New Vertical Datum for the Dead Sea Works, Israel 2008

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Key words: orthometric correction, geoid undulation

SUMMARY

The Survey of Israel (SOI) funded an applied research project, to establish "Improved Geoid for the South Dead Sea, 2008". The purpose of the project, was to assess the contribution of orthometric corrections to leveling lines, and to improve the Statutory Geoid of Israel, over the southern (Israeli) part of the Dead Sea.
SOI computed geoid "undulations" (such as they are), at 855 anchor-points all over the country, where both "orthometric" elevations (actually, "heights-above-sea-level") and "ellipsoidal" elevations are known. With these point values, a kriging process established the official IsraeL Undulation Model (at present, ILUM1.2, 2008).
Thus, at the Dead Sea area, one can not establish a piece of the actual geoid – as one is tied to the national elevation network. One can only improve the precise leveling, apply strict orthometric corrections, and execute precise GPS observations; or, one can establish a local vertical datum, free of the corrupting influences of the national net.
The Dead Sea Works (DSW) carried out a precise leveling line (along Route 90, 2004), and a big loop (encircling the evaporation ponds, 2007/08) – all at better than 2nd order tolerances ($4_{mm}\sqrt{L_{km}}$ for a line of length L; $3_{mm}\sqrt{K_{km}}$ for a loop of length K). GPS observations were carried out for at least 4 hours, on two separate days. SOI observed gravity at some select points (2004), and did the calculations.
The SOI adjustment of the leveling line (2004) degraded its measured accuracy – as it was based on control points of 2nd to 4th order. Thus the resulting elevations were classified as 5th order ($60_{mm}\sqrt{L_{km}}$ and $40_{mm}\sqrt{K_{km}}$), or worse than engineering tolerances. Clearly this was not acceptable; the DSW requires precise orthometric heights – as their processes are gravity-based. Therefore, already in 2004 (with preliminary data for the line along route 90 alone, but with orthometric corrections applied), a preliminary local vertical datum for the DSW was established. It was based on one stable point alone; with 2nd order accuracy. As a by-product, a local undulation strip was produced.
After further precise leveling of the loop by the DSW, additional GPS observations and improved gravity observations by the SOI (2007/08) – orthometric corrections were applied, and the data adjusted. The resulting elevations and undulations refer again to the one stable point, and define the new local "DSW Vertical Datum 2008", and a piece of the "Improved Official Geoid of the DSW, 2008". Elevations agree to 2nd order tolerances. The orthometric correction amounted from -7.2 mm to +8.3 mm (per section, of 2-3 km length), point elevations changed from -8 to +21 mm, and differ from SOI-elevations by -0 to -43 mm; and the final undulations differ from the official ones from -78 mm up to +118 mm.
The SOI approved the local vertical datum; and the DSW gained an improved elevation net.

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1. SURVEYS

The Dead Sea Works (DSW) regularly conducts various surveys, to establish, improve and monitor elevations (and positions) at various points in and around the evaporation ponds and the plants – at the south-western (Israeli) end of the Dead Sea /*Figure 1*/.

Figure 1: DSW and 2004 survey strip

A precise leveling line was surveyed in 2004, along Route 90 (between points 43F and 10U) - together with a narrow strip of precise GPS points. DSW funded the surveys, while SOI provided gravity measurements. These data established improved elevation data, both orthometric and ellipsoidal - as well as an improved geoid strip – along the road.
In 2007/08 a precise leveling loop was added around the big pond (by DSW) /*Figure 2*/, together with precise GPS points and updated gravity observations (by SOI) – further

improving the local leveling net, and now virtually covering the entire area of the southern (Israeli) Dead Sea.

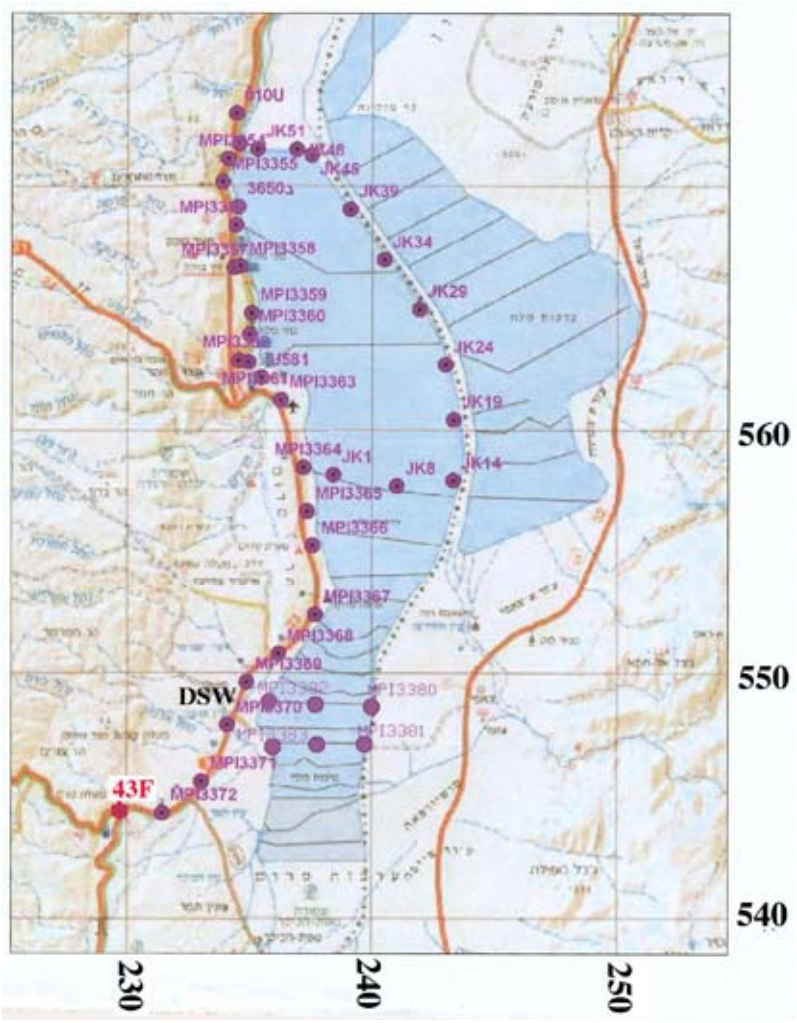

Figure 2: 2007/8 survey loops

2. DATA and CALCULATIONS

2.1 2004

The DSW surveyed a precise leveling line along some 40 km of Route 90, from B.M. 43F in the south, to B.M. 10U in the north. The survey adhered to to 2nd-order specifications (invar 1-section staves, limited hours of operation, temperature correction, no reading below 50 cm, double instrument setups, even number of instrument stations, return leveling, etc.); and achieved a tolerance smaller than that of 2nd order leveling ($4_{mm}\sqrt{L_{km}}$ for a line of length L).

In parallel, the DSW surveyed a strip of precise GPS points, around Route 90, where each point was occupied for at least 4 hours, on 2 different days. The adjusted ellipsoidal elevations are accurate to about ±1 cm.

The SOI made gravity observations at 25 benchmarks.
The author calculated orthometric corrections for the leveling line *[Heiskanen and Moritz, 1967; Sharni, 1998]*. The actual, gravimetric, corrections are significantly different from the normal corrections (from -7.3 to +8.1 mm per 2-3 km leveling-section; with the former having waves of plus and minus effects, whereas the latter have the same effect-sign, since the leveling line lies in the south-north direction); and have values from -7.2 to +8.1 mm per section. These corrections far exceed the allowed tolerances – and definitely must be incorporated.

Once the orthometric corrections were applied, the leveling line was adjusted to SOI data. Here arose a problem, since the national vertical control points in the area are very heterogeneous, and unreliable. This stems from historic background, security considerations, and the current SOI approach to vertical control.
The latest national elevation-data adjustment was carried out in 1997 – on 15 loops of 1st-order leveling, in the north and west of Israel (north of the Negev area). The leveling was corrected with orthometric corrections – but these were estimated only, from interpolated gravity data (rather than measured data). On this partial framework, a 2nd-order net of 15 loops, corrected with only normal corrections, was hierarchically fixed (at 30 common points). This 2nd-order net did not cover Israel from Dan-to-Eilat, and it skirted around the Dead Sea area /*Figure 3*/.

Figure 3: 2nd-order national leveling net

Eventually, some leveling loops were augmented and calculated in the area, with observations from the 1960's to the 2000's (loops 1 and 2) /*Figure 4*/.

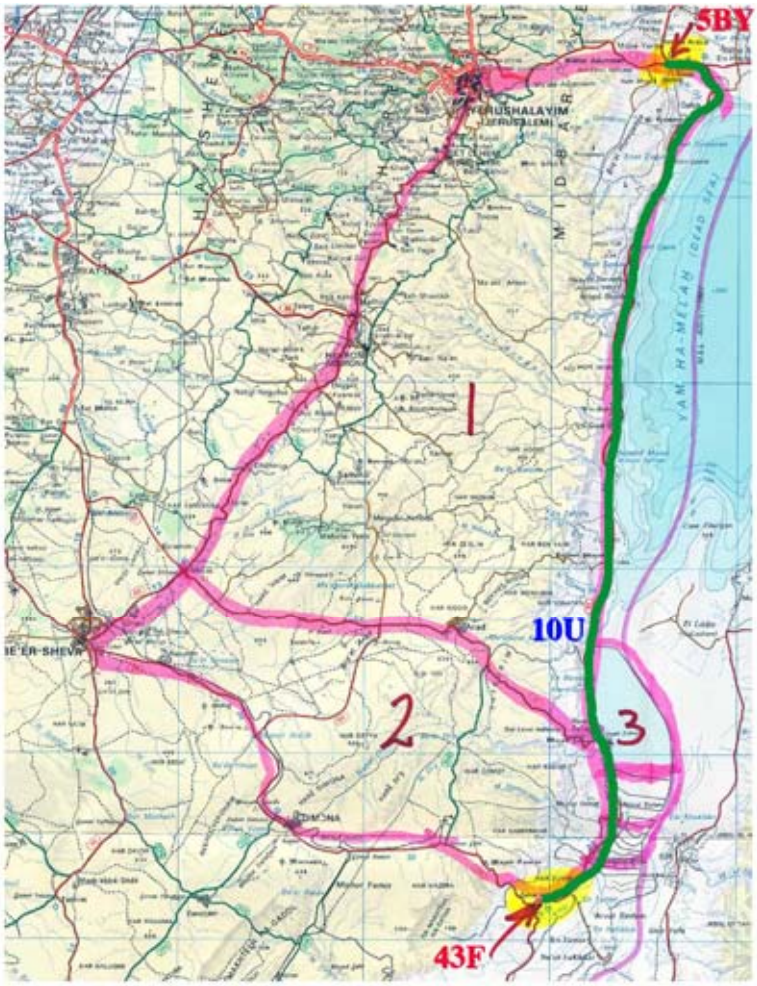

Figure 4: National leveling loops in the area

Loop 1, which borders the Dead Sea, has a length of 256 km, does not stand to 2nd-order specs and possibly includes a gross error. It, consequently, includes control points of nominal 2nd to 5th-order. A leveling line (green), of some 100+ km, was fixed between two junction-points (43F and 5BY, yellow), and carries similar accuracy designations.

Loop 1 should have been resurveyed – were it not for security considerations, and limited interest by the SOI, in upgrading or even maintaining the orthometric network.

The junction point 43F appears to be stable, over time.

Any basing of our 2nd-order leveling on 2nd to 5th-order nominal control points will only degrade the excellent survey results. Indeed, trying to base the 2004 leveling line, from 43F to 10U (constituting, post-factum, a part of the green line above), on the nominal control points along the way – resulted in calculated points designated as 3rd to 5th-order. This is not acceptable. However, when old elevations of control points were incorporated, dating to the same epoch – the results were in the 2nd to 3rd-order. Apparently, the various surveys, executed over many years, affected the consistency of the control elevations. Clearly, this was a datum problem.

At this juncture, the author established a preliminary, local vertical datum for the DSW – based on the single, stable, control point 43F. This datum was named "Vertical Datum for the

DSW, 2004" – and had been in use until 2008. The control points on this datum (along Route 90) were leveled to better than 2nd-order specs; while the base point, 43F, is 2nd-order (in the SOI archives).

2.2 2007/2008

During this period, the DSW surveyed 2 precise leveling loops (one big, in the north; one small, in the south) of some 57 km, around the evaporation ponds /*Figure 2*/. The loops were tied into the previous line, along Route 90 – with excellent agreement, again exceeding 2nd-order specs.
In parallel, the SOI surveyed the area with precise GPS observations - but this time each point was occupied only 45 minutes, on 2 different days (resulting in many problems, evident in the calculations). The adjusted ellipsoidal elevations are estimated to be accurate to somewhat above ±1 cm. The total number of anchor-points, where both leveling and GPS-data is available, is 20.
The SOI updated and expanded the gravity observations, to include 43 points over the area.
The author now calculated orthometric corrections for the leveling loops and lines /*Figure 5*/. These include one big loop, 40 km, in the north (#2; whose west part #2west was surveyed in 2004 along Route 90, while the east part #2east was surveyed in 2007/2008); one small loop, 17 km (#4) in the south; one long line, 20 km, in the south (#1), and finally a very short line, 2 km, in the north (#3) [all aerial distances].
The orthometric corrections now range from -7.3 to +8.3 mm (per 2-3 km leveling-section); and obviously need to be accounted for.
The adjusted elevations – based again on the single, stable point 43F - differ from the previously computed ones (along Route 90 alone, 2004), in moderate waves, by from 0 mm (at the base-point 43F in the south, obviously), through +2 mm, to -14 mm, and finally to -8 mm, at the very north (mostly due to updated gravity data); while the discrepancies between these datum values and the nominal SOI elevations range from 0 mm (at the base-point 43F in the south, obviously), to -43 mm, and finally to -32 mm, at the very north.
Now, the author was able to established the final, local vertical datum for the DSW – based again on the single, stable, control point 43F. This datum was named "Vertical Datum for the DSW, 2008" – and had been adopted by the SOI (October 29, 2008), and entered in their archives. All control points on this datum were leveled to better than 2nd-order specs; while the base point, 43F, is 2nd-order.

2.3 Geoid and Vertical Datum

The surveyed anchor-points, where both orthometric (H) and ellipsoidal (h) elevations were determined - allow the computation of geoid-undulation values, $N = h - H$. There is a catch here, though – as in Israel we don't actually have geoid undulations, but rather, a model thereof, named IsraeL Undulation Model (currently ILUM1.2). This is due to the following:

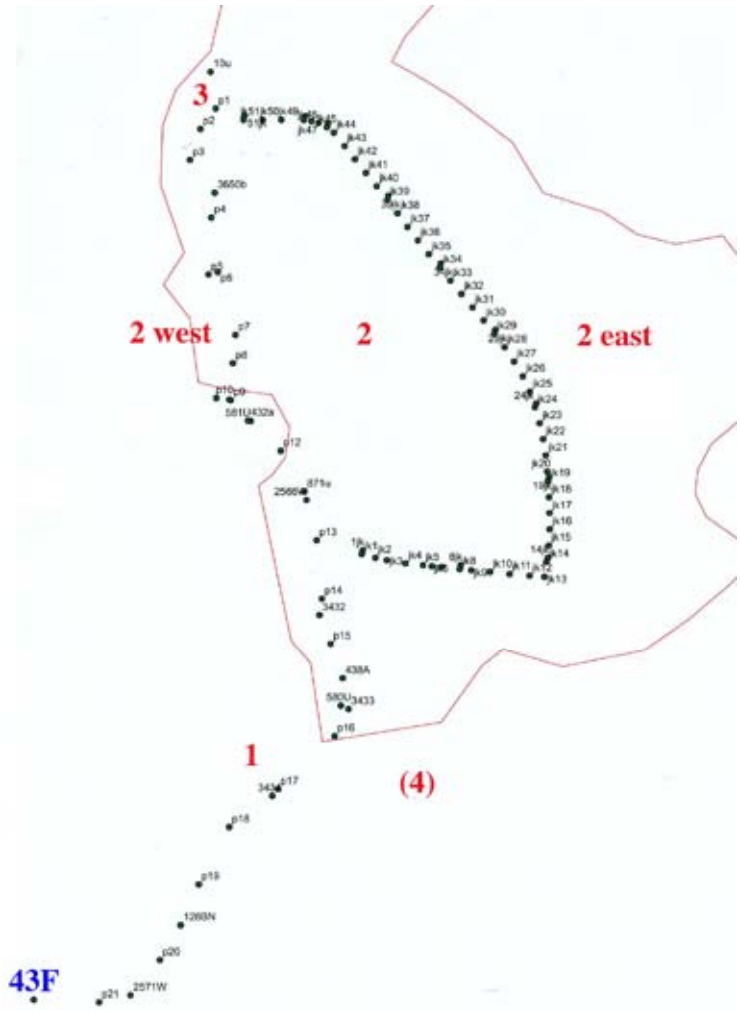

Figure 5: Final leveling loops and lines in the area

The SOI defined Mean-Sea-Level actually from mareograph (tide-gauge) data at one point only, and the observations need to be much improved, to arrive at the actual geoid (full consideration of all dynamic and temporal phenomena affecting sea-surface-topography - effects of wind, currents, temperature, salinity, pressure, etc.); the tie into the national elevation net is tenuous; the leveling data is not reduced with orthometric corrections, nor is it adjusted properly; the leveling was executed over 50 years, and might have time variations and gross errors, nor does it include all available surveys; the GPS observations were not done over sufficient time, to be accurate to within ±1 cm; etc. Thus, what we actually have in Israel is just the official (statutory) undulation model – based on nominal SOI-values of "heights-above-sea-level" and "ellipsoidal" elevations. No detailed and accurate geoid studies were actually done here, to date.

In December 2007 the SOI funded the author, to work on 2 research projects: "Improved official Geoid for Israel, 2008", and "Improved Geoid for the South Dead Sea, 2008".

The former, the Israel project, is in its final stages – and should be reported in parallel to this presentation. It deals with the improvement of the existing official model ILUM1.2 – by means of a Remove/Restore procedure (advanced gravimetric prediction, where all contributing effects to the undulations are accounted for), versus the strict mathematical interpolation between anchor-points (by kriging, as is done in ILUM1.2); and finally, in the application of the University of New Brunswick (UNB) Geoid program-suite – to calculate the actual geoid in Israel (with a modified Stokes/Helmert approach). Once the geoid is established in Israel, and compared to the recent NGA EGM2008 global model – Israel should translate its elevation data, from "sea-level" to true-orthometric elevations.

The latter, the Dead Sea project, had been concluded, and is the subject here *[Sharni, 2008]*. The new Vertical DSW Datum 2008 mentioned above, had been approved by the SOI - and anyone requesting control-point elevations in the area, will be given its values. If SOI keeps its own (faulty) register – such person will be provided with 2 values, differing by as much as 43 mm /*Figure 6*/. These differences are minor, in engineering terms – but crucial for the DSW, whose processes rely on gravitational flow of liquids.

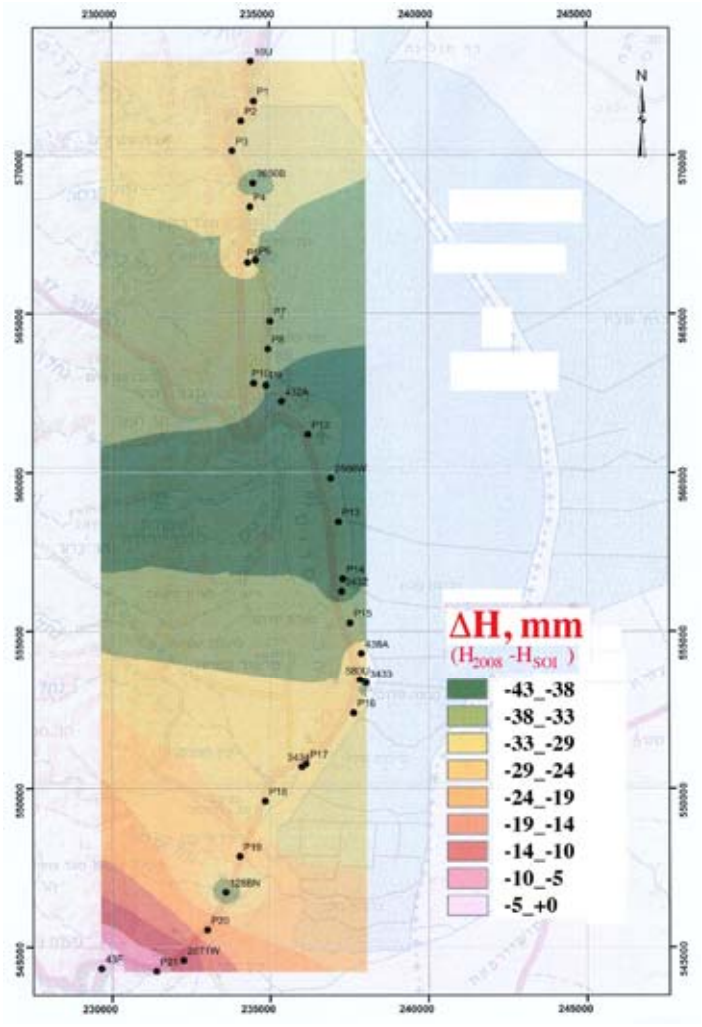

Figure 6: Elevation differences, DSW minus SOI

The undulation data computed by the author /*Figure 7*/, diffecrs from the official values of ILUM1.2, by from -77 to +120 mm /*Figure 8*/. This is due in part to the orthometric corrections applied, in part to the application of the local DSW Datum, and in part to the new GPS data – even though the basis-point, 43F, is the same in both files, as well as some of the GPS data.

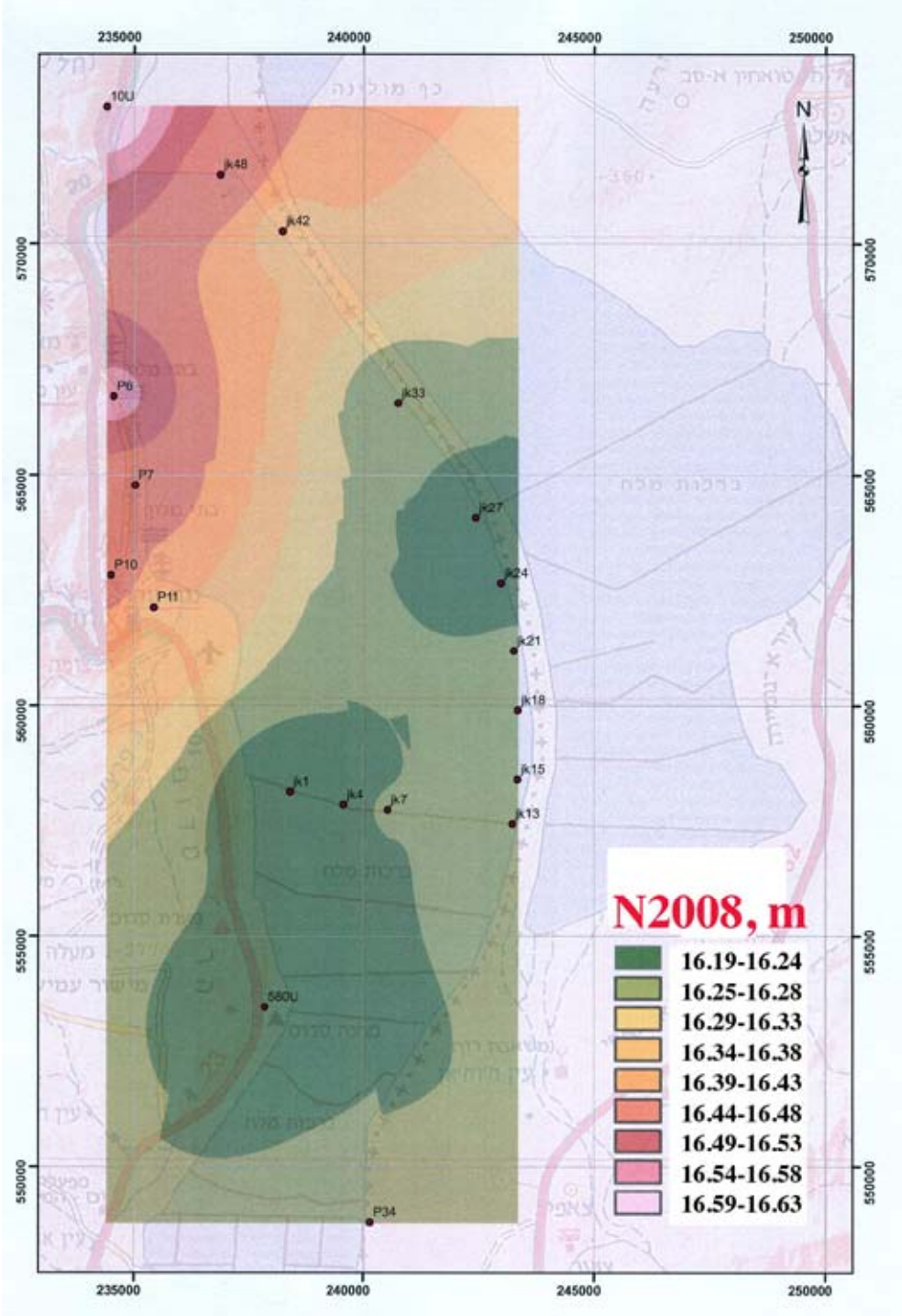

Figure 7: 2008-Undulations in the area

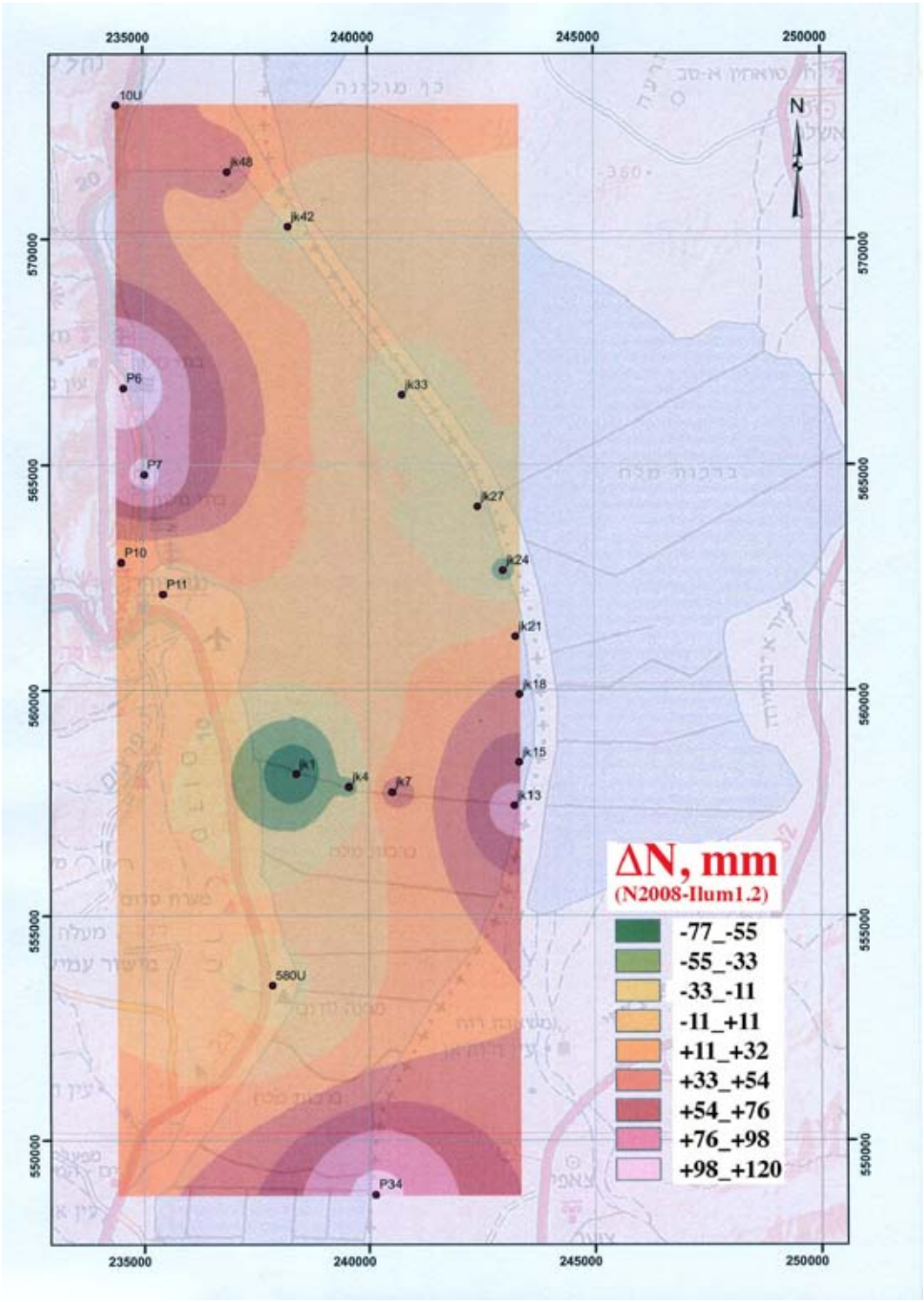

Figure 8: Undulation differences, DSW2008 minus ILUM1.2

The differences above are not extreme, in that the ILUM1.2 has its own accuracy estimates /*Figure 9*/. They range in the 10-cm neighborhood in the area concerned. The DSW-2008 ”undulation” values are just better, and different.
We will have to await the compilation, and application, of the true geoid in Israel – before these data can be further improved.

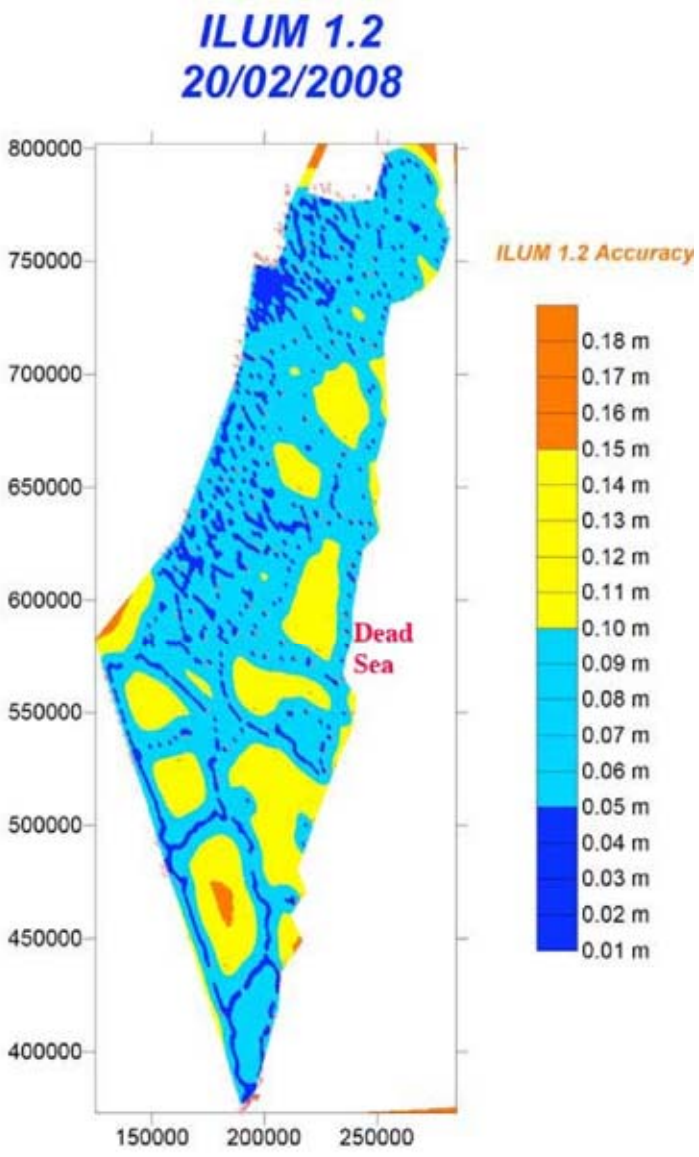

Figure 9: ILUM1.2 accuracy estimates

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BIOGRAPHICAL NOTES

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Born in Tel Aviv, 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),
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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.

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