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The influence of variations of the Earth' magnetic field on the elaboration of geomagnetic observations in Poland

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Abstract. The increase of accuracy of magnetic measurements generated the need of testing of the influence of variations of the geomagnetic field on their elaboration.
On the basis of the magnetic data obtained from European observatories and from magnetic stations operating in 2010 and 2011, the chart of amplitude changes of *Y* magnetic field component (magnetic declination too) in Poland and the chart of time shift between the records of Belsk Observatory – considered as central observatory – as well as the records from other measurement points were processed.
Data from some geomagnetic stations operating in the 1960. (with records of *D*, *H* and *Z* components) stored in the database at the Institute of Geodesy and Cartography, Warsaw, were re-used to analyse geomagnetic field intensity changes (Uhrynowski, 1962, 1964). The error of transforming analogue data from paper records to the digital form is bigger than amplitude changes of declination *D* and *H* component.
The results of Fourier transformation of millions of data from magnetic observatories allowed for mapping the distribution of amplitude changes of *Y* component and time shift of records from chosen European observatories with respect to Belsk Observatory.
The range of amplitude changes of the *X, Y* and *Z* components of the geomagnetic field intensity in Poland is exceptionally small. It reaches only ±2–3 nT which is at the level of the error of geomagnetic data elaboration. The range of time shift of the record from points by eastern border of Poland with respect to those by western border of Poland vary from –6 to +15 minutes for *Y* component. The test made with data from secular point (repeat station) measurements from 2009–2011 shows that the differences between results obtained without and with time corrections reach only 10-30² for declination and inclination, and 5 nT for total intensity vector length. The use of the magnetograms from Belsk Observatory for the geomagnetic measurement reduction without any time corrections does not, however, generate any significant error influencing the measured components accuracy.

Keywords: variations of geomagnetic field elements, geomagnetic vector components, regional changes of geomagnetic field, magnetic declination changes

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1. Introduction

The character of geomagnetic field changes differs depending on the geological, geophysical and cosmic constraints. The existence of regional and local anomalies affects the elaboration of the geomagnetic observations (Beblo and Schultz, 1983). The field geomagnetic stations are used to account for this effect (Korte and Haak, 2000). In Poland, the first elaboration of geomagnetic field changes was performed with the use of analogue data recorded by field variograph stations operating in 1960. (Jankowski and Krolikowski, 1962).

Data from some geomagnetic stations operating in 1960. stored in the database at the Institute of Geodesy and Cartography, Warsaw (IGiK) were re-used to analyse geomagnetic field intensity changes (Uhrynowski, 1964). The results obtained from processing the variograph stations data are not satisfactory since the geomagnetic field changes obtained are not easily modelled and changes determined are smaller than the precision of the geomagnetic observations.

The increase of accuracy of magnetic measurements generated the need of testing of the influence of variations of the geomagnetic field on their elaboration. In different European countries the magnetic field stations were used for verification of the accuracy of elaboration of magnetic measurements at repeat stations and other magnetic points (Babour et al., 1976; Socias et al., 2005).

In the first years of 21st century it became possible to use magnetic stations for the determination of magnetic field variations and their influence on the elaboration of magnetic observations. In the period of 2004 – 2005 four magnetic stations were installed in the eastern (2 stations) and the western (2 stations) outskirts of Poland. Data records from those stations were used only to elaborate the magnetic observations at the repeat stations. The results obtained using momentary reduction of observed data to magnetic station record are almost the same as those reduced directly to Belsk Observatory magnetogram (Sas-Uhrynowski et al., 2006). The differences were smaller than errors of magnetic observations. The stations operated only several days. The data series recorded was too short to detect systematic changes between observatory and stations records.

In 2010 and 2011, new 17 field stations were operating in Poland and the records containing variations of *D* (magnetic declination), *H* (horizontal component of magnetic intensity vector) and *Z* (vertical component of magnetic intensity vector) components provide a new material for analysis of the regional and local geomagnetic field intensity changes.

On the basis of the geomagnetic data obtained from the European observatories (INTERMAGNET) and from magnetic field stations, the chart of amplitude changes of *Y* component (magnetic declination too) in Poland and the chart of time shift between Belsk Observatory – considered as central observatory – and other measurement points records were processed.

2. Elaboration of the archive data

In the 1960. on the Polish territory there were established about 20 stations with Askania variographs for analogue recording of 3 elements of geomagnetic field changes: *D*, *H* and *Z* components (Małkowski, 1962) (Fig. 1).

Fig. 1. Location of the variograph stations in Poland in 1960. with Askania variograph (analogue recording)

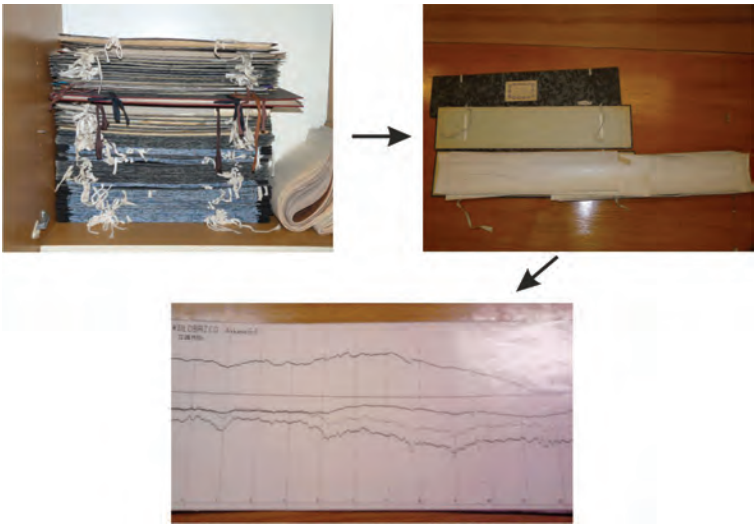

Fig. 2. The archives with analogue recording of the geomagnetic field changes and the picture of partial recording for Kolobrzeg station (Uhrynowski, 1964)

The archive with paper recording from all stations, one part for one station and their scanned part is shown in Figure 2. It was difficult to choose from the archive files parts with good pictures of lines and records coefficients correctly defined for them. Finally 2 stations: Kolobrzeg and Samborowo were chosen for the analysis. The chosen parts of graphic recording from 2 days in July 1964 and 2 days in May 1965 for Samborowo and 2 days in June 1971 and 2 days in June 1972 for Kolobrzeg were transformed from analogue to digital form.

There was a problem with the base observatory because the Central Geophysical Observatory of the Polish Academy of Sciences in Belsk started to work in 1964. The Hel Magnetic Observatory has been operating since 1921 and it has accessible archives with paper records. The result of comparison between Belsk and Kolobrzeg stations and Hel and Samborowo stations (shown in Fig. 3–4) is useful only for the research interest because differences between amplitude changes are smaller than 1′ for declination and 5–10 nT for *H* component. The error of their determination is bigger than the accuracy of contemporary observations.

The data from the records in 1963–1965 (Uhrynowski, 1968) allowed to elaborate the changes of daily amplitudes of the declination in Poland from all stations, reduced to Belsk Observatory (Fig. 5). The changes do not show any systematic trend. The strange anomalies may either indicate some local magnetic changes connected with distribution of the geomagnetic field in Poland (Sas-Uhrynowski and Welker, 2003) or the use of improper coefficients for transformation of analogue recording to digital files.

3. New magnetic stations in Poland with permanent recording

Two new Polish magnetic stations with permanent recording were included in the elaboration. They are Suwalki station (Institute of Geophysics of the Polish Academy of Sciences) and Borowa Gora (Institute of Geodesy and Cartography) (Fig. 6). Both stations used LEMI magnetometers for recording of the geomagnetic components.

The station Borowa Gora was installed in 2006 but continuous recording (with technical breaks) is available from last 4 years. The bases for recording changes of *X, Y* and *Z* magnetic field components are elaborated every half a year. A comparison between Belsk and Hel observatories and Borowa Gora and Suwalki stations was made to verify the station quality. Figure 6 shows the stations with

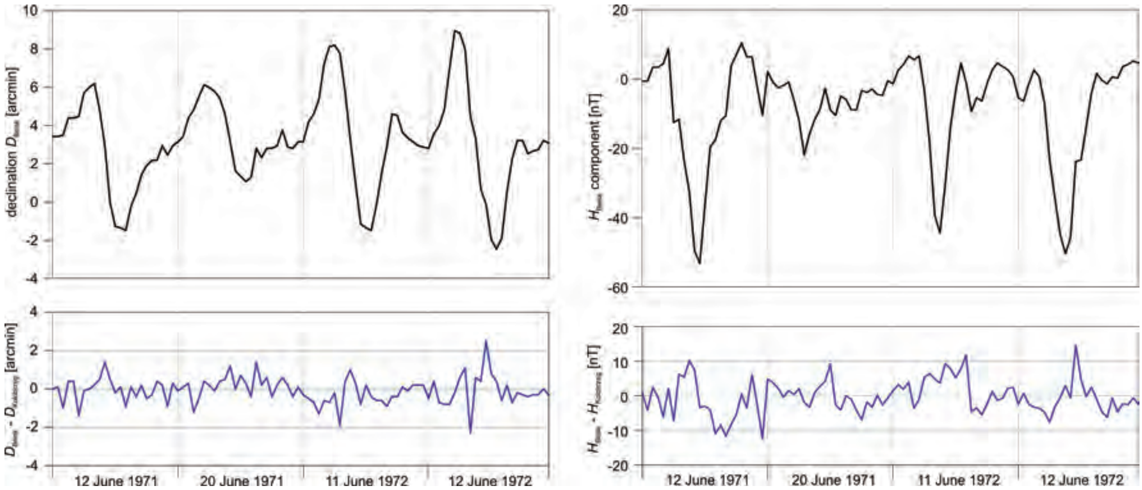

Fig. 3. Variations of *D* and *H* for Belsk Observatory (black) and differences between Belsk Observatory and Kolobrzeg stations (blue) in June 1971 and June 1972

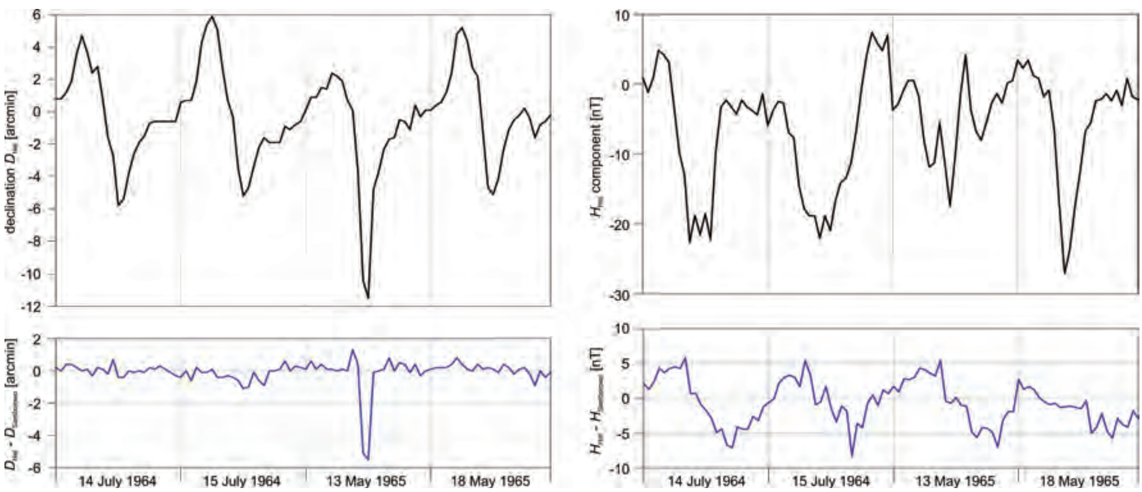

Fig. 4. Variations of *D* and *H* for Hel Observatory (black) and differences between Hel Observatory and Samborowo station (blue) in July 1964 and May 1965

LEMI magnetometer used for recording *X*, *Y* and *Z* changes. Variations of *X*, *Y* and *Z* geomagnetic field intensity components in chosen days of month, i.e. July and October 2010 are shown in Figure 7. The graph in Figure 8 presents changes of monthly means of *Y* component in 2010.

The biggest differences in *X* and *Z* magnetic field intensity components reached 4–5 nT in the summer and winter months but with the opposite sign. That may be caused not only by magnetic field distribution but also by temperature changes at the stations. Further study of data from observatories shows the same varying nature of the *X* and *Z* component changes.

The stations can be used as base stations for the momentary reduction of magnetic field measurements (Sas-Uhrynowski et al., 2006).

The changes of *Y* component have systematic linear character (they reflect the known annual changes). The *Y* component of the geomagnetic field will be the major component for further elaboration of data from European observatories.

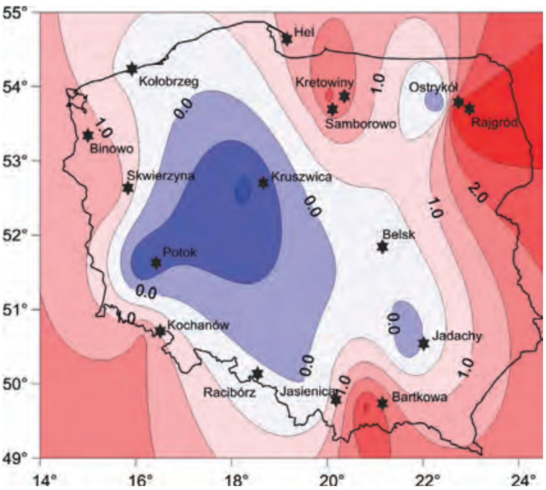

Fig. 5. Amplitude changes of *D* [arcminutes] between archive stations from the 1964–1965 reduced to Belsk Obsevatory

Its variations are similar to variations of declination (Fig. 9) which are the most important for magnetic measurements reduction in geodesy. The comparison of declination variations with *Y* component variations allows to analyse in future only *Y* changes in nT units and assume that the declination changes are the same. One minute of declination change corresponds to about 5.5 nT of *Y* component change. The local and regional changes of *X* and *Z* components of the geomagnetic field intensity are more important for geophysical investigations.

4. The elaboration of amplitude changes of *Y* geomagnetic field intensity component and its time shift between Belsk Observatory records and the records in different magnetic points

The first step was the analysis of magnetic field intensity changes in observatories. The following geomagnetic observatories in Europe were chosen for elaboration:

1. North of Poland: Hel (Poland), Uppsala (Sweden), Nurmijarvi, Sodankyla (Finland),
2. South of Poland: Hurbanovo (Slovakia), Panagyurishte (Bulgaria),
3. East of Poland: Lviv (Ukraine), Pleshchenitsi (Belorussia), Krasna Pachra (Russia), Dymer (Ukraine),
4. West of Poland: Budkov (Czech Republic), Niemegk (Germany), Chambon La Foret (France), Ebro (Spain), Valentia (Ireland),

with Central Polish Geophysical Observatory in Belsk as reference (Fig. 10).

After the first step of analysis the following observatories were rejected:

– Sodankyla because of big ionospheric disturbances (Fig. 11),
– Pleshchenitsi and Krasna Pachra because data are no accessible,
– Ebro and Valentia since they are too far from Poland.

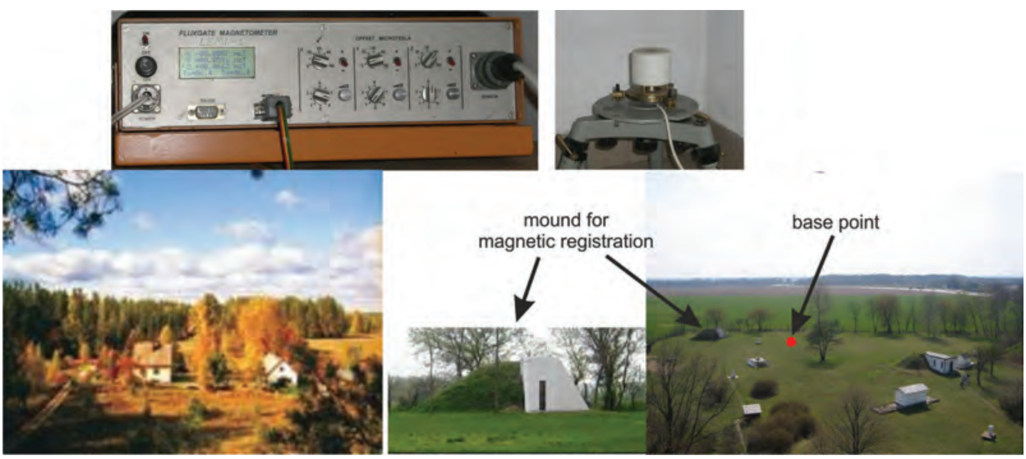

Fig. 6. Suwalki and Borowa Gora magnetic stations with LEMI magnetometer

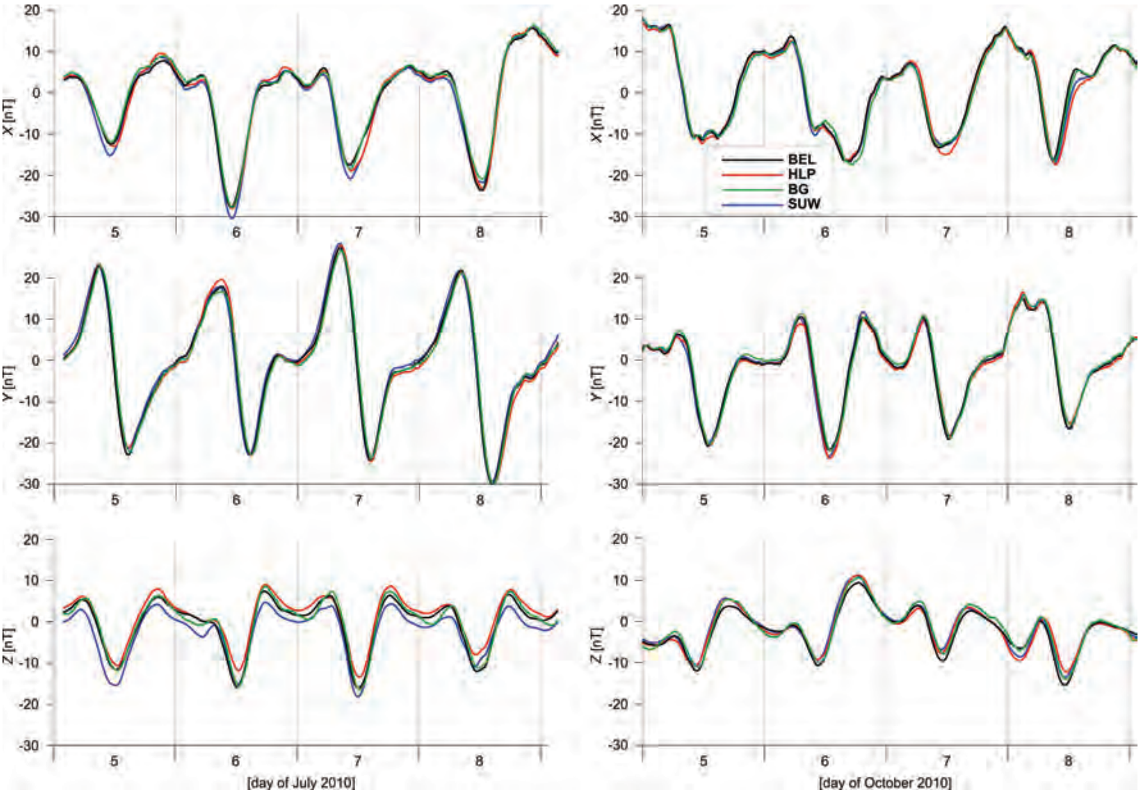

Fig. 7. Variations of *X*, *Y* and *Z* components in selected records from July and October 2010 in Belsk, Hel, Borowa Gora, and Suwalki

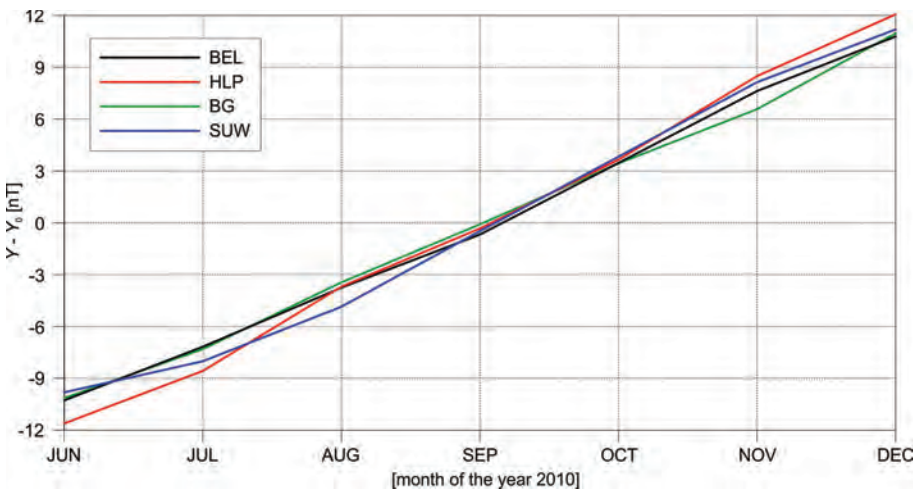

Fig. 8. Changes of monthly means of *Y* component in 2010 in Belsk, Hel, Borowa Gora and Suwalki

The data from Dymer Observatory was accessible only from January 2011.

Finally only 6 observatories were chosen for further data elaboration. They are both Polish geo-

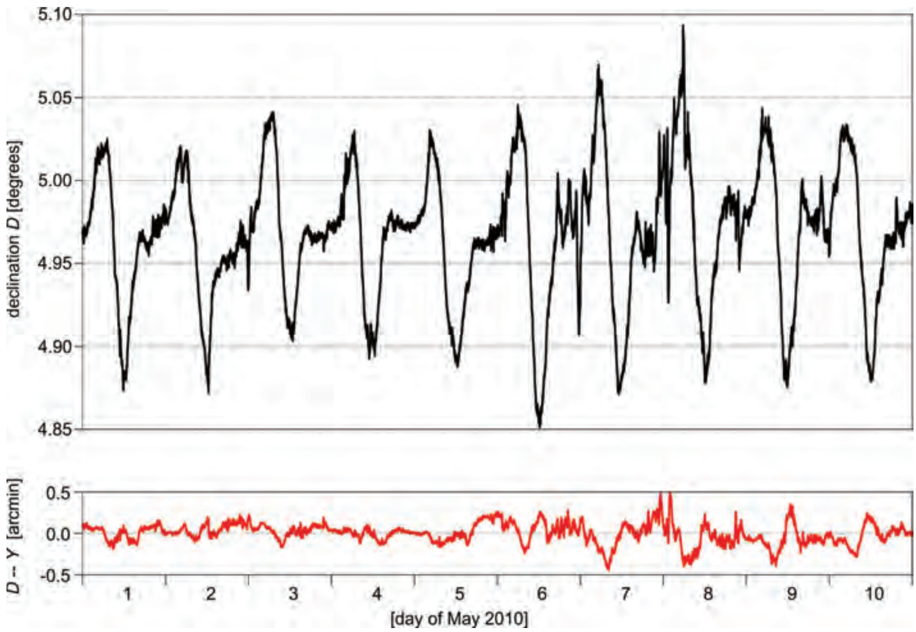

Fig. 9. Variations of magnetic declination in Belsk Observatory (black) and changes of differences between *D* and *Y* components (red) for 1 – 10 May 2010

magnetic observatories and observatories around Poland with similar magnetic field changes. Two more observatories: Chambon La Foret and Nurmijarvi are located substantially further to the West (longitude component) and North (latitude component) and they were included for initial determination of the trends of *Y* changes.

All the data from chosen observatories from the period of 2008 – 2011 were analysed. As the record data for *Y* component in observatories have different amplitudes and are shifted in time (Fig. 12) due to Earth rotation (varying position of the Sun with respect to the station) they need to be determined.

Figure 13 shows changes of monthly mean amplitudes of *Y* component for Belsk Observatory and the differences between monthly mean amplitudes of *Y* component for Belsk and chosen observatories in the 2009 and 2010. In summer the amplitudes are nearly the same and the biggest, while in winter the amplitudes are shorter and their differences between observatories are the biggest. The amplitude changes reduced to Belsk Observatory amplitudes for each month 2010 are shown in Figure 14.

The trends of *Y* component (declination) amplitude changes in Europe are similar (Fig. 13), espe-

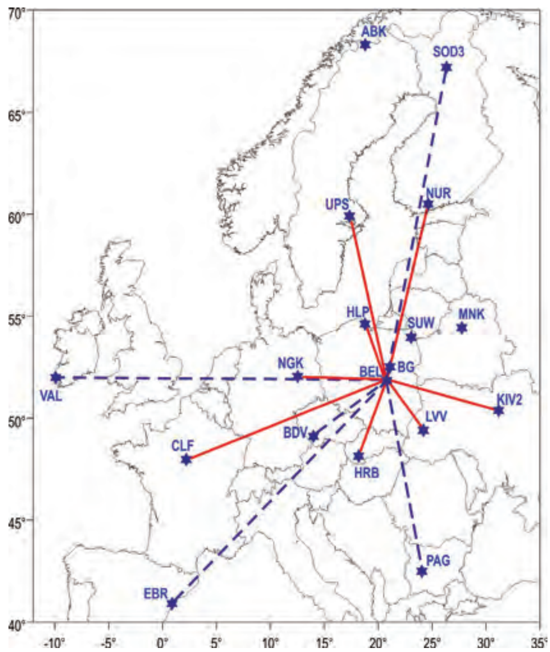

Fig. 10. The observatories chosen for elaboration – the first choice (blue lines) and the final choice (red lines)

cially for European observatories close to Poland, but the ranges of their changes reduced to Belsk

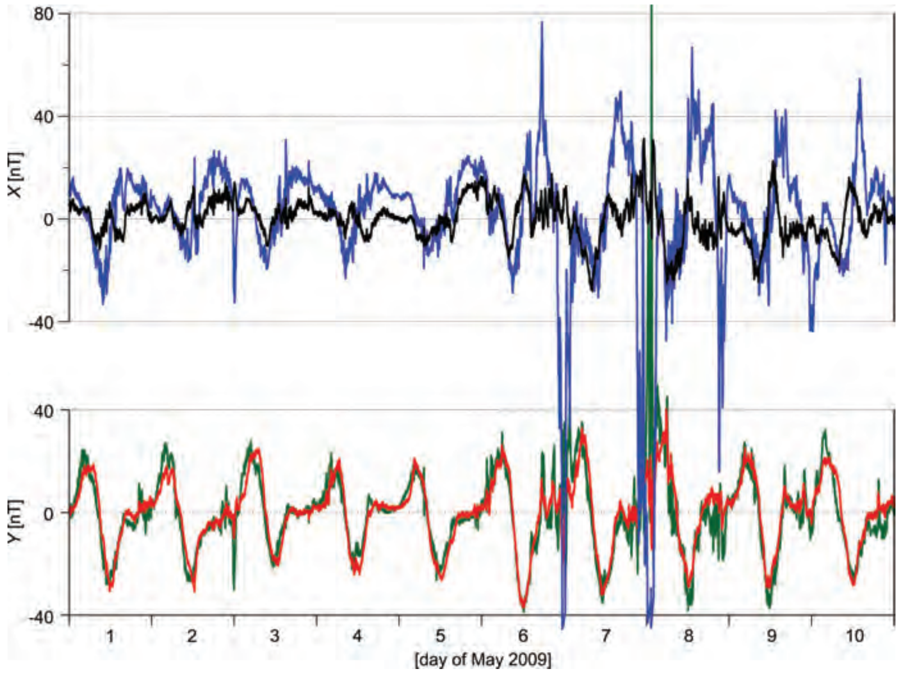

Fig. 11. Variations of *X* (blue) and *Y* (green) in Sodankyla Observatory and *X* (black) and *Y* (red) in Belsk Observatory within the period of 1 – 10 May 2009

Observatory are different in different periods of the year (Fig. 14). These changes also depend on the choice of test period in a month.

Figure 15 shows declination changes during 2009 and 2010 in chosen observatories. These changes are linear and they are determined by mathematical formula. Knowing the different declination changes during 20th century, the linear trend may be used only for a short period – about 5 years.

Continuous data records for *X*, *Y* and *Z* components from chosen observatories in the period of 2008–2011 were elaborated using Fourier transformation. The record for *Y* component from Belsk Observatory, as an example, is given in Figure 16. The processing procedure for data from each observatory was the same: 1) frequency analysis of time series (Fig. 17), 2) defining time shift between observatory records (Belsk) and other observatories by using cross correlation (Fig. 18), 3) defining of the observatory magnetic registrations accuracy.

Two periodic components of 24h and 12h periods have dominating amplitudes in the spectrum of

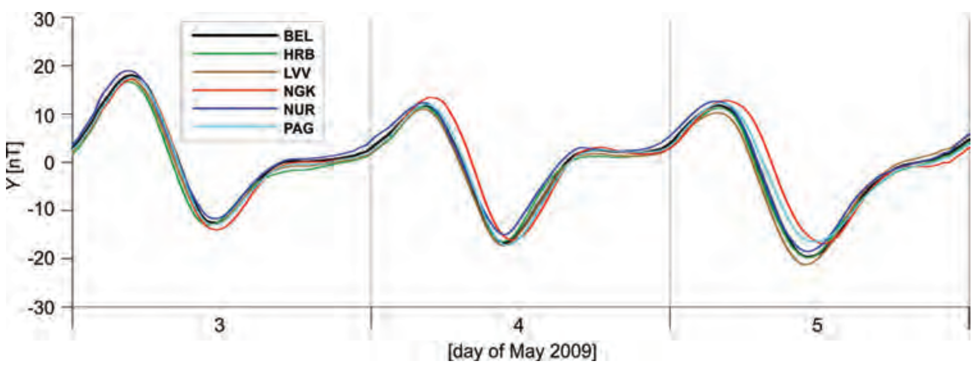

Fig. 12. Variations of *Y* component after generalization in chosen observatories in May 2009

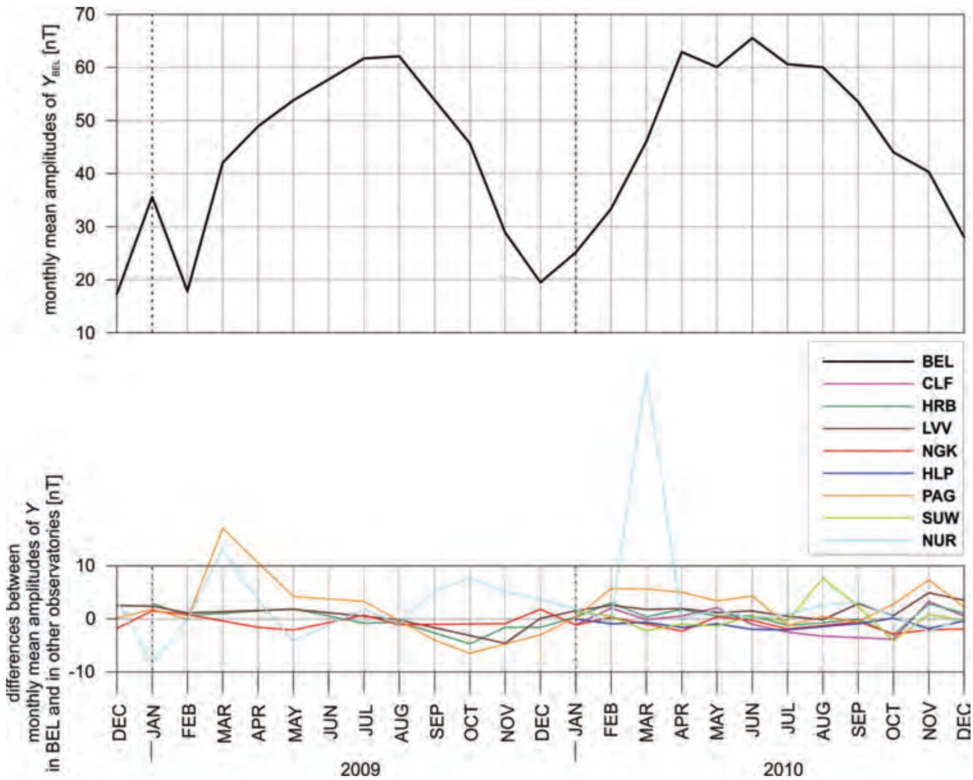

Fig. 13. Changes of monthly mean amplitudes of *Y* component in Belsk Observatory (black) and their differences with respective data from other observatories in 2009 and 2010

Y variations. Amplitudes of the remaining two periodic components detected in that spectrum are smaller than the errors of elaboration.

The average annual amplitudes of *Y* component and the change of its trends for 4 years together with the average over 4 years computed for chosen observatories: Belsk and Niemegk, are presented in Table 1. The values of amplitudes obtained are growing from 2008 to 2011 but the trend of *Y* changes after 2009 become smaller in Belsk Observatory (Welker, 2007). The linear trend for Niemegk Observatory is bigger than for Belsk Observatory and it is consistent with the results of the study of the geomagnetic field secular variations (Sas-Uhrynowski and Welker, 2009). The decrease of annual variations is probably due to 80 years cycle of magnetic field changes connected with solar cycle. An apex of solar cycle (maximum) takes place in 2012, and up to 2050 the decrease of annual changes of geomagnetic field (INTERMAGNET) is expected to be observed.

5. The elaboration of the data records from the field magnetic stations 2010–2011

In 2010 there were 9 and in 2011 6 variograph stations in Poland recording magnetic field changes (Fig. 19). The stations operated from May until September each year. Near the stations, magnetic absolute measurements of *D*, *I* and *F* (total intensity vector length) were conducted. They were necessary to compute the bases for the records.

The same strategy was used to process of all data records. First for all stations with continuous records and without magnetic perturbations (May–June) one period was chosen. Then daily means of amplitudes of *D* component from the magnetic station data for 2010 and 2011 were calculated. Changes of the declination amplitudes reduced to Belsk Observatory are presented in Figure 21a.

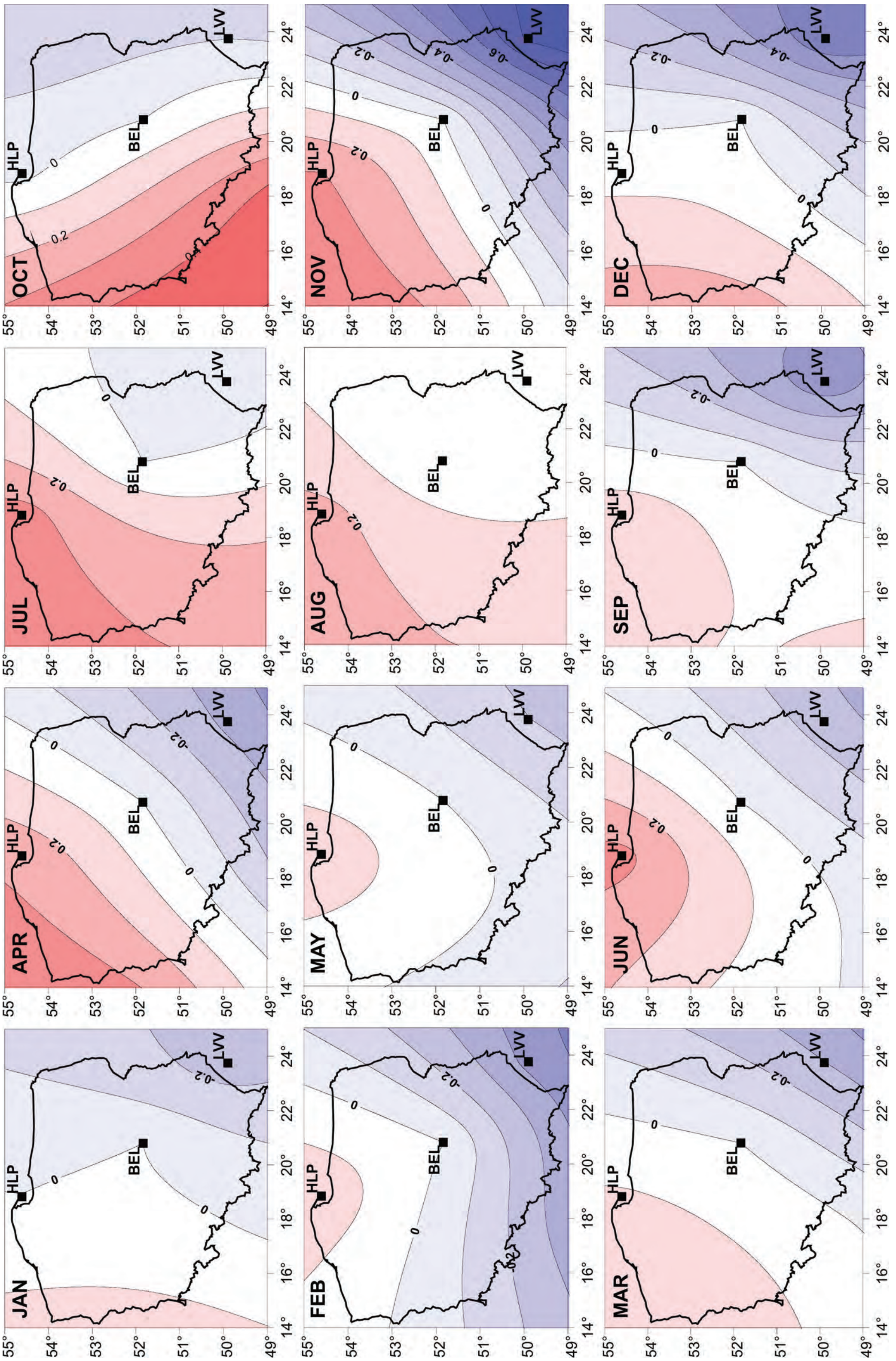

Fig. 14. Maps of amplitude changes of magnetic declination in European observatories reduced to Belsk Observatory (2010 epoch)

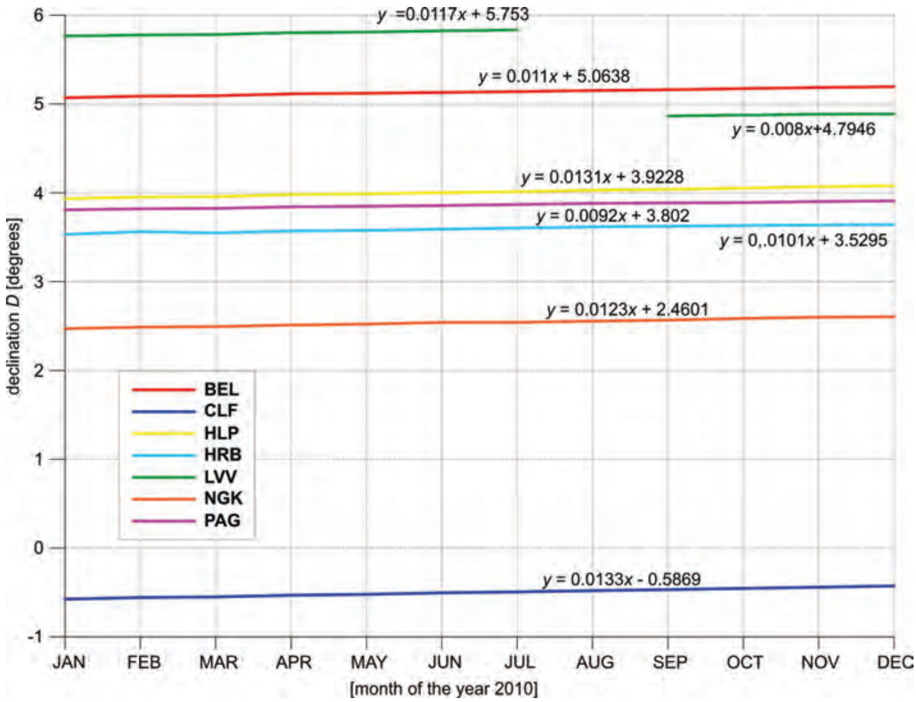

Fig. 15. Monthly means of magnetic declination *D* in chosen observatories and their linear trends (2010 epoch)

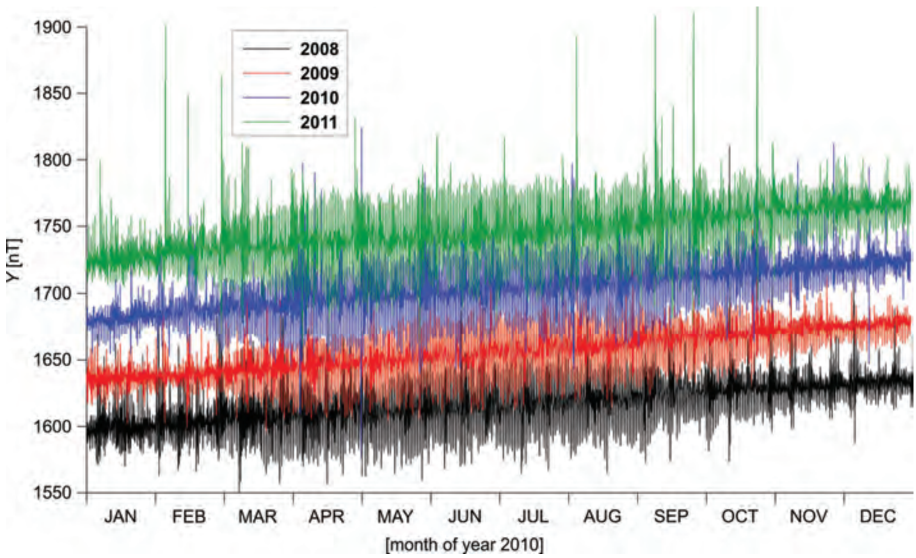

Fig. 16. Variations of *Y* component in Belsk Observatory in the period of 2008 – 2011

Independently the Fourier transformation was applied for the elaboration of station data in the same way as it has been done for observatory data. Figure 20 shows variations of declination recorded on all stations and in Belsk Observatory in a chosen period of 2011.

Frequency analysis of data from the stations indicated 3 periodic components of geomagnetic

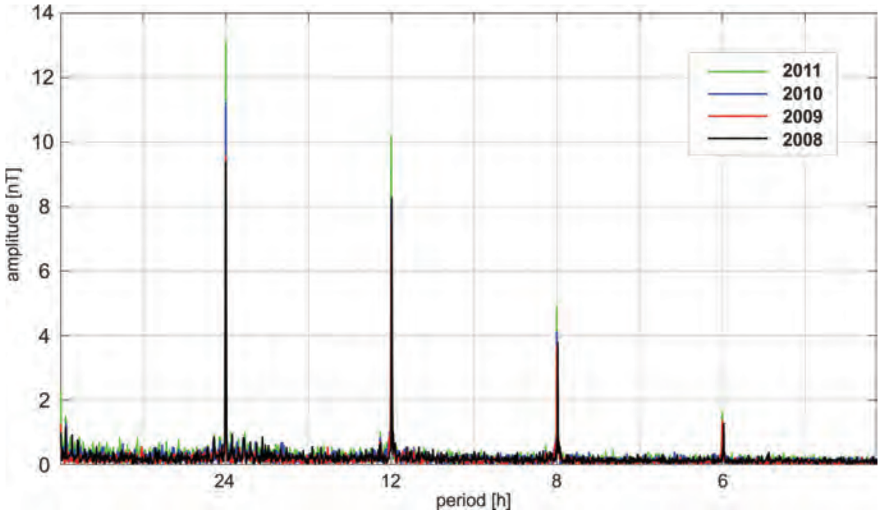

Fig. 17. Selected 4 cycles of frequency in geomagnetic field component variations

Table 1. The mean amplitudes and trends of *Y* component for 4 years period

Year	Amplitudes of *Y* changes Belsk				Error [nT]	Linear trend [nT]	Amplitudes of *Y* changes Niemegk				Error [nT]	Linear trend [nT]
	24h	12h	8h	6h			24h	12h	8h	6h		
2008	9.38	8.27	3.76	1.27	3.62	35.91	9.31	8.35	3.69	1.35	3.99	37.98
2009	9.55	7.44	3.67	1.37	2.06	44.99	9.44	7.58	3.61	1.43	2.24	44.77
2010	11.22	8.10	4.12	1.31	3.12	42.93	11.12	8.52	4.03	1.41	3.49	48.08
2011	13.11	10.16	4.87	1.62	3.85	40.52	12.93	10.44	4.83	1.62	4.21	47.51
4 years	10.80	8.47	4.09	1.39	3.24	173.8	10.68	8.70	4.03	1.45	3.56	189.10

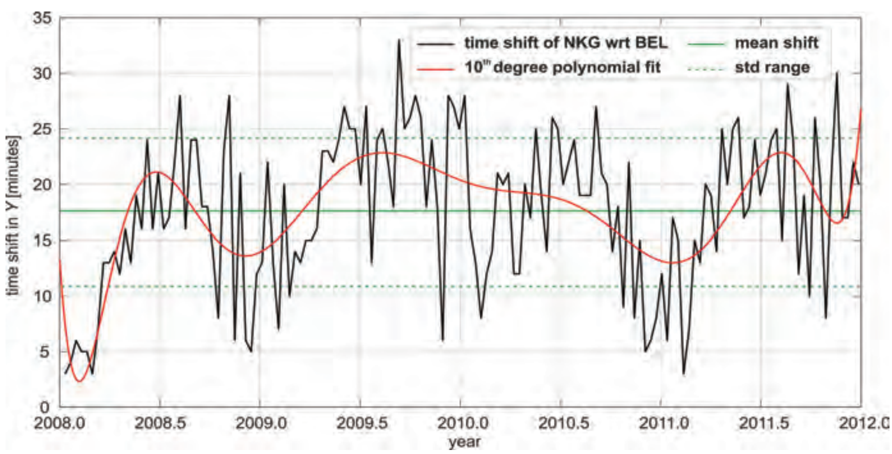

Fig. 18. Time shift during 2008 – 2011 between records for *Y* component of geomagnetic field of Belsk and Niemegk observatories

field variations the identical with cycles obtain for data observatories. Chart of declination amplitude changes reduced to Belsk Observatory from data 2010 and 2011 year was made on the basis of the results of amplitude calculations (Fig. 21b).

Cross correlation obtained for observatories and stations data allows to show the chart of time shift between the records of *Y* component at the investigated magnetic points and Belsk Observatory records (Fig. 22).

Fig. 19. The new variograph stations 2010 – 2011 in Poland

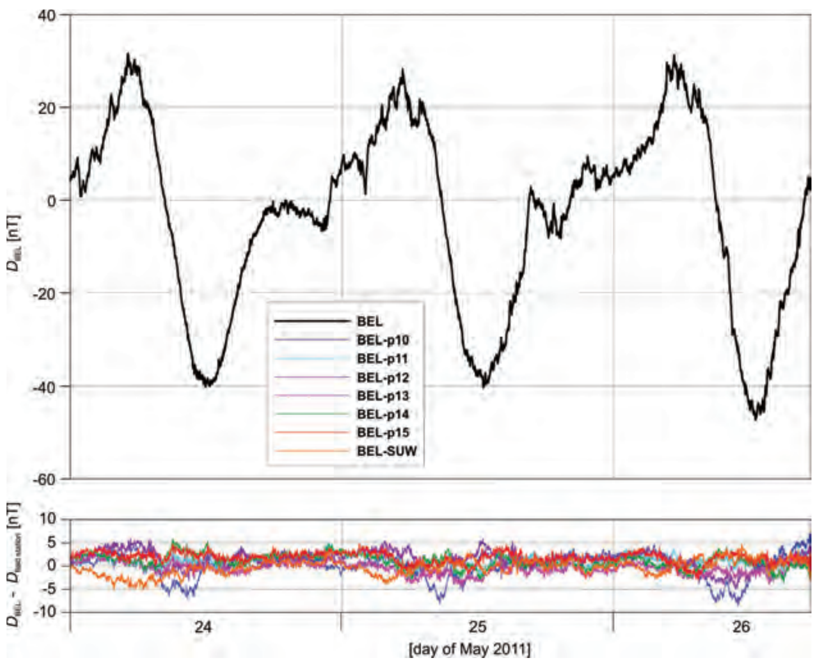

Fig. 20. Variations of declination *D* in Belsk Observatory (black) and differences between Belsk Observatory and all stations in 3 days of May 2011

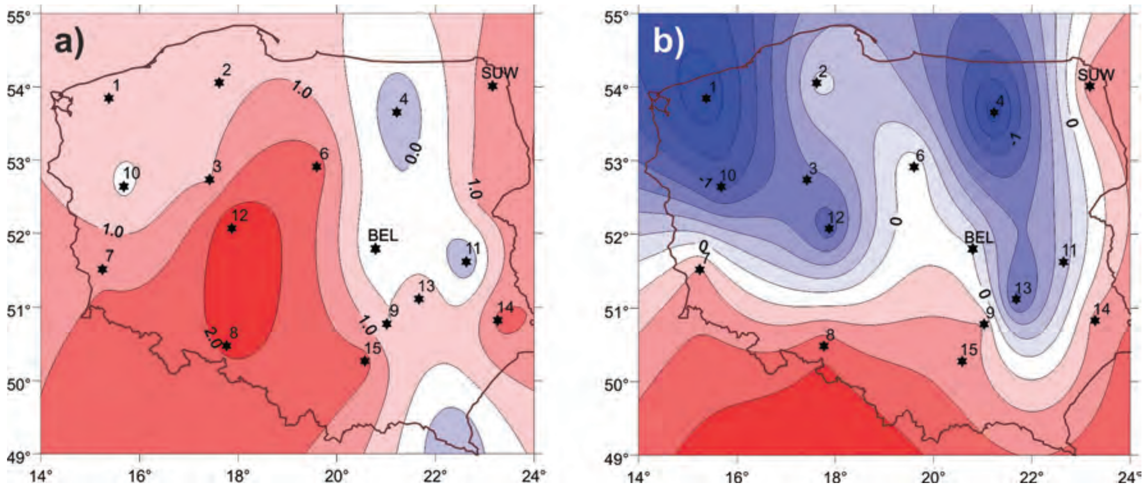

Fig. 21. Amplitude changes of declination reduced to Belsk Observatory from data of 2010 and 2011 – daily means a), and results of Fourier transformation b)

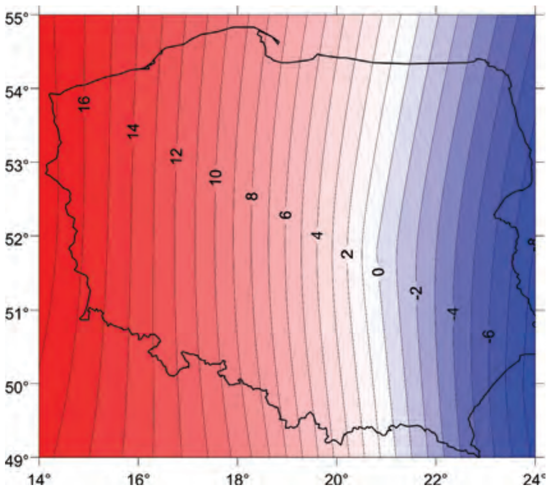

Fig. 22. Time shift between the records of the stations and others European observatories and Belsk Observatory records (*Y* component)

The magnetic measurement data from chosen repeat stations (2009–2011) were used for verification of the results. All results of the magnetic measurements were reduced to Belsk magnetogram without any corrections and with them. Figure 23 shows magnetogram from Belsk Observatory and the corrected magnetograms for stations located by eastern (+6 minutes) and western (–15 minutes) borders as well as diagrams with differences between base magnetogram and corrected magnetograms. The differences reached 5 nT.

The verification confirms that the differences in final results from different elaborations of measurement data do not exceed the measurement error.

6. Conclusions

Only declination variations (*Y* variations) have a linear trend; the trend grows from East to West of Poland; the declination (*Y* component) can be predicted but only up to 3–5 years ahead (Sas-Uhrynowski and Welker, 2008).

- The changes of amplitudes of *D* and *Y* components in Poland are so small that they do not affect the reduction of magnetic measurements.
- Time corrections (from +6 to –15 minutes) should be applied when elaborating magnetic measurements data on continental scale in Europe. When processing magnetic data in Poland, those corrections can be neglected since they generate error smaller than measurement error (result of verification).
- It has been shown that the reduction of magnetic measurements from the points around central observatory (100 – 200 km) does not generate any error influencing declination accuracy.

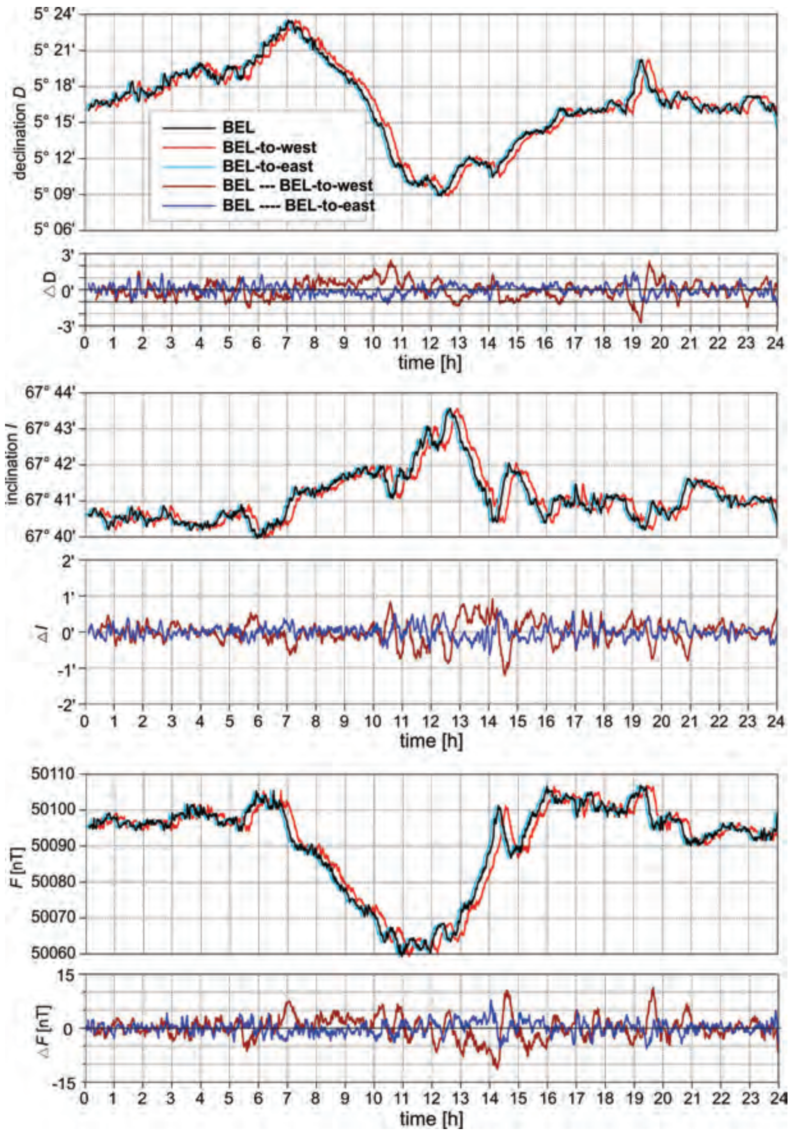

Fig. 23. Magnetogram from Belsk Observatory (black) and shift-corrected magnetograms for stations by eastern (marine blue) and western (red) borders – 25 July 2011 as well as the differences between Belsk Observatory magnetogram and magnetograms for stations by eastern (navy blue) and western (brown) borders

- The magnetic measurements near Polish borders should be reduced to one of the closest observatories: Belsk, Hel, Hurbanovo, Niemegk or Lviv.

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Wpływ krótkookresowych zmian pola magnetycznego Ziemi na dokładność opracowania magnetycznych obserwacji w Polsce

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Streszczenie. Wobec wzrostu dokładności pomiarów magnetycznych pojawia się konieczność zbadania wpływu rozkładu wariacji pola geomagnetycznego na terenie Polski na wyniki ich opracowania. W latach 60. ubiegłego wieku na terenie Polski rozmieszczono kilkanaście stacji wariograficznych, rejestrujących

w sposób analogowy zmiany składowych: *D* (deklinacji magnetycznej), *H* (składowej poziomej) i *Z* (składowej pionowej) wektora natężenia pola geomagnetycznego. Opracowane wówczas wyniki graficznych rejestracji, jak i próba ich opracowania podjęta obecnie (na podstawie archiwalnych zasobów IGiK) nie dały satysfakcjonujących, z punktu widzenia geodezji, wyników. Wartości zmian amplitud składowych pola geomagnetycznego lub przesunięcia rejestracji w czasie były mniejsze niż błędy samego opracowania.

Obecnie na stacjach polowych można przeprowadzać rejestruję zmian pola geomagnetycznego z większą częstotliwością i dużo większą dokładnością. W latach 2010 – 2011 na terenie Polski rozlokowano 15 nowych stacji polowych, które w sposób ciągły rejestrowały zmiany pola geomagnetycznego w okresie minimum 3 – 4 miesięcy. Dane te wykorzystano do opracowania rozkładu amplitud zmian deklinacji magnetycznej oraz do wyznaczenia przesunięć czasowych (związanych z efektem solarnym) między rejestracjami.

Zebrany materiał z obserwatoriów magnetycznych Polski i z wybranych obserwatoriów Europy (głównie z krajów sąsiednich) pozwolił na podobne opracowanie zmian amplitud rejestrowanych składowych natężenia pola geomagnetycznego *X, Y* i *Z* oraz przesunięcia czasowego między zapisami w poszczególnych obserwatoriach.

Wszystkie dane opracowane zostały w sposób klasyczny – jako średnie wartości dobowe – i przy wykorzystaniu transformaty Fouriera. Opracowanie ciągu milionowych danych magnetycznych z lat 2008–2011 pozwoliło na dokładniejsze wyznaczenie cykli zmian poszczególnych składowych wektora natężenia pola geomagnetycznego, wartości zmian ich amplitud na przestrzeni kilku lat oraz przesunięcia obserwatoryjnych magnetogramów względem magnetogramów z Belska (Centralne Obserwatorium Geofizyczne PAN).

Zakres zmian amplitud składowych pola geomagnetycznego jest niespodziewanie mały; wynosi on zaledwie ±2 – 3 nT i jest on na poziomie błędu opracowania danych. Wyniki opracowania danych obserwatoryjnych i polowych jednoznacznie wskazują na przypadkowy charakter zmian amplitud składowych pola geomagnetycznego na terenie Polski. Ich rozkład zależy od danych przyjętych do analizy: roku opracowania, pory roku, wybranego przedziału czasowego itp.

Obraz przesunięć czasowych rejestracji magnetycznych dla Polski jest systematyczny, a poprawki czasowe mieszczą się w przedziale od +6 minut dla pomiarów na granicy wschodniej do –15 minut dla pomiarów na granicy zachodniej.

Testowe opracowanie wyników polowych pomiarów magnetycznych z wybranych punktów wiekowych z lat 2009–2011 wykazało, że nieuwzględnienie poprawek czasowych może spowodować różnice w wynikach końcowych mniejsze od błędów samych pomiarów.

Pomiary magnetyczne wykonane na terenie Polski można, bez utraty dokładności, redukować do polskiego centralnego obserwatorium w Belsku. Pomiary wykonywane blisko granic powinno się redukować do najbliższego obserwatorium magnetycznego kraju sąsiedniego.

Słowa kluczowe: krótkookresowe zmiany składowych pola geomagnetycznego; zmiany regionalne pola geomagnetycznego, zmiany deklinacji magnetycznej