Kinematic Datum Based on the ITRF as a Precise, Accurate, and Lasting TRF for Israel

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Abstract: The network of Continuously Operating Reference Stations (CORS) in Israel realized Israel's current geodetic datum and is used to monitor it. It was done by adopting a set of fixed International Terrestrial Reference Frame (ITRF) coordinates for the Israeli CORS stations. This datum serves as the infrastructure for all mapping, surveying, and especially the Cadastre system. The relative motion (3–6 mm/year) along the Dead Sea Fault causes the degradation of the Israeli datum over a relative short time. To manage this problem, the authors examined the use of a kinematic datum. This datum includes a 14-parameter transformation, between ITRF05 to the Israeli plane coordinate system, which is static, in conjunction with a velocity field, all evaluated from global positioning system (GPS) time-series solutions of the CORS in Israel from the past 10 years. The results of this examination are promising and show that with a kinematic datum, the accuracy can be maintained over a long period of time. **DOI:** 10.1061/(ASCE)SU.1943-5428.0000228. *© 2017 American Society of Civil Engineers.*

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Introduction

A geodetic datum is a set of parameters and control points that are fixed to the surface of the Earth. It is used to define the size, shape, and surface of the Earth mathematically and the origin and orientation of the coordinate systems used to map it. The datum is used as the basis for a plane-coordinate system.

Historically, mainly because of surveying methods, there were two kinds of datum. A horizontal datum, which includes points on a national coverage and their coordinates, determined in a geodetic reference system [e.g., GRS80; Mortiz (1980)], and a vertical datum on the basis of one or more points, with the heights arbitrarily determined by or based on mean sea-level height. Today, thanks to the proliferation of continuously operating global navigation satellite system (GNSS) stations, Continuously Operating Reference Stations (CORS), and the advances in technology, the modern geodetic datum is three-dimensional (3D) and surpasses the classical datums in accuracy.

The accuracy and precision of a geodetic datum that is based on continuously operating GNSS stations enables, besides precise measurements, the monitoring of defining parameters, namely the origin, orientation, scale, and variations in time, and the coordinates of the stations that move with the Earth's crust.

Many of the geodetic datums today are static. A static datum models the Earth's crust as unchanging throughout time so that coordinates do not change. Usually, static datums are referenced to one of the realizations of the International Terrestrial Reference System (ITRS) [e.g., ITRF2008; Altamimi et al. (2011)] at a particular moment in time and from that moment on depart from it.

Because the surface of the Earth is constantly changing as a result of tectonic movements and many other dynamic activities, the coordinates, which determine the location of points in the International Terrestrial Reference Frame (ITRF), change. For countries on more than one tectonic plate or near plate boundaries, this fact is of major importance. These countries usually suffer from sporadic, broad or local, geophysical phenomena such as earthquakes that can cause an almost instantaneous substantial movement of the Earth's crust. In addition to these phenomena, the relative motion between adjacent plates and the irregular movements seen at plate boundaries can cause the degradation of a geodetic datum over a relatively short period of time and needs to be addressed.

The existing solutions for geodetic datums, which are defined over deforming areas, include use of different datums for each plate, datum updates every few years, and incorporation of a national deformation model that includes a secular velocity model to deal with relative plate movements and local deformation patches of measured displacements caused by geophysical phenomena (Pearson et al. 2009; Even-Tzur 2011; Blick et al. 2011).

A geodetic datum that incorporates changes in the surface of the Earth is considered *semikinematic datum* (also referred to as a *semidynamic datum* in literature). It allows for the change of coordinates, and it can be used to calculate coordinates at different moments in time.

Another possible solution, which is the subject of this paper, is to define a kinematic geodetic datum (or dynamic datum) as an extension of a semikinematic geodetic datum.

A kinematic datum is defined as a set of physical points attached to the Earth's surface spanning one or more tectonic plates. The points have fixed velocities and coordinates that continuously change through time, primarily because of crustal movements. The coordinates and velocities are defined in a stable ITRS. The kinematic datum includes a national deformation model, which includes a velocity field that allows the estimation of the plate velocity at any point in the country and patches of modeled displacements to account for substantial ground movements.

To achieve such a datum, it is important to understand that a network of CORS is crucial for its realization because it allows for the continuous monitoring of the datum and is closely tied to the International Reference Frame (ITR).

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Other essential parts of the kinematic datum are a national velocity field and local patches. These are required so that measured points on the Earth's surface, which are not continuously observed, could be transformed from the measurement epoch to the plane coordinate system (which, unlike the datum, is fixed in time). To evaluate these parts, the use of first- and second-order control networks, which are denser than the sparse CORS, are needed with the condition that they are remeasured every few years so the velocities can be evaluated.

In a semikinematic datum, changes in the Earth's surface are tracked but do not necessarily become a part of the datum unless they exceed a certain critical level. The distinction between a kinematic and semikinematic datum is that coordinates used in semikinematic datum always refer to a specific epoch and do not vary until the datum is updated. The coordinates in a kinematic datum change regularly with time.

An example of a kinematic datum is ITRF (Altamimi et al. 2002). ITRF is a datum that consists of coordinates and velocities of control points, which can provide users with realistic positions of sites within the network that reflect the results of tectonic movements or any other local or regional motion. ITRF relies on the time series of station positions and their changes over time. The positions are determined from observations of continuously operating GNSS stations, very long baseline interferometry (VLBI), satellite laser ranging (SLR) and Doppler orbitography and radiopositioning integrated by satellite (DORIS) stations (Petit and Luzum 2010). The advantage of using a time series of station positions is that it allows for monitoring of a station's nonlinear motion and discontinuities (Altamimi et al. 2007).

In New Zealand, for example, a semidynamic datum was introduced as one where coordinates remain fixed at a reference epoch (Blick et al. 2005). The datum includes a deformation model enabling coordinates to be generated at the reference epoch from observations made at a time other than the reference epoch. This kind of semidynamic datum is not suitable for GNSS users who measure with reference to a network of CORS. For GNSS users, it is essential to use coordinates that accurately represent the positions of the CORS sites at the epoch in which the GNSS observations are being measured and not as fixed coordinates at a reference epoch (Blick et al. 2006). Depending on the application, CORS sites should reflect the real positions of the sites or the fixed position at a reference epoch [or both, as in the USA CORS network, which has both the semidynamic NAD 83, as described by Pursell and Potterfield (2008), and dynamic ITRF coordinates on each CORS].

GNSS CORS in Israel, Datum Definition, and the National Grid System

The network of CORS in Israel currently consists of 22 stations (Fig. 1). The name of the network is the Active Permanent Network (APN). The APN provides a reference frame for precise GNSS measurements in Israel. It was designed and constructed to serve basic and applied geophysical research, and it serves as the major geodetic control network in Israel.

In 2004, the APN contained 13 stations, which were used to define a new geodetic datum for Israel. A set of coordinates that was valid for global positioning system (GPS) Day 275 of the year 2004 in the ITRF2000 (Altamimi et al. 2002) reference frame was chosen as the fixed coordinates set for the APN. This set of coordinates realized a new datum for the APN, *called IGD05–Israel Geodetic Datum 2005* (Steinberg and Even-Tzur 2005). The ITRF2000 position estimations of the APN sites resulted in a model fitting the position time series estimated daily, using the static positioning of 24-h

Fig. 1. Israel's network of GNSS Continuously Operating Reference Stations called APN (image courtesy of the Survey of Israel)

batches of 30-s GPS observations by Scripps Orbital and Permanent Array Center (SOPAC). The model included site velocities, coseismic and postseismic deformations, and annual and semiannual variations. The modeled daily ITRF2000 static positions had a horizontal precision (1 sigma) of approximately 1 mm and a vertical precision of approximately 3 mm, and hence, provided an accurate datum definition (Bock et al. 2004).

A set of adjusted plane coordinates for the APN was adopted (Steinberg and Even-Tzur 2005). It was used as the basis for a new plane coordinates system titled Israel Grid 2005 (IG05), which is defined on the reference ellipsoid GRS80. On the basis of 13 APN stations, a 3D similarity transformation between IGD05 and IG05 reference ellipsoid [plane coordinates that convert to φ and λ by using the mapping equations of the Israel Transverse Mercator (ITM) projection together with the ellipsoidal heights that were adopted from IGD05] led to a set of seven official parameters. Using these seven parameters with the fixed APN coordinates in any GNSS-based project ensures receiving the same plane coordinates of any GNSS-measured point independent of the GNSS CORS that is connected to the GNSS project.

Israel is located in an area where three major tectonic plates, the African, Arabian, and Eurasian, meet. Most of Israel is on the Sinai subplate that is part of the African plate, while other parts of Israel are on the Arabian plate (Wdowinski et al. 2004). The border between the Sinai subplate and the Arabian plate is known as the Dead Sea Transform (DST), which is a series of faults from the tip of the Red Sea to the Taurus mountains in Turkey (Garfunkel 1981; Garfunkel and Ben-Avraham 1996). These faults are the main cause for major earthquakes in the region that happen every 100 years or so.

The dynamic nature of the Earth's crust in Israel affects the relative positions of the APN stations. Because these positions are not fixed, but rather are time dependent, the set of coordinates valid for the APN in 2004 does not represent the current position of the set.

Examination of the relative position variations between the network points reveals the need for coordinate updates, and consequently, the need for a datum update. Relative position variations can cause degradation of the datum to the extent that the accuracy of new measured points would exceed the permitted threshold.

In 2012, seven years after IGD05 was created, Israel's geodetic datum was updated as four stations that where part of the datum definition showed significant movements relative to the other network stations (Table 1). This was not surprising as three stations, KATZ, ELRO, and HRMN (HRMN is a new station that was not part of the 2004 datum definition) are on the Arabian plate in the Golan Heights, and another station, ELAT, in the south of Israel, is on the plate boundary between the Sinai subplate and the Arabian plate.

The updated datum, called IGD05/12, is based on 17 stations, which are all located on the Sinai subplate. The coordinates of the stations were updated to eliminate relative movements. The solution of leaving 4 stations, located on the Arabian plate, out of the datum definition and updating their coordinates when the relative movement superseded the needed accuracy might have been necessary at the time; however, it is far from being the optimal solution because little consideration was given to the fact that coordinates of new control points, boundary marks, and topographic points also change through time. Without using some kind of solution to fix the coordinates to the reference epoch (i.e., 2004.75), all measurements included errors that were datum related, in addition to the error of the measurement itself, and would eventually not withstand needed or regulatory-defined accuracy.

Table 1. Relative Velocities of APN Stations to Center of Mass

Station	East velocity (mm/year)	North velocity (mm/year)	UP velocity (mm/year)
ALON[a]	0.02	−0.79	0.19
AREL[a]	0.00	0.56	0.52
BSHM[a]	−0.41	−0.03	-0.60
CSAR[a]	−0.54	−0.26	−0.63
DRAG	0.41	0.52	2.05
DSEA	1.48[b]	1.94[b]	−1.18
ELAT	2.58[b]	0.98	0.29
ELRO	−0.32	2.96[b]	−0.96
GILB[a]	−0.40	0.82	−0.11
HRMN	−1.09	2.64	−1.06
JSLM[a]	0.35	0.19	0.64
KABR[a]	−0.63	0.35	−0.98
KATZ	0.65	3.59[b]	−0.97
KLHV[a]	0.18	−0.16	−0.37
LHAV[a]	0.23	−0.65	0.35
NRIF	1.75[b]	0.72	0.56
NZRT[a]	−0.43	0.56	−1.32
RAMO[a]	0.94	−0.53	0.85
SLOM	0.84	−0.96	−1.24
TELA[a]	0.01	−0.10	0.91
YOSH[a]	0.02	0.49	−0.60
YRCM[a]	0.65	−0.44	1.17

[a] Stable stations (14) on Sinai subplate far from the Dead Sea Rift.

[b] Significant horizontal motion relative to the center of mass (5 stations); ELAT, ELRO, and KATZ, were not included in the datum definition in 2012.

In conclusion, the authors realized that the datum of Israel was defined as semikinematic; it was designed as a series of static datums that were connected to the ITRS I in one of its realizations and at a specific epoch.

In attempt to establish a datum that is based on all available data and stations and that takes into account the relative motion between the APN stations, the authors examined the use of a kinematic datum for Israel and present their findings in this paper.

One of the issues with a kinematic datum is that coordinates change continuously, which can be problematic for surveyors and for people dealing with the data, because the datum is very difficult to manage, and most spatial databases and geographic information systems today are not yet capable of handling kinematic datums. The suggested solution is to calculate a 14-parameter transformation between the ITRF05 and IG05 intermediate datums in conjunction with a velocity field, as all derived from GPS time-series solutions of the APN during the past 15 years.

With this solution, the projected coordinates are fixed in time to a chosen date and are stable for a very long period.

Analysis of the APN Position Time Series and Velocity Computation

Time series of daily solutions for GPS station positions are the cornerstones of kinematic datum creation. The daily solutions enable continuous monitoring of the GPS stations, calculation of station velocities, calculation of transformation parameters, and monitoring of parameter variations in time.

The long-term time series used in this study were from the Solid Earth Science (Earth Science Data Records (ESDR) System (SESES), which is part of The National Aeronautics and Space Administration

(NASA) Making Earth Science Data Records for Use in Research Environments (MEaSUREs) project. It is a combined solution obtained by combining SOPAC, *GLOBK* (Herring et al. 2010), and the Jet Propulsion Laboratory's *GIPSY* solutions (Solid Earth Science ESDR System 2012). The combined solutions are aligned to the ITRF2005.

The authors used the combined raw time series, which contain various jumps caused by either geophysical sources (seismic events) or nongeophysical errors (antenna height metadata error, phase center modeling error, or other man-made and software-dependent errors).

The raw time series, combined and aligned to IGS05, are available for download from the SOPAC ftp site, after a registration process, from http://sopac-ftp.ucsd.edu/pub/timeseries/measures. Twenty-two stations from the APN were used for the analysis.

The coordinates and their variances were transformed from Cartesian system (X, Y, Z) to local horizontal coordinate system (N, E, U).

The mathematical model $F(t_i)$ to fit the observed motion of each site in each component can be written as a function of time t_i of the daily solution (Nikolaidis 2002) as

$$F(t_i) = X_0 + vt_i + c\sin(2\pi t_i) + d\cos(2\pi t_i) + e\sin(4\pi t_i) + f\cos(4\pi t_i) + \sum_{n=1}^{j}\left[g_j H(t_i - T_{g_j})\right] \qquad (1)$$

where X_0 = site position with linear velocity v; coefficients c and d = the annual periodic motion; e and f = semiannual motion; and H = Heaviside step function, which is used to correct any number, j, of offsets (jumps) with magnitudes g_j at epochs T_{g_j}. Because only 22 stations were involved, no attempt was made to automate the detection of the offset epochs, T_{g_j}. Instead, the offset epochs were carefully identified by visually inspecting the time series data from station-configuration logs and nearby seismic events. Then the unknown parameters (X_0, v, c, d, e, f, and g_j) were estimated by weighted least- square adjustment for each APN station. The process itself required several iterations because each time series was cleaned from outliers by the well-known w-test (Baarda 1968; Kok 1984) and then adjusted again, leaving out the detected outliers.

A close examination of the annual and semiannual motion shows a significant effect of the annual motion on the vertical position, with a variation of 1 cm, but an effect of approximately 1 mm for each of the horizontal components. The cause of the annual and semiannual signals is the subject of many papers and is primarily attributed to geophysical phenomena (Bogusz and Figurski 2014) and artificial signal related to the draconitic year (the time it takes the GPS constellation to repeat itself) (Ray et al. 2008).

In deformed zones, nonlinear motion is commonly seen as a result of postseismic deformation (Stanaway et al. 2012) and needs to be addressed (Bogusz 2015).

Evaluation of Relative Station Velocities

After the adjustment of the time series has been completed, the absolute velocities of the APN stations in the local horizontal system allow the calculation and examination of the relative movement between the stations and the calculations of a national velocity field.

The relative velocities of the APN sites were calculated relative to the center of mass of 14 stations that are located on the Sinai subplate (except the SLOM station, which is located on an unstable building) and are presented in Table 1. The relative velocities of KATZ, ELRO, and HRMN that are located on the Arabian plate were consistent with results from other studies [e.g., Sadeh et al. (2012)]. The relative velocities of ELAT, NRIF, and DSEA showed abnormalities in the east component, most likely because of their proximity to the fault line.

These results reinforce the need to create a kinematic datum in Israel, which unlike a static datum, remains stable for a long time.

A kinematic datum incorporates a velocity field and a deformation model that are used to calculate the velocity of the plate, and if needed, the movement at a new measurement point. The accuracy of these models depends not only on the amount of data collected for the CORS but also on the number and sparsity of network stations. For this reason a passive control network can be used as long as it has been remeasured. That is why, in addition to the APN, the Survey of Israel (SOI) maintains a geodetic-geodynamic network called the *G1*. The G1 network was designed, constructed, and established during the beginning of the 1990s by the SOI and the Geological Survey of Israel (GSOI). It contains approximately 150 points that homogeneously cover the state of Israel. The location of the points were designed mainly according to geological considerations, so that it would have the potential of monitoring deformations in primary and secondary known faults over Israel. In addition, the G1 network was planned to serve as the major geodetic control network of Israel (Even-Tzur et al. 2004). The points were built according to very high technical specifications to ensure their geotechnical stability (Karcz 1994). The network was measured four times, in 1996, 2002, 2008, and 2015. The campaigns allowed calculating the velocity of the G1 points (Sadeh et al. 2012). Fig. 2 shows a map with absolute velocities of APN and G1 points in the local East-North frame.

Velocity Field

To estimate a national velocity field that includes various tectonic plates by interpolation, one can define the boundaries of each plate and use an interpolation method that takes into account the common borders of polygons. In this study, a Kernel interpolation with barriers method (KIB), available in the Geostatistical Analyst extension of *ArcGIS* from the Environmental Systems Research Institute (ESRI), was applied as the interpolation method (Gribov and Krivoruchko 2011). KIB is a variant of a first-order local polynomial interpolation (LPI) that improves traditional kernel estimation methods by accounting for barriers within the study area (Fan and Gijbels 1996). In this method, for each point in space, a first-order polynom is adjusted from observations that are in predefined window size around the point. Each observation is given a weight calculated from a kernel function that is dependent on the distance from the observation to the point and the size of the searching window. If an observation is within the searching window but is divided by a barrier, KIB uses the shortest distance between the point and the observation as the sum of series of straight lines; if the connection is not possible, the observation will not be used even though it is within the searching window.

The velocities of the APN sites together with the velocities of the G1 points were used (in total 162 points) to create a prediction of a horizontal velocity field for Israel by KIB. First-order polynomials with Gaussian kernel functions were used. Fig. 3 shows the East and North components of the Israel national prediction-velocity map. In most of the study area, the standard error of the predicted velocities was less than 0.25 mm/year.

The velocity field allows distinguishing patterns of deformation occurring in Israel and once again demonstrates the need for a kinematic or semikinematic datum.

In a kinematic datum, the velocity field plays an important and valuable role in transforming ITRF coordinates (the kinematic datum) into the projection system datum (ITRFxx to IG05).

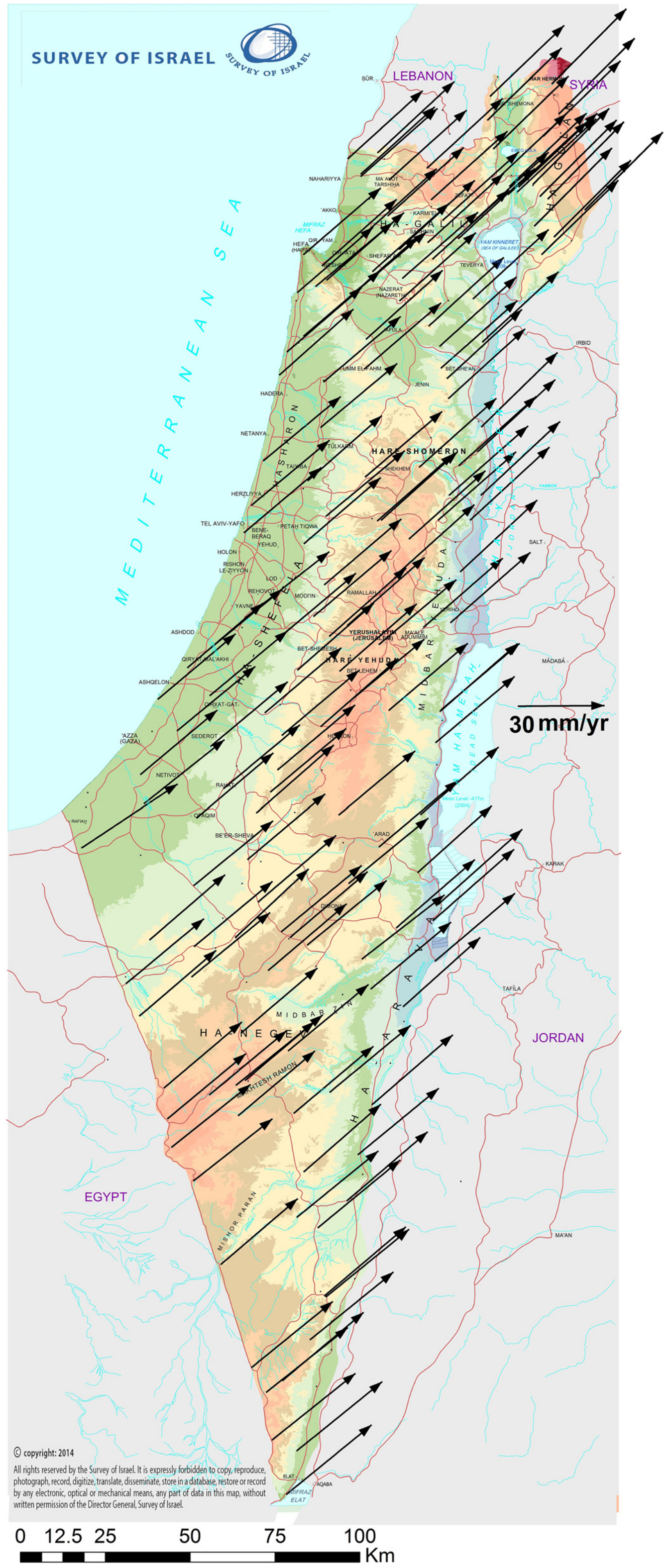

Fig. 2. ITRF05 velocities of APN and G1 points (162 points) in local E,N frame (image courtesy of the Survey of Israel)

Multiparameter Transformation

A 3D similarity transformation is the ruling tool for converting coordinates in 3D space between two frames. The transformation is done by seven parameters that describe the relations between the frames; three translations, three rotation angles, and one scale parameter. Therefore, by using at least three common points in both frames, the seven parameters can be calculated by least-squares adjustment.

The dynamic nature of the Earth, and especially the Earth's crust, affects the position of points within the frames. As a consequence, absolute and relative positions of points are time dependent, which makes coordinate (and velocity) transformation complex. To cope with the dynamic nature of the Earth and effects on coordinate transformations, multiparameter transformation should be considered. One option is to extend the classical 7-parameter Helmert transformation to a complex 14-parameter formulation of the original 7 parameters with their time derivatives.

To calculate the 14 parameters, all one needs are the position time series of the common points in the ITRF frame and the coordinates in the target frame, which make up the projection geodetic datum. Although mathematically possible, this will miss the point that control points are located on the crust that is moving within the frame; hence, the 14 parameters will absorb these movements. In the long run, this would affect the accuracy of the transformation.

Therefore, the velocities of the control points should be augmented in the transformation formulation. These add three additional parameters, three velocity components of the tectonic plate at the measured location, into the equation.

The general formulation of 14-parameter transformation is given in Soler and Marshall (2002). In the presented formulas, terms that are higher than second order were neglected. A complete solution of the 14-parameter transformation between geocentric frames without neglecting any terms is provided in Soler and Marshall (2003).

In this study, the authors used Equation (15) from Soler and Marshall (2002) as the 14-parameters transformation model. The 14-parameters were estimated using least-squares adjustment on the basis of time series of APN points. The time series used are free from the effect of outliers, offsets, and annual and semiannual periodic variations. In total, approximately 68,000 solutions in the ITRF05 frame and their variances, corresponding to more than 15 years of measurements, were used to adjust the 14-parameters.

The velocities that were used were the APN stations adjusted velocities that were transformed from local coordinates to the ITRF05 frame.

The outcome was a set of 7 parameters, their rates, and the full variance-covariance matrix, allowing transformation from ITRF05 to IG05.

As discussed, to use the 14-parameter transformation to transform the ITRF05 coordinates of a measured point into IG05, the velocity of the tectonic plate at the measured location was needed. This was achieved with the national velocity model introduced in the previous section.

Experiment

With the foundations for a geodetic kinematic datum in place, the time series of the APN network stations were used to model the kinematic changes in station positions and velocities. These, with the velocities of the G1 network, where used to evaluate a nationwide velocity model to support the kinematic datum. A multiparameter transformation was also calculated so that coordinates can be transformed into a static national grid.

To check the feasibility of such a datum, an experiment was needed. The purpose of the experiment was to compare solutions obtained by using kinematic datum and by the current semikinematic Israeli datum. Another goal was to test the hypothesis that the solution on the basis of the kinematic datum remains stable over a

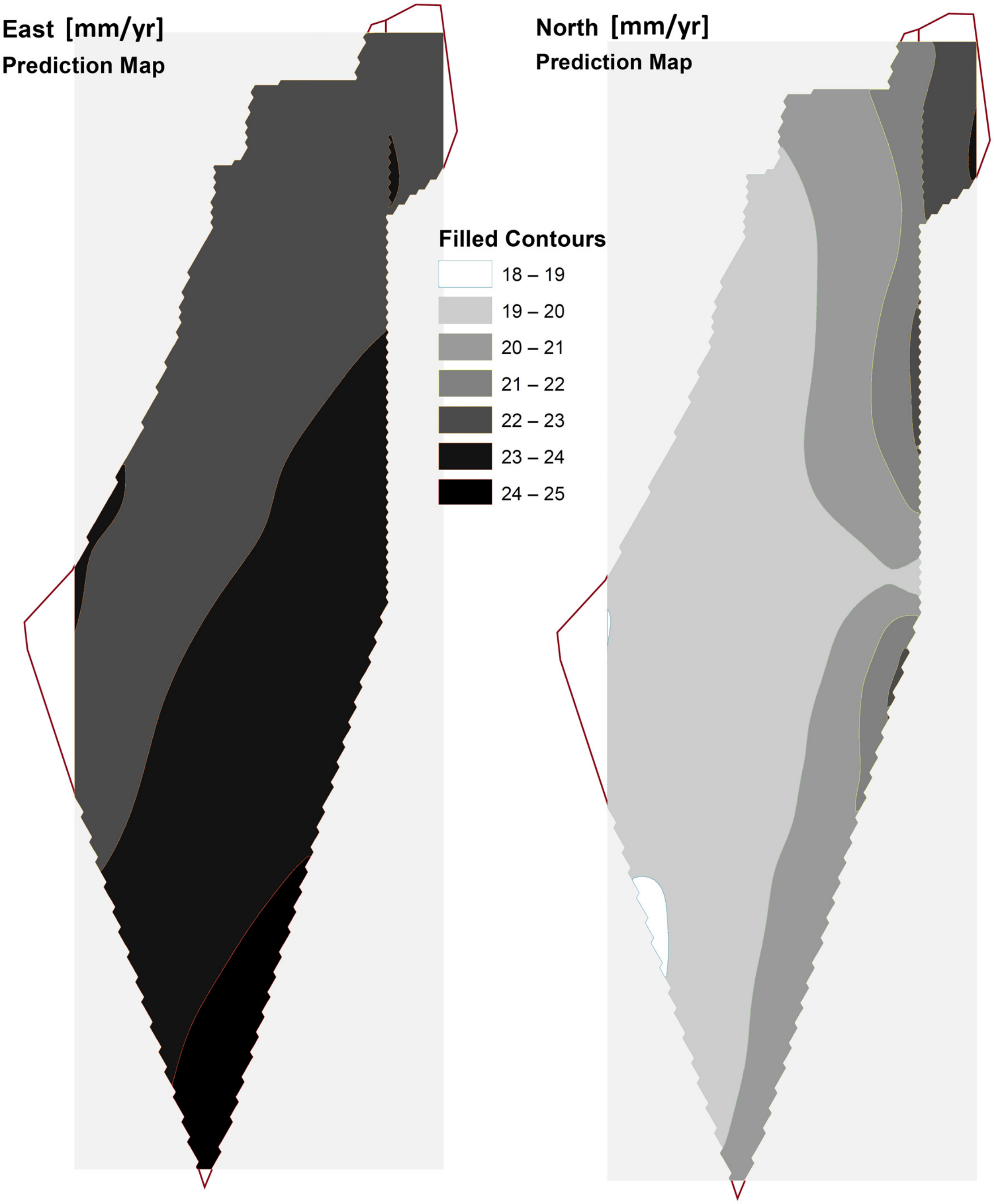

Fig. 3. Israel national velocity map (months/year) on the basis of APN and G1 velocities and KIB, east and north components

long time, and thus, constitutes a solution to the problem faced by countries located on more than one tectonic plate or near fault boundaries.

The kinematic datum the authors used was based on the APN network, which refers to ITRF05 and velocities. The nationwide velocity model created by KIB gives the velocity of the tectonic plate at any location in Israel, and the 14 estimated parameters enable transformation from the ITRF05 to IG05 reference ellipsoid as was calculated and explained in previous section.

The G1 network can be a good laboratory to carry out various tests. The network points were measured at least twice with an interval of six years. It is a critical issue because it allows us to examine the differences between solutions obtained from the use of proposed kinematic and existing semikinematic datum, especially for points that are located on the Arabian plate or near the DST.

Other benefits are related to the geotechnical stability of G1 points and the existing forced centering, which reduces the error in placing the antenna above the point.

Six G1 points were selected for the test; three of them are located on the Arabian plate and three on the Sinai subplate, in addition to the three APN stations: BSHM, KABR, and ELRO (Fig. 4). Each G1 point was measured twice in 2002 and 2008; three points were measured also in 2010. The observation time spans 8 h with a 30 s sampling rate.

From each G1 point, a vector was processed to each of the APN stations by using *Spectra Precision Survey Office* software. The vectors were processed by using precise orbits made available by the International GNSS Service (IGS).

In each vector solution, the coordinates of the APN station were set as fixed and two solutions were obtained. One solution was obtained according to IGD05 (semikinematic datum) and the other according to the ITRF05 coordinates that represent the true position of the point to the date of measurement (kinematic datum). The correct coordinates of the APN stations for the time of measurements were defined on the basis of the same station time series of daily solutions from SOPAC. Transformation of coordinates from IGD05 to IG05 reference ellipsoid was done by the official 7 parameters. Transformation of coordinates from ITRF05 to IG05 was done by 14 parameters and the velocity field.

For each G1 point, the authors have three pairs of coordinates for every measurement epoch. These allowed for calculation of the means and standard deviations between solutions in the same datum at different epochs and the differences between semikinematic datum solutions to those from the kinematic datum.

The differences between semikinematic datum solutions in different epochs show that as long as the G1 point and the APN station lie in the same tectonic plate the solution remains stable. However, where the G1 point is on one plate and the APN station on another, the differences between solutions vary from 1.3 to 3 cm in the north component, which reflects a movement of 2–6 mm per year.

Another interesting and significant result is that the differences between kinematic datum solutions in different epochs were generally stable and smaller than those obtained from the semikinematic solution regardless of the position of the G1 point and APN station.

The averages and standard deviations of differences between solutions based on semikinematic datum and kinematic datum from different epochs are presented in Fig. 5. The results were in favor of the kinematic datum as differences in it were smaller, especially because the relative motion between the plates was addressed in a kinematic datum.

Conclusions

A kinematic geodetic datum was realized by a set of physical points attached to the Earth's surface spanning one or more tectonic plates. The points have fixed velocities and coordinates that continuously change through time, primarily because of crustal movements. The coordinates and velocities are defined in a stable ITRS. Kinematic datum includes a national deformation model, which is comprised of a velocity field that allows the estimation of plate velocity at any point in the country of modeled displacements to account for substantial ground movements.

To achieve a kinematic datum, a network of continuously operating reference GNSS stations is crucial for datum definition because they allow for the continuous monitoring of datum and is closely tied to the ITRs.

To test the developed concept of a kinematic datum in Israel, an experiment was conducted to calculate point coordinates. Six G1 points, three on the Sinai subplate and three on the Arabian plate, where chosen and were calculated once in the Kinematic datum and then in the IGD05 datum.

Because the G1 points were measured at least twice, the results could be compared. The results were in favor of the kinematic datum because the differences in it were smaller, especially because the relative motion between the plates was addressed in a kinematic datum.

The quality of the solution of the kinematic datum versus semikinematic datum shows that if IGD05 was set as a kinematic datum, as defined in this paper, the datum would remain stable and accurate for a long time. Therefore, there would be no need to update the datum from 2012 to IGD05/12 (Even-Tzur 2011) as was done.

The conclusion of this research is that, although relative motions between plates and in the DST area are small, the accumulated motion over a period of a few years cannot be ignored and must be addressed. The effect of not incorporating dynamics in the datum

Fig. 4. Map of G1 points (squares) and APN stations (circles) that are located in the region while ELRO, KABR, and BSHM were used in the experiment (Note: The solid line describes the approximate position of DST in the region) (image courtesy of the Survey of Israel)

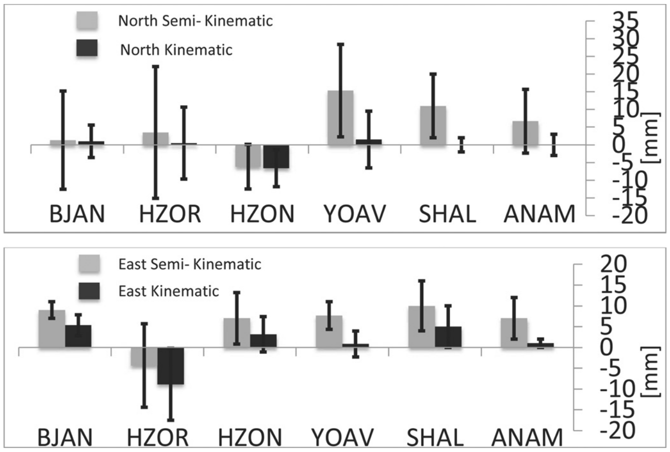

Fig. 5. Averages and standard deviations of differences between solutions from different epochs in the kinematic datum solution (dark gray) and semikinematic datum solution (light gray)

was not only the degradation of the datum but also of the Cadastre system. Measures must be taken to solve this problem.

The 14-parameter transformation in conjunction with the national velocity field calculated here is useful for differential GNSS solutions and can be used as a precise transformation for precise point positioning (Zumberge et al. 1997) that is gaining awareness in recent years.

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