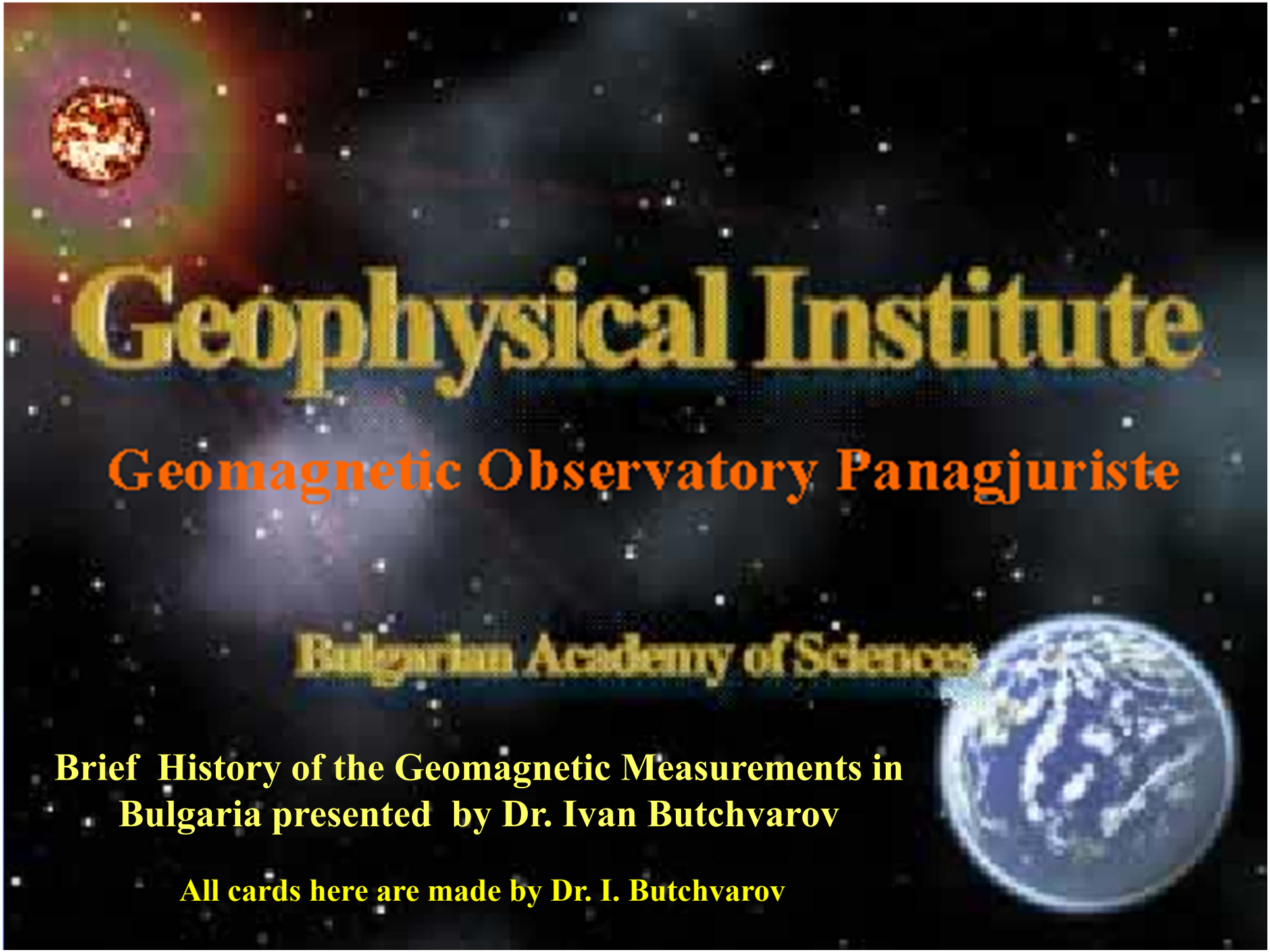

Geophysical Institute
Geomagnetic Observatory Panagjuriste
Bulgarian Academy of Sciences
Brief History of the Geomagnetic Measurements in Bulgaria presented by Dr. Ivan Butchvarov
All cards here are made by Dr. I. Butchvarov


Field and observatory
geomagnetic measurements
in Bulgaria
PAG
ВИДИН
Дунав
СИЛИСТРА
РУСЕ
ДОБРИЧ
ВРАЦА
ТЪРГОВИЩЕ
ШУМЕН
ВАРНА
ЛОВЕЧ
ВЕЛИКО ТЪРНОВО
ГАБРОВО
ПЕРНИК
СЛИВЕН
СТАРА ЗАГОРА
ЯМБОЛ
БУРГАС
КЮСТЕНДИЛ
ПАЗАРДЖИК
ПЛОВДИВ
БЛАГОЕВГРАД
ХАСКОВО
СМОЛЯН
КЪРДЖАЛИ
Географски институт - БАН, София, 2003

Historical geomagnetic measurements in Bulgaria

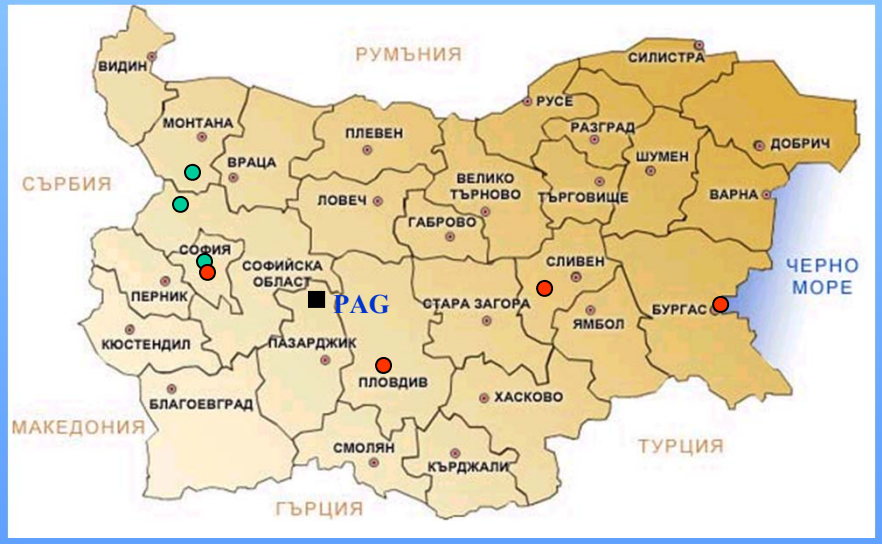
- The first geomagnetic measurements on the territory of Bulgaria were performed during the Russian-Turkish wars at the end of the 18th and the beginning of the 19th century: 1787 – 1791 and 1828 – 1832. Only the declination **D** was measured.
- Later in 1858 Dr. K. Kreil, director of the Central meteorological and magnetic survey in Vienna, made measurements of **D**, **H** and **I**, and in 1859 the Russian military officer Dikov measured **D**.
- A certain number of geomagnetic measurements on the Black sea were made too.
- Some of the measured values are presented in the following table:

Historical measurements of D

	Station	Month	Year	D		Station	Month	Year	D
1	Port Varna	●	1787	-15°00′	12	Karnobat	IX	1829	-11°20′
2	Varna Bay		1829	-11°00′	13	Aitos	IX	1829	-11°32′
3	on sea		1834	-11°00′	14	Burgas	IX	1829	-11°25′
4	Varna city	IX	1829	-9°50′	15	Burgas	○ IX	1858	-6°59
5	Varna city		1859	-7°00′	16	Burgas		1859	-6°36′
6	Baltchik		1859	-6°43′	17	Pomorie	○ IX	1829	-11°19′
7	Kavarna	● VI	1830	-10°12′	18	Sozopol		1859	-6°28′
8	Cape Kaliakra	● X	1858	-6°42′	19	Nesebar	IX	1829	-10°48′
9	Novi Pazar	V	1830	11°06′	20	on sea		1834	-9°30′
10	Provadia	VI	1830	-14°41	21	Jambol	● IX	1829	-11°35′
11	Dobritch	● V	1830	10°41′					

First Bulgarian geomagnetic measurements

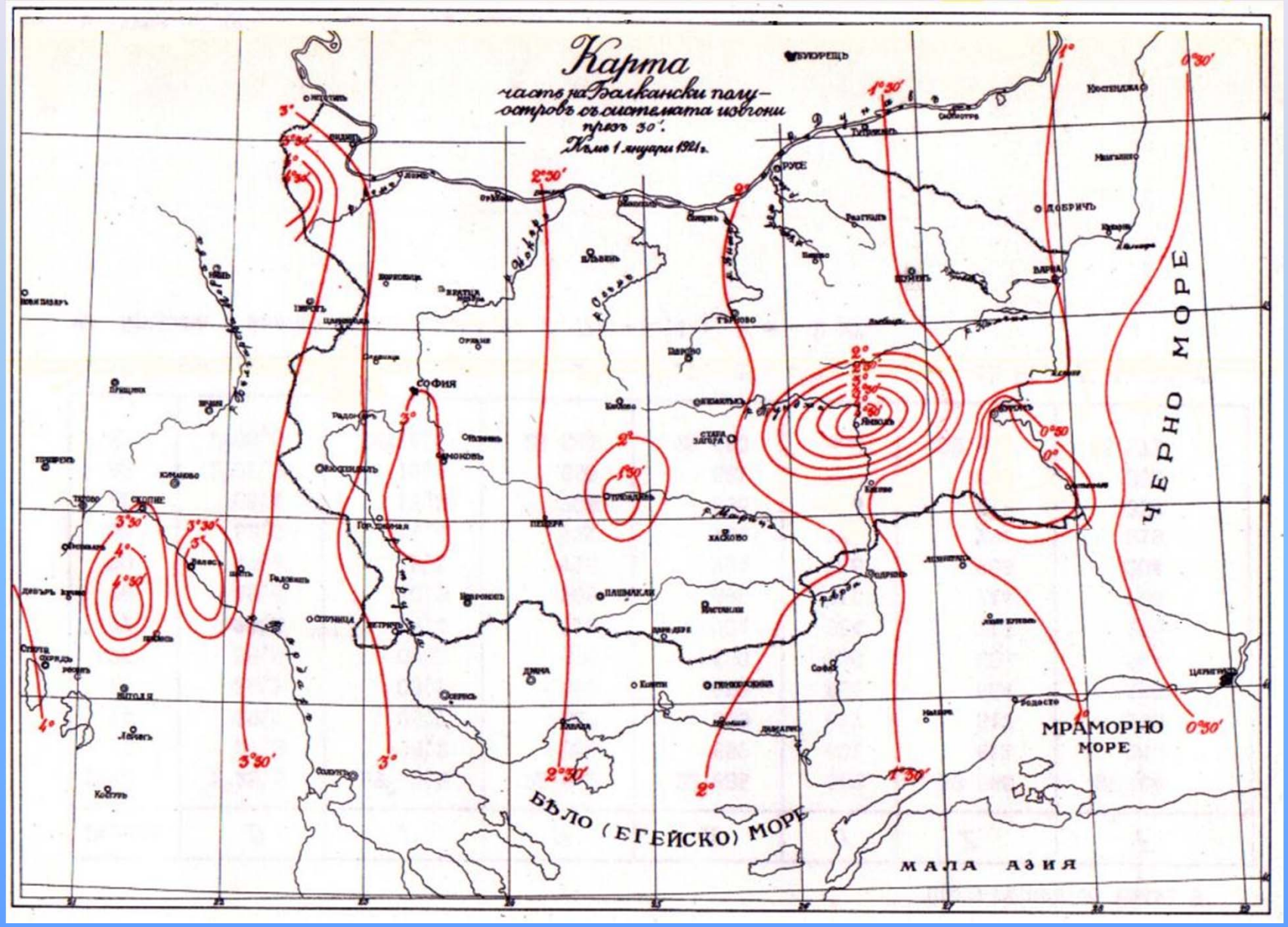
- During the 90's of the 19th century prof. Bahmetiev from the Sofia University performed registrations of the diurnal variations of **D** near Sofia, Petrohan and Berkovitza - ●.
- In 1911 specialists from the Carnegie Institution made measurements of **D**, **H** and **I** near Sofia, Bourgas, Nova Zagora and Plovdiv - ●.



First field Bulgarian geomagnetic measurements used for drawing maps

- Acad. K. Popov carried out the first systematic geomagnetic measurements during 1917 – 1920. The geomagnetic elements **D**, **H** and **I** were measured on **76** stations. The reduction from the diurnal variations were made using the data of Pula geomagnetic observatory.
- On the basis of these measurements the first geomagnetic map (of the declination **D**) on the territory of Bulgaria was drown.

The geomagnetic field of Bulgaria, epoch 1921.0
Declination – D (the values are negative)

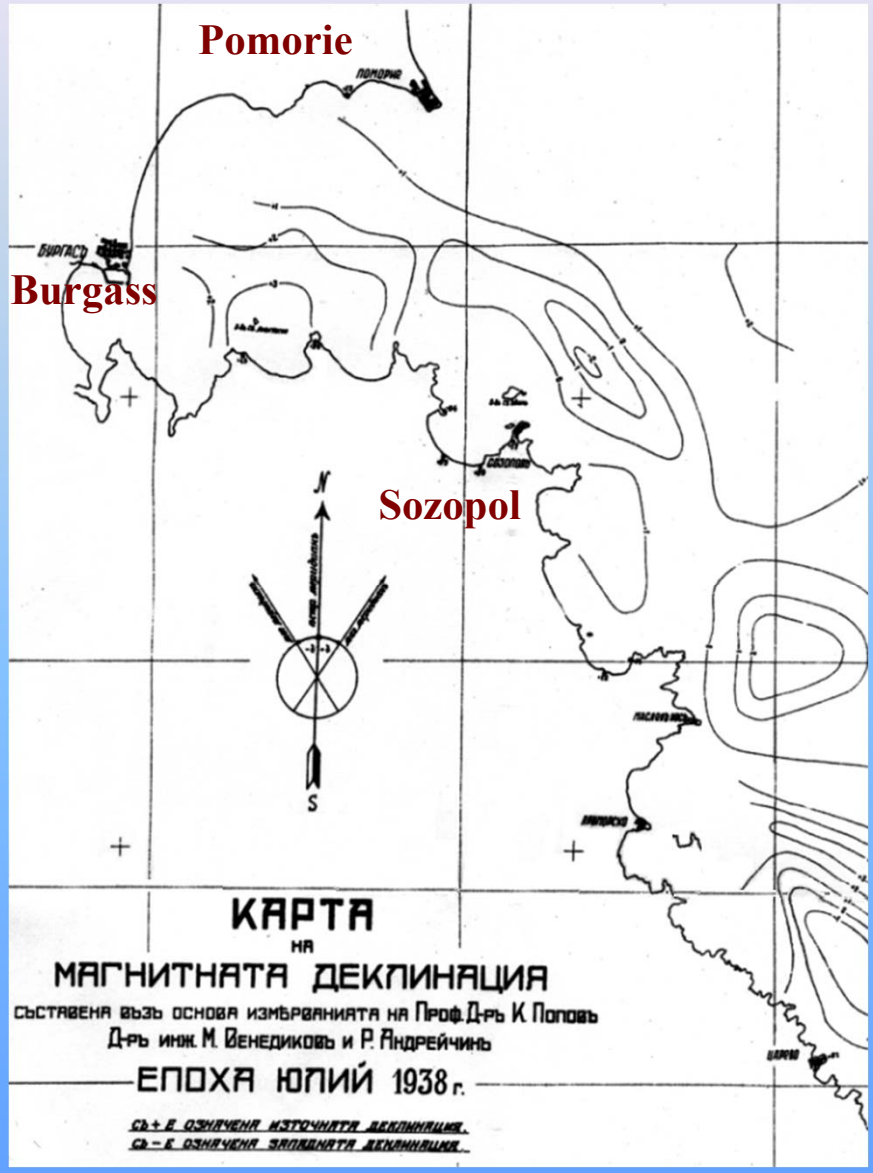


Field geomagnetic measurements in the 30's and in the beginning of the 40's

- In the 30's and in the beginning of the 40's of the last century, many geomagnetic measurements were performed on the territory of Bulgaria and on the Black sea shelf.
- One of the goals of these measurements was the selection of a place for constructing a geomagnetic observatory.
- 13 sites were proposed and the town of Panagjuriste was preferred. At that time, the Bulgarian Geomagnetic Survey was part of the Military Geographical Institute.
- The Observatory was constructed with the assistance of Dr. Fanselau from the Geomagnetic Institute, Potsdam, Germany.

The declination D on Bulgarian Black sea shelf

Epoch 1938.5



The opening ceremony of Panagjuriste geomagnetic observatory, 07.11.1937

Освещаване на Земно-магнитната станция край гр. Панагюрище.

Panagjuriste geomagnetic observatory

- There are 4 main buildings in the Observatory: the office building, two absolute houses and a relative one.
- All buildings were constructed very carefully. All used materials were tested for magnetic properties.
- The relative house is dug into the ground at approximately 2 *m* (8 feet).
- The relative house has a very good temperature isolation. The annual variation of the temperature in it is less then 2ºC.
- The following slides show these buildings:

The office building

Another view of the office building

The absolute house - 1 (exterior)

The absolute house - 2 (exterior)

The relative house (exterior)

Panagjuriste geomagnetic observatory equipment used in the past

- In the beginning the absolute values of the geomagnetic elements **D**, **H** and **Z** were measured by the geomagnetic theodolite **"Shultze-545"** and the registration of its variations were made by a single series of variometers **"Askania-Werke-AG"**, and a recording system **"Edelton"** using photo paper.
- An observatory Earth inductor **"Askania-Werke-AG"** with an optical galvanometer were supplied in 1945 and until 1965 the inclination **I** had been measured with it.
- In 1956 aditional series of variometers **"Mating & Wiesenberg"** were purchased for the registration of the geomagnetic field variations.

Panagjuriste geomagnetic observatory equipment and technology used between 1961 and 2007

In October 1961 the Geophysical Institute of the Bulgarian Academy of Sciences took over the administration of the Observatory. The following scheme of absolute geomagnetic measurements and registration of the geomagnetic field variations was accepted:

❑ Absolute measurements

1. The **Horizontal intensity** **H** was measured by an absolute geomagnetic theodolite **"Mating & Wiesenberg"** mounted on pillar № 1 according to the Gauss-Lamont method. The measurements were performed with three deviating magnets. The semi-period of oscillation of the deviating magnet was determined on pillar № 2 by using an electronic periodometer. Three **QHM** were used too. The accuracy was ~ 1 nT.
2. The **Declination** **D** was measured by the same geomagnetic theodolite **"Mating & Wiesenberg"**. The accuracy was ~ 0.15′.

- **Absolute measurements**

3. The **Inclination I** was measured by an observatory earth inductor **"Mating & Wiesenberg"** mounted on pillar № 6.

4. The **Total intensity F** was measured by means of a **Polish** proton magnetometer **PMP-2P**. The sensor was placed on pillar № 6 above the earth inductor only during the measurements . The accuracy was ~ 1 nT.

The absolute house – 1 (interior)

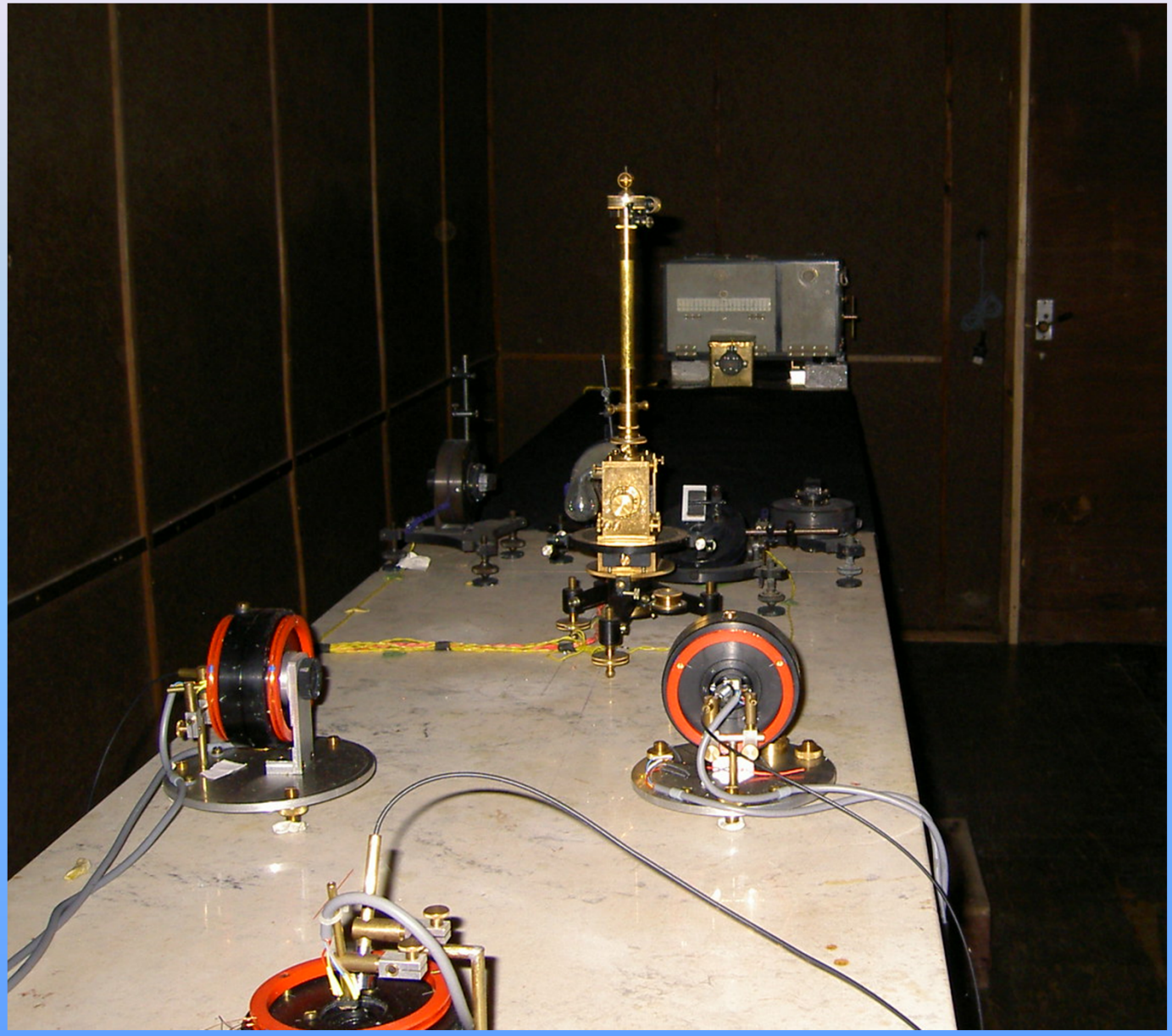
The absolute house – 2 (interior)

Registration of the geomagnetic field variations

Then there were two series of variometers in the variation house. **The main series was the western one.** There were 4 quartz type **"BOBROV"** variometers in each of the series for the registration of the **D**, **H**, **Z** and **F**. The variations were registered on photo paper: standard 48 x 20 cm, i.e. 20 mm/h. The recording instrument in the eastern series had two drums. The first one was with a normal speed of 20 mm/h while the second one – with a normal of 20 mm/h and furthermore with60 mm/h and 240 mm/h. The fast registration was used when making absolute measurements.

First series variometers (western system)

First series variometers from south

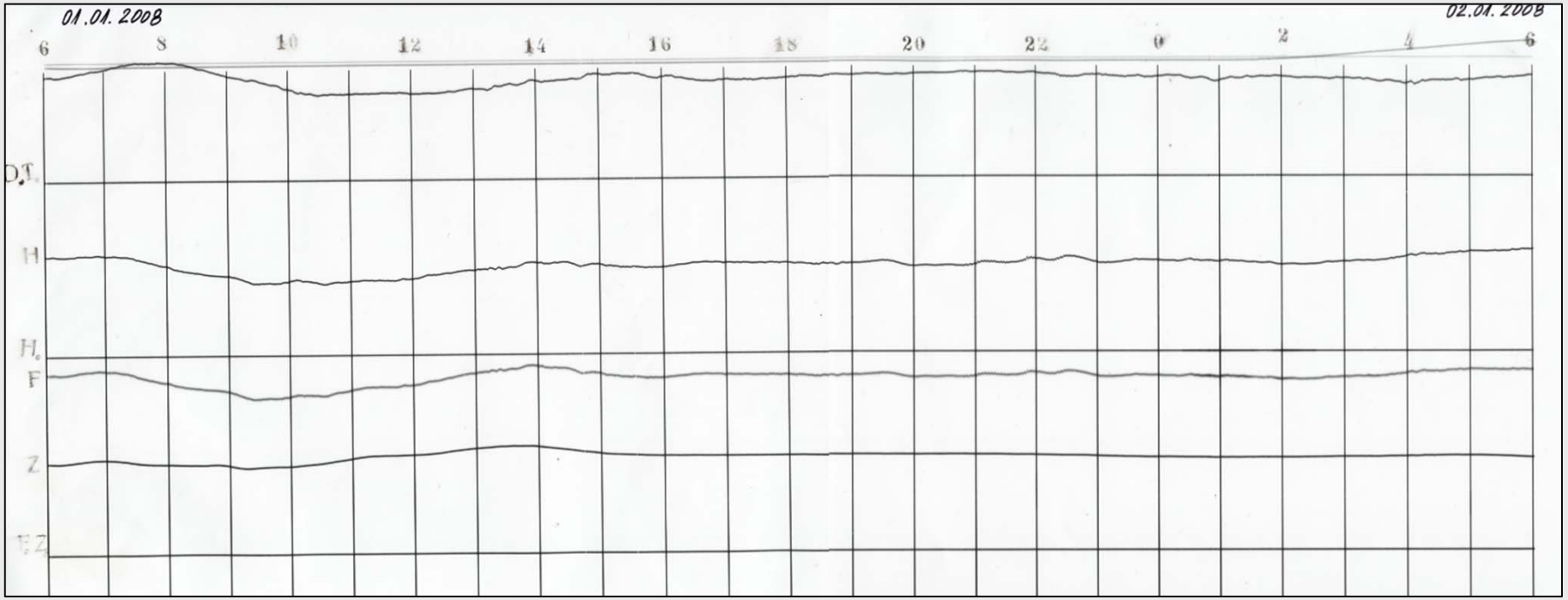


Second series variometers (eastern system)

Second series variometers from south

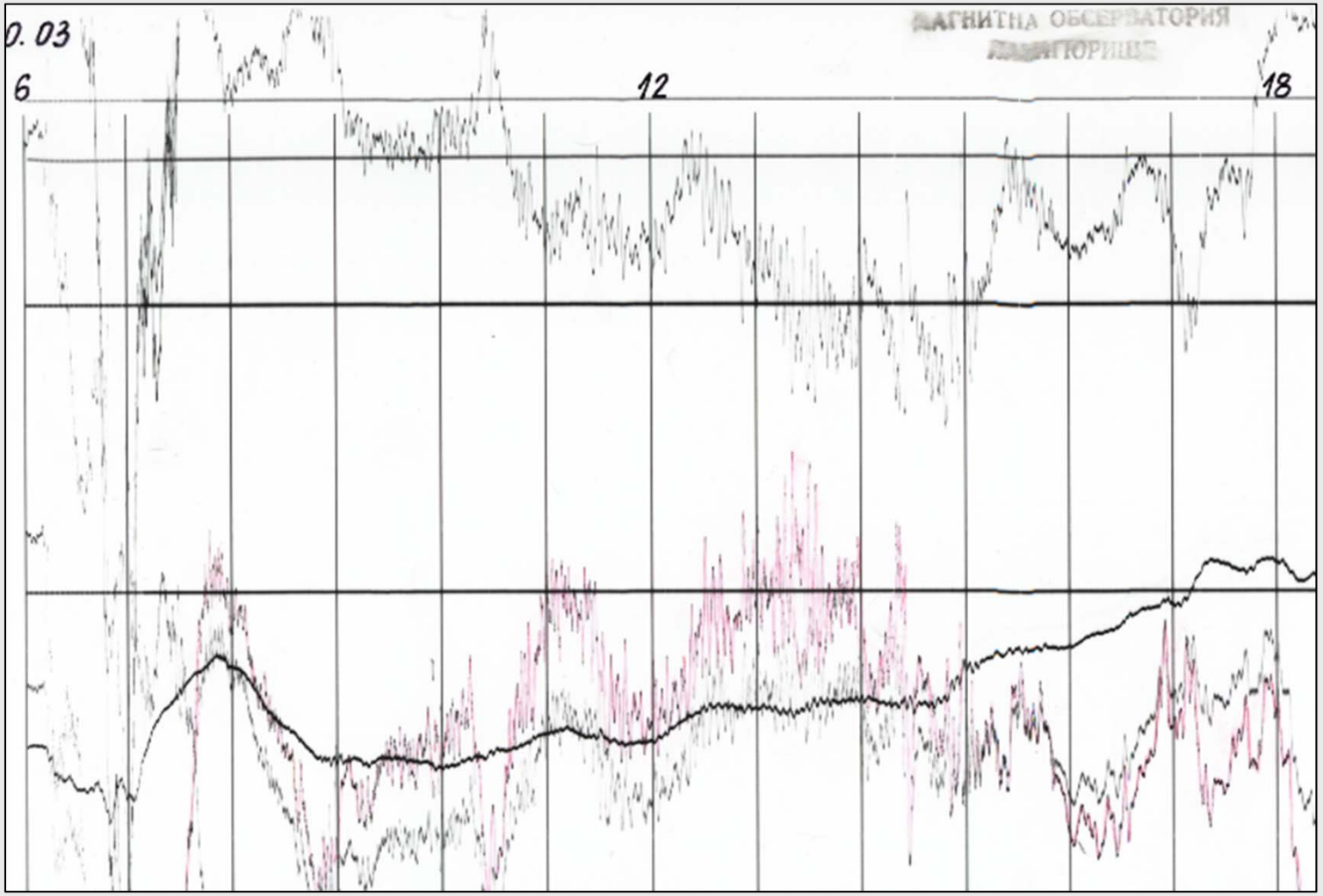
Registration of the geomagnetic field variations

Typical magnetogram in a quiet day:



Registration of the geomagnetic field variations

Typical magnetogram in a disturbet day:



Panagjuriste geomagnetic observatory equipment used after 2007

Between 2005 and 2007, all with the help of colleagues from the German observatory Nimegk, in Panagyurishte was installed and put into operation new digital equipment for measuring the absolute values of the geomagnetic field and the registration of its variations. Thanks to it observatory was included in the network **INTERMAGNET**.

❑ Absolute measurements

1. The **Declination** **D** and the **Inclination** **I** are measured by two **DI-flux (Zeiss theodolite THEO with Bartington MAG01H fluxgate)** one of them mounted on pillar № 1.
2. The **Total intensity** **F** is measured by means of an **Overhauser effect proton precession magnetometer GEM Systems type GSM19**. The sensor is placed on pillar № 6.

The absolute house – 1 (interior)

❑ Registration of the geomagnetic field variations

There are two series of variometers in the variation house. The **MAIN SERIES** consists of:

- **Suspended triaxial fluxgate DMI type FGE.**
- **Overhauser effect proton precession magnetometer GEM Systems type GSM90.**

ORIENTATION: **HDZ, F**.

DYNAMIC RANGE: **HDZ: +/-5,000 nT, F: 18,000 - 150,000 nT.**

RESOLUTION: **HDZ: 0.1 nT, F: 0.01 nT.**

SAMPLING RATE: **HDZ: 0.5 s, F: 5 s.**

FILTER TYPE: **HDZ: Minute mean values centered at sec 30,**
F: Minute mean values centered at sec 30.

The **BACKUP SERIES**:

- 3 component flux-gate magnetometer MAGSON.

- Overhauser effect proton precession magnetometer GEM Systems type SM90.

ORIENTATION: **XYZ, F.**

RESOLUTION: **XYZ: 0.1 nT, F: 0.01 nT.**

SAMPLING RATE: **1 s, F: 5 s.**

FILTER TYPE: **Minute mean values centered at sec 30.**

F: Minute mean values centered at sec 30.

The relative house (interior)

Comparative geomagnetic measurements

The magnetic level of the Panagjuriste observatory has been practically connected to the level of the Observatory "Adolf Scmidt" - Niemegk since the foundation of the Panagjuriste observatory till the present days. In the period 1934 - 1943 five comparative measurements were made in Niemegk with our magnetic theodolite **"Schulze-545"** and the earth inductor. Many measurements were done after World War II in Panagjuriste and in other observatories too (GCK, THY, MOS, KPR, SUA, CLF etc.). The following table shows the comparative geomagnetic measurements in Panagjuriste and Niemegk.

Comparative geomagnetic measurements PAG - NGK

Year of means	Obs. host	Operators	ΔD '	ΔH nT	ΔZ nT	ΔF nT
1963	NGK	K.Kostov	+0.42	0.0	0.0	-
1964	PAG	A.Grafe, W.Zander	-1.30	+3.2	-1.0	-
1966	NGK	K.Kostov	-0.43	+2.2	-	-
1967	PAG	A.Grafe, W.Zander	-0.02	+0.3	-5.6	-
1969	NGK	K.Kostov	+0.7	-0.8	-1.5	-3.0
1971	PAG	K.Lendning, W.Zander	-0.80	+0.5	-2.0	-1.8
1974	NGK	K.Kostov	0.0	-0.4	+0.8	-0.3
1975	PAG	K.Lendning, W.Zander	-0.48	+1.3	+0.3	+0.4
1976	NGK	K.Kostov	-0.04	-1.2	-	-0.1
1978	NGK	K.Kostov	+0.06	-1.1	0.0	-0.3
1980	NGK	K.Kostov, I.Butchvarov	-0.02	+0.2	-	-0.4
1984	PAG	E.Ritter, W.Zander	+0.11	+1.2	-	+0.7
1986	NGK	I.Cholakov, Ch.Georgiev	+0.18	+0.1	-	+0.3
1987	PAG	E.Ritter	-0.86	-2.2	-	-
2003	NGK	I.Cholakov, B.Srebrov	+ 0.23'	-2.6 nT	+ 1.0	+ 0.16

Recent field geomagnetic measurements in Bulgaria

From 1934 till 1947, the physician H. Kalfin measured the declination **D** on **750** points by using the magnetic theodolite **"Shulze"**, and the horizontal intensity **H** and inclination **I** - on **350** points of them. The reduction of the observations in the period 1934 - 1937 was made according to the records of the observatory in Vienna. The rest observations were reduced according to the records of the Panagjuriste observatory. Maps of **D** were drawn for epochs 1940.0 and 1950.5.

Recent field geomagnetic measurements in Bulgaria

The physician K. Kostov accomplished a new geomagnetic survey of Bulgaria during the years 1958 - 1961. **D** was measured on **2000** points, and **H** and **I** on **342** of them. The magnetic theodolite **"Schulze-545"** was used as well as three **QHM**. The inclination **I** was measured with the earth inductor **"Shulze".** The observations were reduced to epoch 1960.0 and maps of the geomagnetic field elements, and its normal and anomalous field were drown.

Recent field geomagnetic measurements in Bulgaria

The last absolute geomagnetic survey was performed in the period 1978 – 1980. The geomagnetic elements **D**, **H** and **F** were measured on **473** points. The magnetic theodolite **"Shulze-545"**, three **QHM** and two proton magnetometers **PMP-2A** were used. The geographic azimuth to the mira in 90 % of the points was determined by a **gyrotheodolite** with two gyroblocks and of the remaining points – by geodetic way. The geographic azimuth accuracy determination (the standard deviation) was ~ 0.2'.

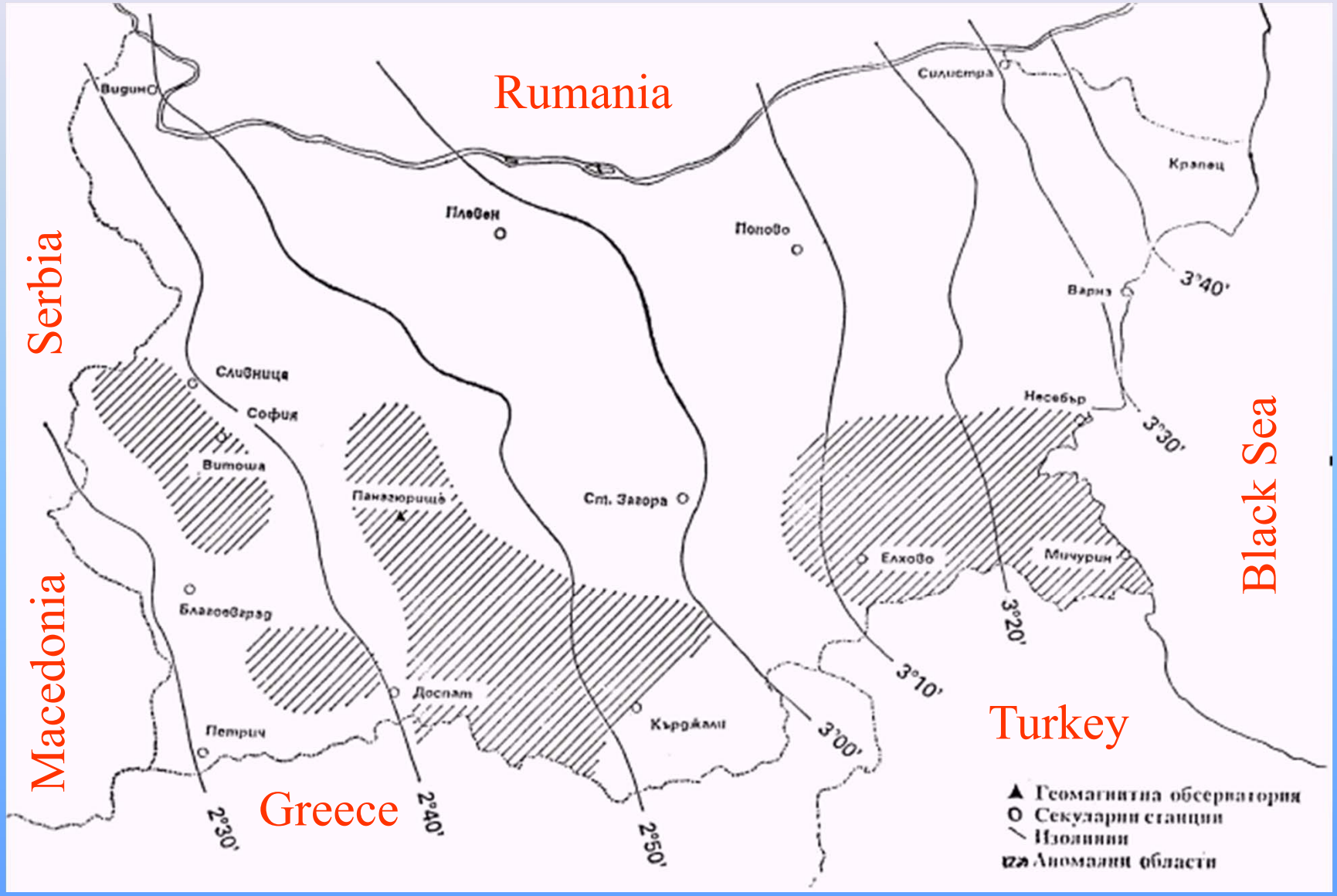
Recent field geomagnetic measurements in Bulgaria

The reduction to the epoch 1980.0 of the observations was made according to the Panagjuriste observatory. The reduced geomagnetic element annual mean values accuracy was:

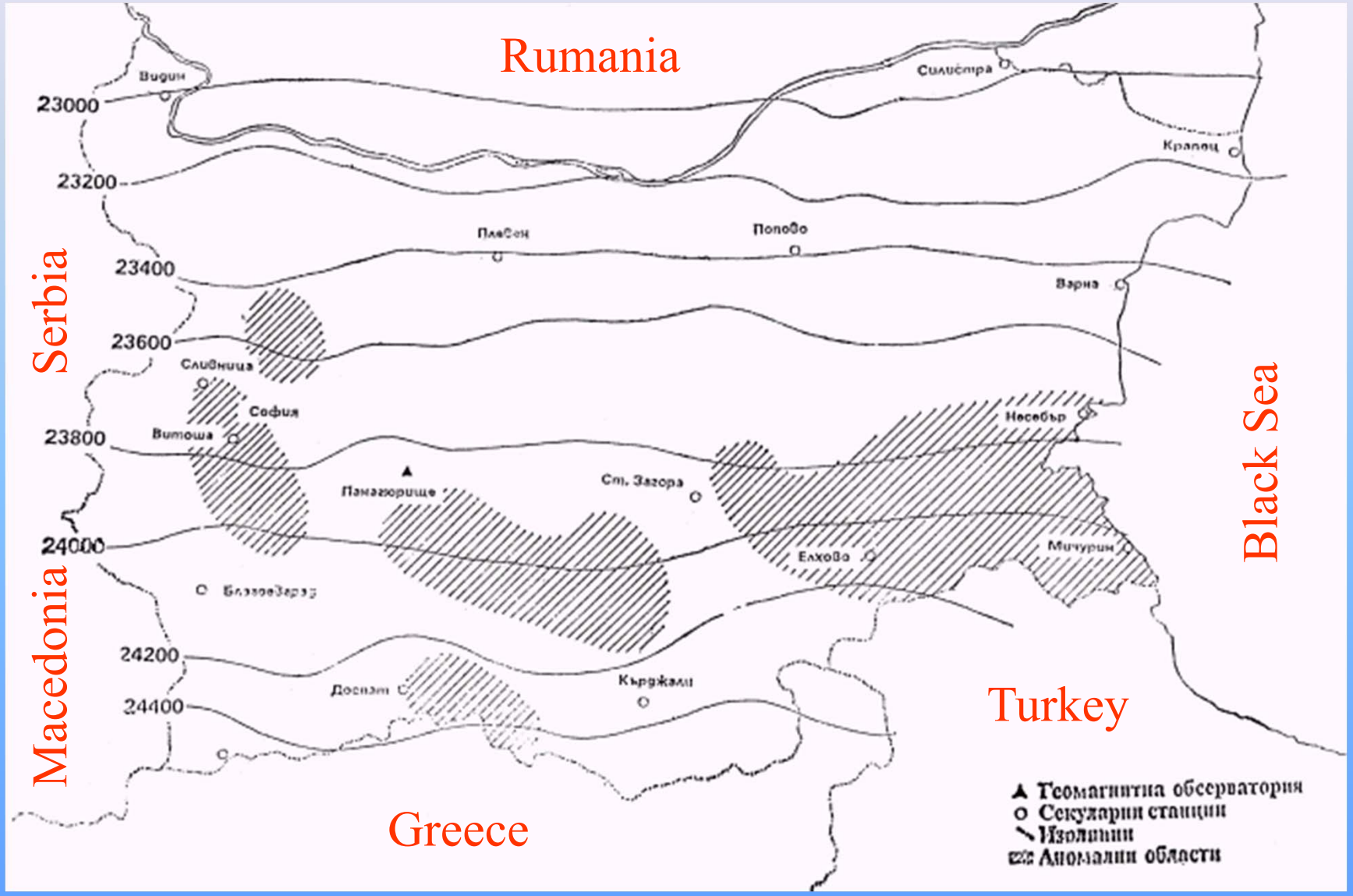
$$\sigma_D \approx 0.5', \ \sigma_H \approx 4.2 \text{ nT}, \ \sigma_F \approx 3.5 \text{ nT}.$$

In 1990 measurements on 15 secular stations were made and all data of the survey in 1978 – 1980 were reduced to epoch 1990.0. The maps were drown. The hatches areas are anomalous zones.

The geomagnetic field of Bulgaria, epoch 1990.0
Declination D



The geomagnetic field of Bulgaria, epoch 1990.0
Horizontal intensity H, nT



The geomagnetic field of Bulgaria, epoch 1990.0
Total intensity F, nT

Normal and anomalous geomagnetic fields of Bulgaria

The normal and anomalous geomagnetic fields were determined for epoch 1960.0, 1965.0, 1970.0 and 1980. On the bases of these series of maps was deduced that the fields mentioned above are practically identical in a morphological point of view. We think that it is so because of the small territory of Bulgaria. The calculation of the fields mentioned above is described in the following slides:

Calculation of the normal geomagnetic field

The normal geomagnetic field is obtained by the method of regression analysis by "sifting out" using an approximating polynomial of 2nd degree (the model) of the geographical coordinates:

$$E(\Delta\varphi, \Delta\lambda) = a_1 + a_2\Delta\varphi + a_3\Delta\lambda + a_4\Delta\varphi^2 + a_5\Delta\lambda^2 + a_6\Delta\varphi\Delta\lambda$$

Where $\Delta\varphi = \varphi - \varphi_0, \Delta\lambda = \lambda - \lambda_0$

$$\varphi_0 = 42^\circ 30', \quad \lambda_0 = 25^\circ 00'$$

Calculation of the normal geomagnetic field

The "sifting out" method consists of consecutively applying the regression analysis over the geomagnetic data removing every time the data having larger deviation from the chosen norm of the obtained model

$$E(\Delta\varphi, \Delta\lambda).$$

When there are no more data surpassing the chosen norm of deviation, the iterations break off and the received model is used for drawing the maps of the normal fields. The anomalous field **A** is received by extracting the normal field **N** from the measured data **R**, i.e.

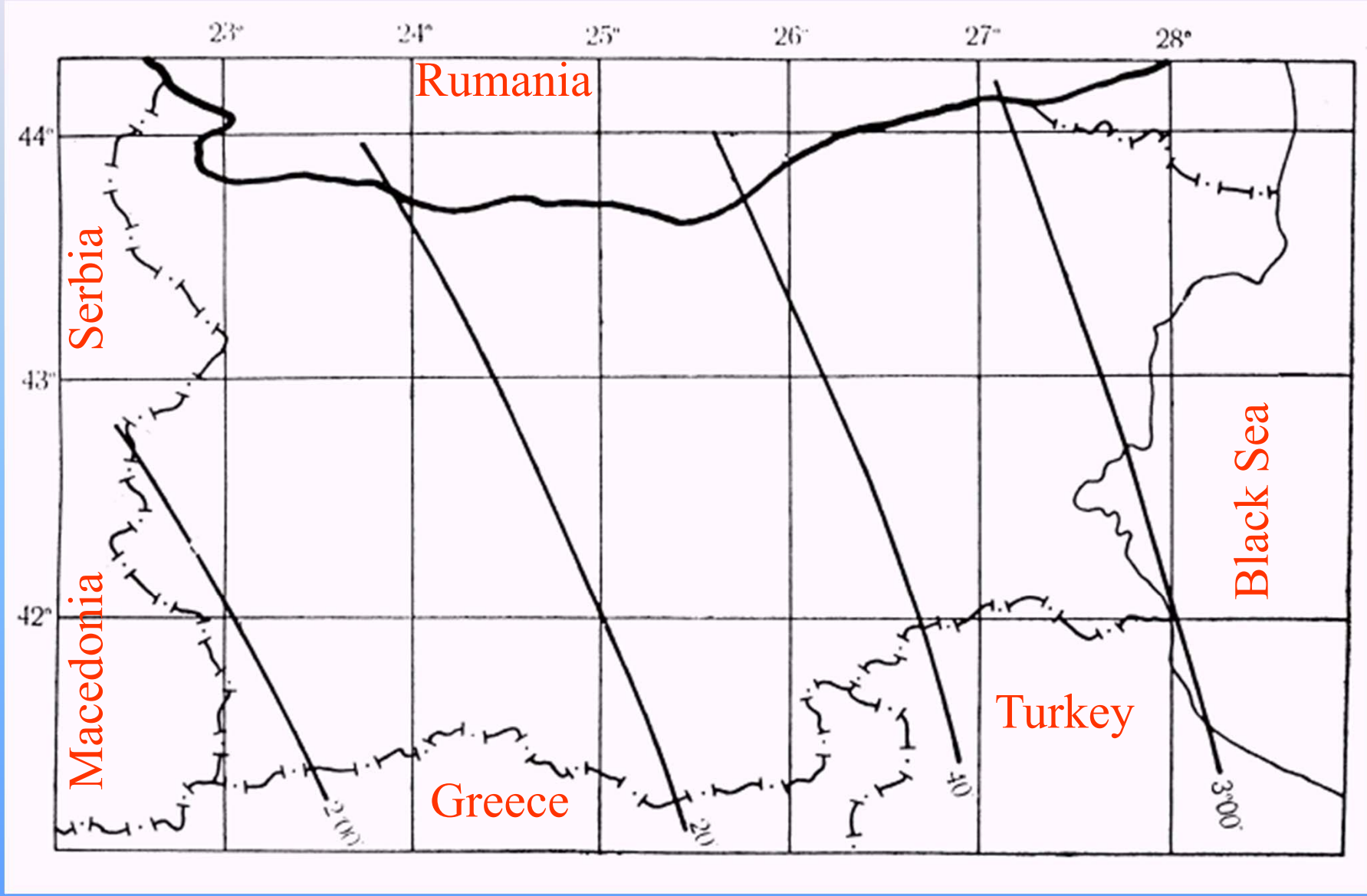
$$\mathbf{A} = \mathbf{R} - \mathbf{N}.$$

Calculation of the normal geomagnetic field

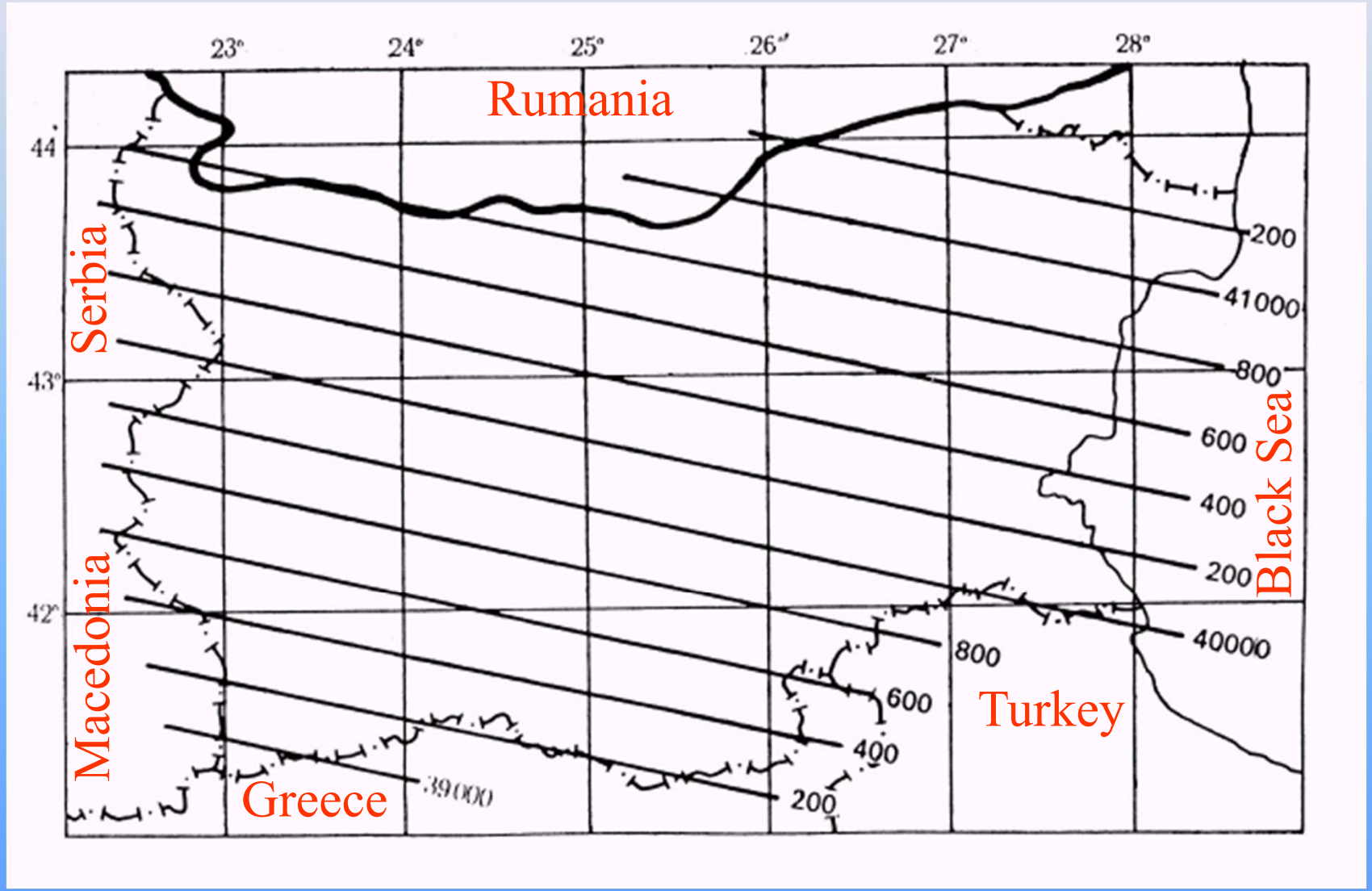
The chosen deviation norms were 80 nT for **F** and **Z**, and 8’ for **D**. The presumption to use these norms was to eliminate the points with measured values deviating from the model ***E*** with more than the interval (the step) between the isolines of the maps.

The described procedure was proposed in the past (in 60’s) by KAPG – the Academy Commission of Planetary Geophysics of former so-called socialist countries.

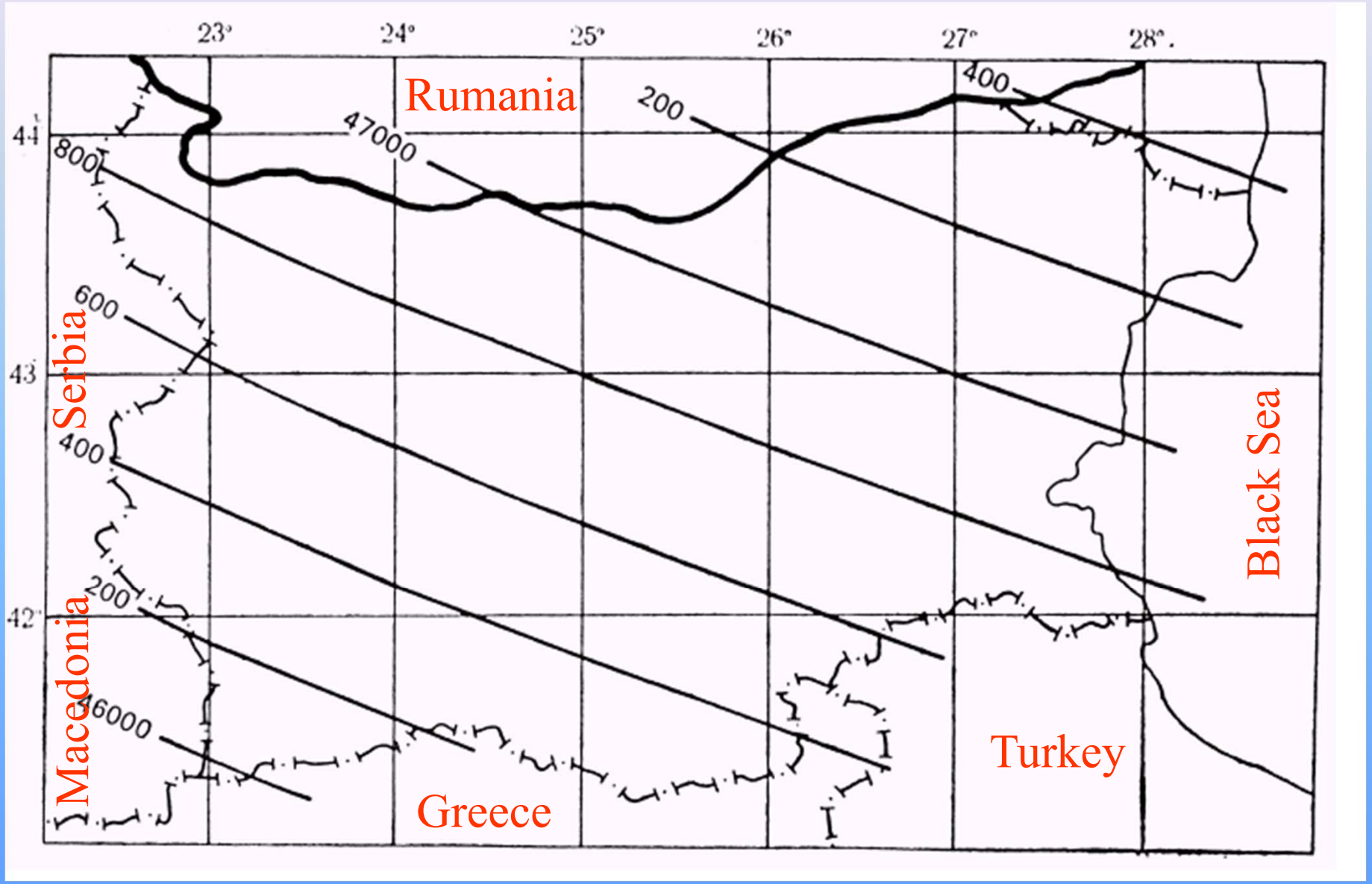
The normal geomagnetic field of Bulgaria, epoch 1980.0
Declination D



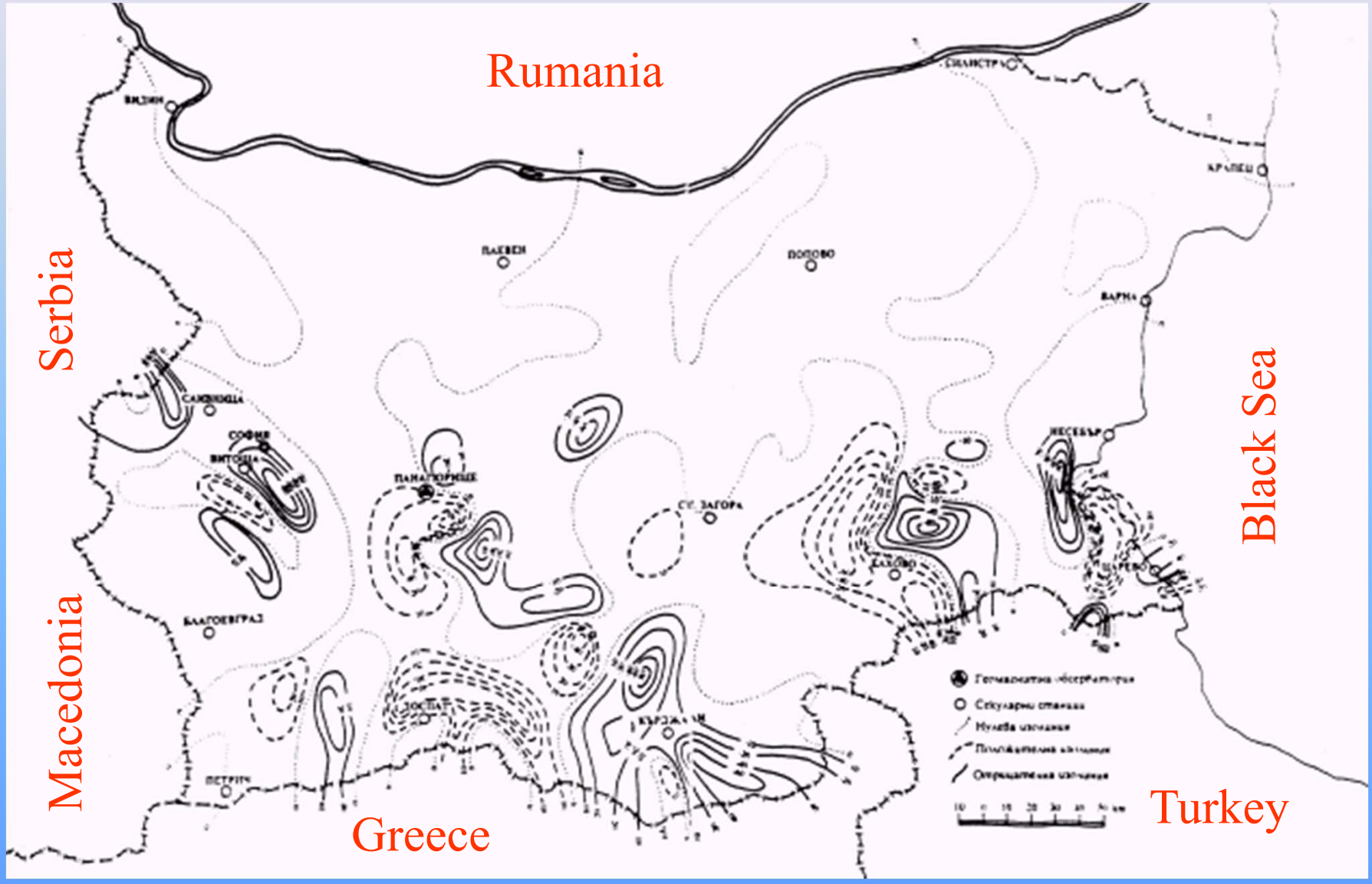
The normal geomagnetic field of Bulgaria, epoch 1980.0
Vertical component Z, nT



The normal geomagnetic field of Bulgaria, epoch 1980.0
Total intensity F, nT



The anomalous geomagnetic field of Bulgaria, epoch 1980.0. Declination D



The anomalous geomagnetic field of Bulgaria, epoch 1980.0. Vertical component Z, nT

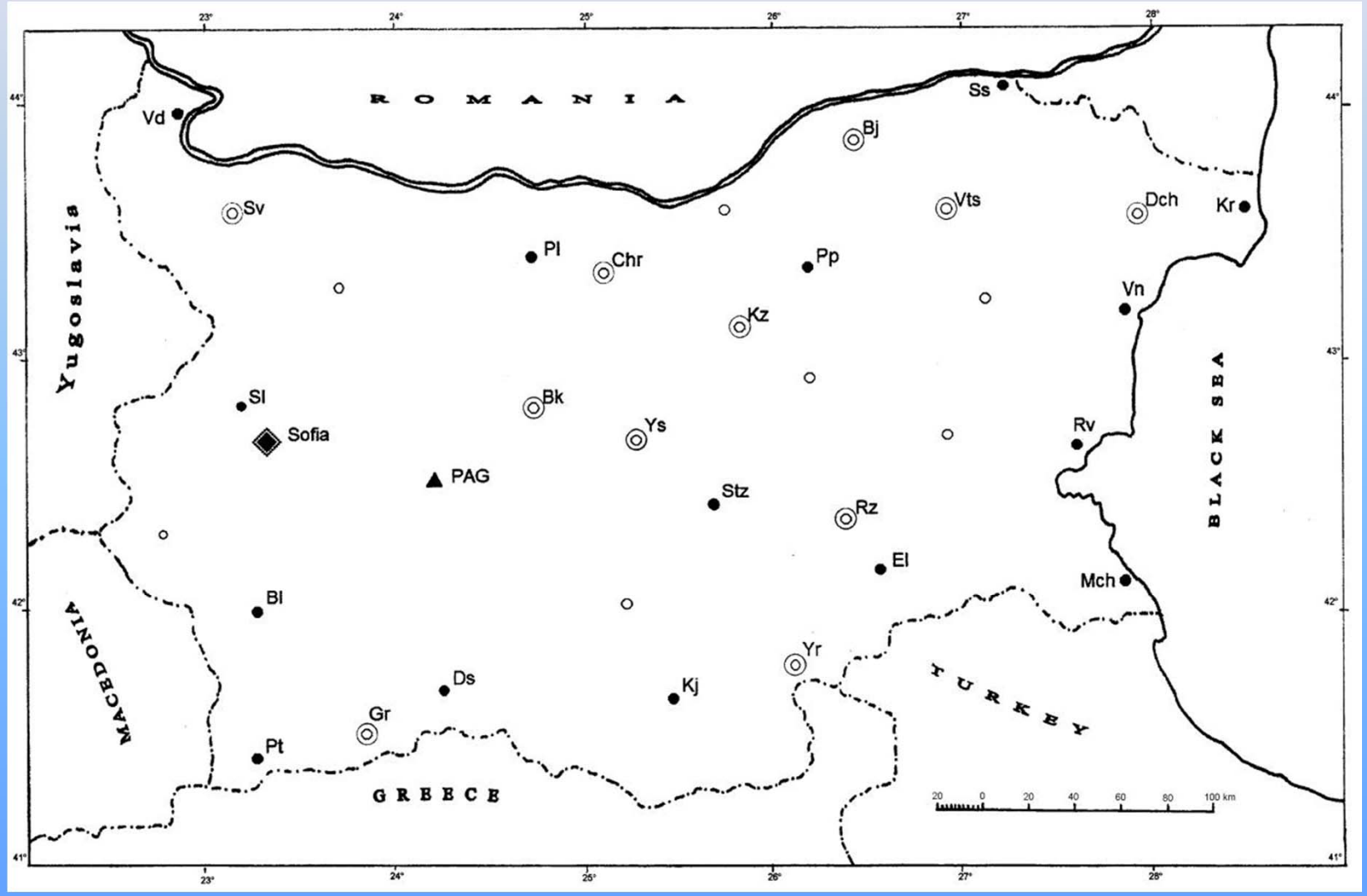
The anomalous geomagnetic field of Bulgaria, epoch 1980.0. Total intensity F, nT

Secular geomagnetic measurements in Bulgaria

The repeat stations network of Bulgaria started in 1934. The eight points selected then were supplemented with seven more in 1964. All points were investigated, stabilized and later duplicated with spare ones and secured with lasting miras. Up to 1980 they were measured every three years and then because of the small secular variations – every five years. Isoporic maps for different periods are elaborated. The repeat stations network and the last secular measurements are shown on the next slides:

Location of the repeat stations in Bulgaria

▲ - Panagjuriste observatory, ● - repeat stations,
◎ - first class points, ○ - new points



Last secular measurements

				2007.0		
Repeat station	**Latitude ° '**	**Longitude ° '**	**H *m***	**D ° '**	**H *nT***	**Z *nT***
Popovo	43°19.7'	26°11.1'	364	4°04.0'	23 440.8	41 656.7
Krapec	43°37.9'	28°34.1'	53	4°47.5'	23 113.6	42 020.0
Silistra	44°02.4'	27°17.0'	171	4°38.5'	23 020.4	42 047.1
Aksakovo	43°15.1'	27°48.1'	143	4°39.0'	23 449.9	41 642.7
				2008.0		
Ravda	42°39.1'	27°40.6'	77	4°28.9'	24 015.3	41 149.3
Elhovo	42°07.7'	26°32.5'	153	4°49.4'	24 226.8	40 492.0
Varvara	42°07.5'	27°54.2'	76	4°05.2'	23 893.9	41 114.7

Processing and organization of the data obtained from the analog magnetograms of Panagjuriste geomagnetic observatory

Brief history of the data processing in the past

In the past the diurnal mean, monthly mean and annual mean values of the geomagnetic elements were calculated only for reduction of the field geomagnetic measurements to the common epoch and they were not published. The first publication of the data was released in 1965 under the guidance of Dr. D. Zidarov, head of the Section of Geomagnetism and Gravimetry of the Geophysical Institute at that time. The Geomagnetic Yearbooks of the hourly mean, monthly mean, annual mean and s. o. values were published according to the standards of the International Association of Geomagnetism and Aeronomy (IAGA).

Brief history of the data processing in the past

The hourly mean values and their extreme values (maximum and minimum) in *mm* were read from the magnetograms manually. The calculation of the geomagnetic elements in respective units and the calculation of the diurnal, monthly and annual means were carried out by using a very primitive calculator. The Geomagnetic Yearbooks were composed on a typewriter and printed off in the printing house of the Military Topographic Service. They were made in this way till 1975 and backward till 1956 inclusive.

Brief history of the data processing in the past

Later all geomagnetic data mentioned above were processed on an IBM 360 computer since 1976 till 1983 and Geomagnetic Yearbooks were printed off according to the IAGA standards. All Yearbooks are available in the WDC's and in the Observatory.

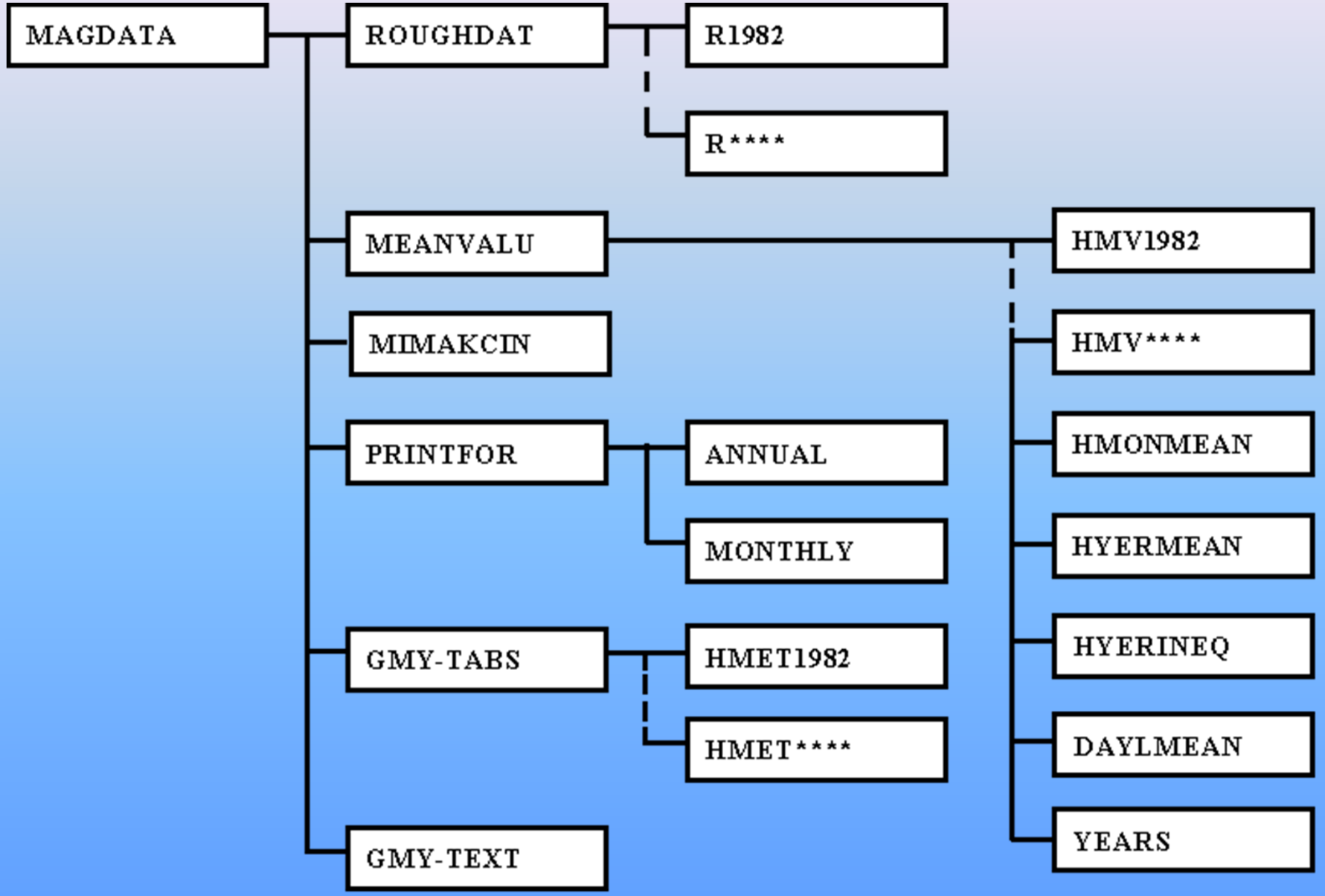
The data processing and data organization between 1983 and 2007

The observatory was not able to purchase digital equipment at that time and the registration of the geomagnetic variations continue to be made on photo paper. The geomagnetic element hourly mean and extreme values (in *mm*) continue to be read manually too. However the data processing is on PC now.

The data processing and data organization between 1983 and 2007

In the end of 80's we developed a package of programs (programming software) in TURBO PASCAL 5.5 code under DOS for processing of the geomagnetic data and their organization in something like a database. The hourly and annual mean values are sent to the WDC's through INTERNET. The data structure is presented in the following picture.

The organization of the data in the Observatory



The folder and file description of the geomagnetic data

Folder	Description
MAGDATA	Main folder. Contains all other folders. There are no files in it.
ROUGHDAT	Contains all folders R**** of the rough data. There are no files in it.
R****	They contain the files R****+++.PAG of the rough data. There is 1 folder of 12 files for every year – each one for ***ONE MONTH*** .
MEANVALU	Contains the folders HMV**** of the hourly mean values for ***ONE MONTH*** and the folders: HYERMEAN, HYERINEQ, HMONMEAN, DAYLMEAN and YEARS described below. Contains also files: MONTMEAN.PAG of the monthly mean values, ANNMEANS.PAG of the annual mean values and MDIMANTH.PAG of the average mean diurnal inequalities for unlimited number of years. The last three files are unique in the Observatory. The first two of them are only for 100 years.
HMV****	They contain the files W****+++.PAG of the hourly mean values for ***ONE MONTH***. There is 1 folder of 12 files for every year – each one for 1 month.
HYERMEAN	Contains the files MDVS****.PAG of the average hourly mean values for ***ONE YEAR*** and for the ***EQUINOX***, ***SUMMER*** and ***WINTER***.

The folder and file description of the geomagnetic data

Folder	Description
HYERINEQ	Contains the files **MDIM****.PAG** of the mean diurnal inequalities for ***ONE YEAR*** and the files **MDIS****.PAG** of the average mean diurnal inequalities for ***ONE YEAR*** and for the ***EQUINOX***, ***SUMMER*** and ***WINTER***.
HMONMEAN	Contains the files **HMMV****.PAG** of the hourly-monthly means values. There is 1 file for every year.
DAYLMEAN	Contains the files **DM****.PAG** of the daily mean values. There is 1 file for every year.
YEARS	Contains the files **PAG****.WDC** of the hourly mean values for ***ONE YEAR***. There is 1 file for every year.
MIMAKCIN	Contains the files **EXKC****.PAG** of D, H and Z extreme values, K and C indices, and the temperature in the "Relative house". There is 1 file for every year.
PRINTFOR	Contains the folders: **ANNUAL** – of the annual mean value files, and **MONTHLY** – of the files containing simultaneously annual and monthly mean values. There are no files in it.

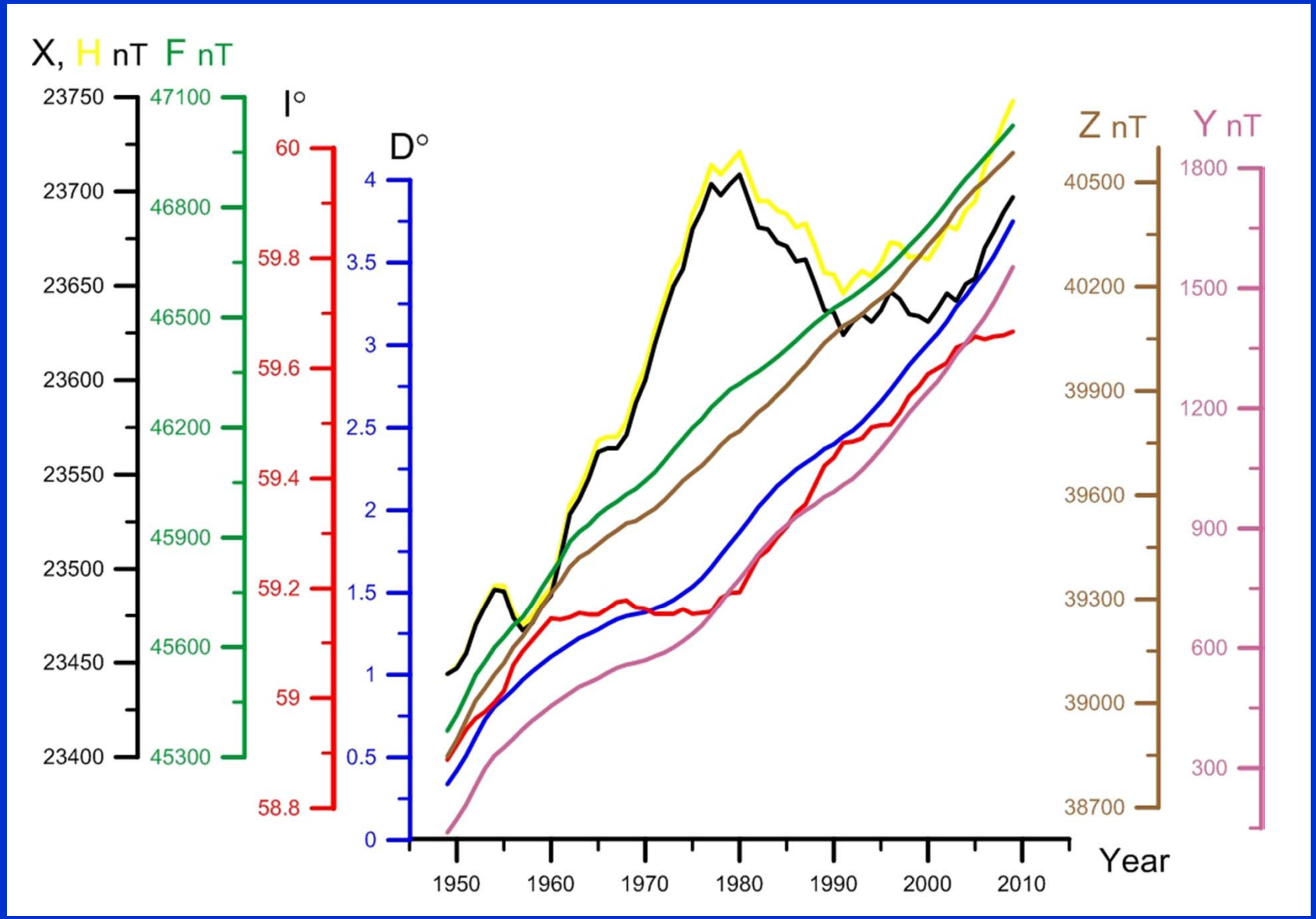
The folder and file description of the geomagnetic data

Folder	Description
ANNUAL	Contains the files PAG-ANN.ALL and PAG-ANND.ALL of the annual mean value tables. In the first one the declination is presented in ° (degrees) and ' (minutes), and in the second one – in degrees and tenth of degrees. There is only 1 file of the two types (2 files only) for all years. The file PAG-ANN.ALL is sending to the WDCC1 in Edinburgh.
MONTHLY	Contains the files PAG****.ALL of the annual and monthly mean value tables simultaneously. There is 1 file for every year.
GMY-TABS	Contains the folders HMET**** of the files &****+++.PAG described below. There are no files in it.
HMET****	They contain the files &****+++.PAG of the GMFE tables and the tables of extreme values, etc. in the same form as the old Geomagnetic Yearbook that was issued like a hard copy. There is 1 folder of 8 files for every year.
GMY-TEXT	Contains different files for the history of the Observatory, some of its characteristics, etc.

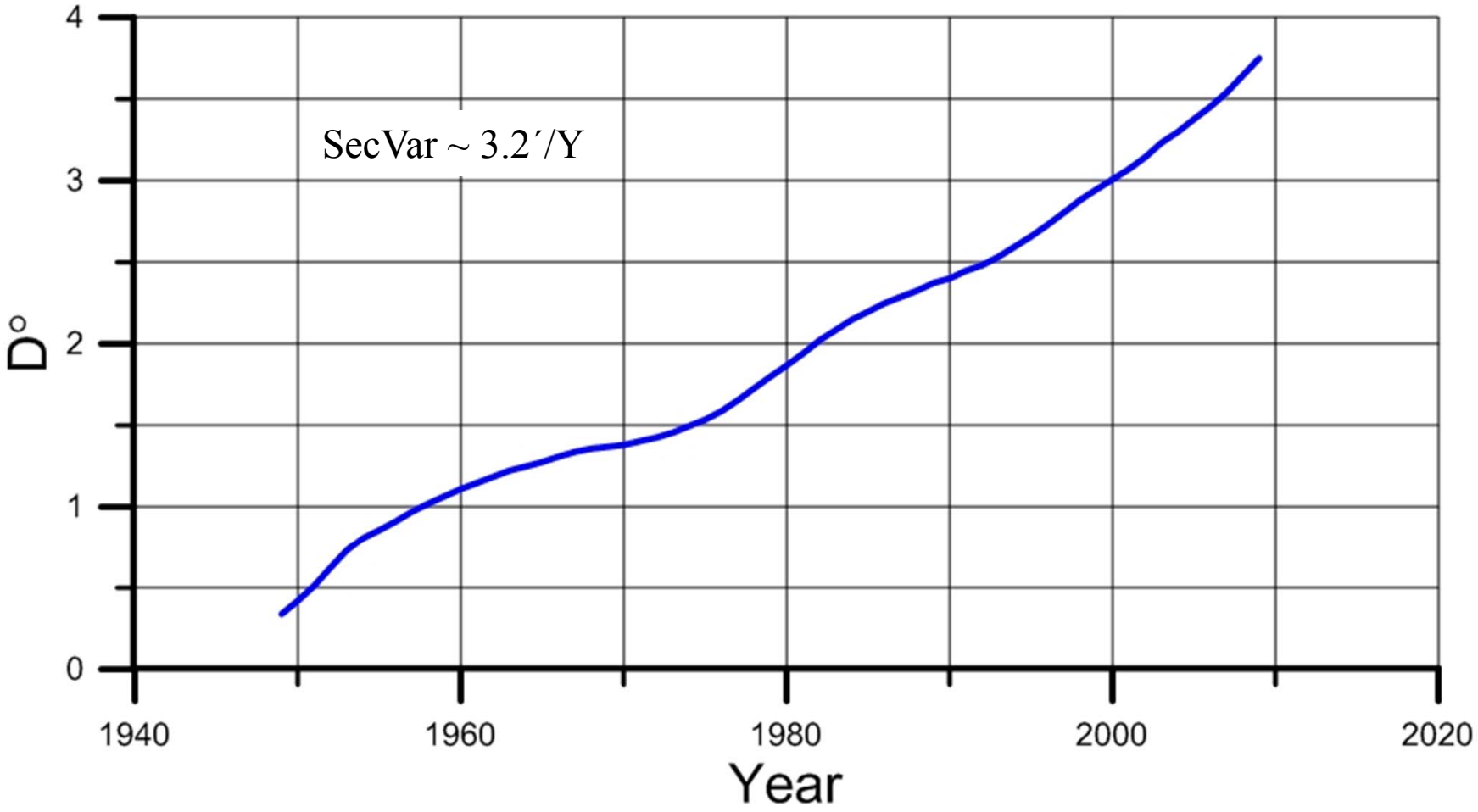
The data processing and data organization after 2007

As it was mentioned above between 2005 and 2007 a new digital equipment for measuring absolute values of the geomagnetic field and the registration of its variations was installed and put into operation in Panagyurishte . The analog registration of geomagnetic variations on photo paper were terminated. The Observatory was included in INTERMAGNET and the data received are processed in the INTERMAGNET standard and sent to the WDC's.

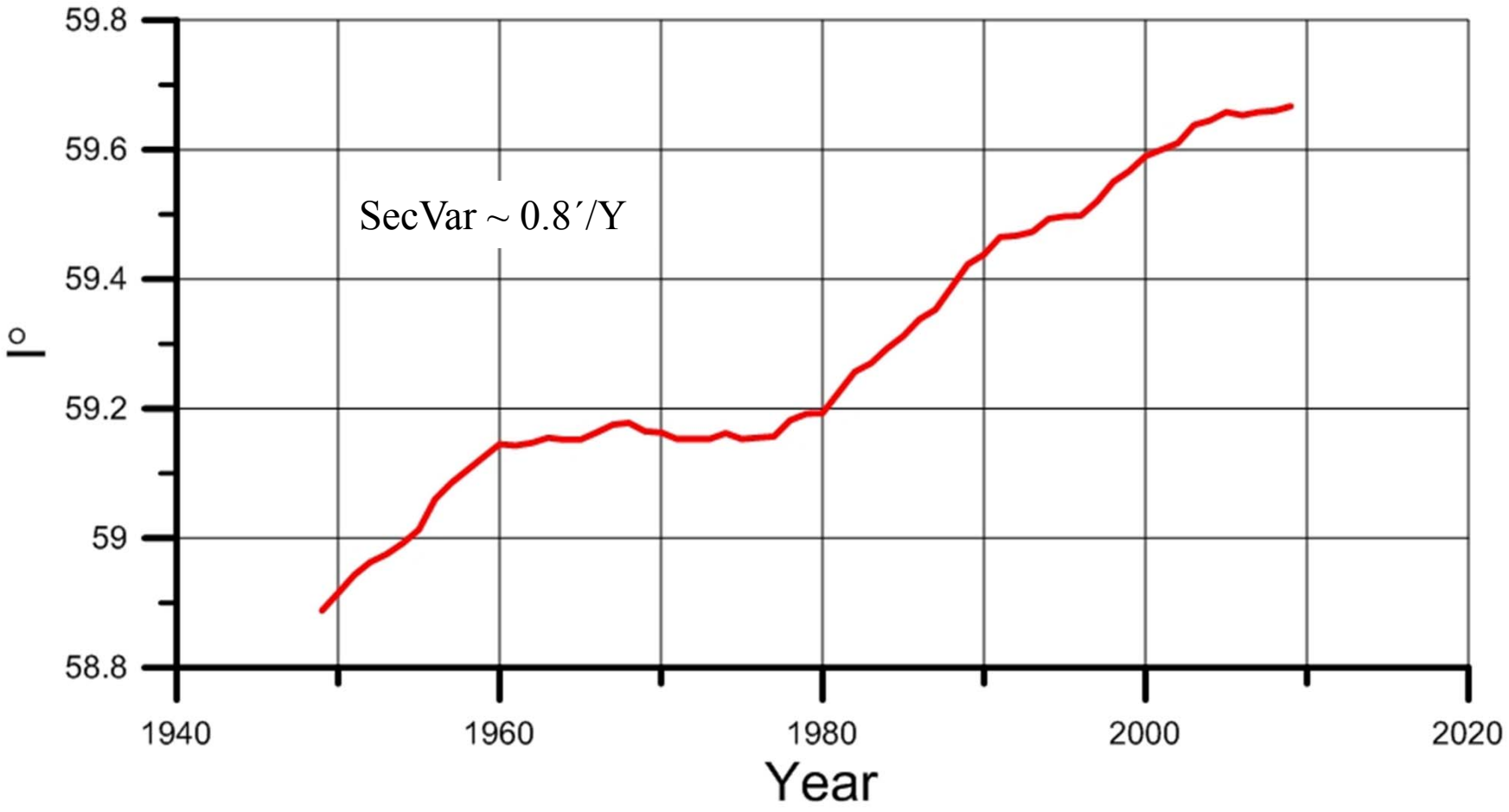
Annual mean values in PAG: 1949 - 2009



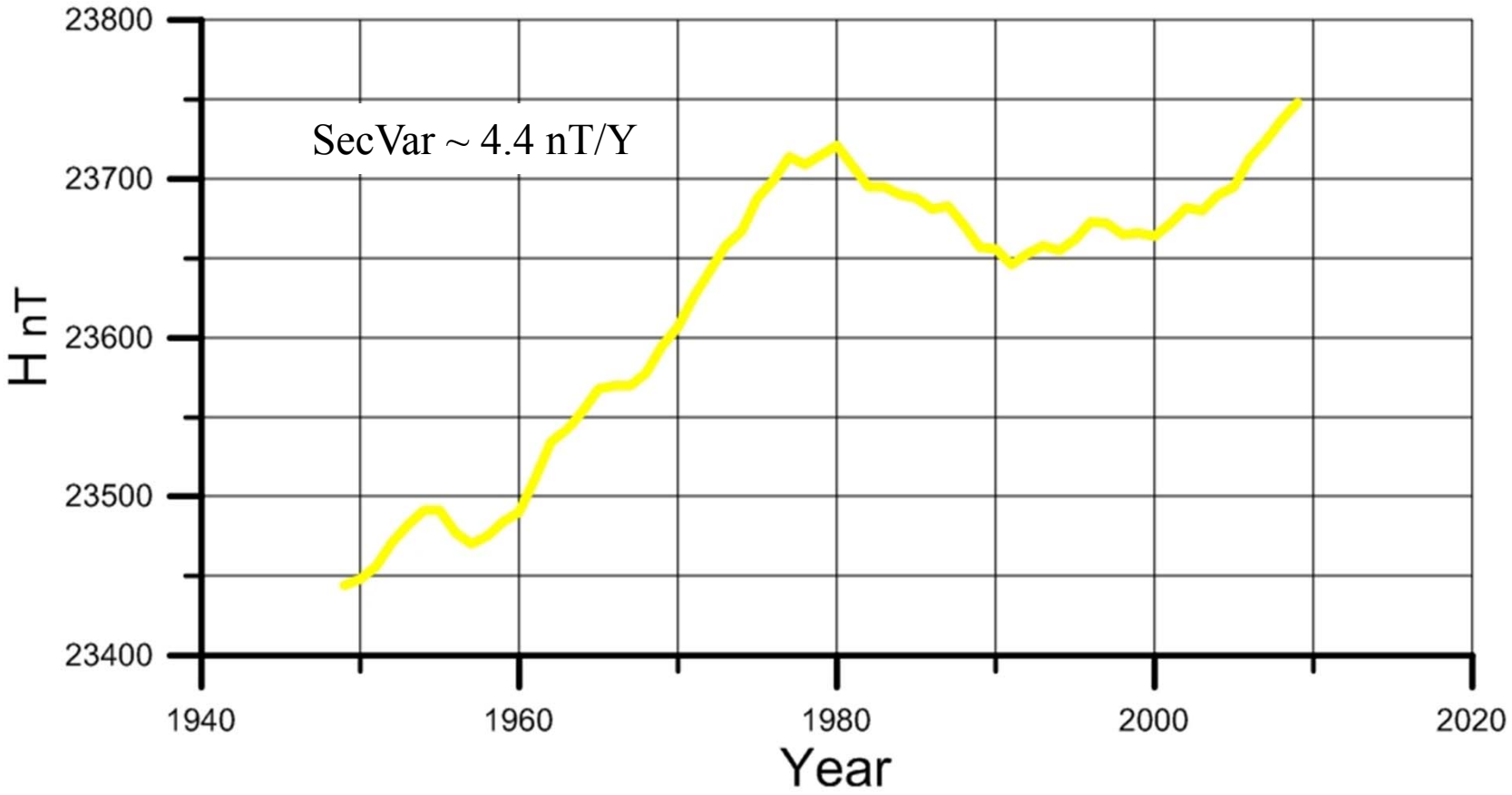
Annual mean values in PAG 1949 - 2009: Declination - D



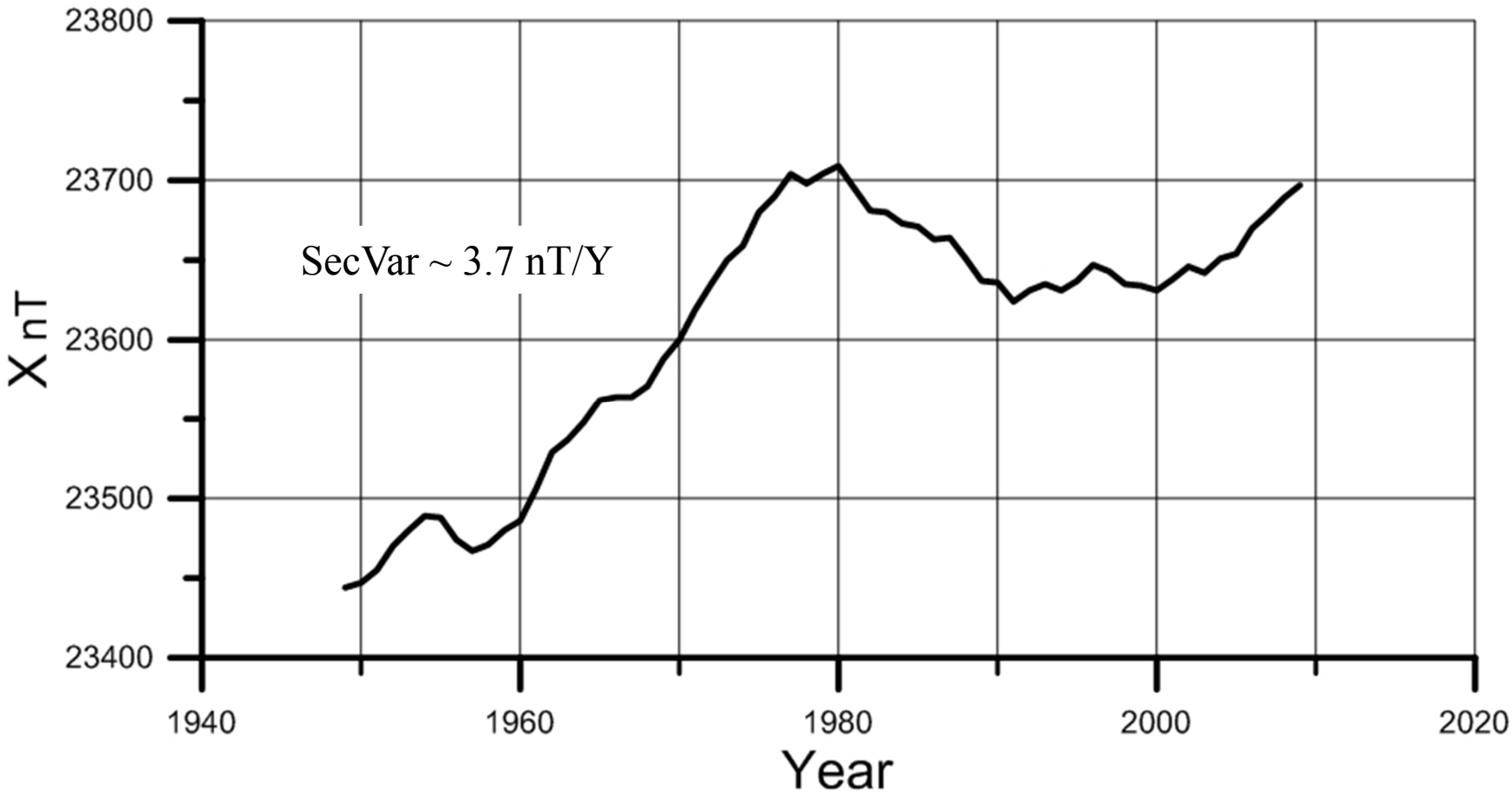
Annual mean values in PAG 1949 - 2009: Inclination - I



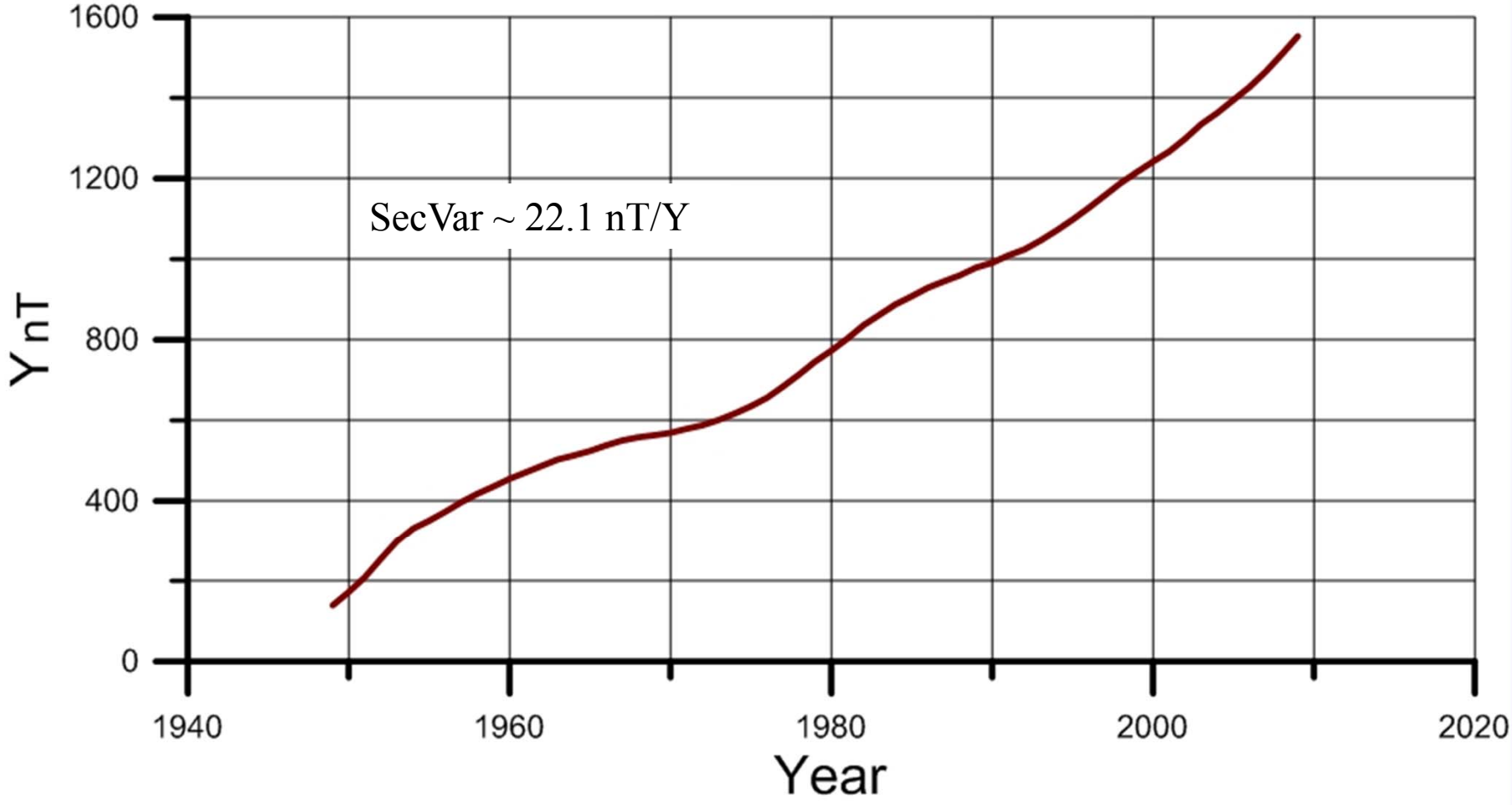
Annual mean values in PAG 1949 - 2009: Horizontal intensity - H



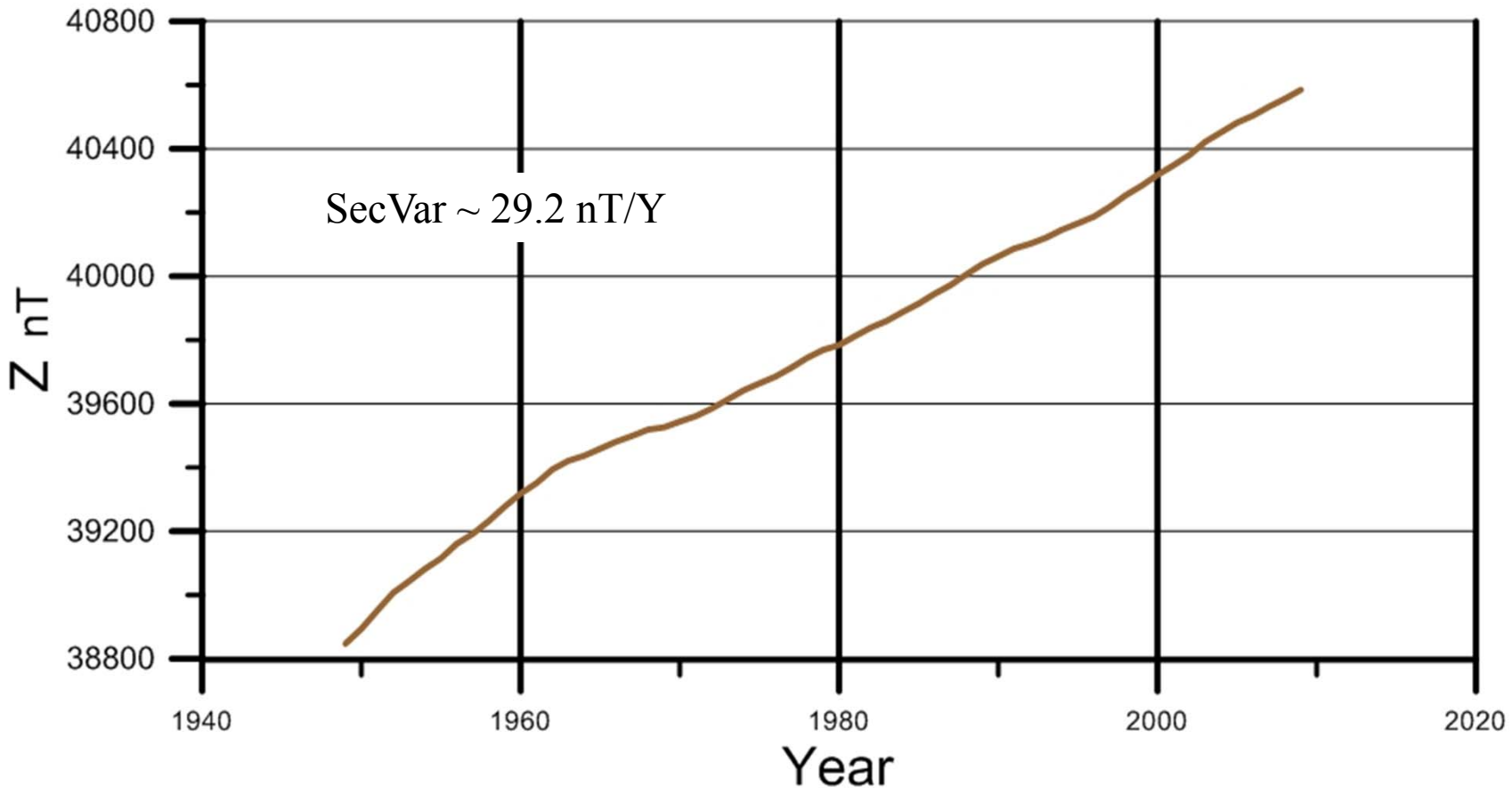
Annual mean values in PAG 1949 - 2009: Component X



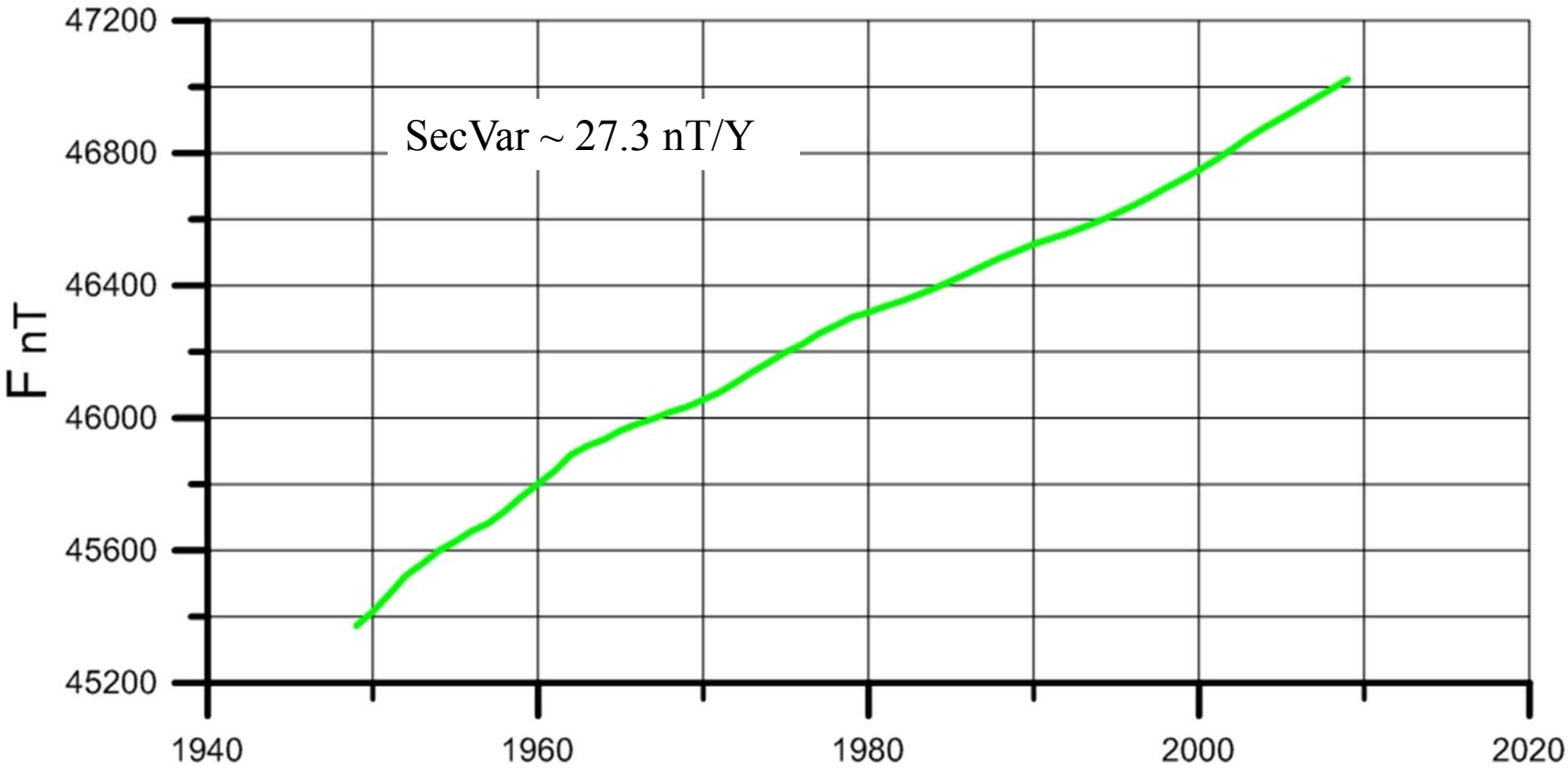
Annual mean values in PAG 1949 - 2009: Component Y



Annual mean values in PAG 1949 - 2009: Component Z



Annual mean values in PAG 1949 - 2009: Total intensity F



The staff in 2000