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Geomagnetic Storms and Acute Myocardial Infarctions Morbidity in Middle Latitudes

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Abstract. Results of collaborative studies on revealing a possible relationship between solar activity (SA) and geomagnetic activity (GMA) and pre-hospital acute myocardial infarction (AMI) morbidity are presented. Studies were based on medical data from Bulgaria and Azerbaijan. Bulgarian data, covering the period from 01.12.1995 to 31.12.2004, concerned daily distribution of number of patients with AMI diagnose (in total 1192 cases) from Sofia Region on the day of admission at the hospital. Azerbaijani data contained 4479 pre-hospital AMI incidence cases for the period 01.01.2003-31.12.2005 and were collected from 21 emergency and first medical aid stations in Grand Baku Area (including Absheron Economical Region with several millions of inhabitants). Data were "cleaned" as much as possible from social and other factors and were subjected to medical and mathematical/statistical analysis. Medical analysis showed reliability of the used data. Method of *ANalysis Of VAriance* (ANOVA) was applied to check the significance of GMA intensity effect and the type of geomagnetic storms - those caused by *magnetic clouds* (MC) and by *high speed solar wind streams* (HSSWS) - on AMI incidences. Relevant correlation coefficients were calculated. Results were outlined for both considered data. Results obtained for the Sofia data showed statistically significant positive correlation between considered GMA indices and AMI occurrence. ANOVA revealed that AMI incidence number was significantly increased from the day before till the day after geomagnetic storms with different intensities. Geomagnetic storms caused by MC were related to significant increase of AMI number in comparison with the storms caused by HSSWS. There was a trend for such different effects even on -1st and +1st day for the period 1995-2004. Results obtained for the Baku data revealed trends similar to those obtained for Sofia data. AMI morbidity increment was observed on the days with higher GMA intensity and after these days as well as on the days of geomagnetic storms caused by MC and after these days.

Keywords: solar activity, geomagnetic storms, pre-hospital acute myocardial infarction morbidity, magnetic clouds, high speed solar wind streams

Introduction

Studies conducted by different groups show that geomagnetic field (GMF) variations may affect human cardio-vascular homeostasis and different types of relationships exist between them. It is found [1] that at least 75% of geomagnetic storms caused increase by 30-80% on average in hospitalization of patients with myocardial infarction, defects of cerebrum vessels and arterial and venous diseases. It was established [2] that during geomagnetic storms the number of cases of myocardial infarction increased 2.5 times, acute cerebral insult - 2 times, angina pectoris and cardiac arrhythmia - 1.5 times and deaths - 1.2 times in comparison with the days without geomagnetic storms. Villoresi et al. [3] showed a statistically significant increase in myocardial infarction occurrence during geomagnetic storms, defined by the days of the descending phase of cosmic ray Forbush decreases.

Magnetic storms were associated with a decrease in heart rate variability [4-6] and with an increase in myocardial infarctions and strokes [7]. Other studies revealed negative correlation between monthly acute myocardial infarctions (AMI) incidences and solar activity (SA) and geomagnetic activity (GMA) indices [8-9] and monthly number of sudden cardiac death (SCD) and GMA [10]. Paper [11] supposes that medico-biological phenomena that increase during periods of low SA and/or GMA may be stimulated by physical processes provoked by the concomitant increase in proton flux. Investigations taking into account daily GMA levels revealed that the number of SCD [10] and the incidences and pre-admission mortality from AMI [12] increased on the days both of highest and lowest daily levels of GMA.

TABLE 1

Gradation of GMA levels

GMA index	I quiet GMA	II weak storm	III moderate storm	IV major storm	V severe storm
Dst, nT	Dst>-20	-50<Dst≤ -20	-100<Dst≤-50	-150<Dst≤-100	Dst≤-150
Ap	Ap < 15	15 ≤ Ap < 30	30 ≤ Ap < 50	50 ≤ Ap < 100	Ap ≥ 100
Am	Am < 15	15 ≤ Am < 30	30 ≤ Am < 50	50 ≤ Am < 100	Am ≥ 100

Available papers on subject show that there are many open questions in this research field and further studies are needed to clarify the possible relationship and biophysical mechanisms through which heliogeophysical factors and their variations affect human being's cardio-health state.

It is quite probable that the differences in SA cycles and the stages (phases) of the solar cycle are interrelated with the different results obtained on the subject. SA has different manifestations – sunspots, solar flares, coronal mass ejections (CME), etc. Two types of solar events are considered as one of the main drivers of GMA: CMEs and magnetic clouds (MC) as their manifestation (most of MC result in geomagnetic storms, and about 30% of storms are due to MC), and high speed solar wind streams (HSSWS) from coronal holes (CH) on the Sun. MC and HSSWS have different links with geomagnetic storms. During maximal SA, geomagnetic storms caused by MC prevail, and during minimal SA - those caused by HSSWS.

The aim of this collaborative investigation was to study and compare the effects of both above-mentioned types of geomagnetic storms and effects of GMA intensity levels on pre-hospital AMI incidences in middle latitudes (between 40-43°N), but in different longitudes (between 23-50°E).

Materials and Methods

Studies were based on medical data from Bulgaria and Azerbaijan:

- Daily data from Sofia Region (Bulgaria) about patients admitted for treatment with AMI diagnose at the University Hospital for Active Treatment "St. Anna", Sofia (42°43' N; 23°20' E) covered the period from 1 December 1995 to 31 December 2004. In total 1192 AMI cases were registered;
- Daily data from Grand Baku Area (Azerbaijan) were from 21 emergency and first medical aid stations in Baku (40°23' N; 49°51' E) for the period 2003-2005 (36 consecutive months). A total of 4479 patients with AMI were admitted and treated in hospitals.

GMA indices were handled from:

- World Data Center for Geomagnetism, Kyoto (daily *Dst*-index);
- Space Weather Prediction Center at the National Oceanic Atmospheric Administration - NOAA, Boulder (planetary *Ap*-index and the index *Am* derived for the middle latitudes).

GMA was divided into five levels (see: Table 1).

"Cleaned" from social and other factors data were subjected to medical and mathematical/statistical analysis:

- Statistical package STATISTICA (StatSoft Inc., version 6, 2001) was used for data visualization and statistical analyses;
- ANalysis Of VAriance (ANOVA) was applied to check the significance of GMA intensity and the type of geomagnetic storms (those caused by MC or HSSWS) effect on AMI morbidity. The effect of geomagnetic storms before and after their development on AMI dynamics was also investigated by ANOVA. GMA impact up to 3 days before and 3 days after sharp geomagnetic changes was studied;
- Post-hoc analysis (Newman-Keuls test) was used to establish statistical significance of the differences between the average values of the registered AMIs in the separate factors levels;
- Relevant correlation coefficients were calculated (the chosen level for statistical significance was p<0.5).

Results

Results for AMI incidences in Sofia region for the period 1995-2004

Table 2 presents the number of the days with the corresponding GMA levels for the considered period and the number of AMI registered for Sofia Region for the respective GMA levels.

TABLE 2

Number of days with the different GMA levels and AMI incidences in Sofia Region for the period 1995-2004

Parameters / GMA Levels	Ap		Am		Dst	
	Days	AMI	Days	AMI	Days	AMI
I quiet GMA	2423	851	2735	954	2177	766
II weak storm	686	236	504	201	952	337
III moderate storm	155	78	59	24	152	65
IV major storm	40	20	14	10	29	20
V severe storm	15	7	7	3	9	4

The number of days and AMI according to the types of geomagnetic storms are shown in Table 3.

TABLE 3

Number of quiet days and days with different types of storms and AMI incidences in Sofia Region for the period 1995-2004

GMA-levels	Days	AMI
Quiet GMA	2927	1031
HSSWS-caused storm	225	82
MC-caused storm	167	79

Fig.1 and Fig.2 show geomagnetic indices dynamics and distribution of AMI incidences for the period of 9 years under consideration for the data systematized respectively per months and years.

Statistically significant correlation coefficients were established for monthly data (r=0.26, p=0.006 for

Am-index and r=0.26, p=0.006 for Ap-index). All of considered GMA indices correlated significantly (positive correlation) with AMI morbidity for the daily data although the correlation coefficients were not high.

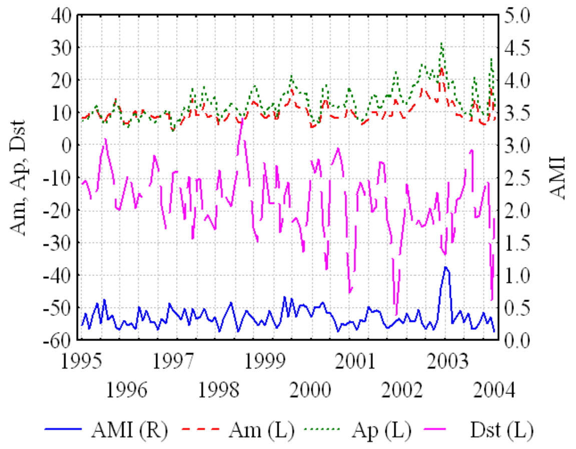

Fig. 1. Monthly averaged geomagnetic indices (Am, Ap and Dst) and monthly averaged AMI incidences (Sofia data, 1995-2004); (L) denotes Left axis while (R) – Right axis.

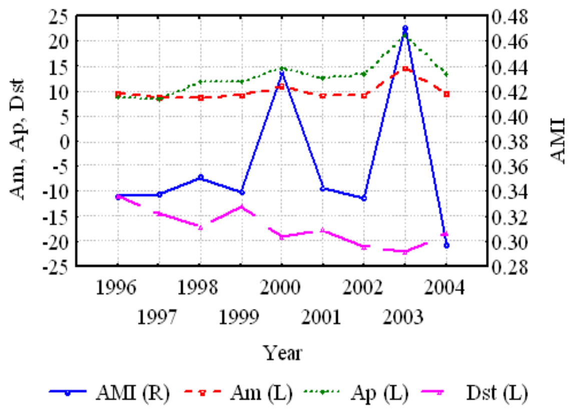

Fig. 2. Yearly averaged geomagnetic indices (Am, Ap and Dst) and yearly averaged AMI incidences (Sofia data, 1996-2004); (L) denotes Left axis while (R) – Right axis.

Fig. 2 shows that maximum and post-maximum years of solar cycle 23, namely 2000 and especially 2003 were geomagnetically very evidently active ones (see in Fig.2.: values of geomagnetic indices increased significantly in comparison to other years) which is typical picture for sunspot maximum and descending phase of solar activity (GMA has double peaks 2-3 years prior to and after maximum). The number of admitted patients with AMI diagnoses also increased in these years. The correlation coefficients for yearly averaged AMI data and yearly averaged geomagnetic indices were statistically significant, positive and high (r=0.89, p=0.001 for Am-index; r=0.74, p=0.023 for Ap-index; r=0.85, p=0.004 for Km-sum index and r=0.69, p=0.038 for Kp-sum index; Km-sum and Kp-sum indices are the sums of the eight 3-hourly Km and Kp values per a day).

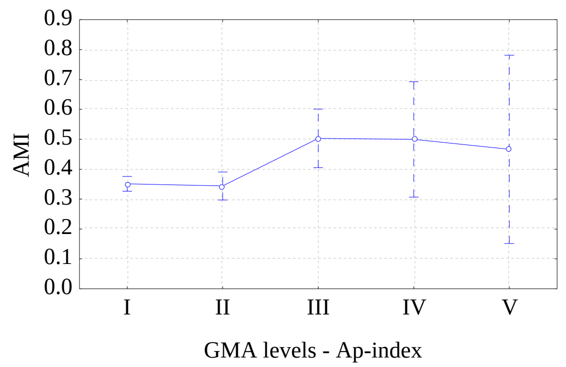

Fig. 3. GMA effect (estimated by Ap-index) on AMI incidences (±95%CI), Sofia data, 1995-2004.

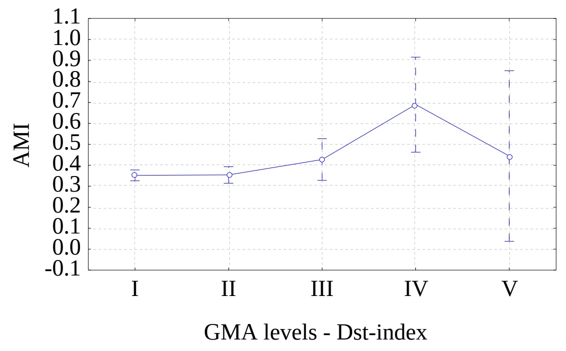

Fig. 4. GMA effect (estimated by Dst-index) on AMI incidences (±95%CI), Sofia data, 1995-2004.

ANOVA revealed statistically significant effect for Ap (p=0.02) and Dst-index (p=0.03) on AMI dynamics. There was an increase of AMI incidence number on the days with high levels of GMA in comparison to days with quiet GMA and weak geomagnetic storms (Figs.3 and 4). Vertical bars in the figures denote 0.95 confidence intervals (CI). There is seen also some decrease during severe stormy days. For establishing this fact there is a need of detailed and long-period investigations. In our studies there were only 9 days with such high levels of GMA (according to Dst-index, see: Table 2) while the number of severe storms according to Ap-index was 15 and the decrease is more gradual than in the case of consideration of Dst-index.

It could be also due to different biophysical mechanisms "activated" by different levels of GMA (there appeared papers stating about significant influence of weak geomagnetic fields) or because of impulsive (described by Dst) and background (described by Ap) character of impact of GMA.

ANOVA applied for a study of GMA effects (through relevant indices) on AMI morbidity for the days before ("-"), during ("0") and after ("+") geomagnetic storms with different intensities revealed statistically significant influence from -1st to +1st day for Am, Ap and Dst-indices on the number of AMI morbidity. Fig. 5 shows AMI dynamics for the different GMA levels according to Ap-index from -3rd to +3rd day. The largest number of AMI were on -1st day of moderate, 0 day of moderate, major and severe, +1st day of major and even +3rd day of severe geomagnetic storms.

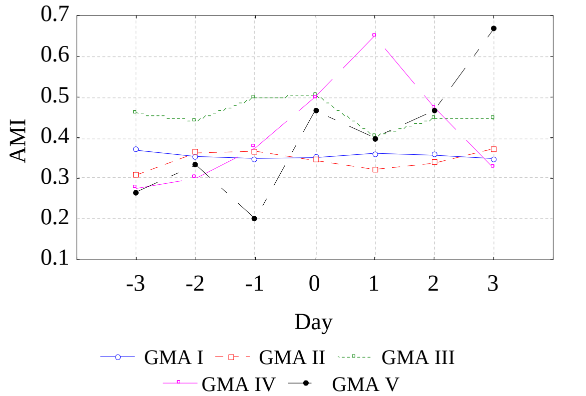

Fig. 5. GMA effect (estimated by Ap-index) on AMI incidences before, during and after geomagnetic storms; "GMA 1- GMA 5" denote different levels of GMA (see: Table 2); Sofia data, 1995-2004.

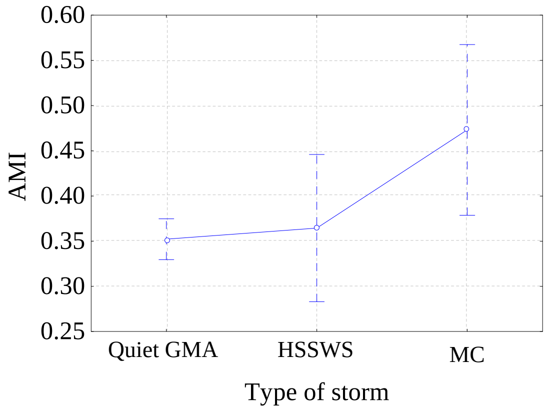

Fig. 6. GMA effect, estimated by the types of geomagnetic storms (Table 3), on AMI incidences (±95%CI), Sofia data, 1995-2004.

The dynamics of AMI incidences at different GMA levels and on the days before and after storms is interesting. AMIs started increasing although slightly on -1st day of III GMA level while after 0 day of III GMA level AMIs decreased. AMI number increased progressively from -2nd to +1st day of IV GMA level while on -1st day of V GMA level AMIs decreased and on 0, +1st and +2nd day of V GMA level they increased above the initial value but the peak was on +3rd day. Possibly the weaker influence (III GMA level) is like classic "irritant", which although weak but is accompanied with psycho-emotional reaction and AMIs increase. The reaction at IV GMA level is similar but at a higher degree manifested and kept to +1st day. Weak external signals can play a role in the self-structure of biological systems [13]. In that case the adequate response is AMI. The intensity of the "irritant" at V GMA level provokes an inadequate response. It is possible that then the protective strengths are maximally mobilized and in a lot of cases it prevents AMIs. However, later on, the strong "irritant" "strikes in", the protection is depleted and AMI number increases. Probably AMIs incidences are maximal on +3rd day namely because the protective strengths are completely exhausted.

It was established that AMI number increased statistically significantly (p=0.05) during the days with storms caused by MC in comparison to days with quiet GMA and storms driven by HSSWS (Fig. 6). This difference was confirmed by Post-hoc analysis as well.

The results revealed a trend for a significant increment (p<0.1) of AMIs on the day before geomagnetic storms caused by MC. Post-hoc analysis showed that AMIs number on -1st day of MC-caused storms was significantly larger (p=0.03) than AMIs on -1st days of storms caused by HSSWS. AMI morbidity remained higher even on the +1st day after the storms caused by MC (Fig. 7).

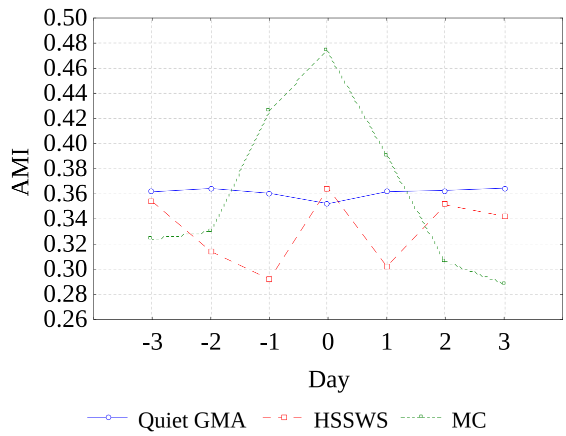

Fig. 7. GMA effect, estimated by the types of storm (Table 3) on AMI incidences before, during and after geomagnetic storms, Sofia data, 1995-2004.

Results for AMI incidences in Grand Baku Area for the period 2003-2005

The number of days with the different GMA levels and type of storms and AMIs are shown in Tables 4 and 5.

TABLE 4

Number of days with different GMA levels and AMI incidences in Grand Baku Area for the period 2003-2005

Parameters / GMA Levels	Ap		Am		Dst	
	Days	AMI	Days	AMI	Days	AMI
I quiet GMA	678	2742	847	3446	607	2464
II weak storm	301	1277	212	859	418	1712
III moderate storm	89	344	26	132	59	253
IV major storm	17	68	6	22	8	30
V severe storm	11	48	5	20	4	20

TABLE 5

Number of quiet days and days with different types of storms and AMI incidences in Grand Baku Area for the period 2003-2005

GMA-levels	Days	AMI
Quiet GMA	951	3895
HSSWS-caused storm	95	372
MC-caused storm	50	212

Monthly averaged GMA indices for the considered period and AMI numbers are shown in Fig. 8.

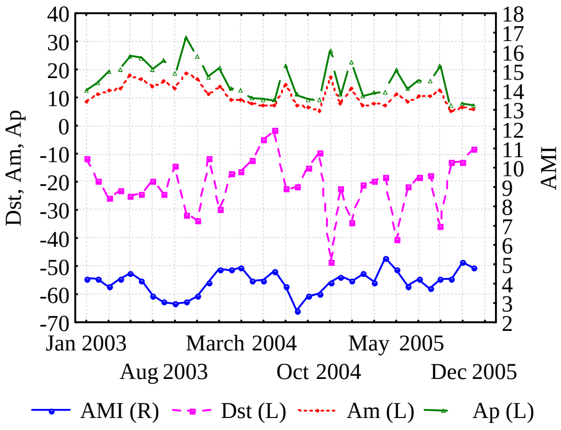

Fig. 8. Monthly averaged geomagnetic indices (Am, Ap and Dst) and monthly averaged AMI incidences (Baku data, 2003-2005); (L) denotes Left axis while (R) – Right axis.

Correlation coefficients between considered GMA indices and AMI incidences (Baku data, 2003-2005) were not significant except the negative correlation established with Kp-sum index for the data averaged by months (r = - 0.34, p=0.042).

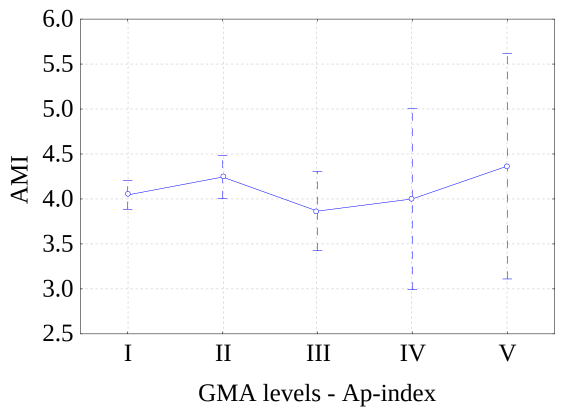

Fig. 9. GMA effect (estimated by Ap-index) on AMI incidences (±95%CI), Baku data, 2003-2005.

ANOVA did not reveal statistically significant effects for the studies on influence of heliogeophysical factors on AMI dynamic in Grand Baku Area for the period 2003-2005 but some of the established trends were similar to those obtained for the data from Sofia Region. Fig. 9 shows AMI incidence having place under changes of geomagnetic situation (through Ap-index). There was an increase in the number of AMI during the period with weak and severe geomagnetic storms. Regarding Dst-index variations, the number of AMI increased during moderate and severe storms (Fig. 10).

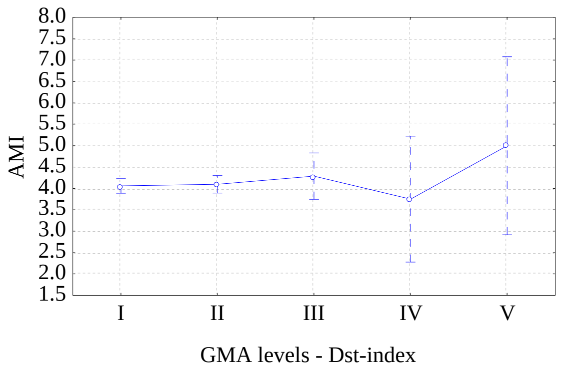

Fig. 10. GMA effect (estimated by Dst-index) on AMI incidences (±95%CI), Baku data, 2003-2005.

Fig.11 presents AMI dynamics for the different Dst-index levels on the days before, during and after geomagnetic storms. The largest numbers of AMIs were on 0 and +2nd day of severe, +1st day of major, and even +3rd day of moderate geomagnetic storms.

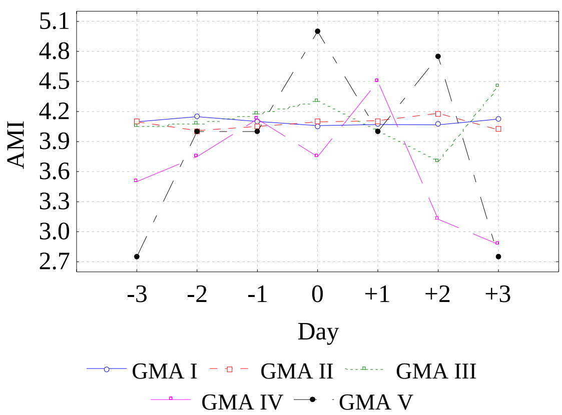

Fig. 11. GMA effect (estimated by Dst-index) on AMI incidences before, during and after geomagnetic storms, Baku data, 2003-2005.

Although the result about the effect of the type of storm was not significant, the established trend showed that AMIs were relatively high during the storms caused by MC and were less during the days with storms caused by HSSWS than in the other 2 considered cases (Fig. 12).

Fig. 13 presents AMI morbidity before, during and after the both types of geomagnetic storms. It shows an increment for AMIs on the day of development of storms caused by MC and even larger number on the day immediately after the both considered in this paper types of storms.

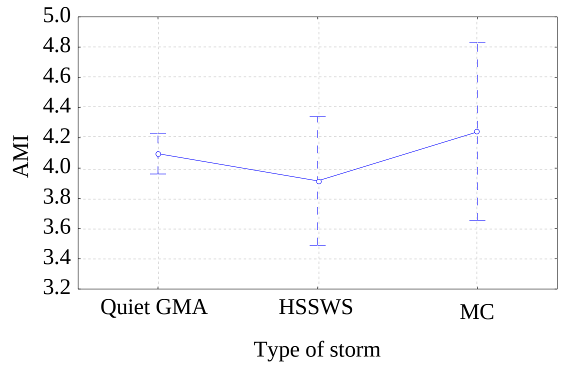

Fig. 12. GMA effect, estimated by the types of geomagnetic storms (Table 5), on AMI incidences (±95%CI), Baku data, 2003-2005.

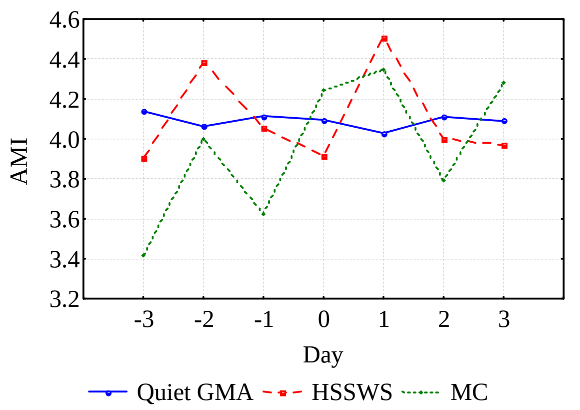

Fig. 13. GMA effect, estimated by the types of storm (Table 5) on AMI incidences before, during and after geomagnetic storms, Baku data, 2003-2005.

Discussions

Results obtained revealed statistically significant positive correlation between GMA indices and AMI incidences for the data for Sofia Region (1995 - 2004).

It was established by the help of ANOVA that AMI incidences were significantly increased from the day before till the day after geomagnetic storms with different intensity, estimated by GMA indices under consideration for the data analyzed for Sofia Region. Geomagnetic storms caused by the different drivers (MC, HSSWS) affected AMI morbidity significantly and differently. Storms caused by MC were related to significant increase of AMI number in comparison to the storms caused by HSSWS. There was a trend for such different effects even on -1st and +1st day.

Although the results obtained for the Baku data (2003-2005) were not statistically significant some of the established trends were similar to those obtained for Sofia data (1995-2004). AMI incidence increment was observed on the days with higher levels of GMA and after them as well as on the days of geomagnetic storms caused by MC and after their occurrence.

During maximal SA, geomagnetic storms caused by MC prevail while during minimal SA - those caused by HSSWS. It should be taken into consideration that the period analyzed for the data for Sofia Region covered almost (ascending, maximum and big part of descending phases) a whole solar cycle 23 while the period for Grand Baku Area was only for the descending phase of solar cycle 23. Probably it is the reason for some of the differences obtained in the data series investigated. A disadvantage for Sofia data is that they are only from one hospital and the data row is not large while the limitation for Baku data is that they cover a shorter period of the descending phase of 11-year SA cycle, but GMA is comparatively high (second peak of background GMA after SA maximum). Descending phase of SA cycle is usually more dramatic and rich with severe geomagnetic storms.

Summary and Conclusions

- This paper is a result of attempts of both teams from Sofia and Baku, to joint the efforts in study the possible influence of GMA on AMI morbidity;
- This collaborative study in 2 middle-latitude locations (between 40-43°N), but in different longitudes (between 23-50°E) enabled to conclude about possible influence of GMA variations on AMI morbidity in general;
- The results obtained for Sofia data (1995–2004) revealed a statistically significant positive correlation between considered GMA indices and AMI incidences. AMI number was significantly increased from the day before till the day after geomagnetic storms with different intensities. Geomagnetic storms caused by Magnetic Clouds were related to significant increase of AMI number in comparison with the storms caused by High Speed Solar Wind Streams. There was a trend for such different effects even on -1st and +1st day for the period 1995-2004.
- Results obtained for the Baku data (2003-2005) revealed trends (for the studied geomagnetic indices) similar to those obtained for Sofia data (1995-2004) and significant negative correlation with Kp-sum index. AMI incidences increment was observed on the days with higher GMA intensity and after these days as well as on the days of geomagnetic storms caused by Magnetic Clouds and after these days.

Future plans

Long-period and detailed studies must be carried out for confirmation and clarifying the results obtained in this paper. For example, it would be interesting to study the negative monthly correlation obtained between AMI incidents and Kp-sum index. It seems that the both types of geomagnetic storms affect cardio-health state of humans by different ways. It is possible that some of the electromagnetic field changes, which accompany geomagnetic storms, have favorable and stimulating effects. At the same time it should not be neglected the possible adverse effect of very low GMA on cardio-vascular diseases. Recently it has been shown that AMIs increased both on the days of lowest and highest levels of GMA [9, 12]. Stoupel [11] suggested that the role of environmental physical factors becoming more active in low GMA, like cosmic ray (neutron) activity, should be object of further studies. A team-work is to clarify the possible biophysical mechanisms through which different GMA indices and different GMA levels affect AMI morbidity.

Acknowledgments

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