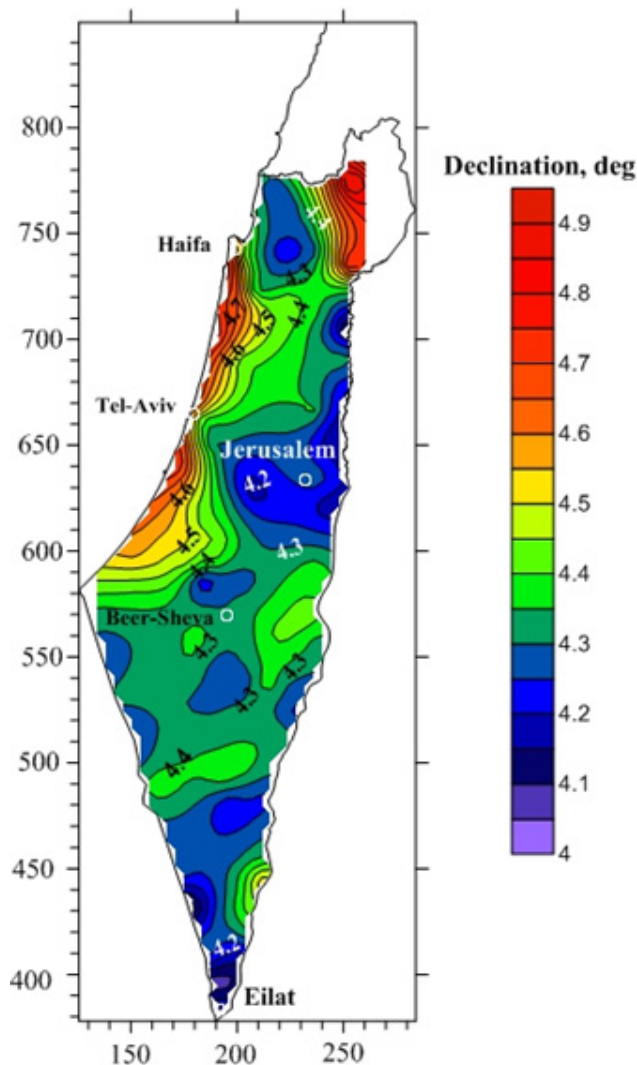




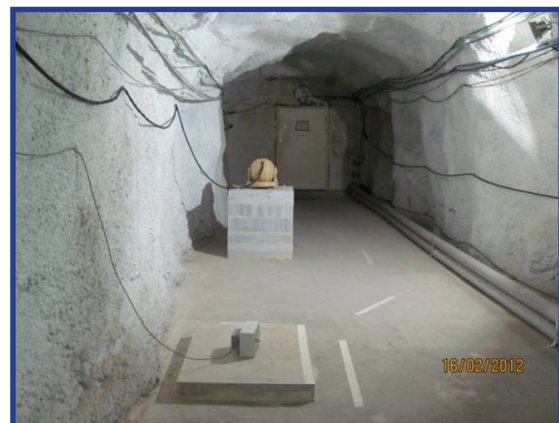
SURVEY OF ISRAEL

40 Years of Magnetic Observatories and 100 Years of Magnetic Declination Measurement in Israel

Magnetic declination map - 2015



Hermon observatory in winter



Geophysical observatory near Eilat

Written by Boris Shirman

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40 years of magnetic observatories and 100 years of magnetic declination measurements in Israel

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Preface

Earth magnetic field is critical to human survival on planet Earth. Without it, the atmosphere will be destroyed by solar flares, and earth will be dried out, becoming similar to planet Mars.

Earth magnetic field has been weakening in the last centuries, which means that we are aiming at poles reversals in the next hundreds of years.

For this reason, many countries, including Israel, put efforts in research aiming at trying to understand earth magnetosphere. This international research include satellites with magnetic sensors (Swarm satellites), magnetic observation stations and data analysis centers.

The Survey of Israel started its research in the field in order to define the direction of the magnetic north in Israeli maps. Then, the Survey developed its capabilities with practical military and industrial applications of magnetic measurements. Recently, there is much interest in this knowledge for tunnel and infrastructure detection for military and construction purposes.

It's my honor and privilege to present this report which summarizes 40 years of magnetic field research in the Survey of Israel.

Prof. Yaron Felus, Chief Scientist

Preface

Measuring the magnetic field has reached the Survey of Israel with the understanding that there is the need at the national level, to define the direction of a magnetic field and track rate of change.

Survey of Israel, which is responsible for mapping at the national level, also provides the information on the magnetic field direction (magnetic north) and on its rate over the years, at any map and any Scale in Israel.

To meet this goal, we need to set a magnetic observatory which run -continuously, reliable and accurate. In fact, we have even two, in case of failure of the first one, and to improve the reliability of magnetic data at the national level. Magnetic Observatory follow continuously the magnetic field on the various components and its location must be isolated in order to minimize the influence which could undermine the credibility of the information.

Today, we operate three magnetic observatories. The main is located in Bar Gyora (near Jerusalem). Two other, are located on Mount Hermon and Amram Mountain near Eilat.

In addition, we set a network of magnetic points all over Israel. Magnetic measurement is carried out by a mobile device and we also measure the direction of the geographic north (by Gyro theodolite). In the past, the network numbered More than 100 points, but now we are satisfied with the 50 points that we come back and measure every 5 years.

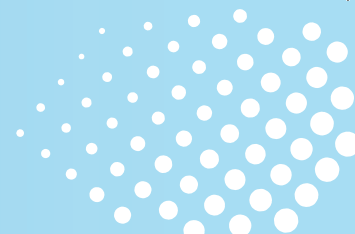
These data allow us to define the direction of the magnetic north all over Israel, for a given year, and if there is a need each time (depending on the accuracy require).

In recent years, we face a weakening strength of the magnetic field and the rate of change of the magnetic north is rising. In recent years the rate of change was about 5 minutes per year. But we should remember that this is an average annual rate whereas it may vary in different directions and intensity miscellaneous during the year.

The magnetic field measuring is not only for defining the magnetic north. We produce more "products" from this data, like finding sinkholes, locating underground bodies and anomalies which described by Dr. Boris Shirman in this professional document.

It is a great privilege for us at the Survey of Israel, to keep this important issue, both for national needs of the State of Israel and for the status of the Survey of Israel.

Yosef Melzer, Head of research division



Abstract

Earth's magnetic field plays an important role in the biosphere of our planet. The magnetic field surrounding the Earth protects humanity from space radiation. On the other hand, strong magnetic storms may inflict damages on various technical systems, such as power grids, radio communications, satellite telecommunications, etc. Monitoring of the stability of the global magnetic field is carried out using the network of magnetic observatories. Israeli magnetic observatories are part of this network. Regular monitoring of the geomagnetic field in Israel started with the opening of the magnetic observatory Amatsia in 1976. This event was preceded by the measurement of the magnetic declination at different times since the 20s of the last century. The second Bar-Gyora observatory was opened in 1989. Both observatories worked in parallel for several years, duplicating each other's measurements.

Currently, magnetic measurements are carried out in three observatories: Mt. Hermon, Bar-Gyora and Eilat. Bar-Gyora is our central observatory and two others, Mt. Hermon and Eilat, were opened and began operating under various projects. The data of the Bar-Gyora and Eilat observatories are sent to the World Data Centers annually. Over the years, the data of Israeli magnetic observatories were used in air navigation, mineral exploration, geological and geophysical studies, as well as in various research projects. Traditionally, work at the magnetic observatories is assigned to employees of the Research Division of Survey of Israel. Along with routine work in observatories, Research Division staff has been engaged in various research projects, both national and international, covered a wide range of the magnetic data, from the study of space weather to the exploration of the volcanic history of Arava, and from ultra-sensitive magnetometer testing to sinkholes detection along the Dead Sea shores. A brief description of these projects is given in Chapter 8.

1. Introduction (basic concepts)

Systematic observations of the geomagnetic field at multiple locations began with the establishment of global magnetic observatory network by the "King of Mathematics" Karl Gauss at the Magnetic Union in Gottingen in 1834. The great educator in those times, Alexander Humboldt, persuaded Russian Tsar to create a chain of stations across the Urals to Siberia. The greatest help came from the British Empire, whose "Magnetic Crusade" led by Sir Edward Sabine set up stations from Canada to Tasmania. Since the establishment of a global network of magnetic observatories, it was possible to determine the Earth's magnetic moment and evaluate internal and external sources of the field. The vast network not only made possible the first global models of the field, but also demonstrated the world-wide character of magnetic storms. Today, after 180 years ago, after the investigations of Gauss and his followers, it can be stated that the dominant "dipole" field is getting weaker, at a rate of about 6% per century. If this trend continues unchanged, about 1500-2000 years from now the magnetic polarity of the Earth will reverse, leading to unpredictable disasters in the biosphere.

1.1 Internal sources of the Earth's magnetic field.

The magnetic field of Earth has internal and external sources. Internal sources include electrical currents generated in the Earth's core and the mantle. The external sources include electrical currents resulting from the impact of the solar wind to the magnetosphere and the ionosphere. The internal part of geomagnetic field represents more than 90% of the total field measured on Earth's surface.

The Earth's magnetic field is similar to the dipole field, but only in a first approximation. The dipole part of geomagnetic field represents about 90% of the total field, but in fact it is much more complicated. The complexity of the Earth's magnetic field configuration is due to the fact that this field resulted from electric currents of complicated configuration induced in the liquid outer core of the Earth. Magnetic dynamo theory says that the magnetic field is produced by swirling motions of conducting liquid material in the planet interiors. Currents of magma in the Earth's liquid outer core is driven by heat flow from the inner hard core, and organized into rolls by the Coriolis force.

1.2 Earth's magnetic moment.

The magnetic moment characterizes the energy of the magnetic field generated by an internal source. The magnetic moment of the Earth changes over time. The Earth's magnetic field is usually measured in Tesla (or in nano-Tesla, nT), and its magnitude depends on the geographical coordinates. Earth's magnetic field reaches its highest value at the magnetic poles and the smallest value is reached at the magnetic equator. Nowadays, those values comprise about 60,000nT and 30,000nT, respectively. Observatory measurements over the two last centuries have shown that the Earth's magnetic field is not stable and varies with time. To evaluate global changes in the magnetic field the term "magnetic dipole moment" should be used. The potential of the magnetic field can be represented on the sphere as the sum of spherical harmonics components:

$$W = R \sum_{n=1}^{\infty} \sum_{l=0}^n \left(\frac{R}{r}\right)^{n+1} (g_n^l \cos l\lambda + h_n^l \sin l\lambda) P_n^l(\cos \vartheta) \quad (1)$$

Where r, ϑ, λ are coordinates (radius, co-latitude (polar angle) and longitude) of a measuring point; R is the Earth's radius.

The coefficient g_1^0 is a main term in the expansion (1) representing the dipole (or the main) part of the magnetic field of the Earth. Using the value of g_1^0 it is possible to

introduce the concept of the magnetic moment: $m = \frac{4\pi}{\mu_0} R^3 g_1^0$ (2)

where μ_0 is the absolute permeability;

The radial and tangential components of magnetic field in the spherical coordinate are

proportional to the magnetic moment: $B_r = \frac{\mu_0}{4\pi} \frac{2m \cos \vartheta}{r^3}; \quad B_\vartheta = \frac{\mu_0}{4\pi} \frac{m \sin \vartheta}{r^3}$ (3)

Thus, by measuring the magnetic field at the surface of the Earth, one can calculate the magnetic moment. Magnetic moment and the coordinates of the pole and magnetic field components are calculated based upon the usage (1) of the worldwide network of magnetic observatories every 5 years.

1.3 Instability of the Earth's magnetic field.

Since the first magnetic field measurements made by Gellibrand in London in 1643, it became clear that the Earth's magnetic field varies slowly in time. Such changes are referred to as Secular Variations. Geomagnetic secular variations are changes in the Earth's magnetic field over time scales of a year, which are determined by the observatory measurements and differ at the various observatories. These variations reflect changes that occur in the Earth's core, and in the mantle as well.

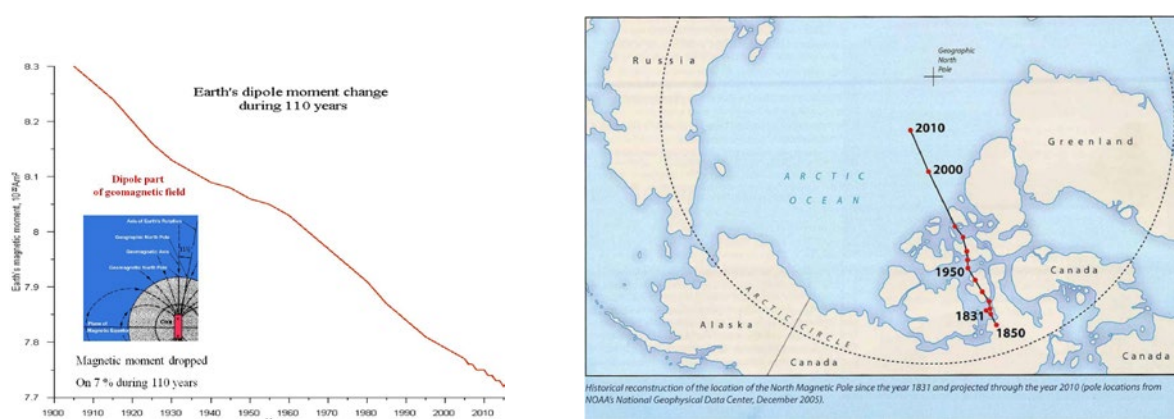


Fig. 1a: The magnetic moment change during 110 years;
1 b: The magnetic pole movement in the North hemisphere since 1850.

<http://50kview.blogspot.co.il/2014/03/april-01-2014-hmo-update-earth-pole.html>

As noted above, the Earth's magnetic moment has steadily decreased at a rate of 6% over a period of 100 years. Since 1850, its strength has decreased from about 8.5×10^{22} to about 7.8×10^{22} amperes per square meter. If this trend continues, the dipole component will vanish in another 1,500-2,000 years.

Similarly to the coordinates of the magnetic moment, the coordinates of the magnetic pole also change over time. Analysis of the a global network data showed that in recent years the north magnetic pole has moved northwest from the Canadian islands at a velocity of about 50 km per year (Fig.1b). The Earth's magnetic field has not always been oriented as it is today. The direction of the dipole component reverses very sudden on a geologic timescale, apparently taking about 5,000 years. The time between reversals is highly variable, sometimes occurring in less than 40,000 years and at other times remaining steady for as long as 35,000,000 years. No regularities or periodicities have yet been discovered in the pattern of reversals. A long interval of one polarity may be followed by a short interval of opposite polarity.

1.4 IGRF and geomagnetic coordinates

The International Geomagnetic Reference Field (IGRF) is the standard mathematical description of the Earth's main magnetic field that is used widely in studies of the Earth's deep interior, its crust and its ionosphere and magnetosphere. The main field model is represented by the series expansion (1).

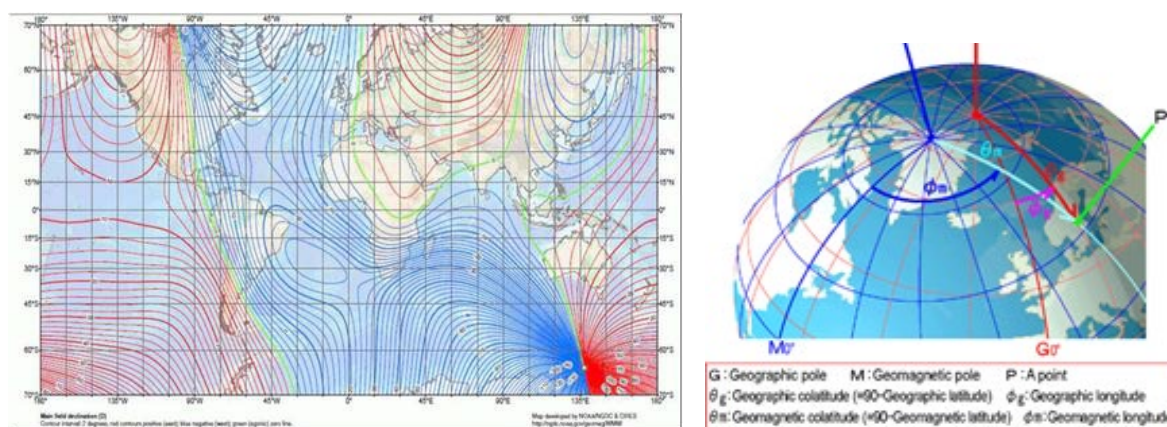


Fig.2a: The contour map of the magnetic field declination based on the World Magnetic Model (WMM) 2010. Accessed from

<http://ngdc.noaa.gov/geomag/WMM/image.shtml>

2b: The geographic and geomagnetic geocentric coordinates. G and M are the geographic and the geomagnetic poles, P is an observation point.

The contour lines (green lines in Fig. 2a) are connecting points where the declination is 0° , and go through true north and magnetic north. Red contour lines denote positive or east declination where the compass points east of true (geographic) north. Blue lines denote negative or west declination, and compass in these areas points west of true north. Contour interval in this graph is two degrees. For example contour line passing through the southern part of Israel is set to 4 degrees to the east. Points along contour line bisecting Vancouver Island (west of Canada) have 18° east declination, while points along the line going through southern New Foundland (eastern Canada) have a -20° or 20° west declination.

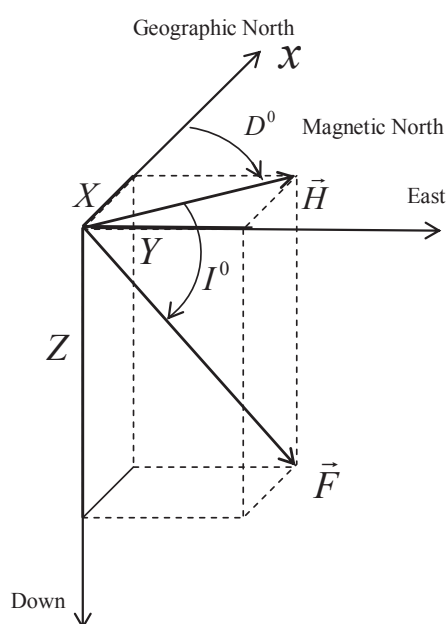
Geomagnetic coordinates (Fig.2b) are the "geomagnetic dipole coordinates" referring to the geocentric dipole field approximating the geomagnetic field based on IGRF. The poles move slowly according to the "secular variation of the geomagnetic field".

1.5 Magnetic observatory

A Geomagnetic observatory is a ground-based station that continually monitors the Earth's magnetic field over long periods of time. The observatory environment should be free of artificial magnetic objects and of the influence of strong natural magnetic anomalies. The aim of each observatory is to define the absolute magnetic field vector at a fixed location and at certain time. Observatory significance is determined by the length of its continuous operation during many years and also by the publication of data to the wider community

(<http://www.bgs.ac.uk/iaga/vobs/home.html>).

Each magnetic observatory uses a local Cartesian coordinate system (Fig.3). In those coordinates F is the vector magnetic field. X , Y , and Z are the three Cartesian components of the field, usually measured with respect to a geographic coordinate system. X is northward, Y is eastward, and, completing a right-handed system, Z is vertically down toward the center of the Earth. The magnitude of the field projected in the horizontal plane is called H . The direction of the vector H is often referred to as magnetic north. This vector H makes an angle D° (declination) measured in positive values from the north to the east. The inclination I° is the angle of the total field vector with respect to the horizontal plane, which is positive for vectors below the plane. It is the complement of the usual polar angle of spherical coordinates (F , I , D). The ratio between the field components is given below.



$$\begin{aligned} H &= F \cdot \cos I; & Z &= F \cdot \sin I; \\ X &= H \cdot \cos D = F \cdot \cos I \cdot \cos D; & Y &= H \cdot \sin D = F \cdot \cos I \cdot \sin D; \end{aligned} \quad (4)$$

$$D = \arctan\left(\frac{Y}{X}\right); \quad (5)$$

$$I = \arctan\left(\frac{Z}{\sqrt{X^2 + Y^2}}\right) = \arctan \frac{Z}{H}; \quad (6)$$

Fig. 3: Magnetic elements of the local coordinate system.

1.6. The contribution of Israeli magnetic observatories to the IAGA global magnetic network.

IAGA (International Association of Geomagnetism and Aeronomy) Working Group V-OBS coordinates all issues related to the operation of geomagnetic observatories and, in collaboration with V-MOD, repeat stations around the world. The Working Group (WG) sets quality standards for measurements and for data processing, and supports observatories in need of modern instrumentation or those in danger of closure. It is responsible for the organization of a workshop on geomagnetic observatory instruments, data acquisition and processing every two years. The WG maintains a list of observatories operating worldwide now and in the past, and allocates IAGA codes (<http://www.bgs.ac.uk/iaga/vobs/home.html>).

Israeli observatories contribute significantly to the database of global geomagnetic network. This database is open to general consumers and used for calculations of the Earth's magnetic moment and IGRF. Indeed, the Bar-Gyora and Eilat magnetic observatories fill the gaps in the vast area between Greece, Pakistan, Ethiopia, and Algeria.

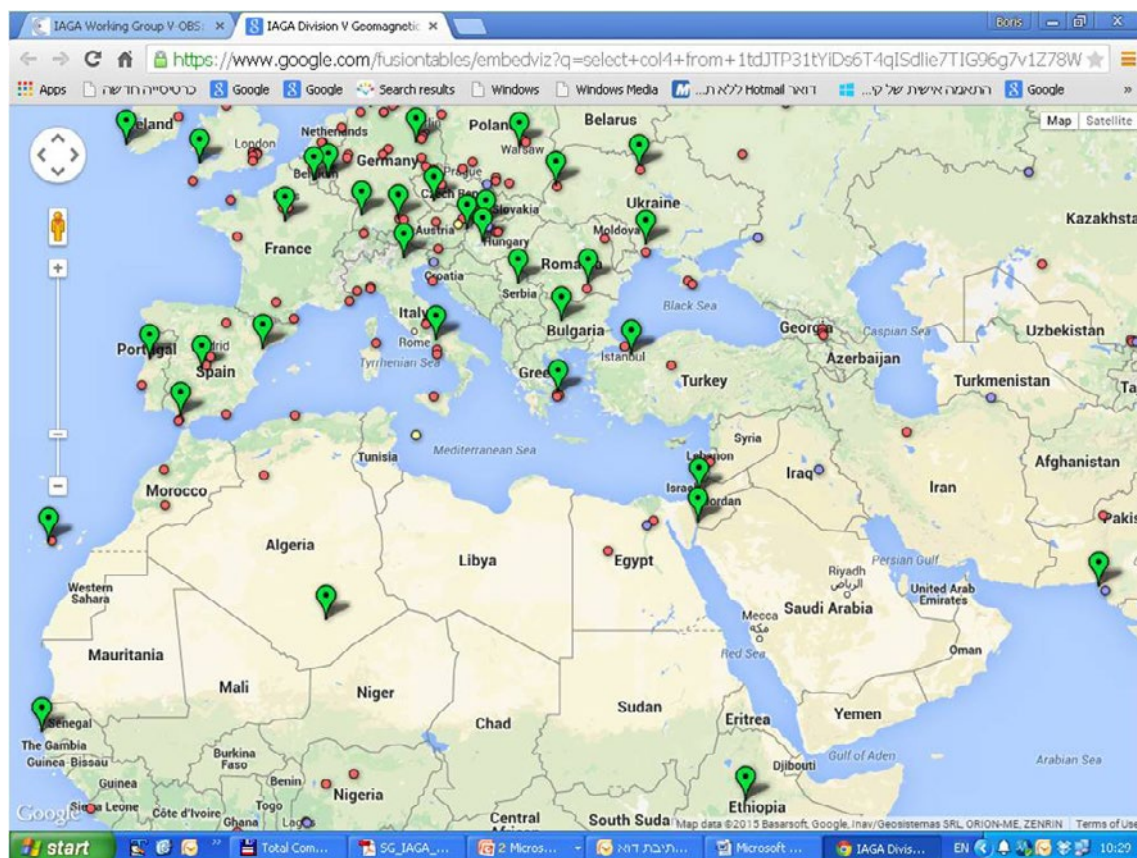


Fig. 4 shows the fragment of IAGA-map magnetic observatories-2015.

The Bar-Gyora and Eilat observatories are located in the center of map.

Green pin = "Open", red circle = "Closed", blue circle = "Uncertain" (Total operating observatories -195)

2. Historical measurements of the magnetic declination in Israel

Measurement of the magnetic field declination is relatively simple and, over the centuries, has served as an effective means for navigation. This may explain why the first historical geomagnetic measurements were the declination measurements.

2.1 The first measurements of the magnetic declination in the eastern Mediterranean were carried out by the British Admiralty in 1918. The maps from the archives of the Survey of Israel shown in Fig. 5a, give the following values of the west declination in the coastal zone for 1918: Atlit - $0^{\circ} 15' W$; Caesarea - $0^{\circ} 20' W$, Yafa - $0^{\circ} 25' W$; port Yavne - $0^{\circ} 20' W$.

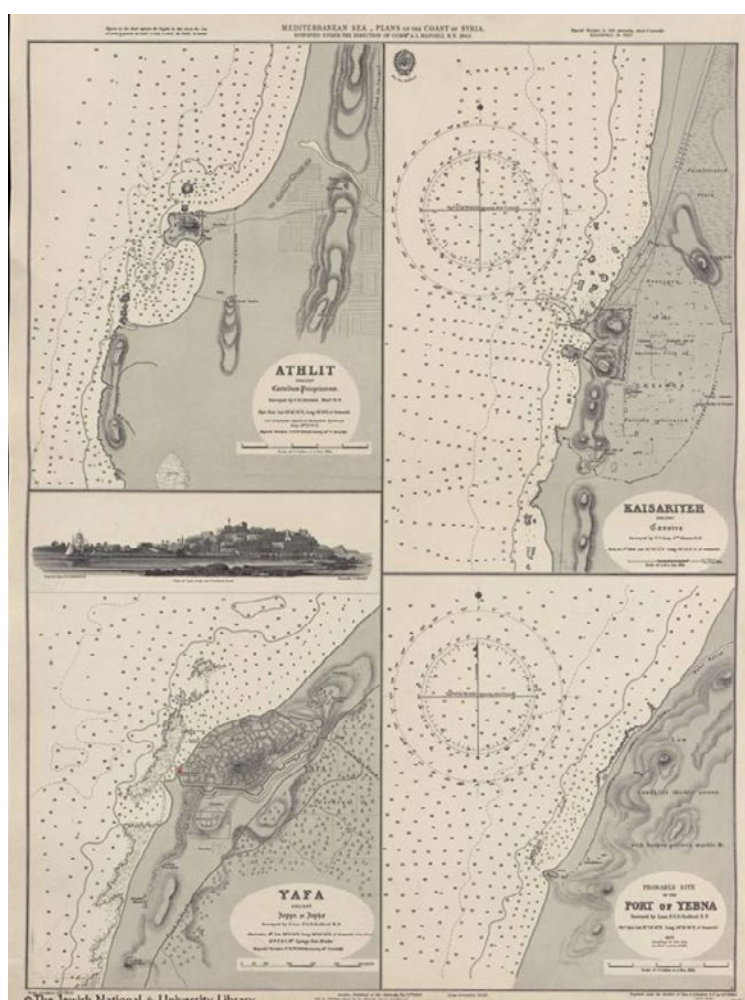


Fig. 5a: The map showing the value of magnetic declination obtained by the British Admiralty in the eastern Mediterranean in 1918;

2.2 Later, in the thirties, during the British Mandate (1917-1948) magnetic measurements were carried out by the Survey of Palestine. Magnetic declination was measured at some points of the central area of the of the Palestine Mandate territory. It used the "Connolly Standard Compass which can be read to single minutes of arc. It has been used as a portable magnetometer for observing the magnetic declination". In the annual report for the 1936 Survey of Palestine noted: "The approximate mean of declination of the needle in December in the coastal plain as obtain from 6 adjusted trough compasses, worked out at $1^{\circ}15'$ east". Measurements were carried out each year and in 1936 the number of repeat stations reached 30. "During the year a "Connolly" standard compasses were purchased and observations were taken a few places to determine the magnetic variations. Sun azimuths were used." About the compass accuracy was written: "Individual readings of the compass newer varied by more than 2 arc minutes". Fig.5b shows the map of Palestine (Property of the archive of Survey of Israel) with repeat points of declination measurements in 1939. It is interesting to note that the observed difference in declination between the central area (Jerusalem) and coastal area (Tel-Aviv) of the territory amounted to about $30'$, which coincides with the contemporary map of declination.

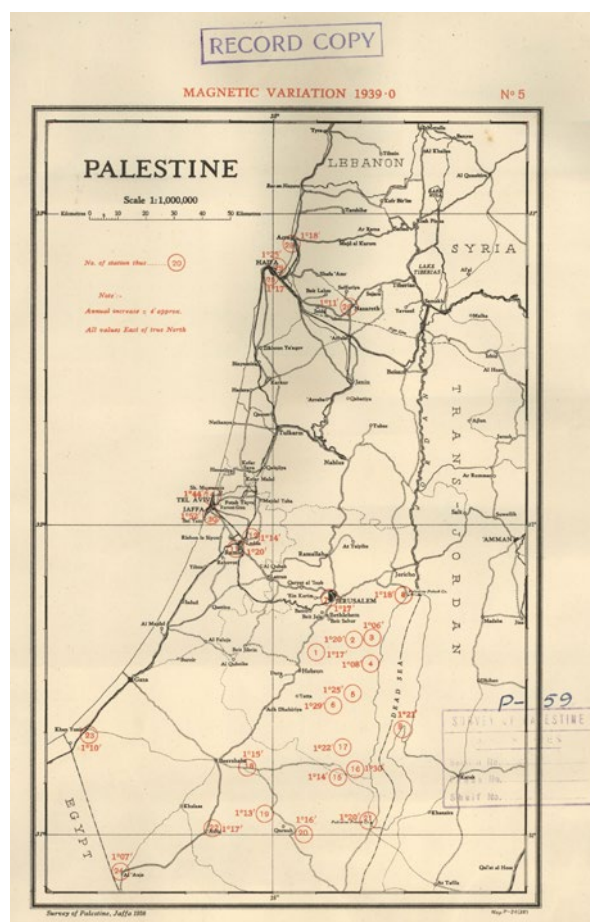


Fig. 5b: The map of Palestine with declination values measured at the repeat stations in 1939.

2.3 In March 1958, Survey of Israel staff performed under the direction of Mr. Ziskind Perelman declination measurements in three areas along Mediterranean coast: In the vicinities of Bat-Yam, in Ramat-Aviv and ten kilometers to the East from Netanya. The average value of declination measured at 9 points amounted to $2^{\circ}03'$. Further declination monitoring was carried out within the magnetic observatories.

3. Israeli magnetic observatories

An extensive search for a suitable location for the magnetic observatory was completed in a hilly area near Moshav Amatsia. A tunnel was dug in a small hill, where a full automatic variation station had been placed. Amatsia, the first Israeli magnetic observatory, was put into operation in 1976. Absolute measurements were performed once a week on the pillar, located 60 meters from the tunnel at the foot of the hill. To measure absolute values of the horizontal (H) and vertical (Z) components, induction magnetometer QHM (quartz horizontal magnetometer) and BMZ (Balance magnetometer zero) were used. In 1989 Bar- Gyora observatory began work in parallel with Amatsia. The Amatsia observatory completed its work in 2002 and now it is in the process of reconstruction. Today it operates three magnetic observatories: Mount Hermon, Bar-Gyora and Eilat, and their locations, heights, geographic and geomagnetic coordinates are given in Fig. 6a and in Table 1.

Once a week, the staff on behalf of the Research Division visits the observatory and carries out absolute measurements there. This fully automated observatory is connected with the main office via wireless communication.

a



b

Stations location-84

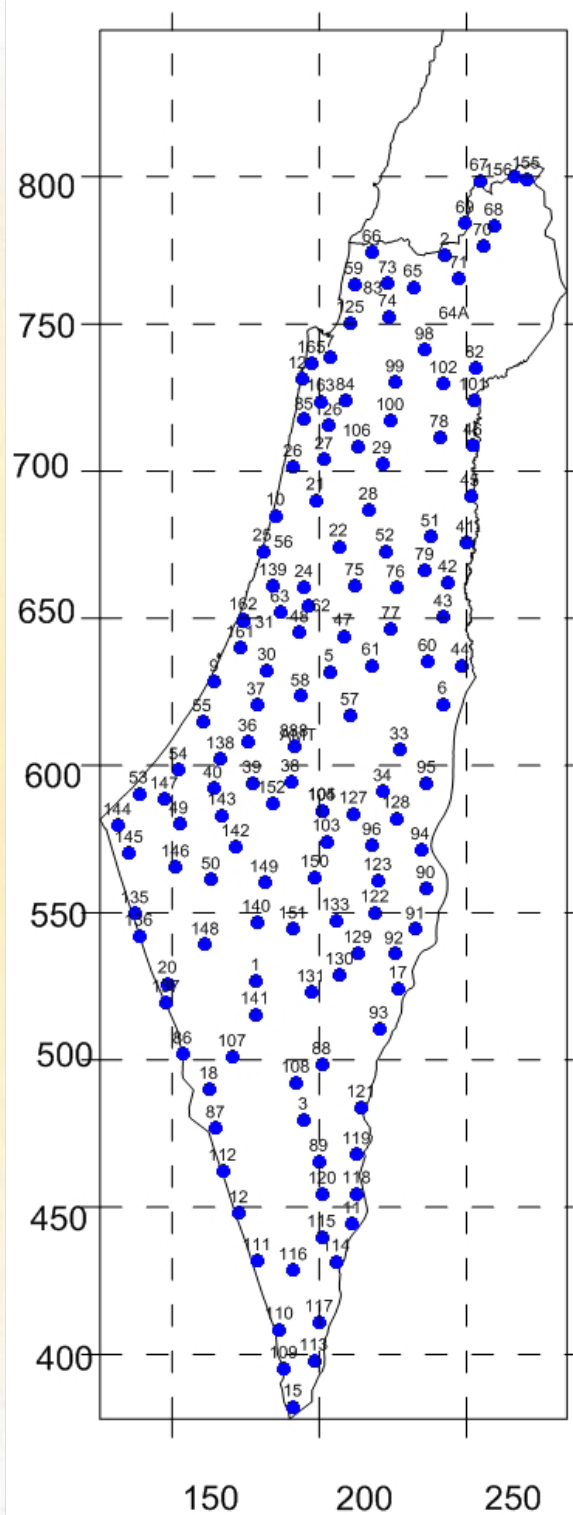


Fig. 6 a: The locations of the four magnetic observatories.

b: The locations of the repeat stations during the magnetic mapping carried out in 1984.

St. Name operate since	Geographic coordinates		Geomagnetic coordinates		Heights m
	Latitude	Longitude	Latitude	Longitude	
Mt. Hermon 2003	33 ⁰ 18'23''	35 ⁰ 47'04''	29.60N	113.89E	2,060
Bar-Gyora 1989	31 ⁰ 43'24''	35 ⁰ 05'17''	28.16N	112.89E	750
Amatsia 1976	31 ⁰ 32'57''	34 ⁰ 54'42''	28.00N	112.69E	350
Eilat 1997	29 ⁰ 40'23''	35 ⁰ 57'31''	26.01N	113.32E	250

Table 1. the geographic and magnetic coordinates and heights above sea level of the four magnetic observatories.

Two observatories, Bar-Gyora and Eilat, are registered at IAGA, and their data are sent annually to the International Data Centers.

The objectives of the magnetic field monitoring carried out by Survey of Israel:

1. To determine magnetic declinations (magnetic North) anywhere within the borders of Israel and to monitor their average annual changes.
2. To map the geomagnetic field components.
3. To perform magnetic measurement services ordered by other organizations (Example: The security, military and civil aviation sectors).
4. Supply of observatory magnetic data to World Data Centers.
5. Supply of magnetic field data for research work in geology, geophysics, archeology, etc.
6. To carry out studies in different areas related to geomagnetic field measurements (Super sensitive magnetic gradiometer, the Dead Sea sinkholes, cosmic weather, geological deep structure, tunnels detection, etc.).

a



b



Fig. 7: The team of the research division at the absolute measurements at the Bar-Giora observatory.

- a: The Declination and Inclination measurements using theodolite DIM;
- b: Automatic total field recordings using GSM-19 v7.0 magnetometer.

4. Implementation of measurements in Israeli magnetic observatories.

4.1 Permanent equipment.

Magnetic variations recording performed by fluxgate magnetometers of FGE and EDA series. The EDA series Three Component Fluxgate magnetometer consists of a compact electronic console, a 60 meters cable and a fluxgate sensor. The three orthogonal elements of the sensor act as zero detectors, so as to minimize effects and non-linearity. The magnetometer provides a relative resolution of 0.4 nT, a sensitivity of 100nT/volt and a temperature coefficient of 1nT/°C.

FGE magnetometer: The fluxgate magnetometer FGE is a modern tri-axial magnetometer manufactured by the Danish Meteorological Institute (DMI). The three sensors are supplied with compensation coils, wound on quartz tubes in order to obtain a sensor drift of less than a few nT per year and temperature coefficient of 0.25nT/°C.

Coils with their cores are mounted on marble cubes, which are suspended in two crossed phosphor-bronze strips to compensate any tilt of the sensor foundation. The fluxgate sensors of the magnetometer provide a relative sensitivity of ~ 320nT/volt. We use such a suspended version at the Bar-Gyora and Hermon (Fig. 7a,b) observatories for magnetic variations recording.



Fig. 8a, b: FGE fluxgate magnetometer installed at the Hermon site

dIdD magnetometer: The Suspended dIdD (delta Inclination, delta Declination) is a vector magnetometer for continuous monitoring of the inclination, declination and total intensity of the Earth's magnetic field, manufactured by the GEM-systems Canada. It comprises a diameter of 250 mm, and a spherical Overhauser sensor with a bidirectional set of bias coils. (<http://www.gemsys.ca/>)

Unlike the fluxgate magnetometers, which only provide inclination and declination, dIdD also measures the absolute values of the field. Its main specifications are as follows: Long term drifts that are less than 2 nT / year, temperature coefficients that reduce drift to less than 0.1 nT / °C, resolution: 0.01 nT.

4.2 Portable equipment

The GSM-19 v7.0 Overhauser instrument (GEM-systems, Canada) is the total field magnetometer, equipped with built-in GPS for accurate positioned ground and time recording. Sensor components are made of carefully screened non-magnetic materials, in order to assist in the maximization of the signal to noise ratio. The display of the data acquisition consol provides both monochrome text and real-time profile data with an easy to use interactive menu to facilitate the performance of all survey functions. The GSM-19 v7.0 magnetometer provides a resolution of 0.01nT and absolute accuracy of +/-0.1nT.

Declination-Inclination Magnetometer (DIM). The DIM consists of steel free ZEISS theodolite (THEO 010 A) with measuring accuracy +/- 1" and a single axis fluxgate magnetometer of the Danish Meteorological Institute. The sensor of the fluxgate magnetometer is mounted on the telescope of the theodolite. The high sensitivity fluxgate magnetometer allows field readings with 0.1 nT resolution. The electronics has a large LCD display with an built-in lamp. The magnetic axis of the sensor fixed on the theodolite is carefully adjusted to the optical axis of the telescope within a few tenths of an arc second.

4.3 Special equipment

The highly sensitive potassium total field Gradiometer (GSMP-20S3, GEM Systems, Canada) with resolution of 0.001 pT, up to 20 readings per second, was designed and installed at the geophysical tunnel near Eilat, within the scope of the Canada –Israel project. The aim of the project is to carry out both long-term and short-term magnetic gradiometer measurements, aiming to detect correlations with tectonic activity and precursor phenomena. The GEM Systems GSMP-20GS is the highest sensitivity total magnetic field measuring device ever developed in the late 90s of the last century.

Supergradiometer run in parallel with the dIdD vector magnetometer (Fig.9a,b)

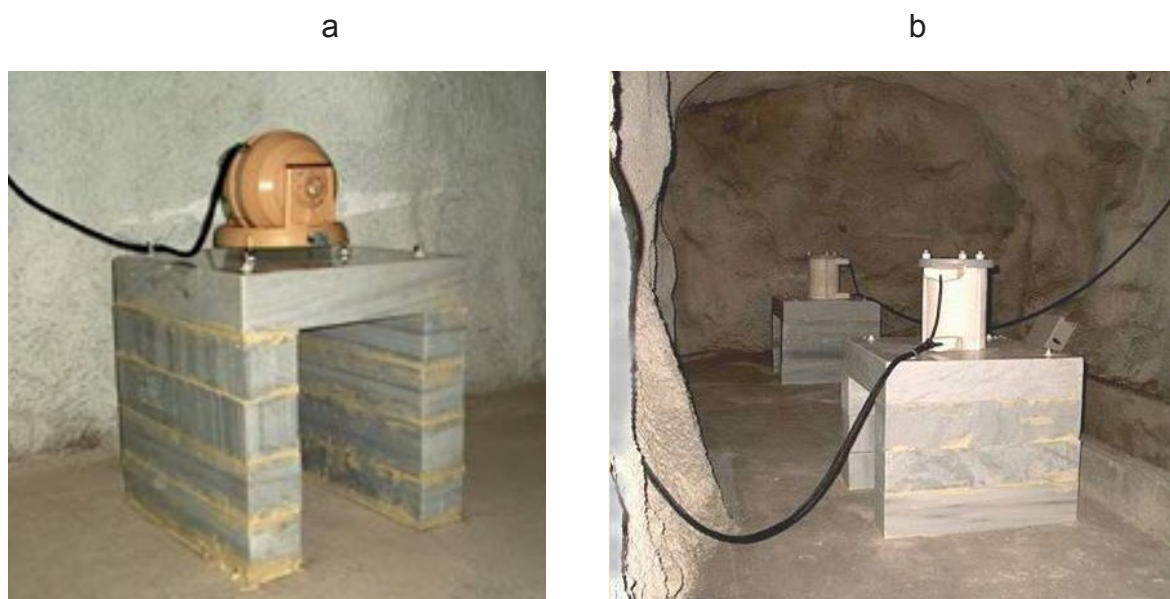


Fig. 9: Magnetic equipment in the Eilat geophysical observatory;
 a) dIdD vector magnetometer; b) Two sensors of the Supergrad magnetometer.

Devices mounted on the pedestal of non-magnetic marbles

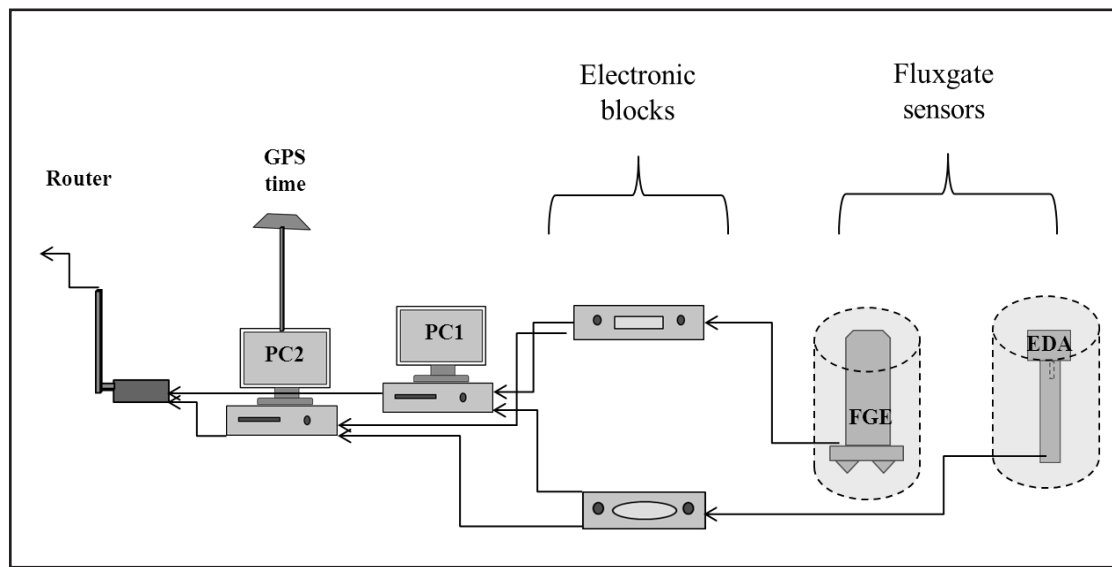
Some of the important benefits of the GSMP-20GS optically pumped supergradiometer include:

- Highest sensitivity ever developed;
- Best absolute accuracy;
- Almost no orientation errors.

4.4 Continuous recording of magnetic field variations

This location, characterized by its minimal spatial gradient and free of artificial magnetic objects, intended for the installation of variometers, was carefully chosen in the territory of the observatories. To this end, a local magnetic survey was conducted. The sensors of the Fluxgate magnetometers (FGE and EDA) at Bar-Gyora and Hermon observatories were installed in the wells at a distance of 60 m from the data acquisition room, away from electromagnetic interferences. The signal from the sensor is transmitted to the electronics boxes in the data acquisition room, and then in analog form to the computers. The signal is converted from analog to digital form by means of a 16-bit A/D converter with discreteness (resolution) of 1 second. One minute averaged values of magnetic field components are recorded in the computer memory. These data are then formed in the 10-day files. Signals from both sensors are duplicated on two computers. Computer time is corrected by means of GPS signals. The software (SDA) has been developed in the Geophysical Institute of Israel.

At the Eilat observatory, recording of the variations is carried by the dIdD magnetometer and duplicate by the fluxgate EDA magnetometer. The wireless connection is carried out by the routers between the observatories and the central office in Tel-Aviv. (See block diagram).



Block diagram of working electronic components at the Bar-Gyora observatory

4.5 Absolute measurements

The aim of the absolute measurement is baseline calculation for continuously recorded variations. The measurements are carried out simultaneously by means of two devices: the magnetic theodolite and the total field magnetometer. The obtained values of declination, inclination and total field are processed along with the variations. These basic values are interpolated and added to the minute values of the variations.

The base lines of the magnetic H, D, Z – components and total field T at the Eilat observatory (dIdD series) over the ten years is shown in Fig. 10. During the period from 2006 to 2010, there was a drift in all three components not exceeding 15 nT, and in the following years the value of the drift was reduced. One of the reasons for the observed drift of the baselines in the recent years can be the stabilization of the pedestal of the non-magnetic marble on which the dIdD magnetometer stood over said period.

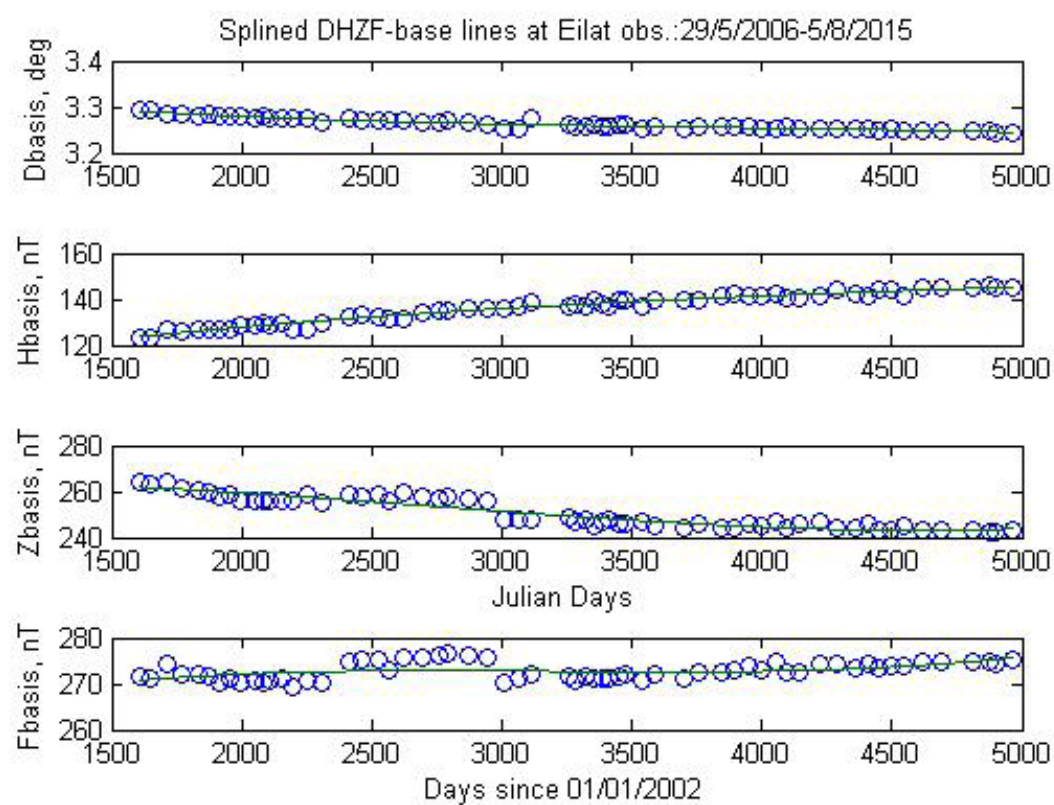


Fig.10: Cubic splined D, H, Z, T base lines at the Eilat observatory during the period from 29/05/2006 to 05/08/2015.

5. Long-term change in the magnetic field. Secular variations in Israel

As noted before, declination is represented by the longest series of measurements over time. Fig. 11 shows the changes in mean annual values of declination in Israel. All values are given to the datum of the Amatsia observatory. Red circles denote measurements made by the British Admiralty, by the Survey of Palestine, as well as measurements made by the Survey of Israel staff in 1958 (Chapter 2). Despite the fact that these measurements were not made within the observatories, they give a clear picture of the declination changing over almost a century. We see a monotonic growth of declination from negative values of about -0.3 degrees to the positive value of +4.5 degrees nowadays. Thus, the magnetic declination increased in our region by about 5 degrees over the last century. We see that growth of declination is not linear, its rate of change varied from two minutes per year since 1976 to five nowadays.

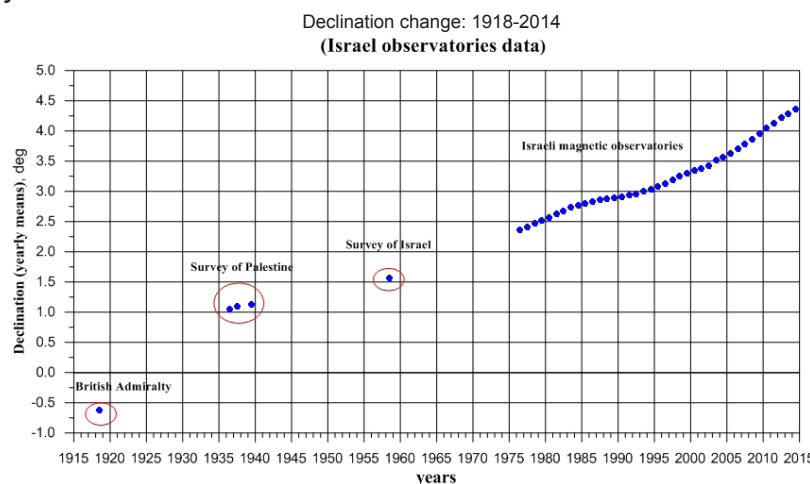


Fig. 11: Declination change for the period between 1918 and 2014.

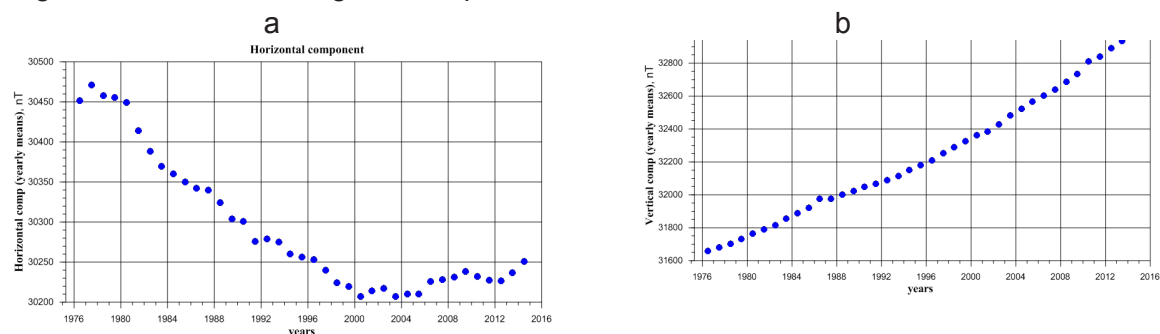


Fig. 12: Annual mean values of the horizontal (a) and vertical components (b) for the period 1976-2014. Average values referred to the middle of each year.

The vertical component monotonously increases with a variable rate from 20nT/year to 50nT/year over the course of the whole period of observations (Fig.12b). In contrast to the vertical component, the horizontal component (Fig.12a) decreases monotonically until 2000 with at a rate between 5 and 20 nT/year.

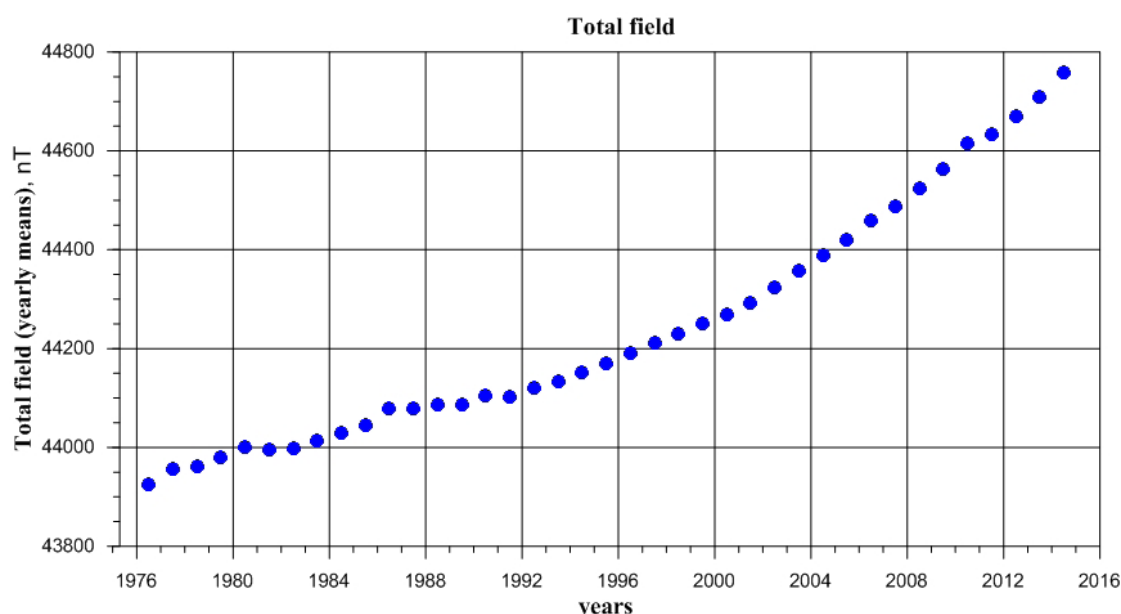


Fig.12c: Early mean values of the total field for the period 1976-2014.

The total field (absolute value of the magnetic vector) increases monotonically with a varying rate (Fig.12c). It has increased by 830 nT for forty years. It is interesting to note that despite the drop in the Earth's magnetic dipole moment, the field in confined areas (like ours) has grown. This indicates the complexity of the sources of the total geomagnetic field.

6. Geomagnetic mapping in Israel

Mapping is one of the priority tasks of the Survey of Israel. Clarification of magnetic maps is one of the important tasks of the geomagnetic service. This is due to the fact that magnetic declination measurements are traditionally used in navigation and in cartography. For this purpose, a network of about 130 repeat stations was established, including the Amatsia and Bar-Gyora observatories. Measurements were carried out in two big campaigns that took place in 1984 and 1993. The network of stations in 1984 almost evenly covered the territory of Israel. The exception was the Golan Heights, where due to the very high and non-uniform magnetization of basalts, the interpretation of ground surveys was difficult. The location of the repeat stations during the 1984 campaign is presented in Fig.6b. The measurements of these surveys were carried out under the direction of Mrs. R. Segal. Later, the number of repeat stations would increase, mainly in the southern part of Israel. At each point of the network, both magnetic and geodetic measurements were performed.

The synchronized measurements of the total field, declination, and inclination were carried out with the GSM-18 and GSM-19 Overhauser instruments and with a steel free magnetic theodolite ZEISS, respectively. To determine the direction of the geographic north, relevant measurements were made with the Wild Gyro instrument GAK1. The geographic azimuth of a target was determined with an accuracy of 20". Calculations were performed according to the standard procedure. The transient magnetic variation, which includes the outer source variations (solar quiet Sq daily variations and irregular disturbances such as geomagnetic storms and pulsations), were eliminated by subtracting the magnetic field variation recorded at the Bar-Gyora or Amatsia observatories, located approximately in the geographical center of Israel. The measurements of the first and the second surveys were brought to baselines of the Amatsia observatory in 1984 and 1993, respectively. The raw data from the two surveys were incorporated into a common data set and were gridded using the kriging method with a grid size of 8 km. Standard deviations of calculated field in a data set did not exceed 2 nT both in the horizontal and vertical components, and 20" in declination (Shirman, 2000).



Fig.13 Instruments for the vector of magnetic field measuring at the one of the point of the network ("River Alexander"). In the foreground: the Wild Gyro instrument GAK1 mounted on the Wild T2 theodolite, in the background, at the left: proton magnetometer sensor GSM19; at the right: theodolite DIM.

6.1 Magnetic absolute values maps.

The magnetic declination value depends on the geographical location. It changes throughout the territory within an interval of 4.85 to 3.95 degrees, for period of 2014 (Fig. 14a). The declination reaches its maximum level in the coastal zone of the Mediterranean Sea and in the area adjacent to the Golan Heights, and its minimum is reached both in the eastern and southern parts of Israel. The total field map is given in Fig. 14.b.

The other two maps show the change in the absolute values of the horizontal (Fig. 15 a) and vertical component (Fig. 15b) for the 2014 period. The values of the horizontal component increase monotonically in the south direction, while the values of the vertical components decrease in the same direction. Such distribution of the field is due to the main part of the Earth's magnetic field. Indeed, the formula (3), in chapter 1 can be written for the field components in a Cartesian coordinate system (Fig. 3):

$$Z = \frac{\mu_0}{4\pi} \frac{2m \cos \vartheta}{R_0^3} = Z_0 \cos \vartheta; \quad H = \frac{\mu_0}{4\pi} \frac{m \sin \vartheta}{R_0^3} = H_0 \sin \vartheta; \quad (7)$$

Where H_0 and Z_0 are the maximum values of the horizontal and the vertical components (at the magnetic equator and at the magnetic pole respectively) and ϑ is magnetic co-latitude. From the formulas (7) follow that the magnetic field at magnetic pole is twice greater than the magnetic field at the equator:

$$Z_0 = 2 \cdot H_0; \quad (8)$$

and the following relation exists between the magnetic declination and the magnetic latitude of an observation point :

$$\frac{Z}{H} = \tan I_0 = 2 \cot \vartheta = 2 \tan \varphi'; \quad (9)$$

Where φ' is magnetic latitude. Now we can estimate the value of inclination, created by the main part of earth's magnetic field at the latitudes of the Israeli magnetic observatories. Proceeding from the formula (9), we estimate I_0 for the Eilat and Bar-Gyora observatories at magnetic latitudes $\Phi_{ELT} = 26.0^\circ$; $\Phi_{BGY} = 28.1^\circ$; ($I_{ELT} = 44^\circ 20'$; $I_{BGY} = 46^\circ 53'$). The observatory measurements yield the following values for the inclinations of the Eilat and Bar-Gyora observatories for 2014: $I'_{ELT} = 44^\circ 20'$, $I'_{BGY} = 47^\circ 44'$. It is interesting to note that despite of the secular variation, it was a good coincidence between the theoretical and calculated values of inclination for the Eilat Observatory, whereas.

Magnetic declination map- 2014

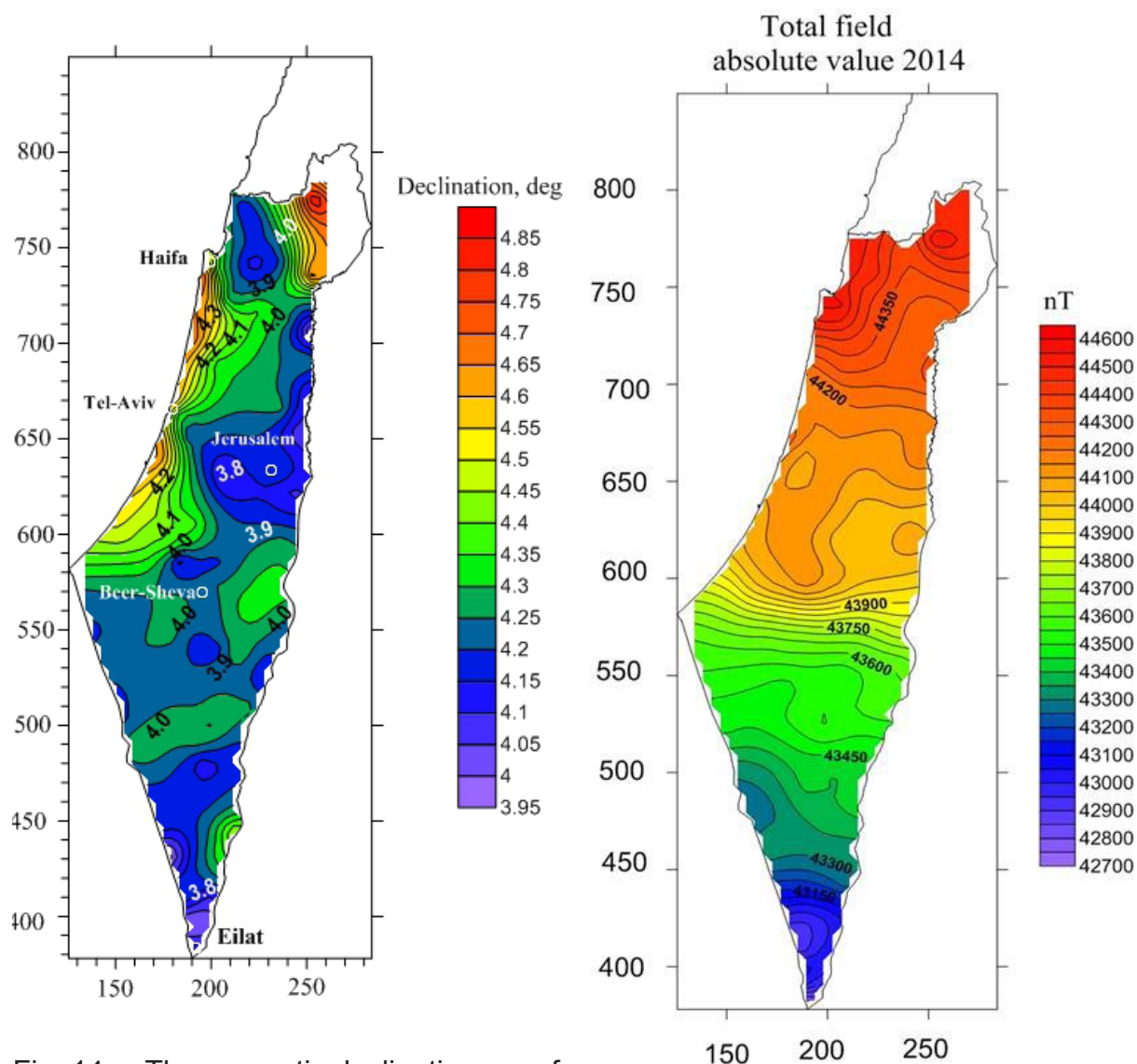


Fig. 14 a: The magnetic declination map for the period 2014
 b: The total field map for the period of 2014

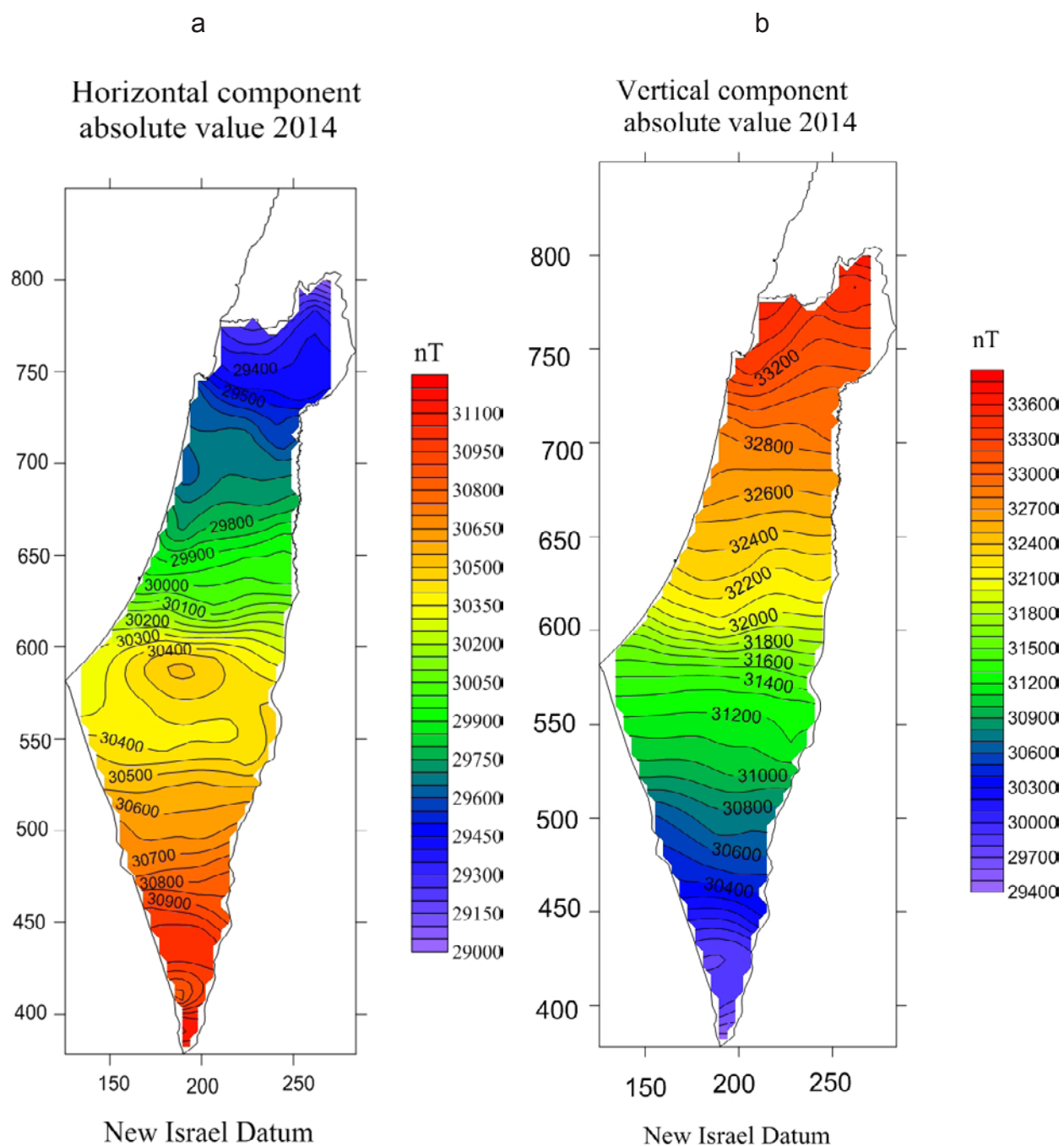


Fig. 15a: Maps of the horizontal and
b: vertical component absolute value

6.2 Magnetic anomaly maps

Local magnetic anomalies caused by the bodies whose magnetization is different from the background magnetization of the Earth's crust (Shirman, 2009). A Magnetic anomaly map allows the detection of the magnetic bodies. The anomaly field was calculated as the difference between the measured field and International Geomagnetic Reference Field (IGRF) (Shirman, 2000). The set of four maps is presented in Fig.16(a-d). Magnetic anomalies are contoured at intervals of 40 nT for H, Z and total field components and at intervals of 2' for declination.

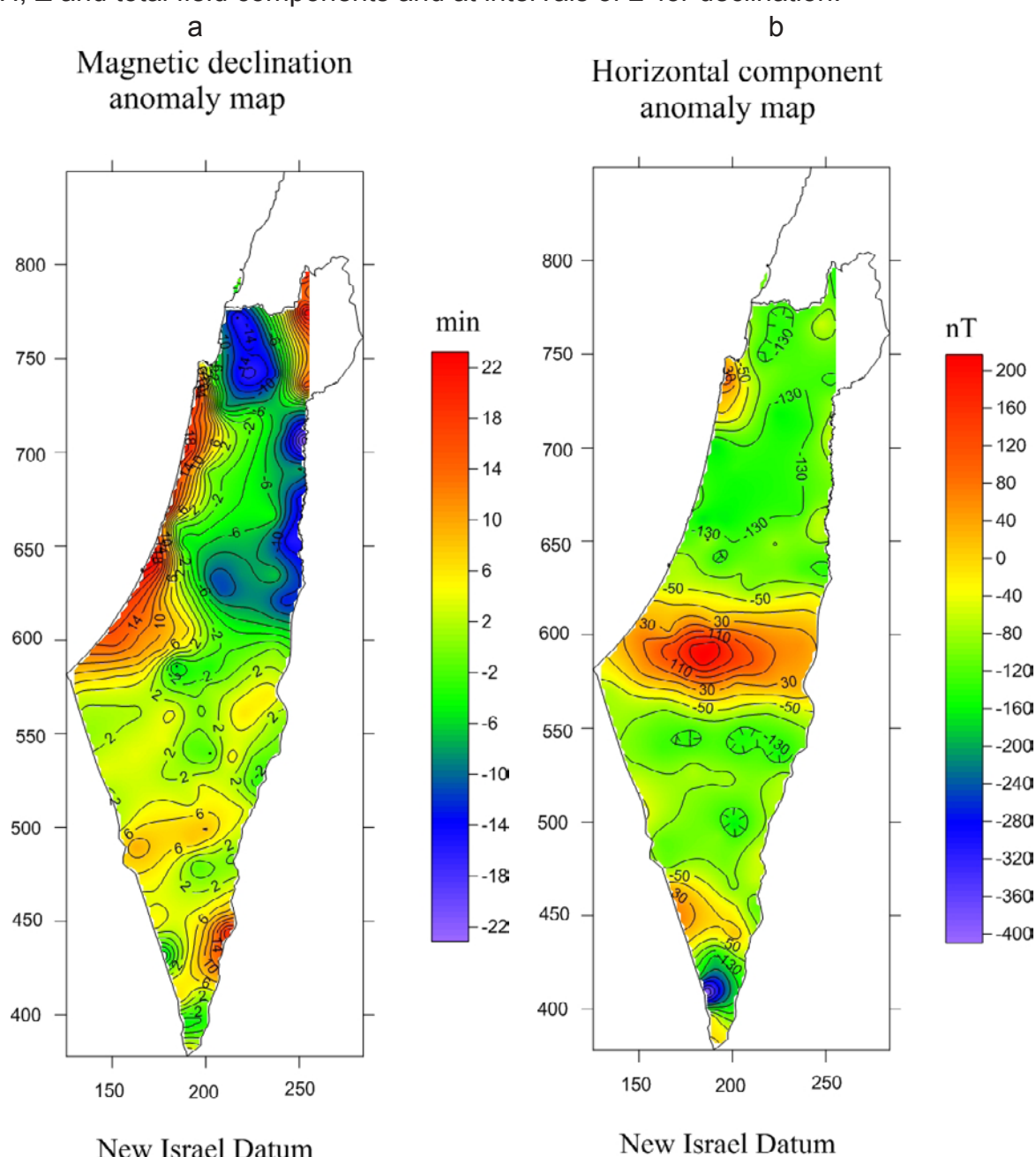


Fig. 16: Magnetic declination (a) and horizontal component (b) anomaly maps

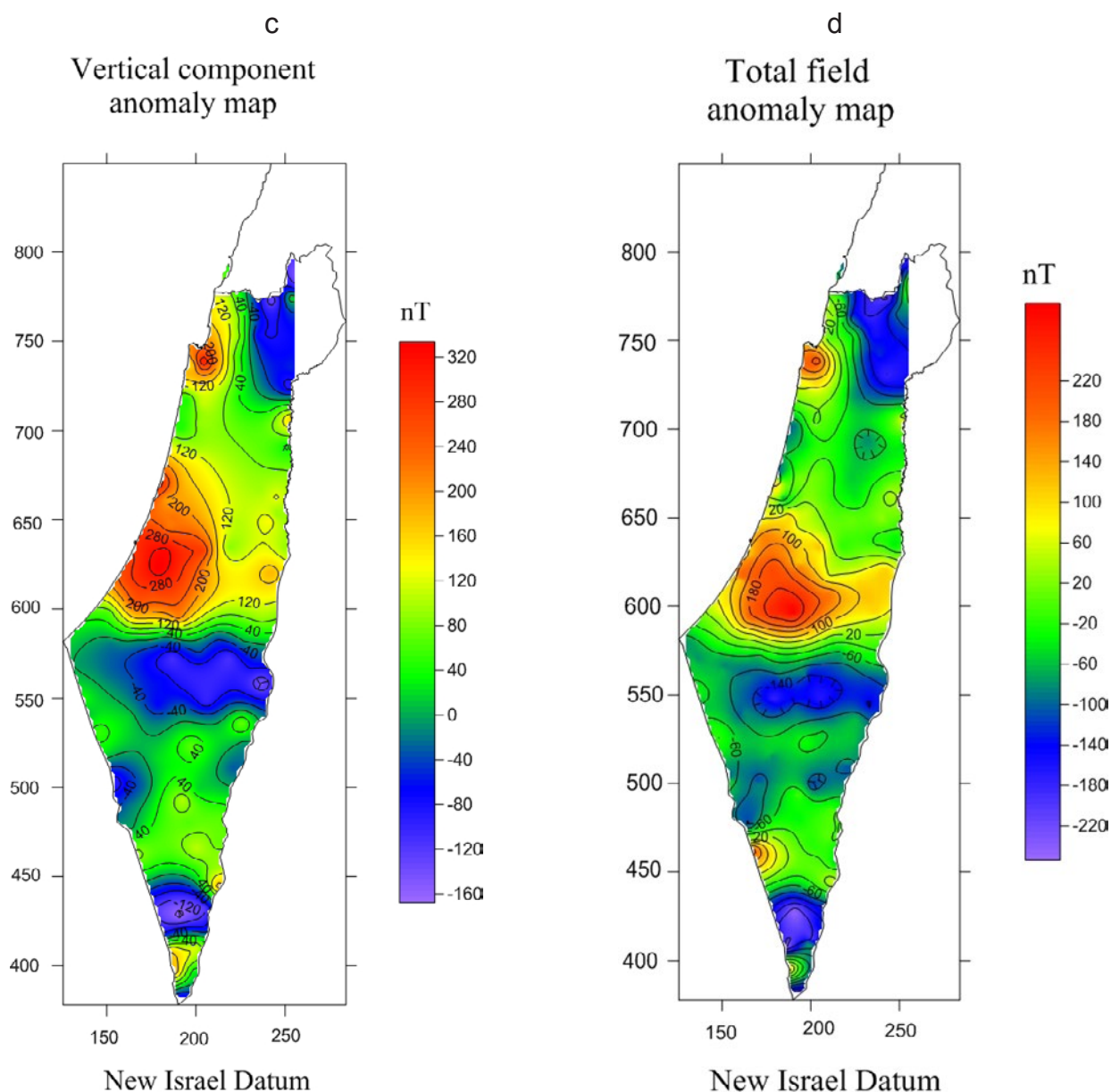


Fig. 16: Vertical component (c) and total field (d) anomaly maps

Below is a brief description of significant anomalies. A positive anomalous zone along the coastal areas of the Mediterranean Sea was detected in the declination. Maximum values in this area are superior to almost half the value of a degree of negative anomalies in the eastern region of Israel (Fig. 16a). The central part of the country is governed by the H-component of the Hebron anomaly. It peaks at about 200 nT against a background of about (–100 nT) (Fig. 16b). The Z component in this area undergoes a change from positive values in the north part of the area to negative values in the south part.

This induction anomaly is caused by the huge underground body with high magnetization. The modeling in the framework of the inverse problem, based on the land and aerial magnetic mapping, was implemented by Faina Nikonova. The model is presented by two bodies with the linear size of about 100 km at the depth of about 10 km. (Figure 17a).

Another example also demonstrates the link of the anomalous magnetic field with geological structures. The Fig.17b shows a detailed map of magnetic declination in the territory of the Negev. The magnetic anomalous zone is allocated to the linear structure of the north-east direction. It is interesting to note that this zone of the magnetic field coincides with area of major tectonic faults. The direction of the fault (according to Geological Shaded-Relief Map of the Negev area) indicated by brown lines in Fig. 17b.

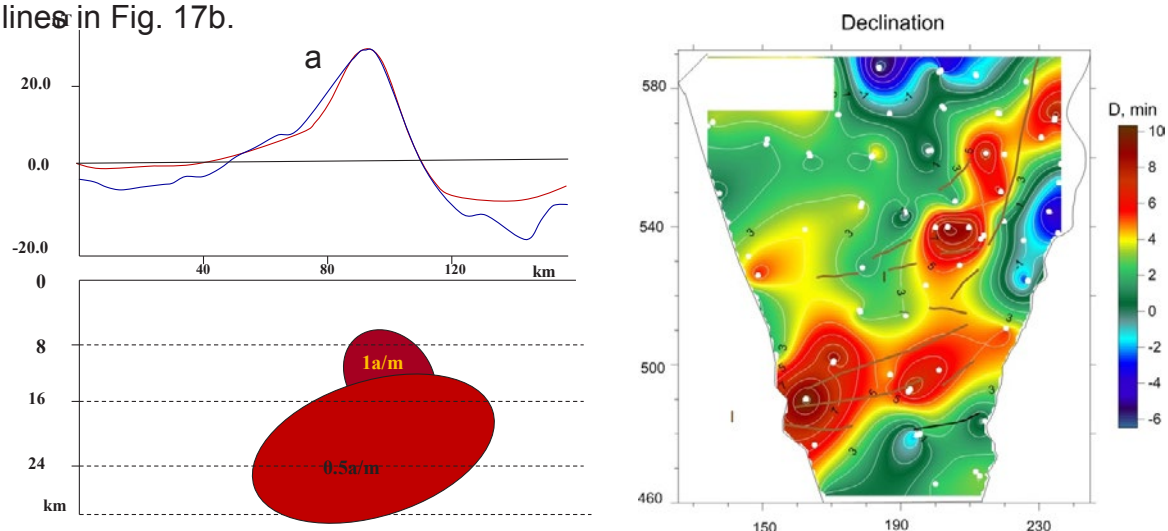


Fig. 17a: the top panel shows two curves: the blue one represents the profile of the aeromagnetic survey across the center of the anomaly and the red is the calculated field due to the two bodies depicted in the bottom panel. The bottom panel shows two ellipsoid representing the body, creates a magnetic anomaly. Horizontal and vertical dimensions are shown in different scales.

b: detailed map of anomalous field in declination, white dots indicate the stations of the network, brown lines indicate the direction of the main faults. Several intense anomalies of 100–200 nT in H and Z components and about 10 min. in declination are observed in the southern region. The positive Carmel anomaly, which peaks at about 200 nT in the vertical component, stands out in the northern part of the country.

7. Magnetic field variations

Sources of magnetic variations with a period between several minutes to several days are electric currents in the magnetosphere and ionosphere. A typical magnetogram from the Bar-Gyora observatory is shown in Fig. 18. Periodic changes are solar quiet (Sq) variations and non-periodic bursts of magnetic fields stem from magnetic storms.

7.1 Diurnal Sq variations

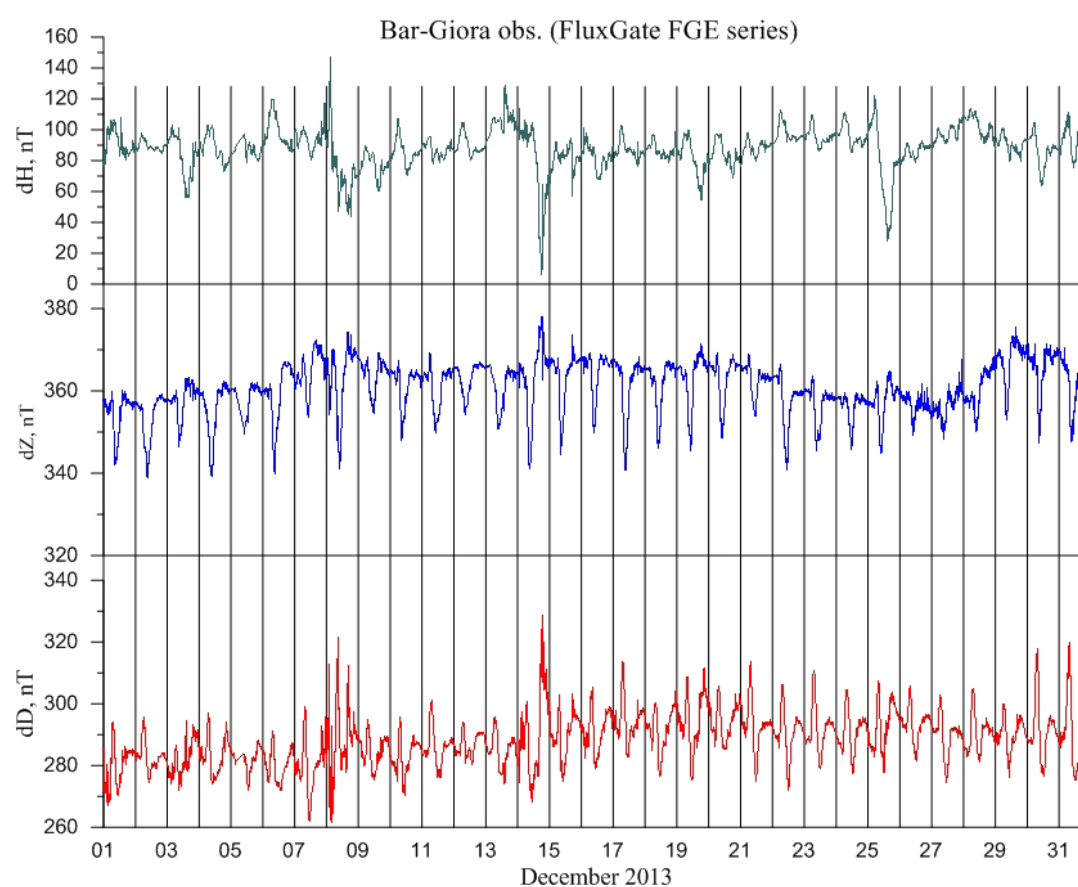


Fig. 18: Monthly recording of H, D, and Z variations at Bar-Gyora observatory.

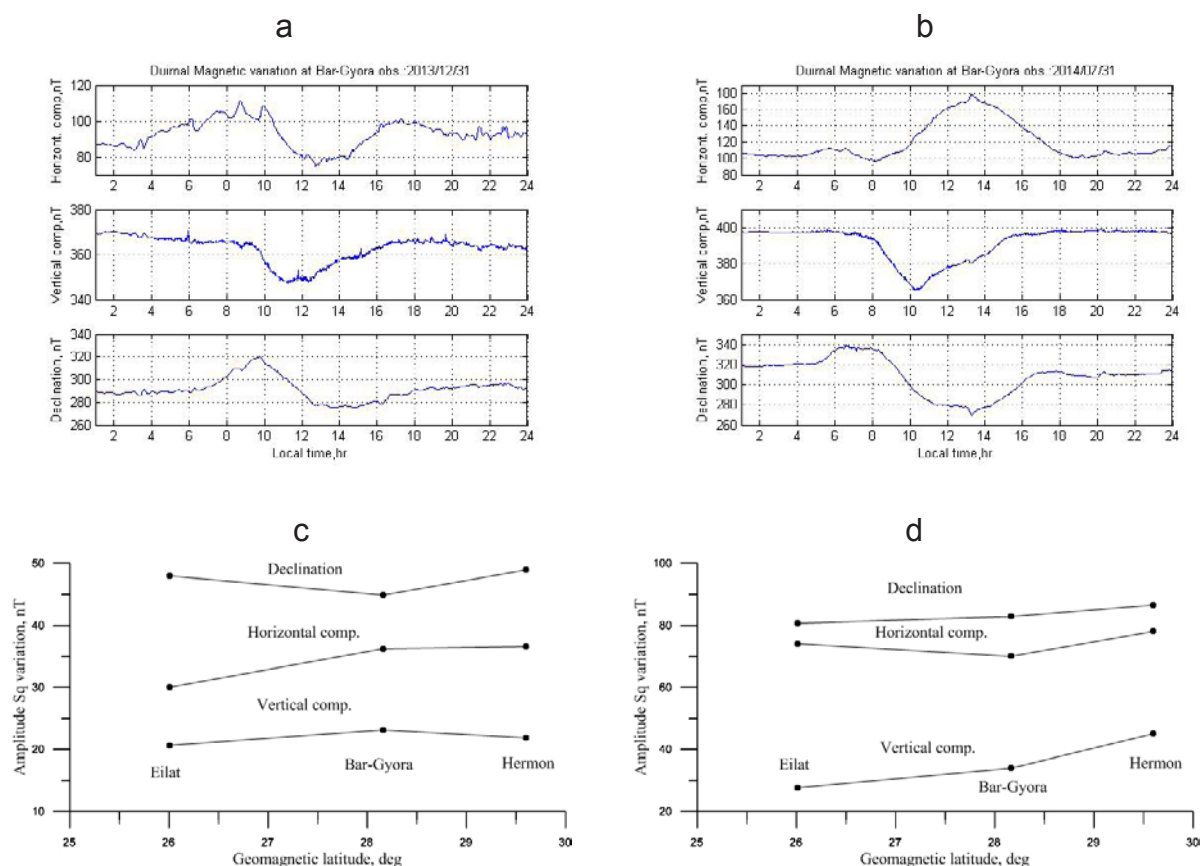


Fig. 19a,b: Diurnal variations at the Bar-Gyora observatory over the winter (a) and summer (b) periods;
 d,c: dependence of the amplitude variations with latitude according to the Eilat, Bar-Gyora and Hermon observatories for the corresponding periods (a, b).

The electric currents responsible for the generation of Sq variations flow in a narrow layer of the ionosphere at an altitude of about 100-130 km from the Earth's surface. Fig. 20a shows current streamlines of an equivalent Sq current as seen from the sun at noon. This current configuration is fixed to the sun, while the earth rotates beneath it. A total current of about 140 kA flows within one daytime vortex. The Sq current depends on season. The summer vortex is intensified compared with the winter vortex that reaches into the winter hemisphere. The center of the vortex of the day side is located approximately at latitude 30° , therefore our observatories pass in its daily motion under the center of the vortex.

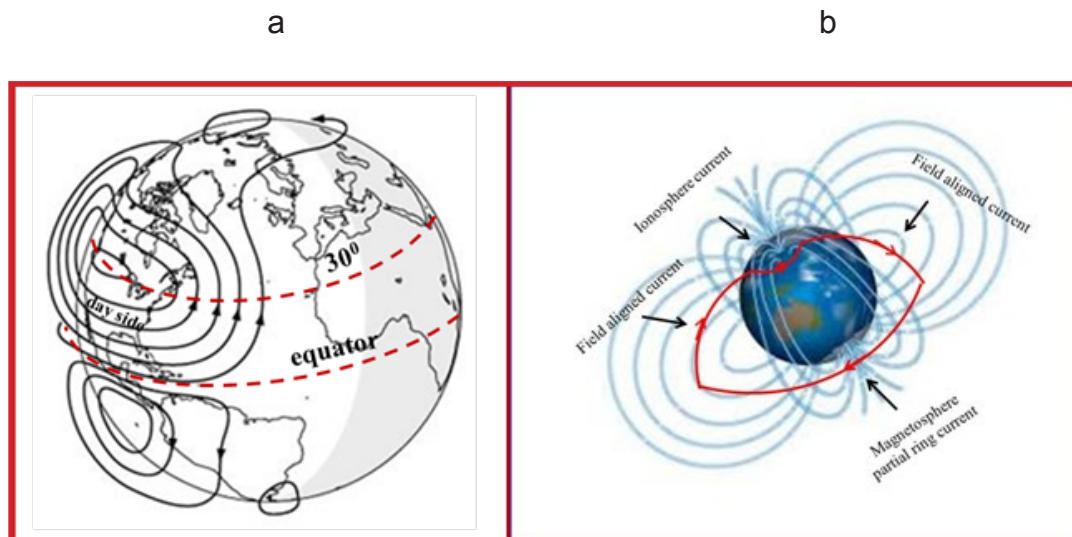


Fig. 20 a: Diurnal variations in the sunward ionosphere produced by electric currents;
b: Model of magnetic storm produced by the global electric current.

(https://en.wikipedia.org/wiki/Ionosphere#E_layer)

7.2 Magnetic storms

Another type of variations recorded on standard magnetograms is magnetic storms. The cause of magnetic storms is sun bursts. As a result, the solar plasma stream reaches the Earth and produces inside the magnetosphere an electric current which reaches millions of amperes. The current system responsible for magnetic storms is located in the polar ionosphere ("The ionosphere current" in Fig. 20b). Therefore, the most intense variations during magnetic storms are observed at high latitudes. The main source of magnetic field variations in the mid-latitude during magnetic storms are field-aligned currents (currents along the magnetic field lines in Fig. 20b), (Shirman, 1979). However, during the strongest storms, the impact of the polar currents is significant even in the mid-latitude. Fig. 21 shows such an event: the magnetic storm recorded at the Eilat observatory which occurred in January 2005. This magnetic storm was characterized by a sharp change in the field within a few hours and thereafter it characterized by the recovery phase within a few days. During the initial phase, the amplitude of the variations in the H component reached almost 300 nT at the Eilat observatory. From the comparison of the recordings from the Eilat, Bar-Gyora and Hermon observatories it follows that the amplitude of the H and Z components increase in the north direction. (Fig. 22).

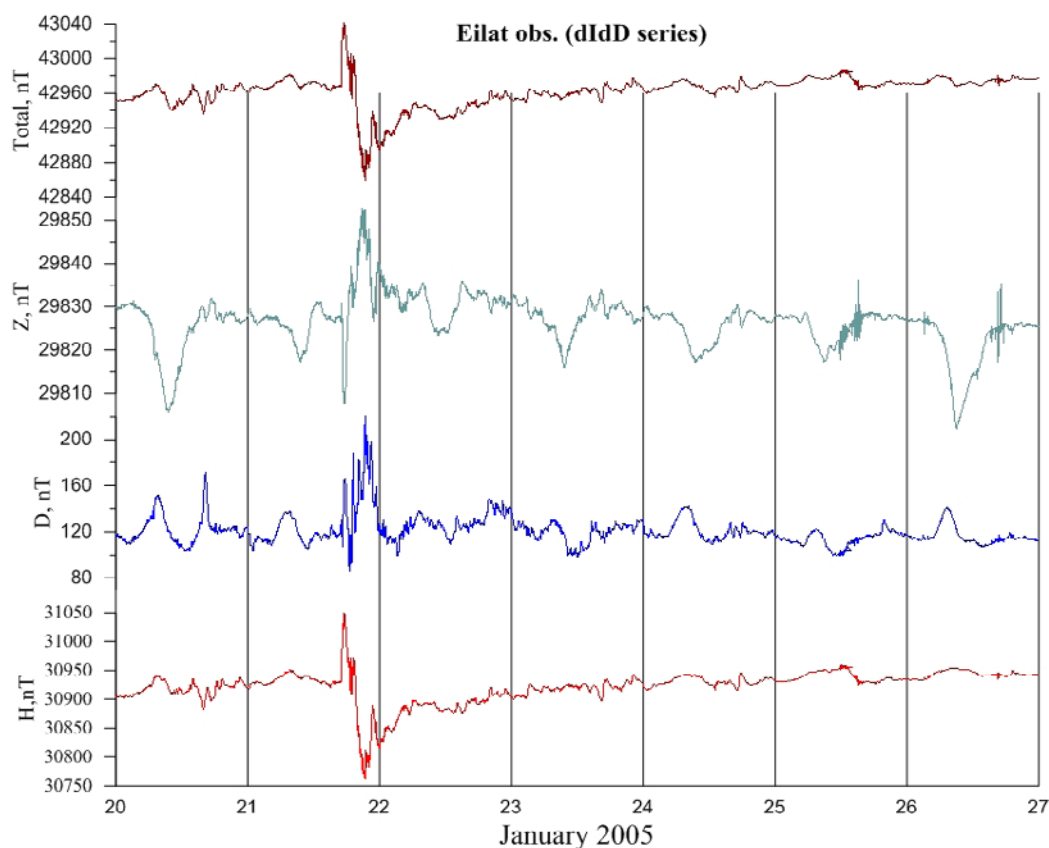


Fig. 21. Magnetic storm during 21-24 January 2005, recorded at the Eilat observatory.

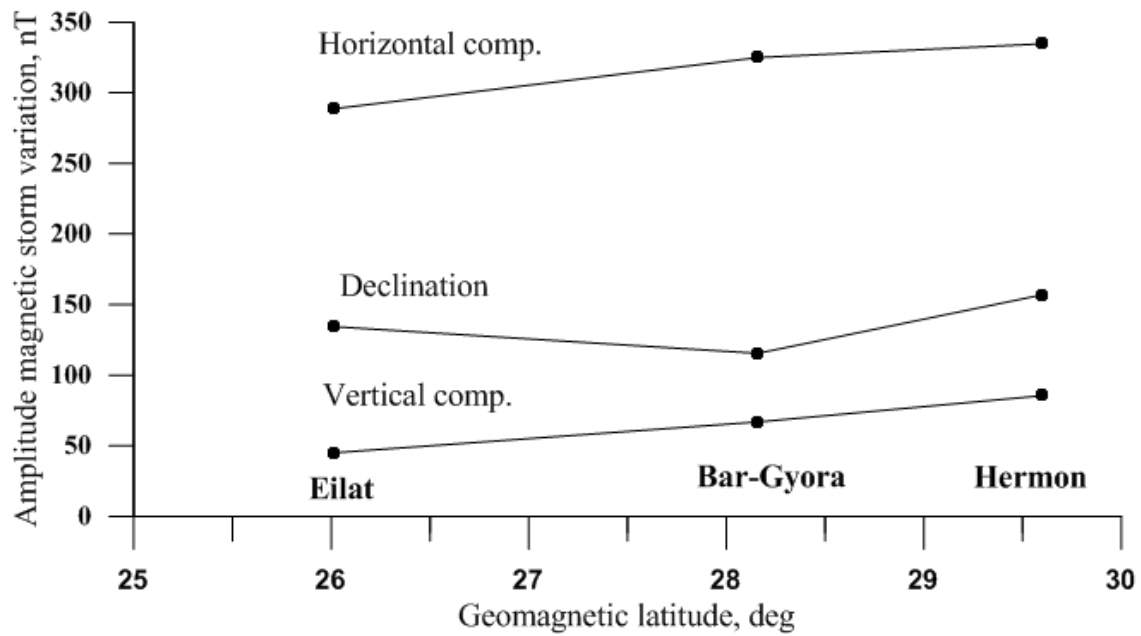


Fig 22. The amplitude of magnetic storm variations at the Eilat, Bar-Gyora and Hermon observatories, 21 January 2005.

8. A brief overview of geomagnetism projects with the participation of the Survey of Israel

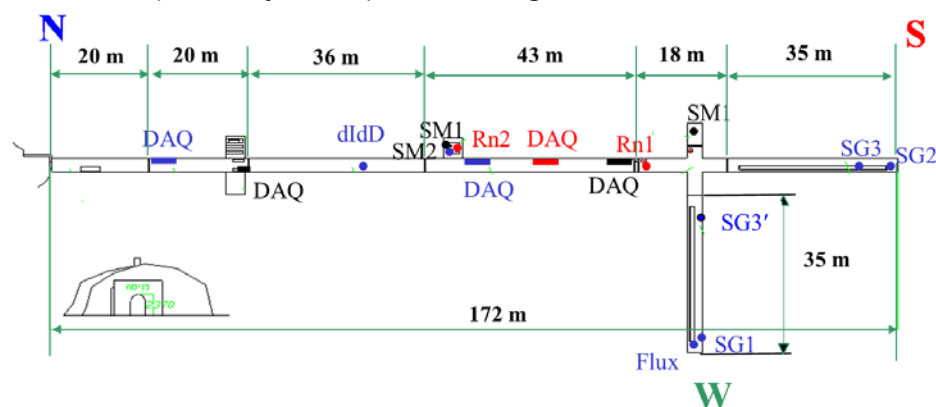
8.1 Supersensitive Magnetic Gradiometer

(Sponsored by Canada- Israel Industrial Research and Development Foundation).

The Supersensitive Magnetic Gradiometer is the most promising Instrument for Monitoring of Earthquake Related Magnetic Field Signals.

Long-term precise magnetic observations are being carried out at the Eilat test site as part of a multi-sensor geophysical monitoring program for active tectonic faults.

A super-sensitive potassium total field magnetic gradiometer (GSMP-20S3) was installed in a horizontal 170-m man-made in-rock tunnel used for a long time as a geophysical observation site. Three GSMP-20S3 sensors with intrinsic noise of $0.05 \text{ pT Hz}^{-1/2}$ constitute a horizontal gradiometer. The distance between the sensors varied in the range 3–50 m, in order to test the system operation in real field conditions (Fig.23). Continuous magnetic component measurements are implemented with the help of the dIdD (GEM Systems) vector magnetometer.



Equipment layout in the geophysical tunnel

Flux – Fluxgate magnetometer	Rn1,2 – radon sensors
SG1,2,3 – SuperGrad sensors	DAQ – control and data acquisition equipment
dIdD – component Overhauser magnetometer	SM1,2 – seismometer sensors
DAQ – control and data acquisition equipment	DAQ – control and data acquisition equipment

Fig. 23: Equipment layout in the Eilat geophysical tunnel. Three GSMP-20S3 sensors SG1, SG2, SG3 are placed at the southern part of the tunnel.

Our results show gradiometer time series, apparently containing residuals of external diurnal and high frequency variations, which are essentially homogeneous over such short distances. The residual amplitude makes up less than 0.6% of the change in intensity of the external magnetic field but can be distinctly revealed thanks to extremely high gradiometer sensitivity. A 'cleaning' procedure based on mutual regression analysis of the gradiometer and vector magnetometer time series, which was found to be an effective tool for reducing the influence of an external variation, was proposed.

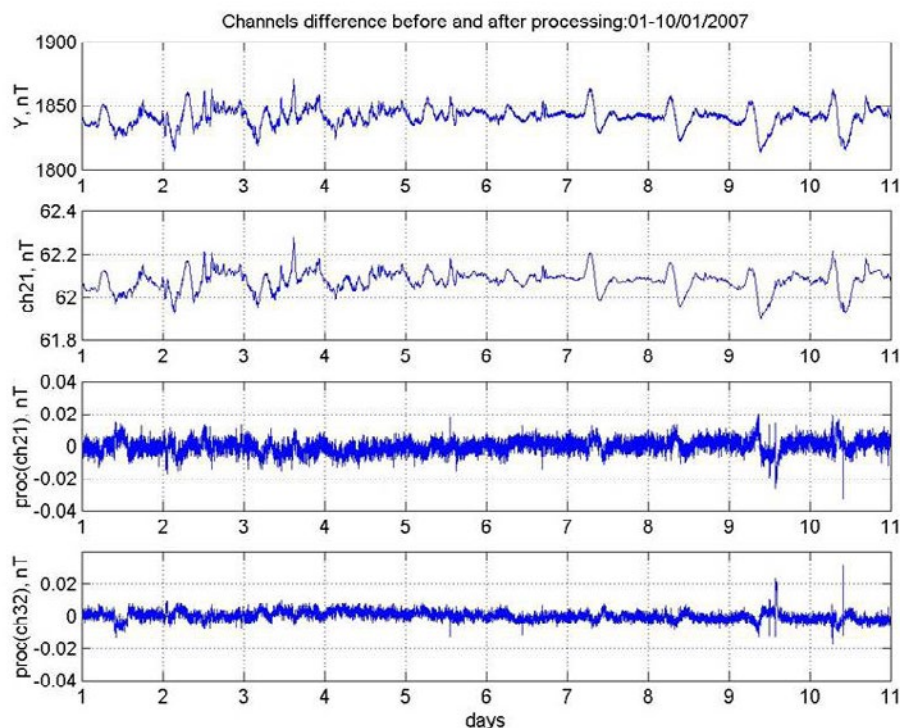


Fig. 24: Result of the “cleaning” procedure.

The two top graphs show the identity of Y-variation (West-East direction) of the external field, recorded by dldD-magnetometer and the difference between two sensors inside the tunnel registered by Super gradiometer. At the bottom the same differences are shown, after implementing the procedure of “cleaning” of the influence of external variations (Fig. 24) (Shirman and Ginzburg, 2004).

Later interest in the research of active tectonic faults was stimulated by the study of the strong magnetic anomaly located 800 meters southern of the tunnel. The magnetic anomaly was detected as a result of a ground survey carried out in the accessible part of the Amram massif. In this area measurements of the rocks susceptibility were made. Rocks (monzonite) with high magnetic susceptibility, which generate an induction magnetic field ($\sim 50 \cdot 10^{-4} \text{SI}$) were detected (Shirman et al., 2015, Ginzburg and Shirman, 2011). The aeromagnetic survey (Fig. 25) provides a complete picture of the magnetic anomaly gives. The magnetic body of horizontal dimension N-SXE-W $\sim 300\text{m} \times 700\text{m}$ generates an inductive anomaly field that contributes to the heterogeneity in the tunnel area.

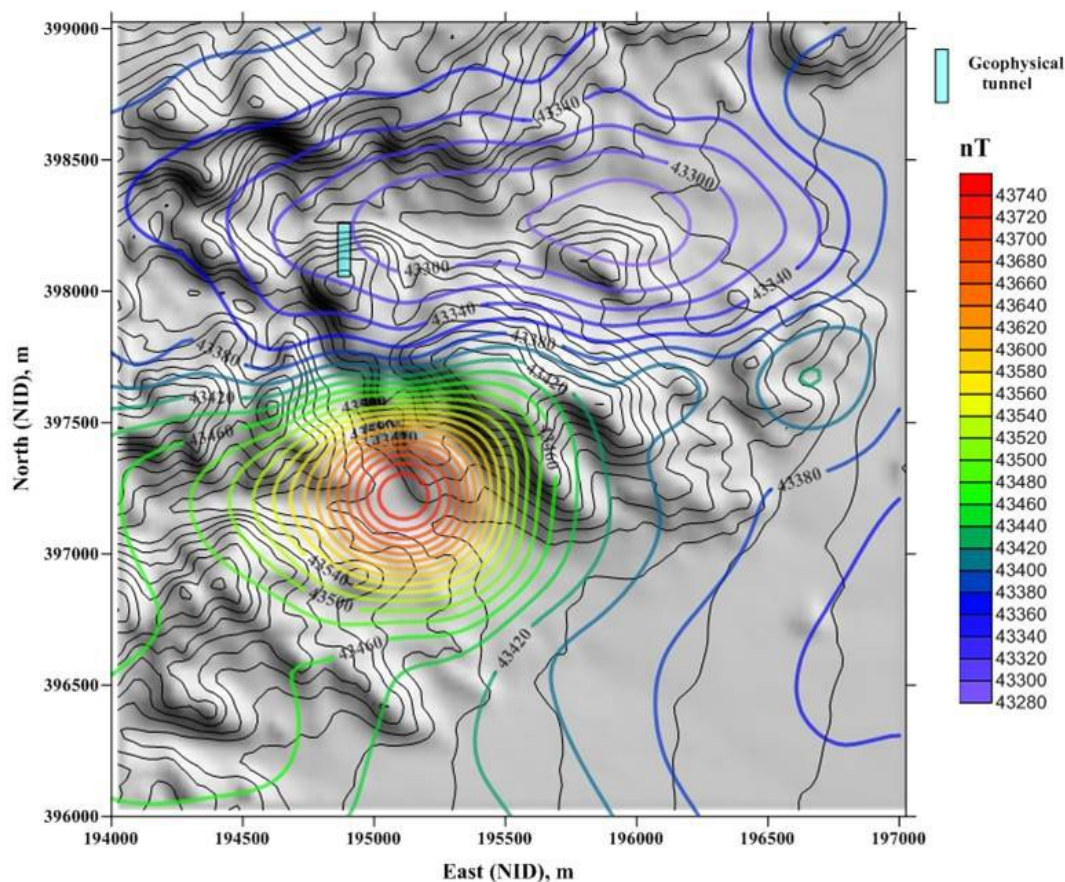


Fig. 25: Aeromagnetic map on the background of the Amram massif shaded relief

On the other hand, the magnetic body situated between faults may be a sensitive element for the tectonic stresses registration, as the result of the reverse magnetostriction phenomenon.

Since the beginning of the project (2000) did not happen in Israel a strong earthquake with a magnitude of more than 5; that is, we had no chance to test the effectiveness of the proposed method. However, there is no doubt that nowadays the Supersensitive Magnetic Gradiometer is the most promising Instrument for Monitoring of Earthquake Related Magnetic Field Signals.

8.2 Detection of sinkholes along the shores of the Dead Sea

(Together with the Institute of Geophysics)

Sinkholes are a serious hazard in the Dead Sea region. They started appearing in the area in the last two decades due to the dramatic drop in the Dead Sea's water level and soon became a major problem for commercial and industrial development. Sites with large, open sinkholes and collapse features have been identified throughout a wide region. The most alarming cases are sinkholes that have occurred recently in resort areas, on and around Highway 90, and at the Israeli and Jordanian potash plants. Several geophysical methods have been employed to investigate and predict such occurrences, including seismic, geoelectric, EM and microgravity methods.

In order to design a magnetic survey, we simulated possible observed anomalies over a buried cavity inside low magnetization media ($40 \times 10^{-5} \text{SI}$). (Rybakov et.al., 2005). The magnetic inclination of the area is $\sim 46^\circ$; hence, a normally magnetized body produces a standard dipole anomaly, a positive/negative pair with the low to the north, and the location of the source body at the inflection point of the anomaly. In the case of a nonmagnetic cavity, we look for the opposite effect (the negative anomaly, Fig. 26 b) . A number of field tests confirmed the concepts.

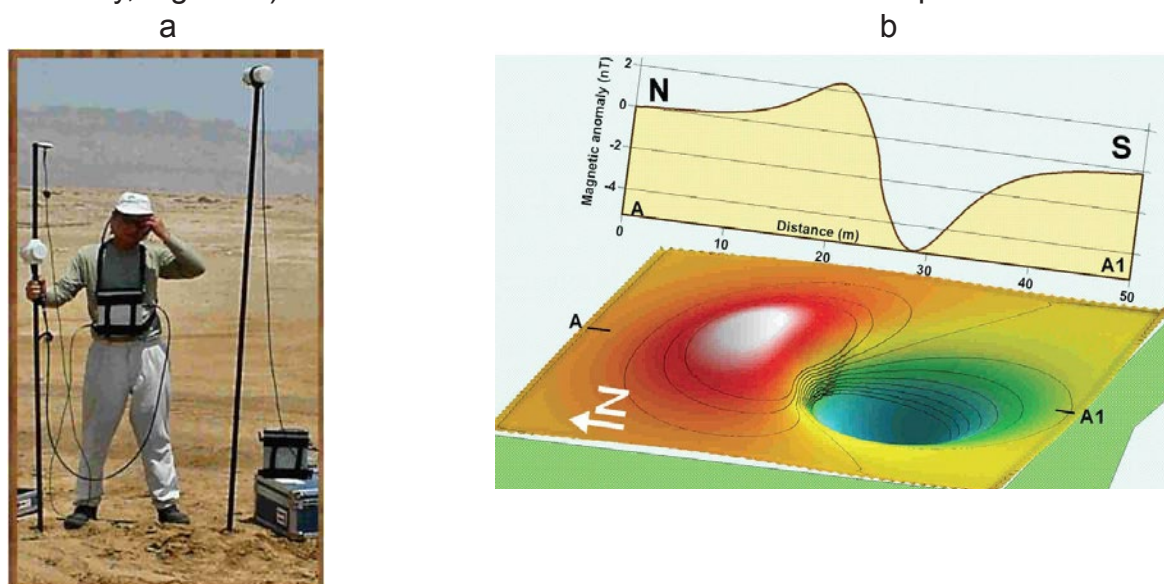


Fig. 26 a: Magnetic survey using the GSM-19 v7.0 total field magnetometer in the west coast of the Dead Sea;
b: Synthetic magnetic anomaly caused by concealed cavern in low magnetic media;

The magnetic inclination of the area is $\sim 46^\circ$; hence, a normally magnetized body produces a standard dipole anomaly, a positive/negative pair with the low to the north, and the location of the source body at the inflection point of the anomaly. In the case of a nonmagnetic cavity, we look for the opposite effect (the negative anomaly, Fig. 26 b). A number of field tests confirmed the concepts.

Magnetic surveys were conducted at five sites with different geologic settings (i.e. alluvial fans, mud flats). The field measurements were carried out using a total field magnetometer and a magnetic susceptibility meter. Sinkholes were recognizable in the data. The surveys also indicated that most collapse features correlated with known tectonic lineaments. Hence, the magnetic method appears to be an efficient method for predicting the sinkholes, and a valuable tool for prediction along existing tectonic elements. (Rybakov et al., 2006).

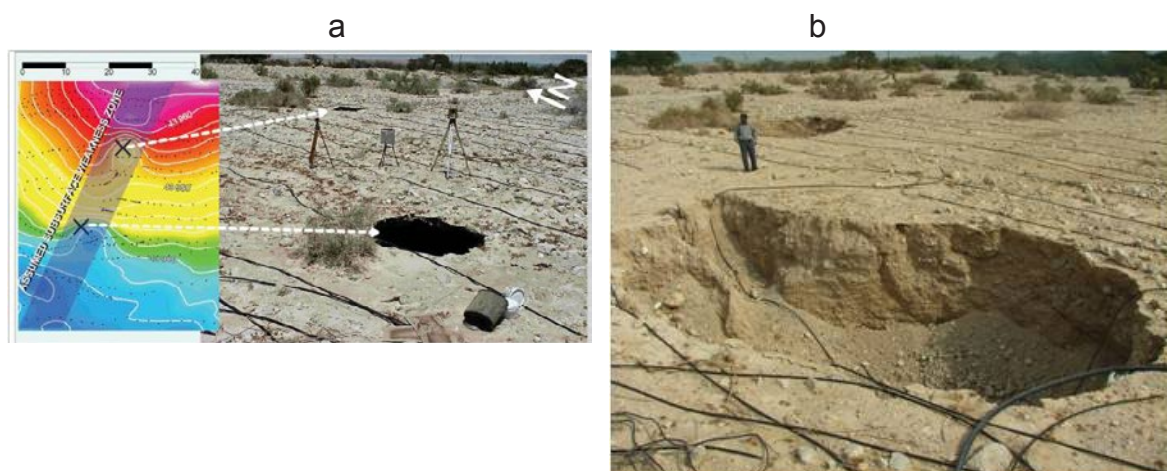


Fig. 27: Neve Zohar site. Here, magnetic measurements were conducted.

a) Two small sinkholes have recently opened. High-resolution magnetic map (contour interval 2 nT) shows magnetic anomalies caused by the sinkholes. Magnetic mapping made on 05.05.2004 indicated a subsurface weakness zone as the potential development of sinkholes in the area.

b) During a later visit (15.11.2005) we detected an increase in sinkholes.

8.3 The Establishment of a Space Weather Research Infrastructure in Israel

(A scientific project in cooperation with Tel-Aviv University, and the Ministry of Science foundation).

It is well known that the rapid change of the magnetic field caused by magnetic storms induces electric fields that can damage power grids, lead to a breakdown in communication, etc. The main objective of space weather monitoring is to forecast strong magnetic storms, and related phenomena. Thanks to satellite data, it is possible to find correlations between the parameters in the solar wind and the changes in the Earth's magnetic field and to make predictions based thereupon. In our study, we used data from the Israeli magnetic observatories, as well as data of ACE satellite. Advanced Composition Explorer (ACE) spacecraft orbits the L1 libration point which is a point of Earth-Sun gravitational equilibrium about 1.5 million km from the Earth and 148.5 million km from the Sun. From its location at L1 ACE, it has a privileged view of the solar wind, the interplanetary magnetic field (IMF) and the higher energy particles accelerated by the Sun, as well as particles accelerated in the heliosphere and the galactic regions beyond. At the L1 point, the orbital period of the satellite becomes exactly equal to the Earth's orbital period. We have considered that several strong magnetic storms link the rapid changes of the magnetic field at the Israeli magnetic observatories with the parameters of interplanetary space. One of the examples of fast magnetic disturbances during magnetic storm is presented in Fig.28 and Fig.29

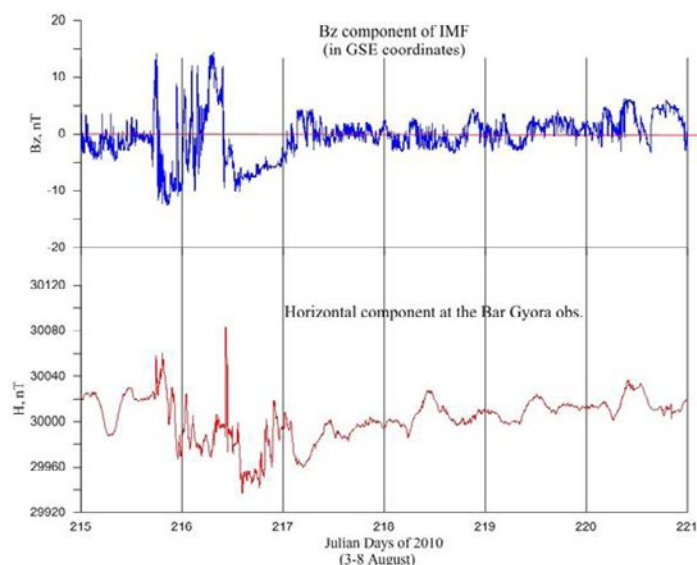


Fig. 28: Comparison between the IMF and the magnetic storm appearance.

Fig. 28 shows a recording of a magnetic storm at the magnetic observatory and the vertical component of the interplanetary magnetic field recorded at the satellite. There is a correspondence between the growth of the vertical component (B_z) of the IMF and the appearance of the storm at the observatory.

Our attention was drawn to the sharp pulse on the background of the magnetic storm recorded on August 4th, 2010. A detailed examination of these phenomena is shown in Figure 29a and 29b. From comparison of records, it follows that the appearance of magnetic disturbances is due to the growth of proton flux density and proton temperature. There is no doubt in the existence of this connection. Indeed, at the distance of about 1,555,000 km, where the satellite orbits the Earth, the average speed of the solar wind is about 550 km/sec. Thus, the time required for solar wind flow to achieve Earth's magnetosphere is 47 minutes. Such a delay in the relative changes in the solar wind parameters during the magnetic storm appearance we see in Fig. 29a and 29b. Further study is necessary to identify the characteristic features of the interplanetary medium parameters that cause magnetic storms on the earth surface.

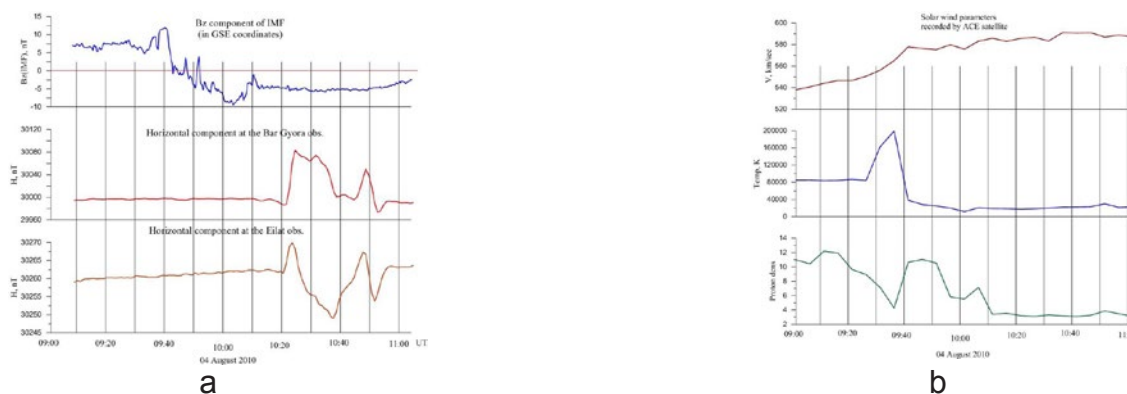


Fig.29 a, b: The connection between the recorded pulse at magnetic observatories and parameters in the solar wind.

8.5 Magmatic Exposures in Arava.

Volcanism in Israel and the Sinai is characterized by dykes, intrusive complexes and a few volcanic fields. The current study was aimed at examining magmatic exposures along the western margins of the Central Arava region (Wadi Ashosh, Tzukim and Menuha) and their surroundings areas and to locate their subsurface sources, by means of gravity, magnetic and seismic data interpretation.

Field data acquisition concentrated on detailed high-resolution land magnetic survey at five sites in the central part of the Arava Valley. More than three thousand magnetic measurements provided the necessary data for state-of-the-art study of the subsurface structure of the area. The collected magnetic measurements allowed us to characterize important magmatic events (Ginat et.al., 2014).

The survey was conducted across the magmatic and volcanoclastic outcrops using an Overhauser total field magnetometer, GSM-19. The magnetic property of rocks (susceptibility) was measured in the outcrops using bridge-kappa meter KT5 simultaneously with the magnetic field measurements. The land survey was complemented by magnetic susceptibility measurements on outcrops of magmatic and sedimentary rocks. High magnetic anomalies connected to a magmatic intrusion and volcanic bodies were found.

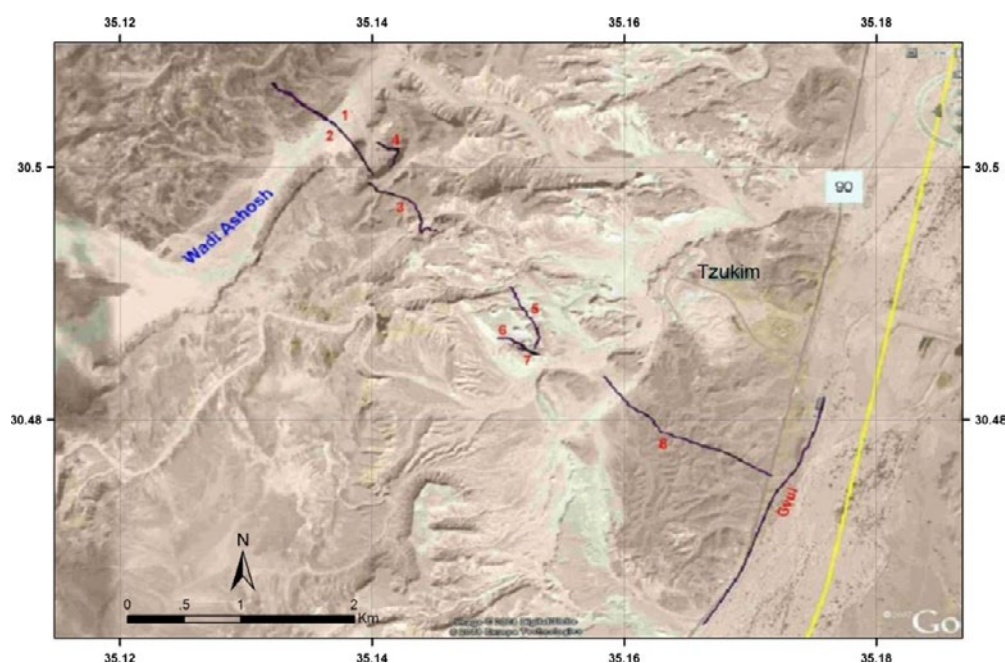


Fig. 34: An overview of the topography of the study area and location of the new magnetic measurements.

More than three thousand points measured along 9 profiles in the vicinity of the Tzukim settlement. Topographic data were used to compile the elevation profile and to illustrate observed magnetic anomalies on the rough relief (Fig.34).

High frequency magnetic anomalies in the NW part of the profile correspond to the exposed Ashosh igneous rocks characterized by high magnetic susceptibility. A very strong magnetic dipole (magnitude of about 1000 nT) in the central part of the profile was observed for the first time. The relatively featureless magnetic field in the SE part of the profile suggests the absence of magmatic bodies in the shallow subsurface. A low frequency magnetic anomaly (magnitude of about 200 nT) indicates a relatively deep magmatic body in the southern part of the line. One of the consequences of this work is the assumption that magmatic activity is probably related to geological activity associated with the early opening of the Red Sea prior to, or concurrent with, the initiation of motion along the Dead Sea Fault.

Conclusion

The importance of the magnetic observatory is determined by the length of its continuous operation during many years. So, forty years of continuous measurements of the magnetic field within the requirements of the IAGA international association is a significant achievement. Survey of Israel operates today three magnetic observatories which provide the high quality data to both commercial and academic users. We also run the net of permanent magnetic stations, which is the basis for the magnetic mapping, (particularly, the declination) and for maps adjustment over the time. Two of our observatories, Bar-Gyora and Eilat, play a significant role in the expansion of the global network of digital magnetic observatories, both for attaining improved global field modelling and for locally implementing the data.

Acknowledgments

The author expresses his gratitude to the staff of the Research Division, which participated in the magnetic and geodetic measurements over the years, and also expresses its thanks to Prof. Yaron Felus, the chief scientist, for his valuable remarks upon reading the manuscript, to Mrs. Rachel Saranga - for editing text in Hebrew, to Mrs. Lea Ezra, for the graphic design of the manuscripts, to Mrs. Elena Rubinstein, for her assistance in locating archival documents.

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תקציר

רשת המצפים המגנטיים העולמית

השדה המגנטי של כדור הארץ ממלא תפקיד חשוב בביוספירה של כדור הארץ. השדה המגנטי מקיף את כדור הארץ ומגן עליו מפני קרינה קוסמית, מחד, אולם סערות מגנטיות עלולות לפגוע במערכות טכניות שונות, כגון אספקת חשמל, תקשורת ועוד, מאידך. מעקב אחר היציבות של השדה המגנטי הגלובלי מתבצע באמצעות רשת המצפים המגנטיים. בשנת 1834 נערך כינוס בגטינגן, גרמניה, בו יזם "מלך המתמטיקה", קארל גאוס, את הקמתה של רשת המצפים המגנטיים הגלובלית. בעזרת רשת זו החלו במקומות רבים בעולם לבצע תצפיות שיטתיות של השדה המגנטי של כדור הארץ. אחד המשכילים הגדולים של תקופה זו, אלכסנדר הומבולדט, שכנע את הצאר הרוסי ליצור רשת של תחנות מגנטיות מהעיר ייקטרינבורג דרך הרי אורל עד לסיביר. בהמשך הקימה האימפריה הבריטית, בראשותו של סר אדוארד סבין, רצף תחנות מגנטיות מקנדה לטסמניה. מאז הקמת הרשת הגלובלית של המצפים המגנטיים ניתן היה לקבוע את השדה המגנטי של כדור הארץ ולהעריך את המקורות הפנימיים והחיצוניים של השדה. הרשת הנרחבת אפשרה לבנות מודל גלובלי ראשוני של השדה המגנטי, וגם לאפיין את הסערות המגנטיות הגלובליות. היום, כ-180 שנה אחרי הממצאים של גאוס וחבריו, ניתן לקבוע כי השדה הגלובלי ירד בהדרגה, כשישה אחוזים במהלך מאה השנים האחרונות. אם מגמה זו תימשך ללא שינוי, בעוד 1500-2000 שנה מהיום יחול היפוך בקוטביות המגנטית של כדור הארץ, דבר שיוביל לאסונות בלתי צפויים בביוספירה.

מצפים מגנטיים בישראל

המצפים המגנטיים של מדינת ישראל מהווים חלק מרשת המצפים המגנטיים העולמית. ניטור קבוע של השדה המגנטי בישראל החל עם פתיחתו של המצפה המגנטי באמציה בשנת 1976. קדמו לאירוע זה מדידות של דקלינציה מגנטית (הזווית בין המשטח של המרידיאן הגאוגרפי לבין הכיוון של וקטור השדה המגנטי) החל משנות ה-20 של המאה עשרים. המצפה השני בבר-גיורא נפתח בשנת 1989. שני המצפים, אמציה ובר-גיורא, עבדו במקביל במשך כמה שנים. כיום המדידות המגנטיות מתבצעות בשלושה מצפים: הר חרמון, בר-גיורא ואילת. מצפה בר-גיורא הוא המצפה המרכזי שלנו, והשניים האחרים, הר חרמון ואילת, קשורים לפרויקטים שונים. הנתונים המתקבלים מהמצפים בר-גיורא ואילת נשלחים מדי שנה למרכזי נתונים עולמיים.

נעשה שימוש בנתונים מהמצפים המגנטיים בישראל בתחומים רבים, כמו ניווט אווירי, חיפוש מינרלים, מחקרים גאולוגיים וגאופיזיים, ועוד. התחזוקה של המצפים המגנטיים מתבצעת על ידי עובדי תחום מחקר של המרכז למיפוי ישראל. במקביל לעבודה השגרתית במצפים, צוות תחום מחקר עוסק בפרויקטים מחקריים שונים, לאומיים ובין-לאומיים, כגון: מחקר בנושא מזג אוויר קוסמי, חקר ההיסטוריה הגאולוגית באזורים וולקניים בערבה, זיהוי בולענים בעזרת מגנטומטריה לאורך חוף ים המלח, ועוד.

מטרות ניטור השדה המגנטי בישראל:

1. קביעת דקלינציה מגנטית בכל מקום בישראל ובניית מפות מגנטיות ארציות, תוך ביצוע תיקונים על פי השינויים בשדה המגנטי, מדי שנה.
2. ביצוע מדידות מגנטיות לפי דרישה מארגונים חיצוניים (למשל מערכת הביטחון, תעופה צבאית ואזרחית ועוד).
3. אספקת נתונים מגנטיים מהמצפים למרכזי נתונים העולמיים.
4. אספקת נתוני שדה מגנטי לעבודות מחקר בתחומים שונים, כגון גאולוגיה, גאופיזיקה, ארכיאולוגיה ועוד.
5. ביצוע מחקרים (מגניטומטר-גראדיאומטר סופר רגיש, מבנים גאולוגיים עמוקים, גילוי מנהרות ועוד).

מדידות היסטוריות של דקלינציה מגנטית בישראל

מדידת דקלינציה מגנטית (או כיוון ל"צפון המגנטי") היא תהליך פשוט יחסית והייתה אמצעי יעיל לניווט במשך מאות שנים. זה עשוי להסביר מדוע המדידות הגאומגנטיות הראשונות היו מדידות של דקלינציה. המדידות הראשונות של דקלינציה מגנטית במזרח הים התיכון בוצעו על ידי האדמירליות הבריטית בשנת 1918. הערכים של דקלינציה באזור החוף על פי מפות מהארכיון הלאומי של המרכז למיפוי ישראל הם: עתלית - $00^{\circ}15'W$; קיסריה - $00^{\circ}20'W$, יפו - $00^{\circ}25'W$; הנמל יבנה - $00^{\circ}20'W$. מאוחר יותר, בתקופת המנדט הבריטי (1917-1948), מדידות מגנטיות נעשו על ידי מחלקת המדידות של פלסטין. הערך של דקלינציה שנמדדה בנקודות מסוימות בחלק המרכזי של פלסטין היה בשנת 1936 $1^{\circ}15'$ מזרחה. מדידות דקלינציה בוצעו לאורך השנים ומספר תחנות המדידה הלך וגדל, ובשנת 1936 מספר התחנות הגיע ל-30.

בחודש מרס 1958 בוצעו מדידות של דקלינציה על ידי צוות מחקר ממחלקת המדידות של מדינת ישראל, בראשותו של זיסקינד פרלמן, בשלושה אזורים לאורך חוף ים התיכון: סמוך לבת-ים, ברמת אביב ובמרחק של כעשרה קילומטרים מזרחה לנתניה. הערך הממוצע של דקלינציה שנמדדה בתשע נקודות הסתכם ב- $2003'$. מאז פתיחת המצפה המגנטי הראשון באמציה, המעקב אחרי שינויי הדקלינציה נמצא בסדר עדיפות עליונה בפעילות המגנטית של מפ"י. בשנות ה-80 הוקמה רשת נקודות מדידה מגנטית שקיימת עד היום. מדידות בנקודות הרשת מתבצעות אחת לכמה שנים לצורך עדכון המפות המגנטיות. ברשותנו תוצאות של מדידות דקלינציה לאורך מאה שנה. במהלך תקופה זו הדקלינציה עלתה בכ- $50'$ לכיוון מזרח. קצב השינוי השנתי נע מ- $1'$ בשנות השבעים של המאה הקודמת עד ל- $5'$ בשנים האחרונות.

מיפוי מגנטי בישראל

לצורך יצירת מפות מגנטיות הוקמה בישראל רשת הכוללת כ-130 נקודות מדידה, בהנהגתה של גב' רנה סגל מהמרכז למיפוי ישראל. בשנים 1984 ו-1993 נערכו מדידות ארציות. בשנת 1984 כיסתה הרשת כמעט את כל שטחה של מדינת ישראל. אזור רמת הגולן היה יוצא מן הכלל עקב מגנטיזציה גבוהה מאוד ולא אחידה של סלעי הבזלת, דבר ששיבש את המדידות ואת פרשנות הנתונים המגנטיים. החישובים בוצעו בהתאם לנוהל הסטנדרטי. הווריאציות המגנטיות בוטלו על ידי חיסור הווריאציות של השדה המגנטי שנרשמו במצפים בר-גיאור או אמציה, הממוקמים באזור גאוגרפי מרכזי של ישראל. המדידות בשטח בשנים שצוינו לעיל היו בהתאם לדטום של מצפה אמציה. הנתונים הגולמיים קובצו ועובדו בשיטת קריגינג לרשת של נקודות במרווחים שווים של $8'Q$. ערך דקלינציה מגנטית משתנה

ממקום למקום בשטח. למשל לאורך חוף ים התיכון הערך של הדקלינציה הסתכם בשנת 2014 ב- 4.85° ובמזרח המדינה ב- 3.95° . הערך המקסימלי של דקלינציה בישראל הוא באזור חוף ים התיכון ובאזור הסמוך לרמת הגולן, והערך המינימלי הוא באזורים המזרחיים והדרומיים של המדינה.

אנומליות מגנטיות מקומית נגרמת על ידי גופים שהמגנטיזציה שלהם שונה מהמגנטיזציה של השכבה העליונה של קרום כדור הארץ. שדה האנומליה חושב כהפרש בין השדה המדוד והשדה הסטנדרטי IGRF. במיפוי שערכנו נמצאה אנומליה חיובית של דקלינציה לאורך חוף ים התיכון. האזור המרכזי של ישראל נשלט על ידי אנומליה מגנטית שהמוקד שלה ברמת חברון. האנומליה במוקד זה היא 200 ננוטסלה, והיא נגרמת על ידי גוף שגודלו הליניארי מסתכם בכמה קילומטרים ונמצא בעומק של כקילומטר אחד מתחת לפני הקרקע. כמה אנומאליות מגנטיות בגודל של 100-200 ננוטסלה נצפו באזור הדרום. באזור הר הכרמל נמצאה אנומליה חיובית ברכיב ההוריוזנטלי (H), שמגיעה למקסימום 200 ננוטסלה ברכיב האנכי (Z).

וריאציות מגנטיות שנרשמות במצפים מגנטיים בישראל

מקורות חיצוניים של השדה המגנטי של כדור הארץ (כלומר זרמים חשמליים במגנטוספירה וביונוספירה) מייצרים וריאציות מגנטיות עם מחזור קצר שנמשך מדקות עד ימים. הזרמים החשמליים האחראים על וריאציות עם מחזור של יממה זורמים בשכבה הדקה של היונוספירה בגובה של 100-130 קילומטר מפני כדור הארץ. סוג אחר של וריאציות שאינן תקופתיות, שנרשמות במצפה המגנטי, הן סערות מגנטיות. סערות אלה נגרמות על ידי זרמי פלזמה מהשמש שמגיעים לכדור הארץ ומייצרים בתוך המגנטוספירה זרמים חשמליים בעוצמה של עד מיליון אמפר. מעגל חשמלי ממגנטוספירה נסגר ביונוספירה פולארית, לכן הווריאציות עם אמפליטודות גדולות ביותר נצפות בקווי רוחב גבוהים. כאשר הסערה המגנטית חזקה, היא נצפית גם בקווי רוחב בינוניים, כלומר היא נרשמת גם במצפים המגנטיים שלנו.

ארבעים שנה של מדידות רציפות של השדה המגנטי בישראלי

חשיבותו של המצפה המגנטי נקבעת לפי הפעילות הרציפה שלו לאורך תקופה ארוכה. בהתאם לכך, ארבעים שנה של מדידות רציפות של השדה המגנטי במסגרת הדרישות של העמותה הבינלאומית IAGA, הן אירוע משמעותי. המרכז למיפוי ישראל מפעיל כיום שלושה מצפים מגנטיים בישראל. המצפים מספקים נתונים באיכות גבוהה למשתמשים מסחריים ואקדמיים. המרכז למיפוי ישראל גם מפעיל את רשת הנקודות המגנטיות, המהווה את הבסיס למיפוי המגנטי, ומכין מפות מגנטיות. למצפה בר גיורא ולמצפה אילת יש תפקיד חשוב בהרחבת הרשת הגלובלית של מצפים מגנטיים דיגיטליים. כמו כן הם מספקים חומר לתאום השדה המגנטי לצורך שימוש במחקרים ובשימושים שונים.