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Secular Variations of the Geomagnetic Field in Europe

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Abstract. The international project MagNetE (Magnetic Net For Europe) was undertaken in 2003. The project has been accepted by the International Association of Geomagnetism and Aeronomy of the IUGG. The common research on the geomagnetic field space and time distribution in Europe, as well as collecting data and its analysis, constitutes the grounds for theoretical works on geomagnetic field models and their parameters. It is also the basis for studying the genesis of the geomagnetic field secular variations and its mechanism. The results of the project enable to increase the accuracy of models on the global, regional, and also on local scale. It has a vital meaning for the regions where the geomagnetic data are not available or, where the existing data, because of their low accuracy, cannot be used. Information about the secular variations of the geomagnetic field makes it possible to update the magnetic data, which is needed in navigation, topography, telecommunication, geology and geophysics and other domains.
The enclosed maps of isopors presented have been compiled using the results of measuring campaigns in the years 2004-2006 together with the archive data. They show the secular variations of the magnetic declination D, the length H of the horizontal intensity vector and the lenght F of the total intensity vector of the geomagnetic field, in the intervals 1995-2000 and 2000-2005. The maps of isopors for Europe have been worked out using data from not only the magnetic observatories, but also from some hundred magnetic secular variation stations (repeated stations), located in 23 European countries. The secular variation differences between data obtained from terrestrial surveys and data from the IGRF model (International Geomagnetic Reference Field) have been presented in the form of maps and histograms.
In several regions of Europe the unexpectedly large secular variation anomalies are visible. Anomalies of so high frequency and large amplitude cannot exist. They are probably caused by data errors, which may have different sources. Their existence cannot be explained by now. Therefore the MagNetE project should be continued.

Keywords: geomagnetic field, secular changes, maps of isopors, IGRF model

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1. Introduction

Internationally coordinated research on the geomagnetic field space and time distribution in Europe, as well as analysis of collected data, is necessary for theoretical works on geomagnetic field models and their parameters, and also for generating maps of geomagnetic field elements as well as maps of their anomalies. That research is also the basis for studying the genesis and mechanism of the secular variations of geomagnetic field (Uhrynowski and Welker, 2008). The international project MagNetE (Magnetic Net For Europe) undertaken in 2003 by more than 20 European countries, and accepted by the International Association of Geomagnetism and Aeronomy of the IUGG, turned out a good solution for working out the standards of magnetic

measurements and collecting magnetic data at the European repeat stations. The conclusions from the last Workshop on the MagNetE project in Helsinki in June 2009 indicate that the amount of data collected is sufficient for generating new magnetic maps of isopors for Europe. The results of the project enable to increase the accuracy of magnetic models on global, regional, and also on local scale. It has a vital meaning for the regions, where the geomagnetic data is not available or, where the existing data, because of their low accuracy, cannot be used for practical purposes. Information about the secular variations of geomagnetic field is necessary for updating the magnetic data, which is needed in navigation, topography, telecommunication, geology, geophysics and other domains. The actual map of Europe repeat stations and geomagnetic observatories is shown in Figure 1.

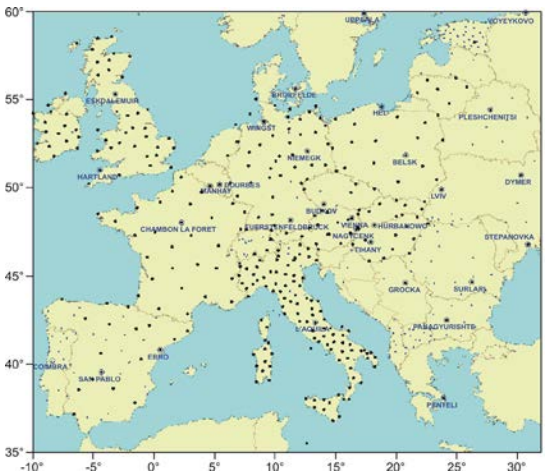

Fig. 1. Localization of the geomagnetic observatories with name and symbol and the magnetic repeat stations in Europe

All magnetic data has been collected in the geomagnetic database, established at the Institute of Geodesy and Cartography, Warsaw, within the framework of the project, as well as in World Data Centre (WDC) in Edinburgh (www.geomag.bgs.ac.uk). Figure 2 shows the magnetic declination contour lines for Europe, calculated with the use of that data.

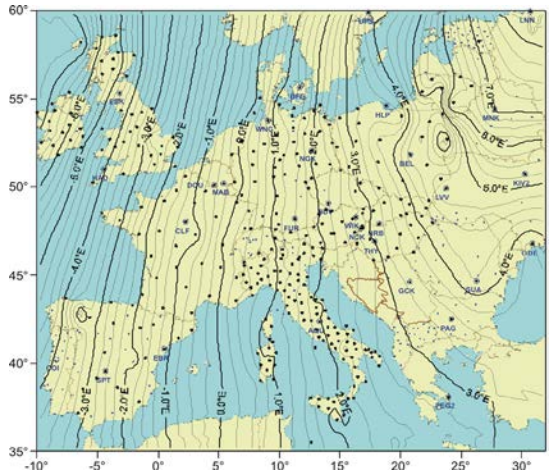

Fig. 2. Map of declination *D* at epoch 2005.5

2. The maps of isopors

The maps of isopors (annual changes) of the geomagnetic field for Europe, presented in the paper, have been compiled using the results of measuring campaigns carried out at the magnetic repeat stations in the years 2004-2006 as well as using the archive data, starting from 1980 (Welker, 2007). They show the secular variations of the three chosen independent elements of the geomagnetic field - declination *D*, length of the horizontal vector **H** and the length of the total intensity vector **F**. The elaboration has been made for two intervals 1995-2000 and 2000-2005. The maps of isopors, compiled within the frame of the project, constitute the first presentation of the secular variations of the Earth magnetic field in Europe, which have been worked out using not only the data from the geomagnetic observatories (Krzemiäski, 1962; Mundt, 1973), but also the data from several hundred of magnetic repeat stations, located in 23 European countries. The results obtained have been compared with the isopors computed from the IGRF model (International Geomagnetic Reference Field) (Langel, 1992). Figures 3a, 3b, 4a, 4b, and 5a, 5b show the isopors of declination *D*, of the length *H* of the horizontal vector **H** and of the length *F* of the total intensity vector **F** of the geomagnetic field, respectively in the intervals 1995-2000 and 2000-2005 (red lines). The black lines show the isopors calculated from the IGRF model .

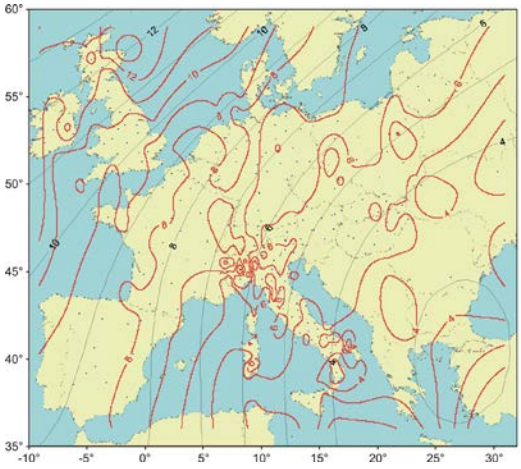

Fig. 3a. The isopors of D
in the interval 1995-2000 [arc minutes]

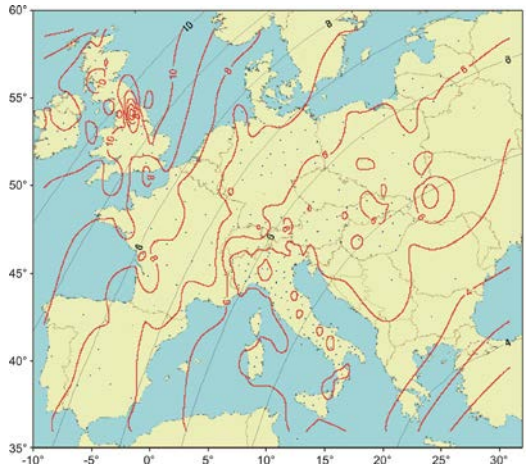

Fig. 3b. The isopors of D
in the interval 2000-2005 [arc minutes]

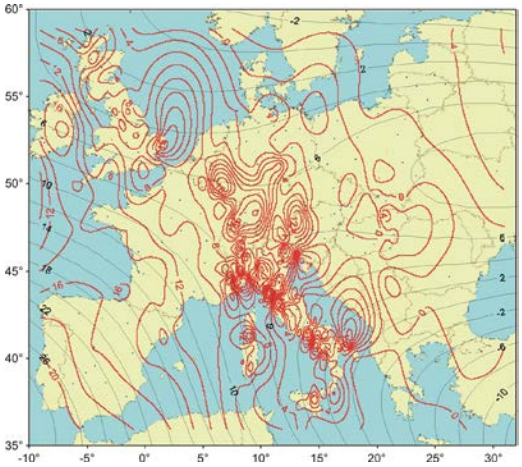

Fig. 4a. The isopors of H
in the interval 1995-2000 [nT]

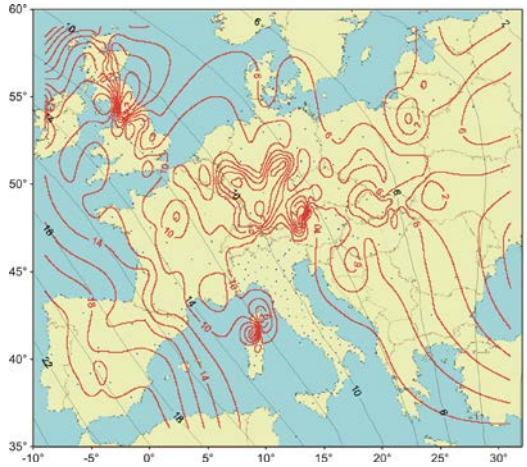

Fig. 4b. The isopors of H
in the interval 2000-2005 [nT]

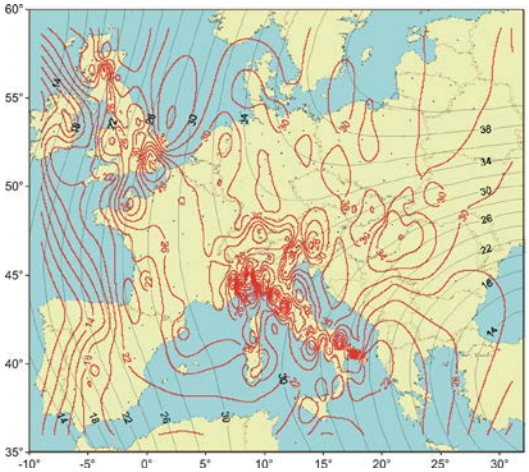

Fig. 5a. The isopors of F
in the interval 1995-2000 [nT]

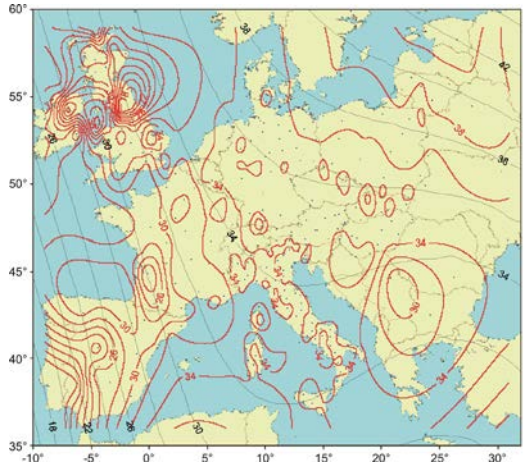

Fig. 5b. The isopors of F
in the interval 2000-2005 [nT]

The isopors of *D*, obtained on the basis of data from measurements at the magnetic observatories as well as at the magnetic repeat stations, were compared with those computed from the IGRF model. The differences obtained are presented in the form of maps as well as in the form of histograms in Figures 6a and 6b.

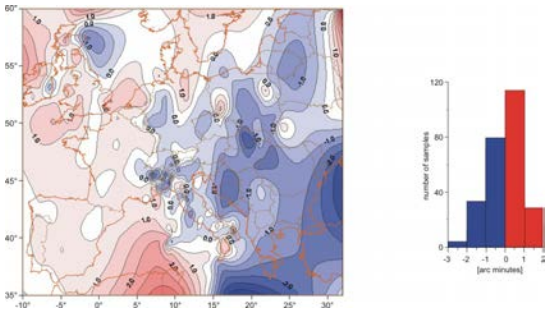

Fig. 6a. Differences between isopors of *D* from the IGRF model and computed from the measurements at the repeat stations and at observatories in the interval 1995-2000 [arc minutes]

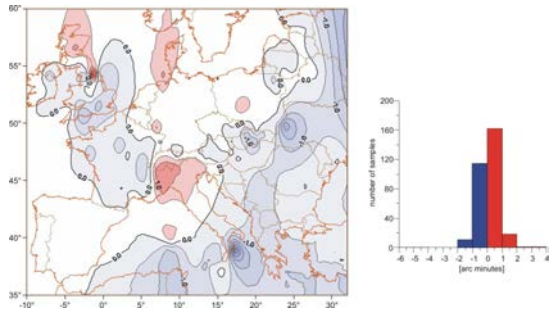

Fig. 6b. Differences between isopors of *D* from the IGRF model and computed from the measurements at the repeat stations and at observatories in the interval 2000-2005 [arc minutes]

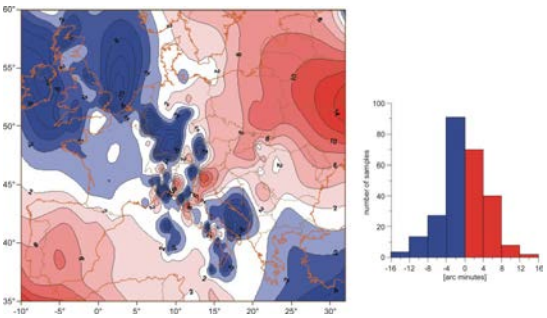

Fig. 7a. Differences between isopors of *H* from the IGRF model and computed from the measurements at the repeat stations and at observatories in the interval 1995-2000 [nT]

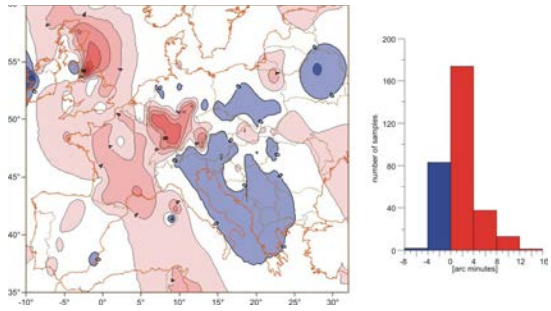

Fig. 7b. Differences between isopors of *H* from the IGRF model and computed from the measurements at the repeat stations and at observatories in the interval 2000-2005 [nT]

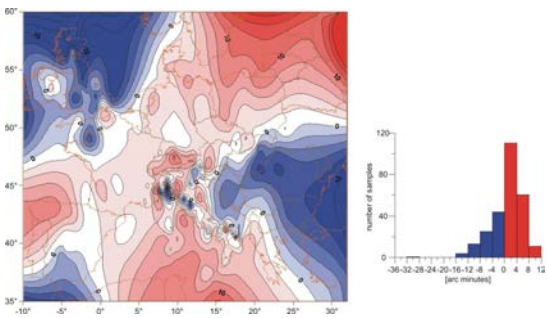

Fig. 8a. Differences between isopors of *F* from the IGRF model and computed from the measurements at the repeat stations and at observatories in the interval 1995-2000 [nT]

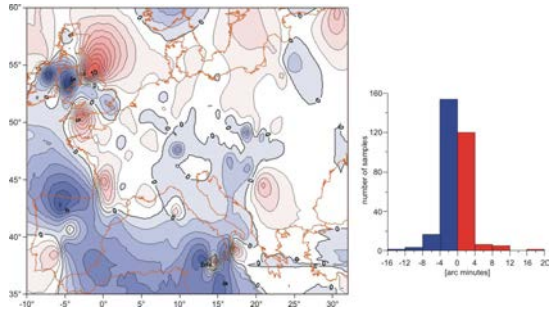

Fig. 8b. Differences between isopors of *F* from the IGRF model and computed from the measurements at the repeat stations and at observatories in the interval 2000-2005 [nT]

The isopors of *H* and *F*, determined on the basis of data from measurements at the magnetic observatories as well as at the magnetic repeat stations, were compared with those computed from the IGRF model. The differences obtained are presented in the form of maps as well as in the form of histograms in Figures 7a, 7b and 8a, 8b, respectively.

3. Discussion on the results

The maps of isopors elaborated show that trends of the changes of geomagnetic field elements computed from the IGRF model are the same as those obtained from data acquired at magnetic observatories and at repeat stations. The maps also show that in several regions of Europe the secular variations of the Earth magnetic field have an anomalous character. These „anomalies" of secular variations have dimensions from tens to several hundred kilometers. Similarly to anomalies of magnetic field elements, one can call them local or regional secular variation anomalies, assuming that their sources are located in the upper Earth's crust. The change of location of these anomalies between the intervals considered, i.e. 1995-2000 and 2000-2005, would point out that the sources move fast inside the crust. It is, of course, not possible.

Therefore, the only explanation, which seems realistic, is that revealed „anomalies" of secular variations are caused by inaccurate data acquired at the ground stations. Such conclusion is confirmed by the fact that in 2003 the measuring and processing procedures were unified in the framework of the project MagNetE, what may be observed looking at the maps for the second interval investigated, where „anomalies" are smaller.

The data errors may have different sources. Some of data may contain the observation errors or errors caused by magnetic field disturbances during the survey. Other errors may be caused by various measuring procedure used during the survey in individual countries. The aim of the project MagNetE was, among others, to induce the unification of measuring and computing procedure but it has probably failed so far. In some countries the survey has been performed at too large number of stations. It has been already stated that it is better to make measurements at the less number of stations and to perform observations for several days, than to increase the number of stations at the expense of a shorter time of survey. The distance between the magnetic repeat station and the magnetic observatory, from which data is used for reduction, may also have an influence for the accuracy of the results of measurements. It mostly concerns those stations, which are far away from the observatory and the field magnetic variometer has been not used during the survey.

After each next measuring campaign, the errors being the source of secular variation of the Earth magnetic field „anomalies" in Europe, should be progressively eliminated.

4. Conclusions

1. Presented maps of isopors contain probably errors, caused by insufficient accurate accessible data obtained for some regions of Europe.
2. The recommendations concerning measuring and computing procedures, which have been worked out in the first stage of the project MagNetE, could be probably observed not enough carefully in some countries. At the last meeting on the MagNetE project, held in Helsinki, some doubts concerning strange anomalies in the UK and Italy were explained. In some countries, e.g. UK an Italy, magnetic network consists of large number of points, many of them with bad localization and stabilization. No special repeat stations devoted to geomagnetic secular changes research, as it has place in e.g. Germany, Poland, Czech Republic and other countries are there selected. The British and Italian researchers, participating in the Workshop, declared to reduce number of points by about 30%-50% and to choose only those ones, which are suitable to serve as repeat stations.
3. The changes of geomagnetic components, needed for the reduction to the other epoch the data obtained from the survey at the magnetic stations, may be interpolated or extrapolated in no more than for 5-year intervals, using the IGRF model. The error will not exceed 10%

of the annual change of component, i.e. 1' for declination and 3 nT for the length of total intensity vector.

4. The results obtained from the survey, particularly in the „anomalous" regions, require very careful verification. Taking into consideration the absolute character of present-day magnetic measurements, the verification may be performed by taking at the same place the measurements repeated more times during several days.
5. It is indispensable to continue the project MagNetE (conclusion of the last meeting) making the next measuring campaigns and exchanging as well as analyzing obtained results. The next MagNetE meeting will be hold in Rome, Italy, in 2011.

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Zmiany wiekowe pola magnetycznego Ziemi w Europie

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Streszczenie. W 2003 roku został podjęty we współpracy międzynarodowej projekt badawczy o nazwie MagNetE (Magnetic Net for Europe). Celem projektu, który ma poparcie Międzynarodowej Asocjacji Geomagnetyzmu i Aeronomii, jest prowadzenie wspólnych badań nad czasowo-przestrzennym rozkładem pola geomagnetycznego w Europie. Gromadzony w wyniku kampanii pomiarowych materiał obserwacyjny, jak również dane archiwalne, poddawane są sukcesywnie kompleksowej analizie, która stanowi podstawę do rozważań teoretycznych nad modelem pola geomagnetycznego i jego parametrów oraz nad przyczynami i mechanizmem zmian wiekowych tego pola. Projekt MagNetE umożliwi podniesienie

dokładności opracowywanych modeli w skali globalnej, regionalnej, a także lokalnej, co ma istotne znaczenie w rejonach gdzie występuje brak naziemnych danych dotyczących pola geomagnetycznego lub gdzie istniejące dane z uwagi na ich niską dokładność są mało przydatne. Poznanie zmian wiekowych ziemskiego pola magnetycznego umożliwi także dokładniejszą aktualizację danych, dotyczących pola geomagnetycznego, które mają zastosowanie w nawigacji, topografii, telekomunikacji, geologii, geofizyki, a także w innych dziedzinach.

Zmiany wiekowe ziemskiego pola magnetycznego zostały przedstawione w postaci map izopor trzech niezależnych elementów pola geomagnetycznego – deklinacji D, modłułu F wektora całkowitego natężenia pola oraz modułu H jego składowej poziomej. Mapy izopor zostały opracowane dla dwóch interwałów czasowych 1995–2000 oraz 2000–2005. Podstawę opracowania stanowiły dane z pomiarów przeprowadzonych na punktach wiekowych w ramach kampanii pomiarowych wykonanych w latach 2004–2006. Wykorzystane zostały także wartości rejestracji z europejskich obserwatoriów magnetycznych oraz zapisy archiwalne. Wszystkie te wartości zostały zgromadzone w utworzonym w ramach projektu banku danych magnetycznych.

Wykonane w ramach projektu badawczego mapy izopor ww. elementów pola geomagnetycznego są pierwszym przedstawieniem zmian wiekowych magnetycznego pola Ziemi, do którego zostały wykorzystane nie tylko dane z obserwatoriów magnetycznych, ale także dane z pomiarów na kilkuset magnetycznych punktach wiekowych, zlokalizowanych w 23 krajach europejskich.

Opracowanie zawiera także analizę zmian wiekowych na tle zmian obliczonych wg modelu IGRF (International Geomagnetic Reference Field). Wyniki analizy są zilustrowane na rysunkach przedstawiających mapy rozbieżności pomiędzy wynikami pomiarów w obserwatoriach magnetycznych i na punktach wiekowych a danymi dla tych samych punktów, obliczonymi według modelu IGRF. Dla każdego elementu pola i dla obu interwałów opracowano także histogramy rozbieżności.

Opracowane mapy ujawniają rejony, które mają charakter anomalny. Jednakże anomalie zmian wiekowych pola geomagnetycznego o tak zmiennej lokalizacji i amplitudzie nie mogą być wywołane przyczynami naturalnymi, czyli nie powinny mieć miejsca. Ich przyczyną są prawdopodobnie błędne dane, często ze zbyt dużej ilości niezbyt starannie dobranych punktów pomiarowych.

Niezbędne jest więc kontynuowanie projektu MagNetE, przeprowadzanie kolejnych kampanii pomiarowych a następnie dokonywanie sukcesywnie analizy otrzymywanych wyników.

Słowa kluczowe: pole magnetyczne Ziemi, zmiany wiekowe, mapy izopor, model IGRF