Standard geomagnetic observatory data in tectonomagnetism: case study related to the *M* 5.7 Timisoara, Romania, earthquake

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Abstract
There has recently been much discussion of large-scale interactions of fault zones and the influence of large-scale processes in the preparation and triggering of earthquakes. As a consequence, an official recommendation was issued to set up observational networks at regional scale. In this context, the existing network of standard geomagnetic observatories might play a more important role in future tectonomagnetic studies. The data from standard geomagnetic observatories are basically not appropriate for the detection of small-magnitude and, in most cases, spatially very localized geomagnetic field changes. However, their advantage is a continuity in a long-time period which enables the study of regional tectonomagnetic features and long-term precursory changes. As the first step of a more extensive study aimed at examining the features of observatory data for this purpose, a three-year data set from five European observatories has been analyzed. Some common statistical procedures have been applied along with a simple difference technique and multivariate linear regression to define local geomagnetic field changes. The distribution of $M \geq 4.5$ earthquakes in Europe, in a corresponding period, was also taken into account. No pronounced field variation, related in time to the M 5.7 Timisoara (Romania) earthquake on July 12, 1991, was found at Grocka observatory at about 80 km from the earthquake epicenter. However, an offset in level of the differences in declination which include Grocka observatory, not seen in the case of differences between other observatories, could be associated with a possible regional effect of the M 4.8 earthquake which occurred in September 1991 at about 70 km SE from Grocka.

1. Introduction

Decades of field observations along with theoretical considerations have yielded a well-developed methodology in tectonomagnetic effect studies. It is commonly accepted that a

network of stations is necessary for recording precursory phenomena. How dense should that network be? In answering this question at least two things have to be kept in mind: 1) the extreme complexity of stress-strain distribution resulting in the corresponding distribution and variation of geophysical fields and characteristic parameters at different scale values, and 2) the importance of estimating the size and shape of the earthquake preparation zone when discussing the tectonomagnetic effect in terms of earthquake occurrence.

We are more familiar with the idea of spatially localized magnetic field anomalies in the vicinity of an active fault (Johnston, 1978;

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Sasai, 1991; Johnston *et al.*, 1994). However, the fact that some phenomena related to earthquake occurrence were detected tens and hundreds of kilometers away from an epicenter cannot be ignored (Shapiro *et al.*, 1978; Shapiro and Abdullabekov, 1982). Also, there has recently been a lot of discussion on large-scale processes in the preparation and triggering of earthquakes. In that context official recommendations were adopted at the meetings of the Subcommission on Earthquake Prediction Research held during the General Assembly of the European Seismological Commission in Prague, 1992, and Athens, 1994 (personal communication). Both recommendations support the concept of «the development of regional scale networks in order to include the study of long-distance phenomena».

Dobrovolsky *et al.* (1979) introduced the idea of so-called «strain radius» which supports the possibility of the existence of long-distance precursors. Namely, it enables the estimation of the size of the effective precursor manifestation zone that is often greater than the focal zone, *i.e.*, the size independent of the physical nature of the precursor. The concept was tested on a number of precursory changes reported by other authors. The result is summarized in fig. 1. It shows that the precursors of a non-mechanical nature, including geomagnetic field changes, can be limited by a theoretical line for the strain value 10^{-8}. Corresponding radius ρ of the manifestation zone, *i.e.*, the greatest distance where a precursor can be detected, is given by $\rho[\mathrm{km}] = 10^{0.433M}$, where M is an earthquake magnitude. In connection with this study it is interesting to mention that the strain value of 10^{-8} was distinctly recorded on Hawaii as the result of the 1964 Alaska earthquake of M 8.6 (Press, 1965).

In the light of these facts there are two questions that we would like to answer. Firstly, is it justified to use the network of standard geomagnetic observatories in tectonomagnetic effect studies, and secondly, what sort of data commonly available from observatories should be used and how are they to be treated in order to reveal eventual magnetic field changes associated with tectonic or, as in this particular case, seismic activity?
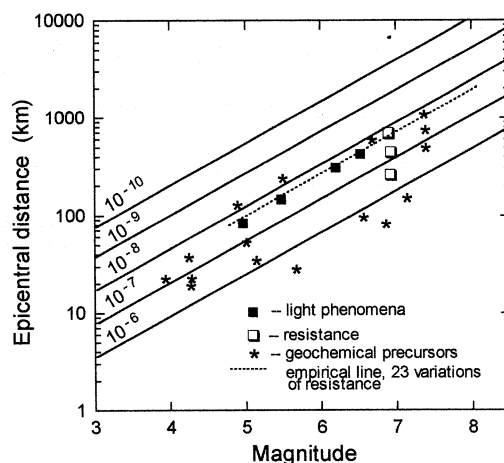

Fig. 1. Relationship between the strain radius and earthquake magnitude for different strain values. Points denoted by symbols stand for different precursors anomalies of a non-mechanical nature (taken from Dobrovolsky *et al.*, 1979).

At least so far as Europe is concerned there is a well-developed network of standard geomagnetic observatories. Many of them have been operating for several decades or even longer thus providing long, continuous data series for studying the time variation of the geomagnetic field and its causes. Also, a relatively dense network of observatories, particularly over some European areas, makes it possible to gain an insight into the changes of the geomagnetic field spatial distribution and its eventual relation to seismic activity.

2. Data analysis and results

Basic data obtained from geomagnetic observatories are hourly mean values of declination (D), horizontal (H) and vertical (Z) intensity or a combination of three mutually orthogonal components X, Y and Z. They are commonly available in the form of yearbooks or nowadays possibly on some other medium more convenient for further computer processing. Daily, monthly and yearly mean values for all, magnetically quiet and disturbed days are

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derived from hourly mean values. Also, most European observatories are taking part in reading instantaneous values of *D*, *H* and *Z* (possibly total geomagnetic field intensity *F*) at 02:00 UT sharp in ten selected days in a month. Like the yearbooks, these data used to be regularly exchanged between observatories. Lately these data are being sent to the Wingst observatory (Germany) that processes 02:00 UT values and distributes the tables of differences in geomagnetic field components for all pairs of observatories.

In this work both sources of data were used. An explanation should be given though concerning the selection of observatories. The choice is inadequate considering the distribution of observatories Dourbes (DOU) Belgium; Niemegk (NGK) Germany; Grocka (GCK) Yugoslavia; Panagyurishte (PAG) Bulgaria and L'Aquila (AQU) Italy, and the corresponding distribution of earthquakes with $M \geq 4.5$ which occurred in the period 1990-1992 (see fig. 2). It is simply the result of the fact that the study
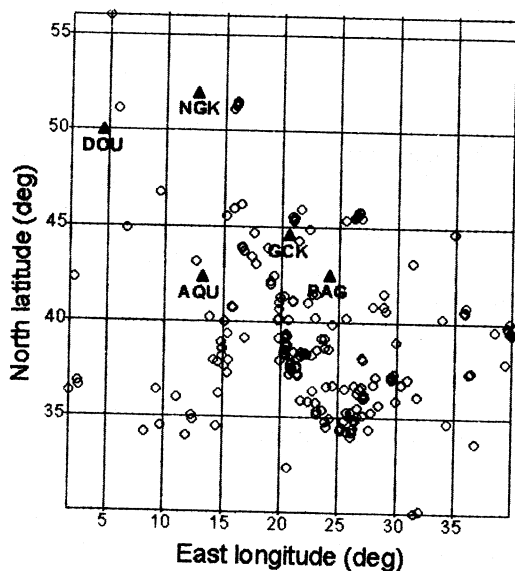
was initiated on the occasion of the *M* 5.7 earthquake on July 12, 1991, near Timisoara, SW Romania. Grocka geomagnetic observatory, at a distance of about 80 km from the epicentral region, happened to be the nearest continuously recording magnetic station which gave us the idea to search for field variations possibly related to earthquake activity. At that time only 02:00 UT data from the above mentioned observatories were at our disposal. Later on the analysis was extended by the data from L'Aquila observatory yearbook for the year 1991. Accordingly, the results will be presented separately for 02:00 UT data and for the data from geomagnetic yearbooks.

2.1. Analysis of data read at 02:00 UT

In detecting generally small intensity magnetic field changes related to tectonic activity, the main problem is the elimination of external source (iono- or magnetospheric) variations. Regarding this point 02:00 UT values have some advantages. Namely, at the reading time the effects of the Sun, conductivity anomalies and the like are at a minimum level. Ispir *et al.* (1976) used this kind of data from Kandilli (Turkey) and two adjacent observatories Surlari (Romania) and Panagyurishte (Bulgaria) to compute tectonomagnetic effect in the past. To the author's knowledge, there are no other works on tectonomagnetism based on analysis of 02:00 UT data.

The interval 1990-1992 was chosen on the basis of relation

$$\log T = 0.6\, M - 1.01$$

given by Rikitake (1975, 1979), where *T* denotes the so-called precursor time (in days) and *M* is an earthquake magnitude. For the main shock magnitude *M* 5.7 of Timisoara earthquakes we obtain $T = 257$ days or approximately 8.5 months. Therefore, possible magnetic field disturbance at Grocka observatory related to the earthquake activity in the Timisoara region, could have appeared before the end of 1990. Also, we assume that a three-year interval is sufficient for defining normal

Fig. 2. The distribution of $M \geq 4.5$ earthquakes in Europe for the period 1990-1992 and the location of five geomagnetic observatories whose data were used in the study.

field variation and, with respect to it, anomalous changes if any.

The analysis was carried out with the data set of *D*, *H* and *Z* values from observatories GCK, PAG. AQU, DOU and NGK. To isolate magnetic field changes of crustal origin characteristic for a particular observatory site, we differentiate data between pairs of observatories. This method, commonly known as simple differences (Rikitake, 1966), reduces noise from iono- and magnetospheric sources. The efficiency of the method, measured by the standard deviation of resulting differences in the magnetic field components, depends very much on the separation between the stations which is rather large in our case. However, we assume that the simple differences method is satisfactory for preliminary analysis.

When plotted as a function of time, all three components, *D*, *H* and *Z*, clearly exhibit in-

creasing linear trend. This trend is still observable in the differences between observatories because the rate of the geomagnetic field secular change differs from one observatory to another. Variation of declination will be shown (see fig. 3) to illustrate what the resulting residuals look like after the elimination of linear trend. Corresponding standard deviation of the differences between Grocka and four other observatories generally increases with the station separation, although it does not depend on latitude (φ) and longitude (λ) in the same manner, which will be discussed later on. No particular variation, except perhaps in the case of differences GCK-PAG due to the smallest standard deviation, can be observed around the time of the Timisoara earthquake and the *M* 4.8 earthquake that happened in Eastern Serbia, about 70 km SE from Grocka observatory. It is possible that an adequate filtering tech-
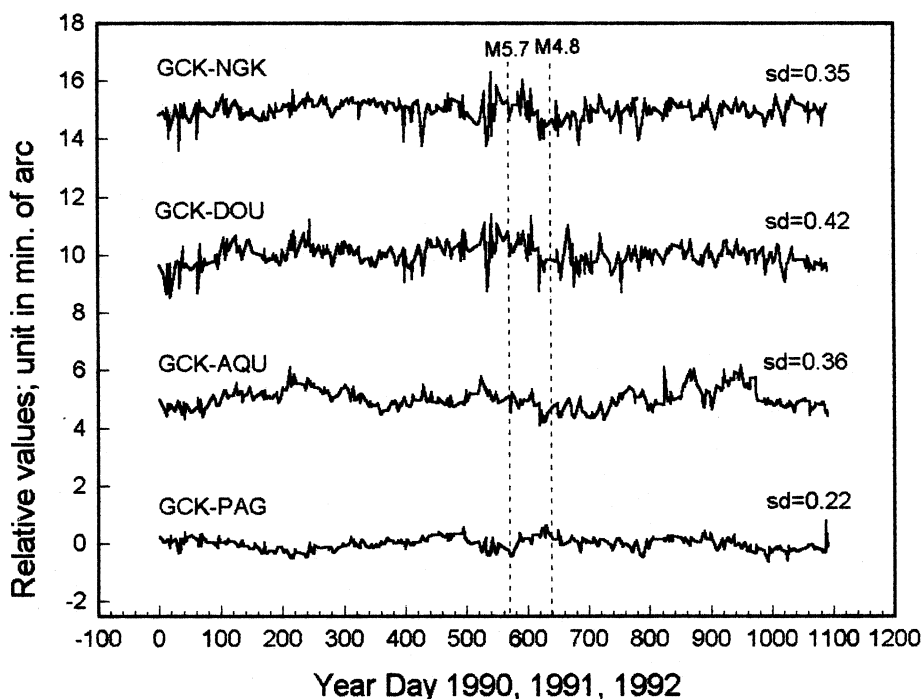

Fig. 3. Simple differences of declination at 02:00 UT between Grocka (GCK) and four other observatories after the removal of linear secular trend. Vertical lines indicate occurrence time of two earthquakes within 80 km from GCK. Respective values of standard deviations are given for each curve.

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nique would reveal more clearly the character of the magnetic field changes. The same is also true for the changes in *H* and *Z* which are not presented here.

The applicability of 02:00 UT data, judged by the standard deviation of simple differences, can also be discussed from the result in fig. 4a,b. It is the summary of standard deviation of simple differences in declination, horizontal and vertical intensity for all pairs of observatories, expressed as a function of difference in latitude ($\Delta\varphi$) and longitude ($\Delta\lambda$) between observatories. The dependence of standard deviation on latitudinal difference is well

Fig. 4a,b. The dependence of standard deviation on difference in (a) latitude and (b) longitude between the observatories. Standard deviation is calculated for three-year sets of simple differences in *D*, *H* and *Z* values read at 02:00 UT for all pairs of observatories. Anomalous values in the case of declination shown in (a) correspond to observatory pairs DOU-GCK and DOU-AQU.

defined; it increases approximately for 0.3 nT and 0.2 nT per one degree difference in φ for *H* and *Z*, respectively, while it is almost independent in the case of declination. Two pairs of observatories producing anomalous standard deviations are GCK, DOU and AQU, DOU. At the moment, we cannot offer any acceptable explanation as to the cause of the observed discrepancy. Longitudinal dependence of standard deviation is pretty vague.

Analyzing in detail the differences in *D*, *H* and *Z* plotted as ten individual values in a month, an interesting feature has been observed. Namely, at the beginning of September 1991 the level of those differences in *D*, which involve GCK, clearly exhibits an offset that is not observable in the differences between other observatories. Figure 5 presents eleven-point smoothed differences during 1991, with Grocka as reference observatory. Besides a slight increase or decrease at about two months before the *M* 5.7 earthquake on July 12, 1991, the offset in level is still well expressed in smoothed differences. Its magnitude is significant with respect to the corresponding values of standard deviation. Considering this point we first carefully checked the values of declination at Grocka but found no errors. Taking into account that the above feature is the least expressed in the differences ΔD (PAG-GCK), it was supposed that its possible cause might be of regional character, influencing both Grocka and Panagyurishte observatories. In connection with this, it is worth mentioning that the *M* 4.8 earthquake occurred on September 28, 1991, S-E from Grocka, towards Panagyurishte. As for the *H* and *Z* component, the above discussed phenomenon is barely visible. It is expressed as a change from slowly increasing to slowly decreasing trend rather than a change of level.

Besides simple difference technique, a multi-variate linear regression was applied on 02:00 UT magnetic field values at Grocka. The result is again illustrated only for declination and shown in fig. 6. Calculated values are obtained from a regression expression for the field values at a particular site as a function of the values at a number of other sites. These calculated values present variations that are common to several sites. Therefore, residuals
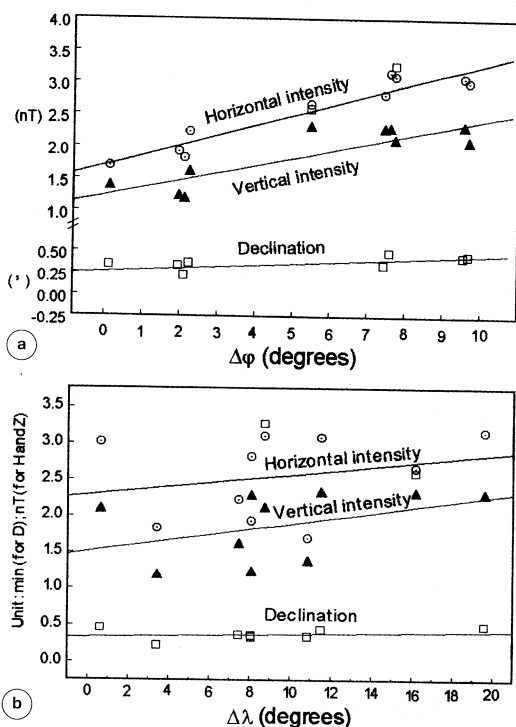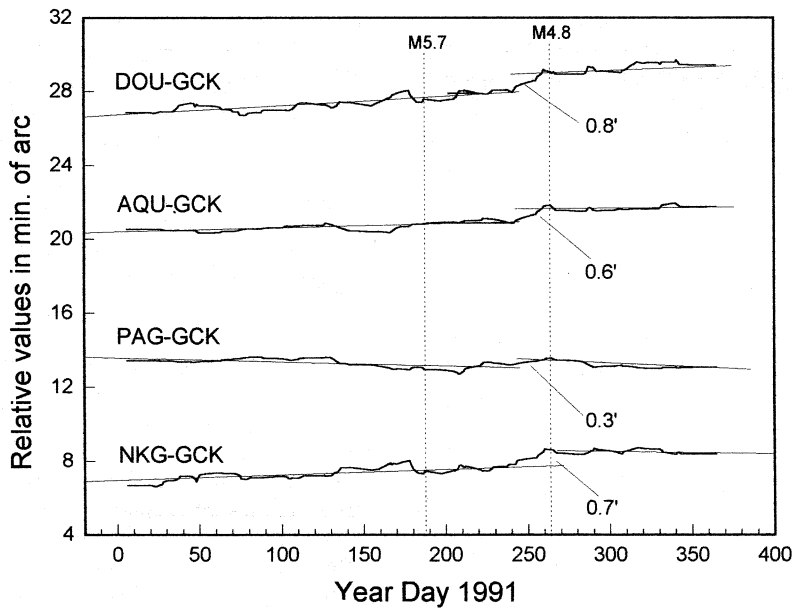
Fig. 5. Smoothed differences in declination values at 02:00 UT between Grocka and four other observatories during 1991. Slight changes can be observed before the M 5.7 earthquake and an offset in level which occurred before the M 4.8 earthquake. The magnitude of offset is either close to or larger than the corresponding values of standard deviation.
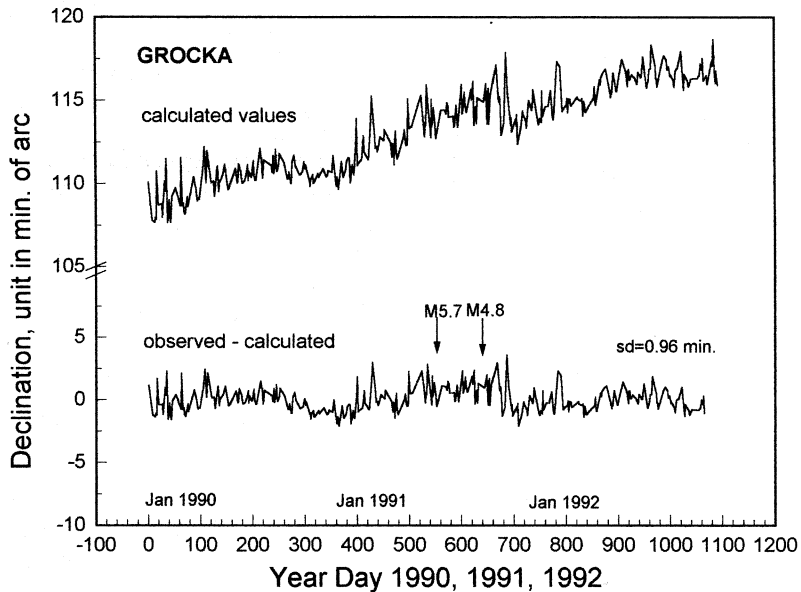

Fig. 6. Multivariate regression: calculated values of declination at Grocka are obtained as a linear combination of values at four remaining observatories.

obtained by subtracting the calculated from the observed values at a particular site, emphasize the effects that are spatially local (Steppe, 1979). In our case the expression is

$$D_{GCK}(cal) = a*D_{PAG}+b*D_{AQU}+$$
$$+c*D_{DOU}+d*D_{NGK}$$

where *a*, *b*, *c* and *d* are regression coefficients. However, no improvement in the reduction of standard deviation was achieved. On the contrary, it drastically increased in comparison with the simple differences. This could have been expected regarding the spatial distribution of observatories used for the definition of that part of the geomagnetic field variation which is common to all sites. For predicting field variations at a particular site, only stations closest to the selected one should be used.

The next data that will be discussed are monthly means of linearly detrended three-year

series of 02:00 UT data shown in fig. 7. These values have smaller standard deviation in comparison with individual values read at 02:00 UT. Obtained curves are smoother, all variations under a one-month period are averaged out and only longer periods appear. Although the pattern is not quite regular, monthly mean values exhibit annual periodicity due to the difference in the amplitude of annual variation at different observatories. On the background of such a variation no particular changes are observed around the middle of 1991 in the variation of horizontal and vertical intensities. In some way, differences in declination between Grocka and Panagyurishte in 1991 exhibit a pattern that is a bit different in comparison with 1990 and 1992. Namely, a broad minimum which appears around the middle of a year seems to be deformed into a more pronounced variation, narrower and with larger intensity. However, we dare not ascribe any sig-
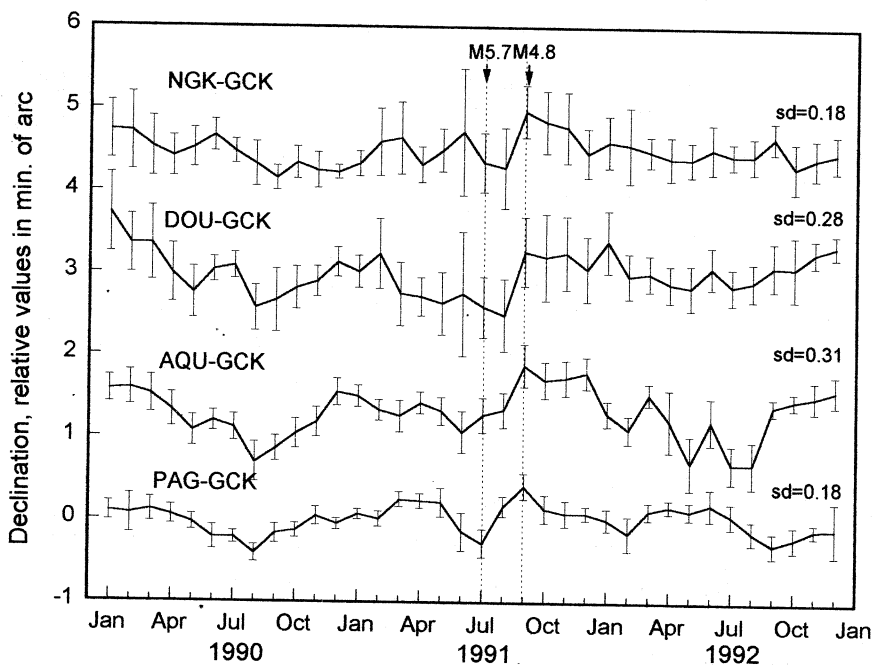

Fig. 7. Monthly mean values of the simple differences in declination at 02:00 UT after the elimination of linear secular variation trend.

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nificance to this variation in a sense of its possible relation to seismic activity in Grocka vicinity.

2.2. *Analysis of data available in geomagnetic yearbooks*

It has already been mentioned what kinds of data are contained in yearbooks issued by standard geomagnetic observatories. These publications actually present the summary of one-year work. Nowadays many observatories are using automatic digital recording systems for practically continuous measurements of the geomagnetic field and its variations. This facilitates further data processing and the choice of adequate sampling rate provides data sets suitable for studying various phenomena related to

the Earth's magnetic field. If well synchronized, data from several geomagnetic observatories may be very useful for a tectonomagnetic effect study.

The choice of observatories whose data are analyzed in this section is again the result of the fact that at the time this work started, the 1991 yearbook from L'Aquila observatory, besides Grocka, was the only available one. This is not a favorable circumstance. The role of L'Aquila observatory as a reference station in this kind of investigations is questionable since it is itself situated in a seismically-active region. This might hinder a possible tectonomagnetic effect detection at the site under investigation.

We first examined the monthly mean values of declination, horizontal and vertical intensity of the geomagnetic field during the year 1991.
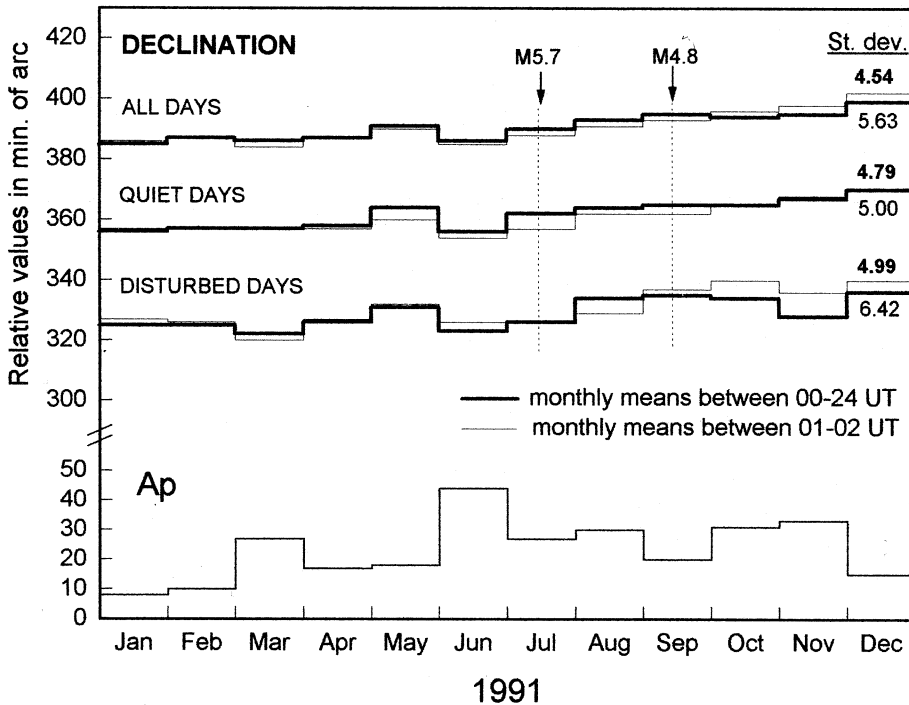

Fig. 8. Monthly means of the simple differences of daily mean values (data from yearbooks) in declination between Grocka and L'Aquila. A_p indices indicate the level of geomagnetic activity. Upper and lower values of standard deviation refer to the interval 00-24 UT and 01-02 UT, respectively.

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The results will be discussed for all three components but illustrated only for declination, shown in fig. 8. Differences of field values between Grocka and L'Aquila have been considered separately for all, quiet and disturbed days. For the sake of comparison two parallel curves are presented in each case: monthly means obtained from daily mean values based on twenty-four hourly mean values, and monthly means averaged over a one-hour interval between 01:00 and 02:00 UT every day in a month. In both cases the standard deviation is much larger compared with values obtained only for data read at 02:00 UT sharp. The interval between 01:00 and 02:00 UT belongs to the period of generally quiet geomagnetic conditions because of the small influence of the solar wave radiation. However, this fact does not reduce the standard deviation of corresponding differences, except in the case of *H* and *Z* for disturbed days. In all other cases it is larger. Generally, monthly mean values might be suitable for studying long-term and trend changes.

Going further on with resolving the details of the geomagnetic field behavior at Grocka observatory, we have analyzed simple differences in *D*, *H* and *Z* of daily mean values in July 1991, and the differences of hourly mean values for three consecutive days comprising the time of the *M* 5.7 earthquake. It was difficult to observe any clear connection between the pattern of variation in differences GCK-AQU and the time of earthquake occurrence. It was only obvious that the most pronounced variations in the differences correspond to magnetically disturbed days, measured by the value of A_p index. Values of standard deviation defined on one-month differences of daily means allow us to observe variations larger than 3′ in declination and about 2-2.5 nT in *H* and *Z*. The standard deviation of twenty-four differences in hourly mean values is rather large due to the difference in the amplitude of daily variation at sites at such a distance, like observatories Grocka and L'Aquila. It drastically increases in the case of magnetically disturbed conditions. This points to difficulties in trying to resolve variations of a short duration, so far as the data from geomagnetic yearbooks are concerned.

3. Conclusions

The results presented in this work are only meant to give an insight into the problem regarding the justification of using the network of standard geomagnetic observatories for tectonomagnetic effect studies. We cannot offer any conclusive evidence. Yet, in our opinion, the idea is worth giving a thought. In many regions of the world geomagnetic observatories are the only continuously recording stations and hence the only available source of information on the geomagnetic field. Also, there are some opinions that the detection of possible tectonomagnetic changes should be more promising if three components of the geomagnetic field are used instead of total intensity alone.

Although very slight, there are some indications of the geomagnetic field changes at Grocka observatory that could be related to the *M* 5.7 and *M* 4.8 earthquakes which occurred within 80 km from the station. However, evaluation criteria for earthquake precursors claim much more than merely time coincidence between the two phenomena.

Regarding the values of standard deviation of resulting field differences, we may expect to discriminate changes with a lower limit between 2 and 5 nT, depending on site separation. To make more definite conclusions, an extensive analysis should be made taking into account the following points:

1) adequate selection of observatories with respect to their separation and location, regarding the distribution of seismically active regions;

2) study on the relationship between magnetic field changes and earthquakes, or generally tectonic processes, in a much longer period along with the application of more sophisticated methods of data analysis. This should enable us to detect possible long-term precursory changes;

3) upon establishing in the past an eventual relationship in the sense mentioned above, we might work on defining a particular way of cooperation that would make the best possible use of existing geomagnetic observatories and their data.

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