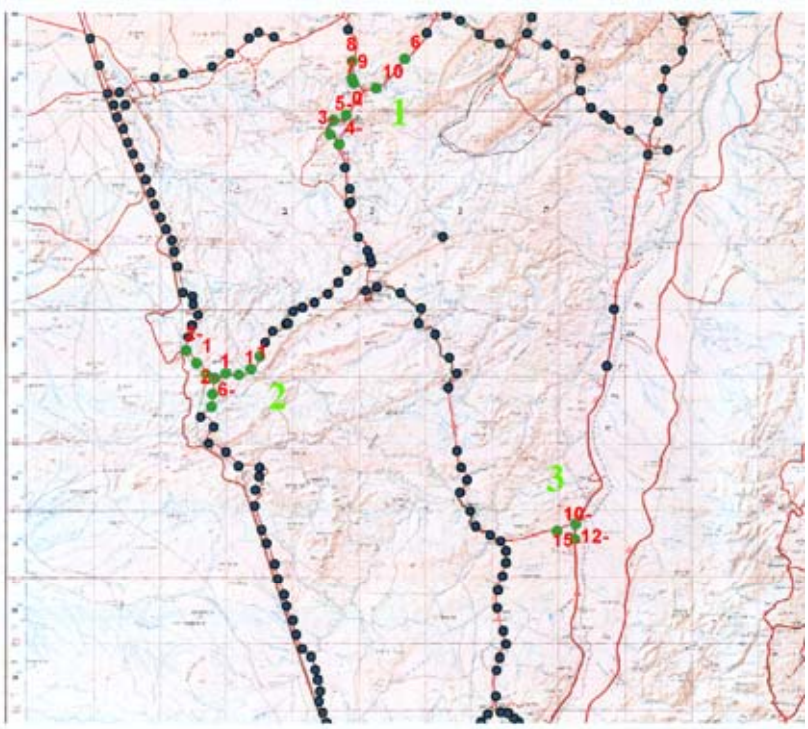

Figure 7: R/R Predictions in Test Areas

The removed points cover areas of some 700/300/1,200 sq.km, for the locations 1/2/3, respectively – thus the achieved predictions are rather good, being on the order of ±7/6/11 cm, respectively. We doubt that the official model could predict them any better.

The R/R process proved its validity and importance – in improving the official undulation model for Israel.

2.3.2 Final results

The final product of stages A+C+D+E of the project, is a 1-minute (ϕ, λ) grid of undulations. This is further developed into an easy interpolation procedure for the client, who enters with ITM (or, now: Israel2005) rectangular (x, y) coordinates, and obtains undulation values (N).

3. THE UNB GEOID PROGRAM SUITE

3.1 The UNB program

The UNB program-suite computes the actual geoid, with a modified Stokes/Helmert procedure. It was licensed to the SOI, courtesy of the Geomatics group, and the kind go-between of the WaterMark Foundation – after Dan Sharni participated in a dedicated workshop (with Prof. Petr Vanicek, Prof. Marcelo Santos, and Mr. David Avalos) on campus, in late July 2008. The program suite had been tested and applied at several locations, and especially adapted for Israel (not many countries have a significant area lying below sea-level).

The program considers even minute effects on accuracy – by employing a deterministically modified integration kernel, a 20-degree satellite-only reference field, with integration of a high-frequency terrestrial gravity anomalies to 7-degrees, and a separate computation of the truncation bias, with degrees 21-120 of a combined global geopotential model. It performs the Stokes integration on the ellipsoid, and account for all geoid deformation, due to mass-transportations, etc.
The programs starts with discrete Bouguer anomalies – as they are considered best for interpolations. From them, the program computes discrete Free-Air anomalies – and converts them into a grid. We do not have the discrete Bouguer data for our area – therefore, we enter the program where it expects the Free-Air grid.
A comparison to EGM2008 values, and to our R/R procedure results, will follow. The results will be presented at the conference.
This is the first time, that the actual geoid is compiled for Israel.

3.2 The Geoid in Israel

The true geoid had not been compiled in Israel – until this year. What we have, is the IsraeL Undulation Model (currently ILUM1.2), which is based on some 849 anchor-points, where model undulations are known – being the difference between "heights-above-sea-level" (as defined by the SOI) and "ellipsoidal elevations" (from GPS). The problems are numerous. [1] Leveling was carried out over 50 years; the data was not corrected orthometrically; the definition of "mean-sea-level" is inaccurate, and does not approximate the geoid; the tie to the leveling network is tenuous; the adjustment was not done properly, nor included all data available. [2] GPS observations were nor carried out a long enough time, and are inaccurate. Furthermore, the ILUM1.2 predicts undulations with a purely mathematical procedure (kriging). Thus, the project sections A+C+D+E discussed earlier, can only improve the ILUM1.2 – as the basic anchor-points data is kept as valid. Only this application of the UNB program, part B of the project, can produce the true geoid for Israel.
Once the geoid is compared with the global model EGM2008 geoid, and possibly some compromise worked out – the SOI should adopt the final geoid for Israel. This will alter the nominal "elevations" in Israel, and will necessitate new definitions and regulations – but it will assure a good basis to our elevations, and proper global footing.

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BIOGRAPHICAL NOTES

HEZI SARID
Born in Israel, 1971. Married.
B.Sc. - 1994, Technion, Israel (Geodesy),
M.Sc. - 2000, Technion, Israel (Geodesy).

HSEIN NASR-ALDIN
Born in Israel, 1983.
B.Sc. - 2006, Technion, Israel (Geodesy).

DAN SHARNI
Born in Israel, 1935. Married.
B.Sc. - 1959, Technion, Israel (C.E./Geodesy) - Cum Laude,
M.Sc. - 1961, Technion, Israel (Geodesy),
Ph.D. - 1966, The Ohio State University (Geodetic Science).
Senior Lecturer - Technion, 1972 (current; retired),
Adjunct Senior Lecturer - Tel Aviv University, 1976,
Visiting Associate Professor - Purdue University, 1979,
Visiting Assistant Professor - The Ohio State University, 1985, 1986.
Teaching experience – Surveying: elementary and higher, optical alignment; Geodesy: geometric and physical, geodetic astronomy, map projections, adjustment computations.
Professional experience: Registered Civil and Geodetic Engineer – Israel, 1962; Registered Land Surveyor – Israel, 1971; Surveyor and geodetic engineer, consultant - self-employed, Israel, 1956 (engineering and control surveys, geodetic control and deformations, photo interpretation); Various jobs abroad (Burma 1972/73, Iran 1976+1977, Nigeria 1985).
Organized and edited 10 conferences in Israel; edited 13 issues of ”SurveyTime”, Israel.
Wrote 8 textbooks, 9 refereed papers, 17 conference papers, 27 articles, 33 reports.

CONTACTS

Dr. Dan Sharni
Mishmar Hayarden 10
Givatayim
ISRAEL
Tel. +972/3/571-3860
Fax +972/3/731-4891
Email: sharni@tx.technion.ac.il