Permanent GPS Network-based Measurement Practice in Israel

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Key words: GPS\GNSS permanent stations, measurement practice, Cadastre, Eastern Mediterranean, Dead Sea fault.

SUMMARY

The development of the permanent GPS network in Israel has been initiated as an ultimate infrastructure for geodetic-geodynamic research. Following its establishment, the network which consists of 19 permanent stations, became a commonly used, multi-purpose measurement system, supporting research as well as geodetic control, cadastral, photogrammetric, engineering, topographic, GIS and mapping tasks. Current development aims at matching between new surveying regulations and high quality permanent GNSS applications and services.

The permanent stations network, with its complementary services, makes the user possible to carry out many kinds of GNSS tasks using a single receiver. The coordinates computed directly refer to the valid datum and grid of the country. The use of a country-wide statutory geoid undulation model enables the user to determine orthometric heights by GNSS measurements, at a 25 ppm accuracy level, implementing a 3 dimensional geodesy practice.

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1. INTRODUCTION

The Survey of Israel (SOI) is the top professional authority in the country. SOI sets standards, initiates legislation, licenses surveyors, initiates and supports research and development, actively manages and maintains the national GIS, is responsible for national mapping, topographical and cadastral, supervises, confirms, collects and maintains all the cadastral mapping, and – as a basic responsibility – sets and updates, from time to time, geodetic datum, projection and grid, develop and maintain the high degree geodetic infrastructure in the country. [For current, general status of SOI and its future see (Srebro, 2008b and 2009).]

The permanent GPS network (more correctly GNSS nowadays, using GPS, GLONASS and in the near future hopefully GALILEO satellites too), has a central role in the geodetic infrastructure in Israel. The intention of this paper is to summarize its development, characteristics, various applications and comprehensive impact on measurement practice. *(For those who are interested in a deeper study of the subject, a detailed bibliography of Israeli authors is attached to this paper.)*

2. THE "EVOLUTION" OF THE PERMANENT GPS STATION NETWORK

2.1. The Classical Control Networks

The horizontal control network in Israel, before the GPS era, was a conventional one: a combination of triangulation-trilateration, with Laplace stations and astronomical azimuths. The accuracy of that network was estimated at about 3 parts per million, which was proper for construction and development and for cadastre, but insufficient for geodynamic studies (Adler et al., 2001).

2.2. Eastern Mediterranean Tectonics

The eastern Mediterranean is the meeting place of three major tectonic plates: Arabia, Nubia and Eurasia, and of two sub-plates, Anatolia and Sinai, see Fig.1. (Wdowinski, 2009).

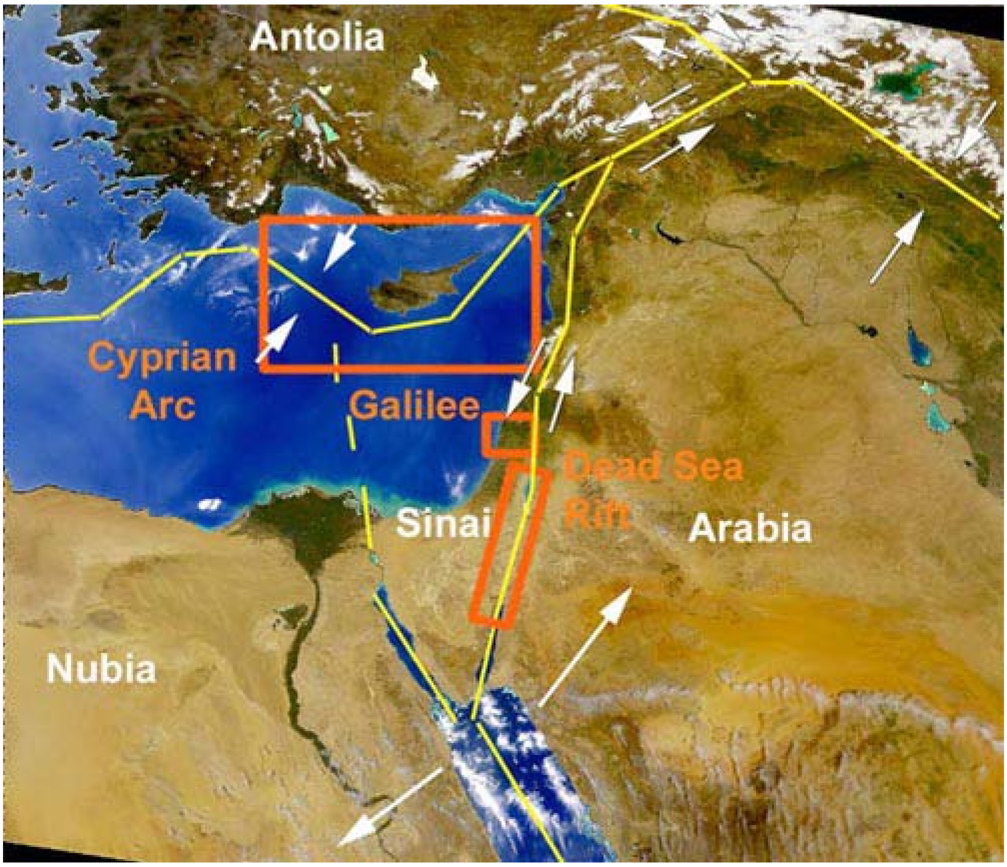

Figure 1. Location map of the Eastern Mediterranean showing the tectonic plates and sub-plates (white caption), plate boundary, relative plate motion (white arrows), and study areas (orange).

The eastern Mediterranean tectonics is a very challenging one, attracting many scientists (mainly geologists, geophysicists and geodesists) to be involved in tectonic movement research. Before the end of the eighties, the precise EDM measurements and precise leveling were the feasible possibilities to detect relative tectonic movements within a reasonable time period, strongly limiting the extension of the investigated area. And then, within a few years, the GPS arose as a meteor, becoming more and more feasible for geodynamic research.

2.3 The Short Story of the GPS Applications in Israel

In the first stage, the scientific intellect acted as the main driving force for GPS applications. The "Kfar Hanassi" monitoring network (see Fig. 2) originally was dedicated to monitoring the relative crustal movement in a small size (3 km times 4 km) area of the Dead See Fault, mainly by precise EDM measurements (Tellurometer MA 100, Geodimeter AGA 114, Mekometer 5000) and precise levelling (Karcz et al., 1984, 1989, 1992). [It is interesting to note that Kfar Hanassi network was re-measured by EDM in 2008! (Even-Tzur, 2009)]. This network was extended to a larger size (20 km by 50 km), named Galil-Golan network, which consisted of 17 sites plus four corner sites of the Kfar Hanassi network (see Fig.3), and was measured, by 10 geodetic GPS receivers in 1990, and also in 1991, 1992 and 1993, (Adler et al., 1994, Karcz 1995, Karcz and Levitte 1996, Karch et al., 1997a and 1997b, Adler et al., 2001). All the frameworks mentioned have been carried out as a joint venture of the Israel Geological Institute and the Survey of Israel, cooperating with the Universities of Karlsruhe and Hannover, partly founded by the German- Israeli Foundation for Scientific Research and Development.

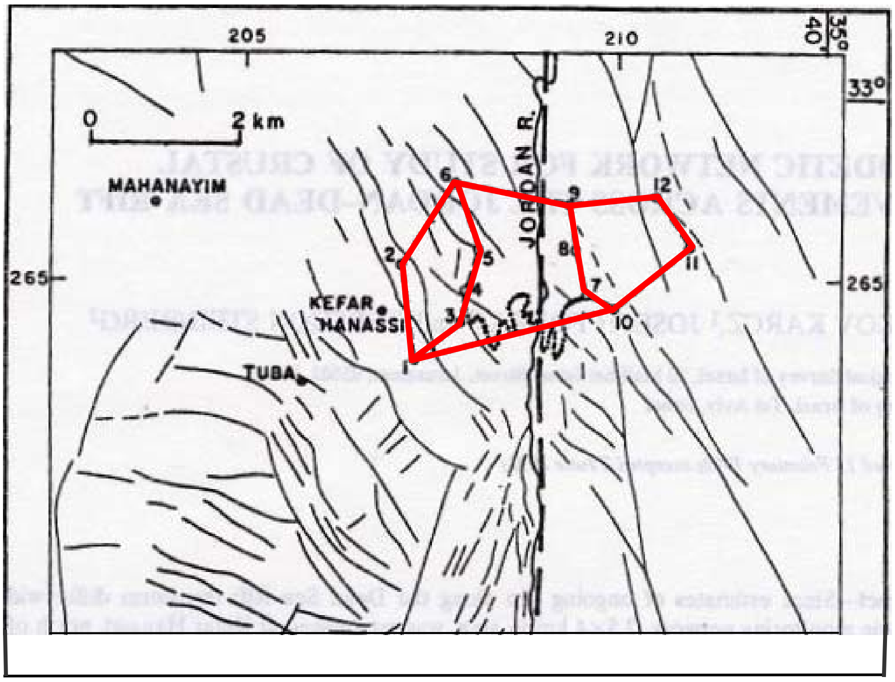

Figure.2. Kfar Hanassi Monitoring Network

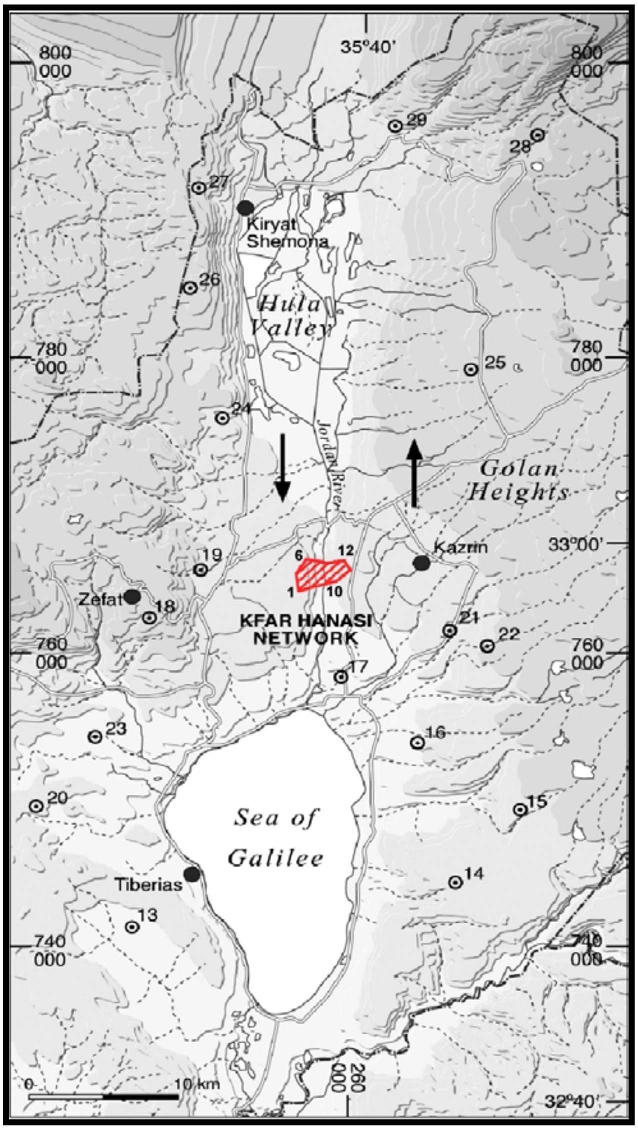

Figure 3. Galil-Golan Network

The next stage of the "evolution" was the establishment of a country-size geodetic-geodynamic network called G1 (see Fig.4), composed of some 160, specially monumented control points, including those of the Galil-Golan network. The network was measured, for the first time, in 1996-1997 (Ostrovsky, 2001). During its survey, 2-3 permanent stations (which had been established during the preceding years), were actively observing, permitting SOI to establish an improved national datum.

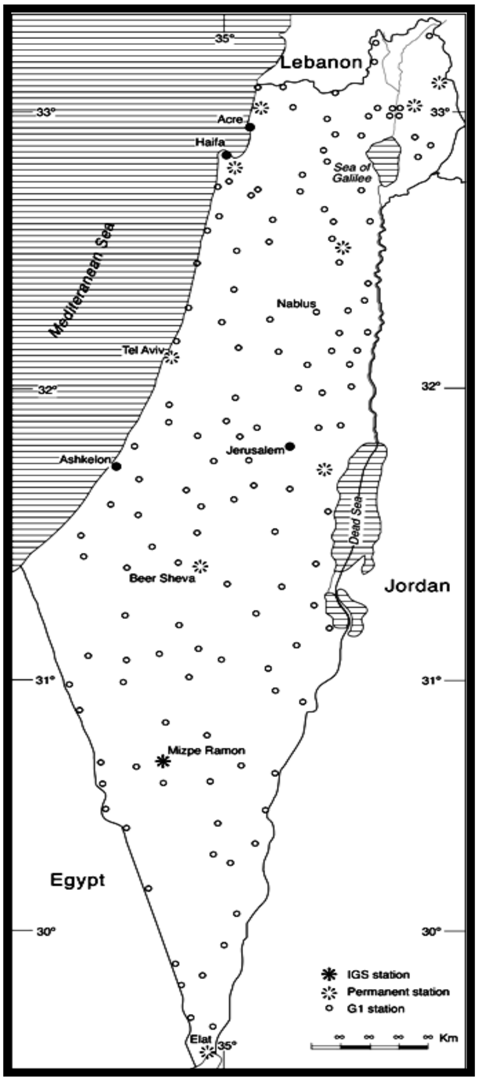

Figure 4. G1 Network

The G1 network has become gradually accomplished with permanent GPS stations forming the GIL network (see Fig. 5). The developing GIL network was applied to continuous monitoring as well as to various geodetic and geophysical applications (Knafo and Wdowinski, 2000, Adler and Forrai, 2000, Wdowinski at al., 2001, Even-Tzur et al., 2004).

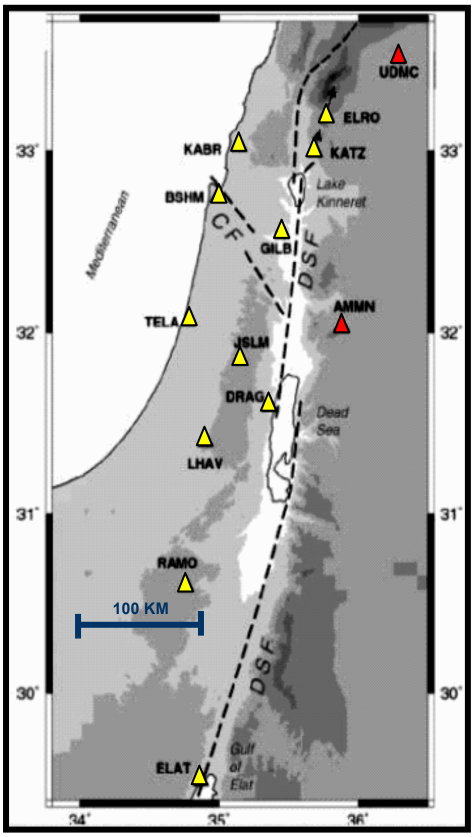

Figure 5. GIL Network (yellow marks), with a Syrian and a Jordanian permanent station (red marks) which were included in a crustal movement research, see paragraph 3.1.2.

2.4 Current APN Configuration and Main Services

At present, the GNSS permanent station network of Israel, called **A**ctive **P**ermanent Station **N**etwork (APN) numbers 19 stations (see Fig. 6), 14 of them receive signals both from GPS and GLONASS satellites. During the last six years, the system is operated and maintained by SOI through a private geodetic company (GSM). Currently, the permanent stations are measuring with 1 second epoch interval. GPS data can be downloaded (in exchange for a fee) via internet. SOI strongly supports RTK and VRS applications (Salmon, 2009). The system works, in fact, at a 98% reliability level. APN stations are involved in international frames: RAMO station is a part of IGS, RAMO and DRAG are involved in GIBS, and all stations are connected to SOPAC.

At present, 211 APN users are registered at SOI. 137 of them are RTK users, 144 users download data for Post Processing (there is an overlapping between them). The number of RTK-users increases from year to year: 33 in 2006, 75 in 2007 and 129 in 2008. In 2008, RTK users consumed 15,000 "service hours" (some 41 hours per day). Post processing users downloaded 15,800 hours of data in 2008. The total income from selling of APN data and services: 450,000 NIS in 2006, 700,000 NIS in 2007 and 900,000 NIS in 2008.

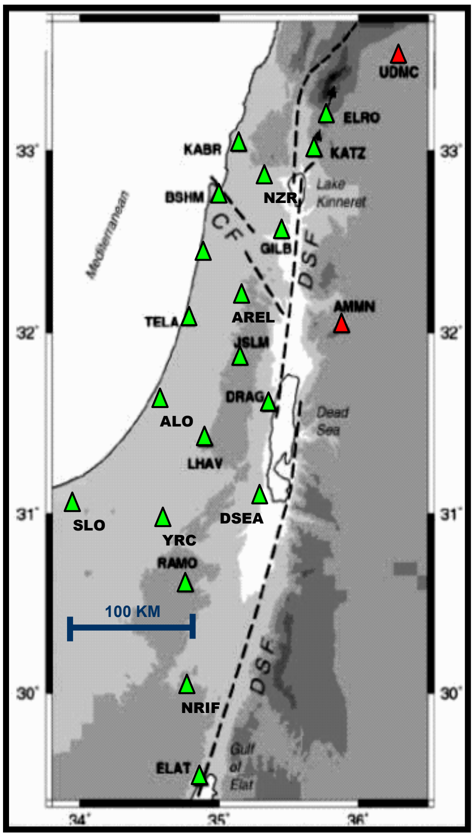

Figure 6. Current Active Permanent Station Network, APN, (green marks), with a Syrian and a Jordanian permanent station (red marks) which were included in a crustal movement research, see paragraph 3.1.2.

2.5 Geodetic Datum, Projection and Grid

The first geodetic datum, still based on re-adjusted classical observations but also aided by GPS measurements, named "New Israel Grid" has been legally introduced to national practice with the 1998 Survey Regulations (Forrai et al., 2001, Steinberg and Even-Tzur, 2004). For this network, GRS80 was adapted as reference ellipsoid, and a special geodetic projection (Israeli Transverse Mercator) was used. Some practical improvements in the grid itself improved the convenience for the user. Preceding its official declaration, the New Israeli Grid "was tested" by applying it for remapping Israel and for establishing the National GIS Topography Database (Peled et al., 1992, Peled, 1995, Forrai et al., 1998, Peled and Raizman, 2000.) The New Israeli Grid brought a new standard of quality of geodetic accuracy and homogeneity.

With the fast improvement of the permanent station network, additional stations were added to GIL stations, leading to the current APN mentioned above. The increased use of APN observation data accelerated the development of a new, "permanent stations ruled" geodetic datum and grid, called "Israel 2005 Grid" (Steinberg and Even-Tzur, 2004 and 2005). This grid essentially is an improved plane coordinate system of the "New Israeli Grid". The "Israel 2005 Datum and Grid" were legally introduced for general use on 1st of May 2007, according to special instructions of the Director General of the Survey of Israel, preceding the new Surveying Regulations under preparation. Users can benefit from using APN, and should carry out all new measurements and mapping tasks in "Israel 2005 Grid". The official use of APN and the new grid gives a strong booster for GPS\GNSS geodetic practice.

2.6 Israel Forum of Infrastructure

The national GPS infrastructure has been established through joint contribution of geologists, geophysicist and geodesists, as a basis for long-term interdisciplinary cooperation. The Treasury also gave support to the promotion of advanced GPS technology. The contribution of the Israel Space Agency has also been considerable.

As a complementary benefit of the GPS infrastructure development, in 1995, a powerful interdisciplinary committee was formed as an inter-ministry framework for both scientific and managing cooperation (Ron and Forrai, 2002), named Israel Forum of Infrastructure. The members of the Forum are: the Geological Survey of Israel, The Geophysical Institute of Israel, the Israel Oceanographic and Limnological Institute Ltd., the Israel Space Agency and the Survey of Israel. The Forum has been confirmed by all responsible ministers. Its objective is to propose solutions to problems connected with physical infrastructure, first of all through the improvement of the quality and availability of background data. The planning at national level requires the knowledge of the available land- and nature resources, the potential of the sea and sea-bottom and the establishment and the continuous update of a National GIS in these areas, which would serve the physical planning authorities, water resources management, ecology and environment and certain sectors of industry.

3. THE IMPACT OF GPS PERMANENT STATIONS ON GEODETIC MEASUREMENTS

3.1 Measurements for Scientific Purposes

3.1.1. G1 Network Measurements

The G1 geodetic-geodynamic network (see in paragraph 2.3 above) has been measured three times during the past 10 years; in 1996-1997 as mentioned, in 2001-2002, and in 2008. As the location of G1 points was designed and constructed, mainly, according to geological considerations, the analysis of the results enabled to study the relative geodynamic movements along the primary and even secondary faults (Shahar and Even-Tzur, 2005, Ostrovsky, 2005). The processing of the data measured in 2008, and the comprehensive analysis of position differences in three epochs will considerably refine our respective geodynamic knowledge.

3.1.2. Crustal Movements along the Dead Sea Fault (DSF)

The permanent station observations of GIL network stations enabled us to analyze the crustal movements along the DSF. An analysis of GIL station observations of seven years, including also one Syrian and one Jordanian permanent station data in the computations, provided us with accurate description of current crustal movements in the region. Two stations located in the Golan Heights and Damascus station showed 1.7-2.8 mm/year northward motion with respect to Sinai, indicating a left lateral motion along the DSF. Using fault-locked models, a 3.3 mm/year slip rate across the DSF can be estimated (Wdowinski et al., 2004).

3.1.3. Vertical Movement Investigations along the Carmel Fault

One of the challenging and long-standing dilemma in the geology of Israel is "whether the Carmel Fault (see Fig. 7.) is currently active and to what extent does it contribute to the seismic hazard of the city of Haifa and the nearby petrochemical industrial area" (Hofstetter et al., 1996, Nof et al., 2007). The results of a 17 year long geodetic monitoring have been evaluated, considering both precise leveling and GPS measurements, as applied to geological research. As a result of it, rather difficult relative movements were interpreted (Sharni and Papo, 2000, Shahar and Even-Tzur, 2004., Even-Tzur and Agmon, 2005.).

3.2 Horizontal Control Network and Its Densification

According to the valid Survey Regulations, seven classes of horizontal control points are allowed to be established, by various (both classical and GPS) geodetic methods (Forrai et al., 2001). The establishment of horizontal control points of the first three classes is the exclusive responsibility of the Survey. 4-7 class points can be measured by private surveyors, but their measurements and computations are carefully supervised and the class of each control point is finally set by the Survey of Israel. The final coordinates are included in the national geodetic database.

The over-all use of APN and the official declaration of the Israel 2005 Datum and Grid (as mentioned in paragraph 2.5 above) practically changed the reality of the geodetic networks and the practice of their densification. The highest class is the G0 network (the 19 permanent GNSS stations). As second class network, some 150 of the G1 network points are included (see paragraph 2.3 above), all of them measured and computed relatively to the G0 network. The third class is the G2 network: some 1200 "good, stable points" of the classical networks (both horizontal and vertical) are included in it. All of them measured and computed relatively to the G0 and G1 networks. G0 stations and their operation, as well as G1 and G2 points and their maintenance are the exclusive responsibility of the Survey of Israel. Private surveyors are authorized to measure and compute S1 (by GNSS only) and S2(either by GNSS or by Total Station). S1 and S2 measurements and computations are carefully supervised, the degree of the new points is finally set by the Survey of Israel. Their final coordinates are also included in the national geodetic database. (Steinberg, 2006, Survey of Israel, 2007., Tuchin et al., 2009.)

3.3 Vertical Control Measurements

The idea of the involvement of ellipsoidal heights in a vertical control system in Israel has been developed and improved during a decade (Melzer et al., 1996, Steinberg and Papo, 1996, 1998 and 1999, Steinberg and Even-Tzur, 2005). As an original solution, Steinberg and Even-Tzur suggested that "the first objective of a primary leveling system can be … achieved … with reasonable accuracy on nationwide basis, by a combination of ellipsoidal vertical control … and Official Geoid Undulations Model, OGUM" (Steinberg and Even-Tzur, 2006). The accuracy of the OGUM applied is better then 10 cm over most of the country (Tuchin, 2006), and its relative accuracy is better then 25 ppm (Steinberg and Tuchin, 2009). High quality ellipsoidal vertical control is easily available with the use of the APN and its relevant services (Salmon, 2009). Since May 2007, according to special technical instructions of the Director General, for the two lower classes (4 and 5) of vertical control points, surveyors are allowed to define orthometric heights, using GNSS measurements and statutory OGUM (Salmon, 2009). The encouraging results of the first two years of practice are summarized in (Steinberg and Tuchin, 2009). Moreover, the orthometric height of each geodetic control point can be easily computed with this method. As a result, the national geodetic control network is gradually becoming a three dimensional system, including both ellipsoidal and orthometric heights.

4. CADASTRAL MEASUREMENTS

4.1 The Cadastre in Israel

Land registration method in Israel (Registration of Titles) is based on the Torrens principles. The State is responsible for description of parcels' boundaries as registered in the Land Registry Office. As mentioned, the State (through the SOI) is also responsible for maintaining the geodetic control network which enables exact reconstruction of surveyed boundaries in the future.

According to the Torrens principles, the subject of registration is the land parcel. The parcel's boundaries and the objects situated inside the parcel (such as buildings, walls and fences) are thoroughly surveyed, and parcel's area is calculated. This type of registration ensures an effective and convenient way for proper real estate management, effective planning and land transaction.

Any change (merging or subdivision of existing parcels) in the original settlement of land rights has to be carried out by means of preparation of mutation plans. According to the Israeli Law of Planning and Construction, mutation plans preparation has to be made on the basis of municipal plans (urban plans) approved by local authorities. The municipal plan, drawn on the background of a topographic map and existing land parcels destined to change, sketches the approximate position of new cadastral boundaries and intended use of new parcels (e.g., residential area, industrial zone, public area etc.). The boundaries' position is defined in a mutation plan, on the basis of accurate surveying. The mutation plan is prepared by a private surveyor, and supervised by a supervising surveyor (Forrai and Kirschner, 2006 and 2009) and \ or SOI and approved for registration by the Land Registry Office (Forrai and Klebanov, 2006).

4.2 Geodetic Control Points for Cadastral mapping

For preparing a cadastral block map or a mutation plan, a surveyor, in general, needs to measure lower class, on site horizontal control points. Before the GPS Permanent Stations era, surveyors established traverses, basing them on higher class, classical control points. GNSS permanent stations contribute to the establishment of GNSS control points as a basis for "local" traverses, or, in many times, instead of them.

4.3 Cadastral Boundary Point Measurements

The relevant technical instructions (Survey of Israel, 2007) permit the use of GPS RTK based on APN, for direct measurement of cadastral boundary points and detail elements. This possibility was significantly increased by the use of GNSS. In 2006, 405 geodetic projects were completed for cadastral purposes by Total Stations, in 2008 only 278 (a decrease of 31%). During these two years, the number of purely GPS geodetic projects for cadastral mapping changed from 706 to 934 (an increase of 32%). In 2008, in general, 77% of the cadastre related geodetic projects were measured with APN related GPS technology. In 2003 some 60 geodetic GPS receivers were used in Israel. At the end of 2008 their number was some 220, owned by some 150 companies (in average, 1.5 receiver per owner), indicating the wide-ranging use of APN-based GPS RTK for accelerated development.

At the beginning of 2009, technical instructions gave legitimacy to GPS RTK based on an appropriate IG05 control point (Survey of Israel, 2009). This opportunity certainly will make the use of GPS RTK even more popular.

GPS RTK is frequently used also for reinstating parcel boundaries and other "real time" field cadastral tasks (Jarroush, 2002, Jarroush et al., 2005).

4.4 Coordinate Based Cadastre

The Idea of the Coordinate Based (Legal) Cadastre is, that in the future, cadastral boundaries should be defined by coordinates (instead of physically established marks), in a homogenous and accurate geodetic control network. The ultimate goal is to achieve an accuracy of 5 cm at 95% confidence level (Steinberg, 2001).

Two of the main problems to be solved are: the establishment of an appropriate technical infrastructure, and the legislation of an appropriate legal background. No doubt, that APN and the Israel 2005 Grid, from technical point of view, make the coordinate based cadastre feasible. The necessary legislation will hopefully be completed soon, within the scope of the new surveying regulations (see paragraph 6.).

Three significant "pilot projects" have been completed over various kinds of areas, consisting of 141 cadastral blocks in total (Gelbman, 2009a), for proving the technical feasibility of the transition from traditional cadastre to a coordinate based one. The main idea is to transform traditional cadastral data from formerly used coordinate systems to Israel Grid 2005, on the basis of current measurements and computed coordinates of "authentic points" which have coordinates in the relevant former coordinate system as well (Steiberg, 2001, Gelbman and Doytsher, 2009). In 2009, a national size project was started. Its aim is to establish coordinate based cadastre over the Negev desert (where just a small part of block- and parcel borders are physically marked and all the lands are registered as a property of the state), including the bordering strip of blocks. The ultimate method of the measurements is GPS RTK, based on APN stations (Klebanov et al., 2009). Different kinds of software have been developed, handling, among others, the implementation of GPS RTK measurements for advanced cadastral purposes (Gelbman, 2009b, Jarroush and Khell, 2009). Further development of National GIS is necessary, for integrating, enhancing and maintenance of future coordinate based cadastral data (Gavish and Benin, 2009).

4.5 Three Dimensional Cadastre

One of the internationally highlighted Israeli developments during a decade is the Three Dimensional Cadastre, 3DCad (Doytsher et al., 2001, Forrai and Kirschner 2001 and 2003, Grinstein 2001 and 2003, Beller and Doytsher 2002, Benhamu and Doytsher 2003, Shoshani et al., 2004, Jarroush and Even-Tsur 2004, Benhamu 2006). The relationship between the 3DCad and the APN is indirect, through the coordinate based cadastre mentioned above. It is worth to note that the relating legislation regarding 3DCad implementation is in a more advanced stage of care than that of the coordinate based cadastre (Caine, 2009).

4.6 Dynamic Cadastre

As mentioned in paragraph 3.1, the analysis of continuous permanent station observations enables us to detect relative (yearly) movement of millimeters between two sides of an active rift (Wdowinski et al., 2004). The accumulation of such a movement during a number of decades can displace cadastral borders and change parcel areas. This fact, and the high quality APN based cadastral measurement practice motivated the elaboration of an idea concerning the need for a "dynamic cadastre" (Jarroush and Even-Tzur, 2006 and 2007).

5. FURTHER APPLICATIONS

The measurement of many further applications is based on GNSS stations. Some of them are:

- For continuous updating of the National Topographic GIS Database, SOI applies GPS measurement technology based on APN stations.
- A new, *digital aerial survey and mapping system* has been developed in Israel (Pechatnikov et al., 2009). The APN station information is successfully applied in the system.

- The definition of the coast line of Israel along the Mediterranean Sea was supported by permanent GPS stations. In order to define the coast lines of the Red Sea and the Sea of Galilee, measurements have been completed by GPS RTK method referred directly to APN stations (Srebro, 2008a, Rosenbloom et al., 2009).
- GPS monitoring contributed to the check of the height difference between the Mediterranean and Red Sea levels (Ben Michael and Even-Tzur, 2006). *[For general information regarding East Mediterranean Sea Level Changes see: (Shirman, 2004).]*

6. THE NEW SURVEYING REGULATIONS

The new Surveying Regulations of Israel (Steinberg, 2006) are in an advanced stage of preparations. They are expected to be published within a year and a half. Regarding geodesy and permanent station applications, they will "rectify" the present situation, in which the hierarchically lower rank (but, for legislation, more flexible) technical instructions precede the more "senior" legislation level of regulations. In the new regulations, important, APN based national size applications (like coordinate based cadastre, 3DCad, special plans for cadastre boundary documentation, etc.) will be established.

7. CONSEQUENCIES

The introduction and use of a GPS\GNSS permanent station network and APN in Israel have a considerable and positive effect on the measurement practice. New standards of accuracy, homogeneity, reliability and work-schedules are applied, contributing to the success of surveyors' activity in everyday tasks of accelerated development. For geo-scientists, APN network is considered and used as a basic, sophisticated and indispensable scientific infrastructure, contributing to their multilateral research activity.

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