Geo-magnetic Measurements in Israel

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SUMMARY

Earth's geomagnetic field or as it's more commonly known – earth's magnetic field, plays an imperative role in protecting the Earth against solar wind and cosmic rays, essentially preventing the disastrous aftereffect of exposure to radiation. Consequently, observation of the current state of the field and its stability is of a high value and as such are being monitored in special observatories worldwide. Israel is among those countries which research Earth's magnetosphere, measure total field values, its corresponding components and analyze the data for the last few decades.

Furthermore, magnetic observations enable calculation of the aforementioned components, such as magnetic declination and extraction of the magnetic north, surprisingly enough still useful for navigation purposes even in the technological era.

This paper presents a brief overview of the various activities of the Survey of Israel in the geomagnetic field, including ongoing and future projects, such as prediction of magnetic declination based on absolute declination annual measurements values using and formulation of an interactive comprehensive declination model. The main purpose of the latter is to allow online calculation of declination values anywhere within the boundaries of Israeli state.

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1. INTRODUCTION

One of the oldest studies in geophysical sciences is geomagnetism - the study of Earth's magnetic field, also referred to as the geomagnetic field. The phenomena associated with the geomagnetic field have been researched and monitored for centuries by many countries throughout the globe, mainly for its imperative role in protecting the biosphere of our planet. The surrounding geomagnetic field deflects substantial amount of plasma streamed from the sun in high velocities and extreme temperature – the solar wind. The interaction between the solar wind and the magnetic field of the Earth forms the magnetosphere, without which sun flares would erode Earth's atmosphere rendering it vulnerable to space radiation and thus uninhabitable.

Furthermore, there is a strong connection between the discovery and motion of continents as well as exploration of oceans and the probing of the Earth's magnetic field (Wardinski, 2005). Another benefit of geomagnetic studies is the capability they provide to search for mineral aggregates such as metal ores. However, the most popular use of the Earth's magnetic field observations is for orientation and navigation purposes, ever since the discovery that a compass needle does not in fact points to the geographic north.

Given the above, systematic observation and monitoring of the geomagnetic field are of a great importance. Much effort has been devoted to research in order to further explore and achieve greater understanding of the magnetic field of the Earth. To this end, observatories worldwide were established as well as designated satellite network and analysis centers.

The Survey of Israel joined the geomagnetic collaboration nearly 40 years ago. Thenceforth its primary goal was to define the direction of the magnetic north in Israel and to determine its yearly variation as well as to carry out geomagnetic measurements, to process acquired data and to provide the data to the global geomagnetic network affiliated with YAGA (International Association of Geomagnetism and Aeronomy).

1.1 Sources of Earth's Magnetic Field

Earth's magnetic field is very complex. It is commonly represented as a superposition of both internal and external sources. While the dominant component of all is, the *Main Field* or the *Core Filed* which is produced by the electrical currents originated in the Earth's core. According to Paleomagnetic records, the geomagnetic filed was initially created approximately three billion years ago. However, due to Earth's core characteristics, such as size and electric conductivity, it would have been not able to sustain for billions of years. Dynamo theory is an explanation offered by scientists for this phenomenon that suggests a mechanism in the earth's outer fluid core that constantly generates the geomagnetic main field. Second contributor to the internal components is the *Crustal Filed*, also known as *Lithospheric* or *Anomalous Field* which is caused by magnetic minerals in the crust and upper mantle. The external source called the *Combined Disturbance Field* is the product of electrical currents in the ionized upper atmosphere and magnetosphere (Amm, 2016, Chulliat et. al., 2015). Therefore, the total Earth's magnetic field B (also denoted as *F*) is a vector quantity represented by the sum of its components:

(1) $B_{Total} = B_{Core} + B_{crust} + B_{Disturbance}$

The mathematical methods used to denote the geomagnetic *Main Filed*, are very complex; several models based on spherical harmonic functions can be applied, among them the *International Geomagnetic Reference Field* (IGRF) and *World Magnetic Model* (WMM). However, the *Dipole Model*, which is the first order approximation of the Earth's magnetic field, provides a good description. This model views the Earth, as a spherical magnet whereas the generated filed resembles a dipole, with North and South poles located near the South and North geographic poles respectively. Those are theoretical antipodal poles connected by the dipole axis, which is tilted about 11 degrees from the Earth's rotation axis.

1.2 Geomagnetic Field Components

The Earth's magnetic field is a vector quantity, i.e. it is characterized in a specific point by its direction and magnitude, which has different values at any given time or location. The geomagnetic field can be described by seven elements. Those include the *Total Field* (*total Intensity*) - $\vec{F}$ and its three perpendicular components: the *Northerly Intensity* - $\vec{X}$, the *Easterly Intensity* - $\vec{Y}$ and the *Vertical Intensity* (*Down Intensity*) - $\vec{Z}$; the *Horizontal Intensity* - $\vec{H}$ and two direction angels the *Declination* angle *D* and the *Inclination* angle *I* (Wardinski et. al., 2015). The magnitude is generally given in *Nano-Tesla* (nT) and the angular elements are measured in arc *Degrees, Minutes and Seconds* (DMS).

The *Inclination* or the *Magnetic Dip* angle is defined as the angular distance from the horizontal plane to the *Total Filed* vector and receives positive values downwards. Counter to geomagnetic poles, the *Magnetic Poles* represent the area on the surface of the Earth where *I* is $\pm 90^{\circ}$or in other words the *Horizontal Intensity* of the geomagnetic filed equals to zero.

At any given point on Earth, the compass needle aligns itself with the *Horizontal Component* or the *Magnetic North* direction, which does not coincide with the *Geographical* or the *True North* direction. The difference between these two directions, which is measured clockwise from the True North toward *H*, is the *Declination* angle or the *Magnetic Variation*. D is considered negative toward the West.

A *Cartesian coordinate system*, with X axis pointing to the geographical North, Y to the East and Z downward, is often employed in order to represent the Earth's magnetic field parameters, as given in *Figure 1* below.

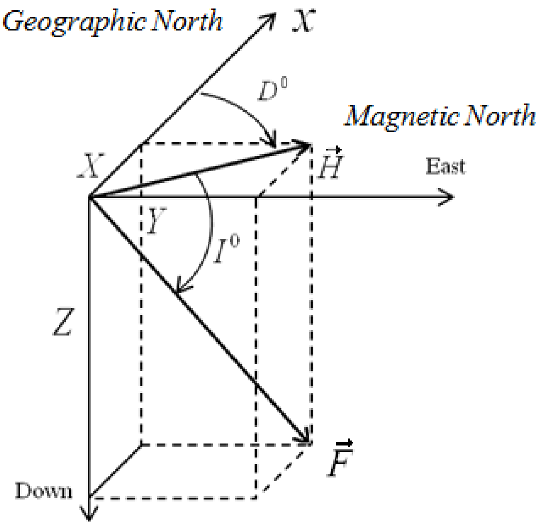


***Figure 1**: Geomagnetic Field Vector Elements in a Local Cartesian Coordinate System*

1.3 Geomagnetic Measurements

Earth's magnetic field is constantly changes in time. These changes can be classified into two main categories: short-term and long-term variations. The former is referred to as *Secular Variation* and reflects the annual changes in the field. Whereas the latter depicts rapid changes due to magnetic activities. Expression of these changes is manifested in the inconsistent values of the *Declination*.

Earth's polarity is not a constant and has a pattern of pole reversals every 200000 to 30000 years. During the last centuries, the magnetic field has been weakening, which may serve as an indication to yet another approaching pole reversal. Such an event will have devastating implications on life on Earth in general and humankind in particular. Furthermore, in the short run changes in the magnetic field influence numerous applications in navigation practices, equipment calibrations and research in various fields.

Monitoring of the changes in magnetic field requires two types of measurements: *Absolute* discrete measurements and continues measurements of filed *Variations*. Absolute measurements, which are commonly carried out on a weekly basis, include the two angular components: *Declination* and *Inclination* (in DMS) and the *Total Filed* magnitude – *F* (in nT). The vector components are then obtained using the following equations:

(2) $X = B^* \cos I * \cos D$
$Y = B * \cos I * \sin D$
$Z = B * \sin I$

Magnetic variations recordings are performed in observatories. The main objective of the geomagnetic observatories is to continuously monitor the changes of the three field's components ΔX, ΔY and ΔZ over long period of time and to maintain the accurate absolute value of the field in a fixed location and at a certain time (Amm, 2016).

2. GEOMAGNETIC OBSERVATIONS IN ISRAEL

The magnetic observations of Israel are performed by the *Survey of Israel*, which is a government agency for Mapping, Geodesy, Cadastre and Geoinformatics.
Israel is part of the global network of magnetic observatories and was established with the following objectives in mind:

1. To determine the local magnetic Declination (magnetic North) within the borders of Israel and to monitor its annual changes.

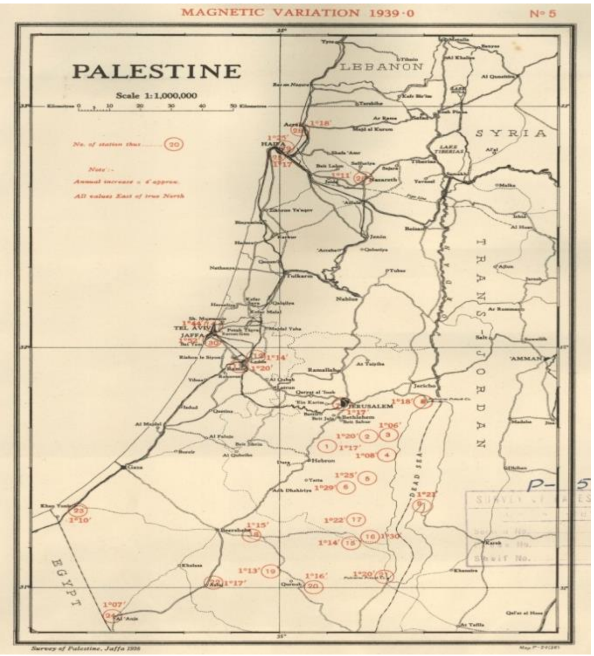
2. To map the geomagnetic field components.

3. To provide data and services to various organizations, such as Israel Defense Force and civil aviation companies.

4. To contribute to the global geomagnetic network by supplying magnetic data to World Data Centers.

5. To provide data for research work in fields of geology, geophysics, archeology, etc. to research facilities both nationally and internationally.

6. To carry out studies in different areas related to geomagnetic field measurements, e.g.: super sensitive magnetic gradiometer, the Dead Sea sinkholes, cosmic weather, geological deep structure, tunnels detection, etc. (Shirman, 2016).



During the period of the British Mandate, the British Admiralty carried out the first geomagnetic measurements of the Declination in 1918. Following are the values obtained in several locations along the coastal zone: *Atlit* - 0° 15' W; *Caesarea* - 0°20' W, *Yafo* - 0° 25' W; and *port Yavne* - 0° 20' W. In the years of 1917-1948 *Magnetic Variation* observations were continued by Survey of Palestine at several stations located in the central area of the Mandate territory as well as along the cost.

Figure 2 presents an archive map depicting declination values. It is important to note that all values are East of true north contrary to the values recorded at 1918 with values ranging between 1˚06′ and 1˚52′.

Additionally, the declination value at the coastal area and the central area is about 30'.

Further *Magnetic Variation* measurements were carried out by the *Survey of Israel* in 1958 at three locations along the coast and from there after within the 4 magnetic observatories.

Regular geomagnetic observations in Israel started in 1976 with the establishment of the *Amatsia* magnetic observatory, located in the center of Israel. The *Bar-Gyora* observatory was opened in 1989 and was operating simultaneously with *Amatsia* for several years. Presently there are three active observatories, which serve for the purposes of continuous magnetic data acquisition and monitoring: *Mt. Hermon* (in the North), *Bar-Gyora* (in the Center) and *Eilat* (in the South) observatories. *Bar-Gyora* is the central station that provides data to the World Data center along with the *Eilat* observatory. Weekly absolute measurements of *Total Field*, *Declination* and *Inclination* are performed at the observatories' locations as well.

For the past 40 years, *Research Division* of SOI was responsible for performing geomagnetic observations, processing the acquired data and supplying it to numerous organizations for navigation and mineral exploration purposes, geological and geophysical studies, as well as in various research projects. Following a brief review of the observed data.

Figure 3 presents the *Secular Variations* of the geomagnetic field. The changes are shown in *Total Field* values as well as in *Horizontal* and *Vertical* components (*Figures 3a and* respectively).

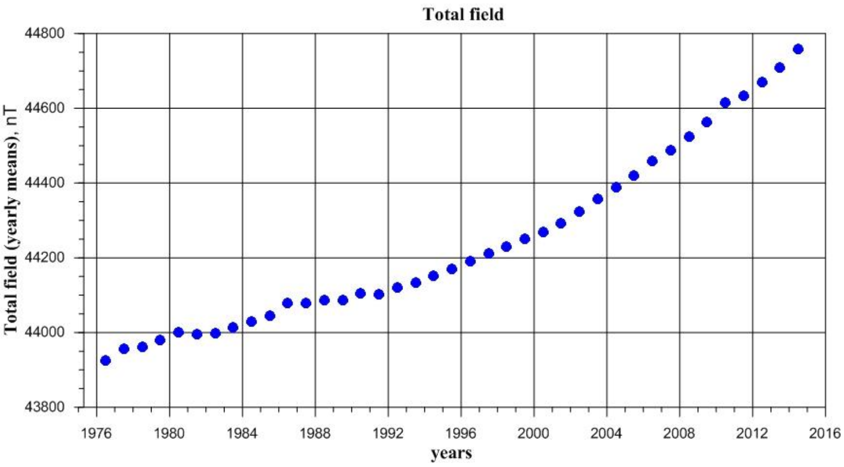


Figure 3a: Total Field Mean Annual Values for the period of 1976-2014

It is worth mentioning that contrary to the global trend of decreasing magnetic dipole, the total filed at certain areas, like Israel, is growing stronger.

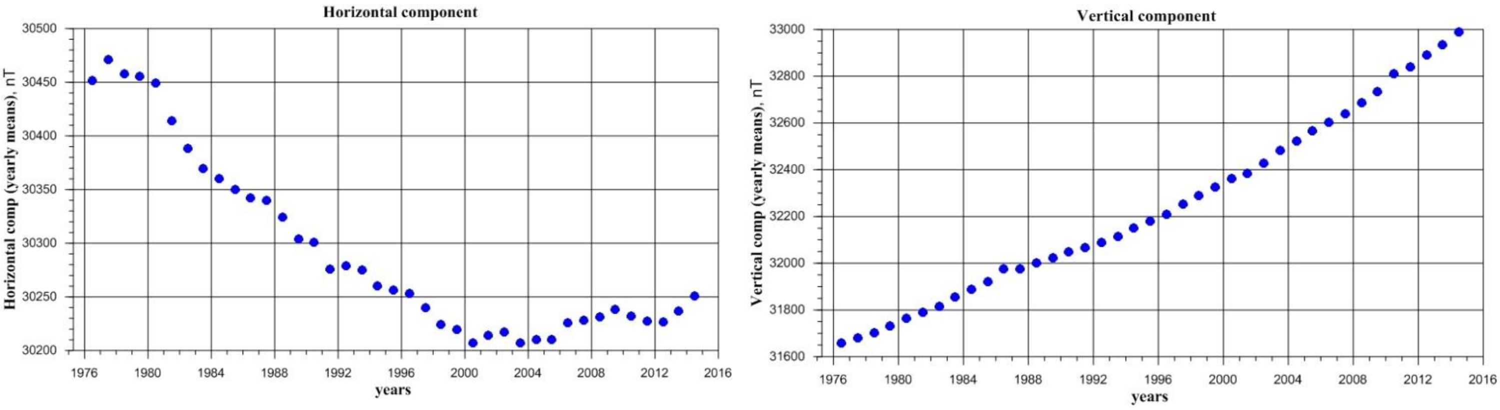


Figure 3b: Horizontal and Vertical Components Annual Mean Values *for the period of 1976-2014*

As mentioned earlier, changes in the geomagnetic filed are reflected in the Declination values as shown in *Figure 4*. As can be clearly seen from the chart, over the past century or so, there was a monotonic increase in Declination values. Starting at approximately 0.3 degrees to the West and growing toward 4.5 degrees to the East nowadays. Those changes correspond to the *Horizontal Component* decrease at a rate of 5 to 20 nT per year.

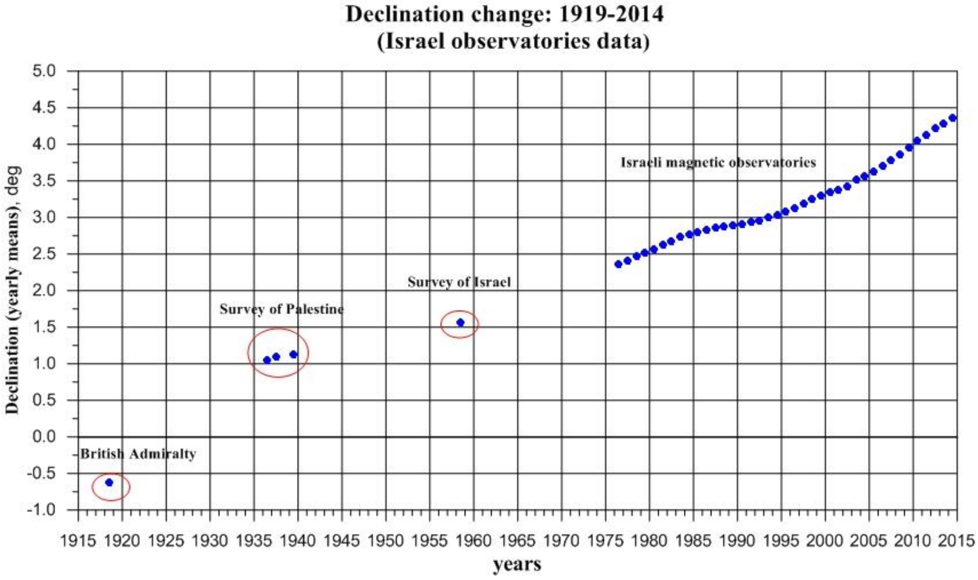


Figure 4: Declination Values for the period of 1918-2014

3. GEOMAGNATIC MAPPING IN ISRAEL

One of the most significant efforts undertaken by the Survey of Israel is mapping. Given that *Delineation* measurements are vastly used for navigation and cartography, manufacturing of geomagnetic charts is a priority service. To facilitate this requirement a repeat station network was established including the Amatsia and Bar-Gyora observatories. Measurements were performed during two surveys taking place in 1984 and 1993 years.

Figure 5 depicts a map of magnetic declination and the *Total Filed*. As mentioned previously, magnetic declination value varies depending on geographic location. It can be seen from the map that for the period of 2014 the *Magnetic Variation* values are changing within the interval of 4.85 to 3.95 degrees throughout the territory of Israel. The declination reaches its maximum level in the coastal zone of the Mediterranean Sea and in the area adjacent to the Golan Heights, whereas its minimum is reached both in the eastern and southern parts of Israel.

The total filed values vary from 42700 nT at the Southern region and increase to 44600 nT toward the Northern part of Israel.

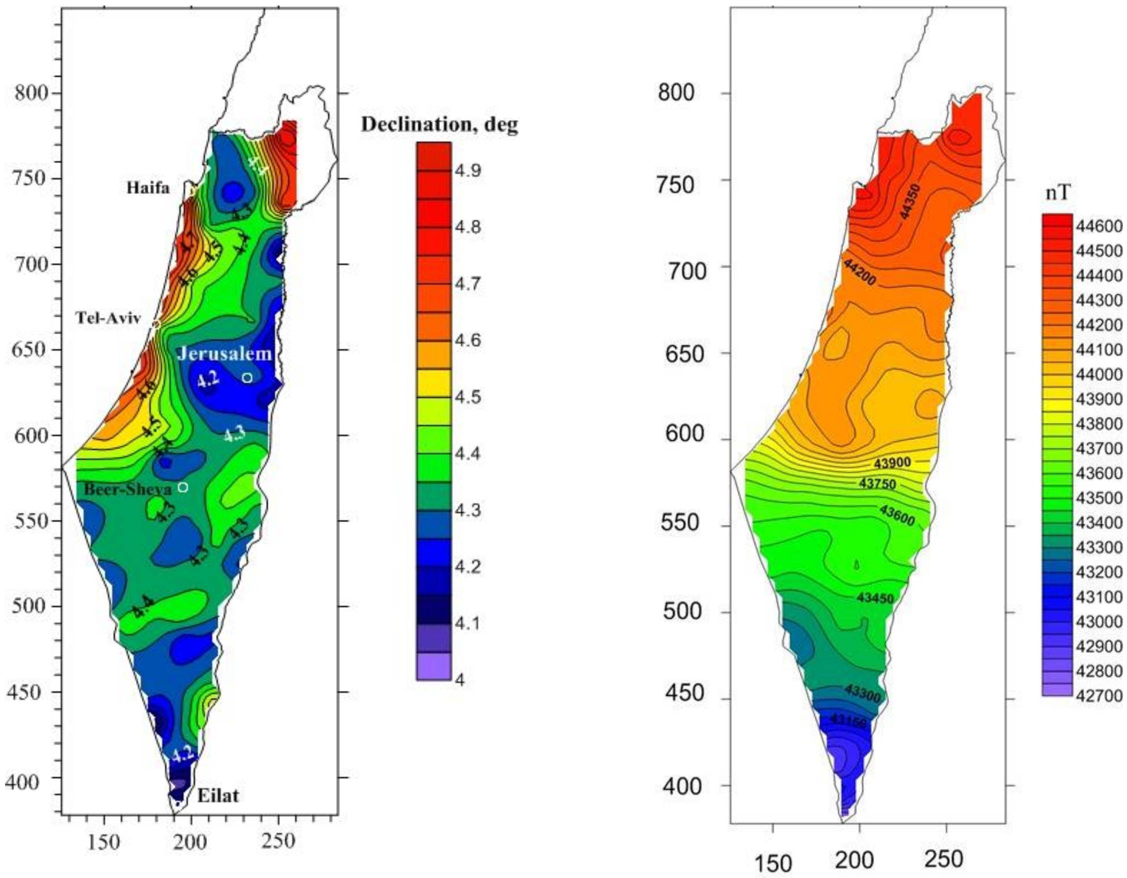


Figure 5: Magnetic Declination and Total Field Maps - 2014

4. ONGOING AND FUTURE PROJECTS

Main purpose of the geomagnetic observatories is to collect data, which in turn allow monitoring the changes in magnetic components. Routine work of SOI Research Division includes carrying out discrete measurements, monitor the continuous observation, conducting scientific analysis of the data and regularly maintain the facilities for accurate observations. However, alongside routine, day-to-day duties the members of the Research Division have been engaged in various research projects. Following is a brief overview.

An international collaboration between Canada and Israel gave rise to innovative project, which address the subject of potential Earthquake prediction. The long-term precise observations of field anomalies concerning this project are part of a multi-sensor geophysical monitoring program for observing active tectonic faults. A supersensitive total field Magnetic Gradiometer used to this end is the most promising instrument for monitoring earthquake related magnetic field signals.

Another partnership, national in this case, between SOI and the Israeli Institute of Geophysics utilizes magnetic data to detect sinkholes along the shores of the Dead see. This highly hazardous phenomenon started occurring in the Dead Sea region for the last two decades and caused significant damage. The geomagnetic method for detecting these sinkholes employs observations of dipole anomaly and shows great promise.

The establishment of a Space Weather Research Infrastructure is a scientific project, which is the result of a mutual effort by Tel-Aviv University, the Ministry of Science Foundation and the SOI. Magnetic Storms inflict rapid changes on the magnetic field, which in turn may cause damage to power grids, lead to breakdowns in communication networks etc. Weather monitoring might just provide the magnetic storms forecast needed to anticipate such events (Shirman, 2016).

Future projects include prediction of magnetic *Declination* based on absolute measurements of the last several years. By analyzing the data and determining the rate of annual change, it is possible to calculate the *Declination* value in a given time and location to a great extent. Another thrilling project is the establishment of an interactive *Declination* model. The main purpose of which is to allow online calculation of *Declination* values anywhere within the boundaries of Israeli state.

5. SUMMARY

The importance of geomagnetic observation is evident both from scientific and practical aspects. The need for defining the magnetic north and tracking changes in the magnetic field of the Earth is stems from this understanding. Thus, magnetic observatories must remain functional for many years to come.

Survey of Israel considers forty years of continuous geomagnetic measurements that meet the requirements of IAGA international association, a notable achievement. Currently there are three operating magnetic observatories on the territory of Israel, which pose a significant contribution to the widening of global geomagnetic network in addition to providing high quality magnetic data for commercial as well as academic uses.

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BIOGRAPHICAL NOTES

Dr. Anna Shnaidman is a Geophysical Surveys and Research Administrator in the Research Division at the Survey of Israel and a Part-time Lecturer in the Department of Civil Engineering at the Technion - Israeli Institute of Technology. She received her BSc (2008, Cum Laude) and MSc (2010) and PhD (2016) degrees in Mapping and Geo-Information engineering from Israeli Institute of Technology. Dr. Shnaidman is a Licensed Surveyor as well.

Her current work focuses on Geomagnetism, Gravimetry and 3D Cadaster. During her studies, Dr. Shnaidman published several papers on improvement of current Cadaster and the transition to Analytical Cadaster based on Genetic Algorithm, in conference proceedings and journals.

Dr. Boris Shirman is a formal geophysicist with Survey of Israel (SOI). He received his M.Sc. in astronomy from the Physics Faculty of the Ural University (Ekaterinburg Russia) in 1973. He obtained his Ph.D. in physics & mathematics from Institute of Geophysics (Ekaterinburg, Russia) in 1982. Since 1993, he headed a geophysics group in the Research Division of Survey of Israel, Tel – Aviv. His effort mainly concentrated on geomagnetic observatories in Israel and seas tide gages maintenance, on applications development for data processing in geomagnetism, sea leveling and geodesy. Currently Dr. Shirman is employed as a consultant at the Survey of Israel.

Yosef Melzer is the head of Research Department at the Survey of Israel. He received his Bachelor degree in Geodesy and Cartography from the Tel Aviv University in 1982 and His Mater degree in Geo-information from the Technion in 1988. His current fields of interest are: Satellite Geodesy, Sea Level, Magnetometry, Geodesy in general.

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