# Solar and Geomagnetic Activity and Acute Myocardial Infarction Morbidity and Mortality

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*The purpose of this research is to study the possible relationship between solar and geomagnetic activity (GMA) and acute myocardial infarction (AMI) morbidity and mortality. Medical data used covered the period 01.12.1995 - 31.12.2004 and concerned daily incidences from AMI in Sofia region. Results revealed that AMI morbidity and mortality were significantly increased on the days preceding, during and following geomagnetic storms with different intensities. It was established that storms caused by magnetic clouds were related to significant increase of AMI morbidity and mortality in comparison with the storms caused by high speed solar wind streams and quiet GMA days.*

## Introduction

Different studies show that geomagnetic field (GMF) variations may affect human cardio-vascular homeostasis. Reference [1] found that at least 75% of geomagnetic storms caused increase with 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 insults 2 times, angina pectoris and cardiac arrhythmia 1.5 times and deaths 1.2 times in comparison with the days without geomagnetic storms. Reference [3] showed statistically significant increase in myocardial infarction occurrence during geomagnetic storms, defined by the days of the descending phase of cosmic ray Forbush decreases. Geomagnetic storms were associated with a decrease in heart rate variability as well [4, 5, 6, 7]. Reduced heart rate variability is regarded as a prognostic factor for cardio-vascular diseases [8, 9].

The possible influence of solar activity on cardio-vascular homeostasis is by no means simple. For example, [10] has shown that moderate and severe geomagnetic storms have different effects on human health. Moderate and severe storms are as a rule caused by different solar activity agents: severe storms, most frequent during the maximum phase of the 11-year sunspot cycle, are almost entirely caused by solar coronal mass ejections (CME), [11]. Especially geo-effective are a subclass of CMEs – magnetic clouds (MCs)– characterized by enhanced magnetic field amplitude, smooth magnetic field rotation, and low plasma temperature [12]. On the sunspot decline and minimum phase, geomagnetic activity (GMA) is mainly due to high speed solar wind streams (HSSWS) from solar coronal holes [13]. These two types of solar drivers not only prevail during different phases of the sunspot cycle, but they also cause different types of geomagnetic storms [14], and have different effects on the atmosphere [15], on seismic activity [16], etc.

One of the purposes of this investigation is to check whether the two types of solar drivers of geomagnetic storms - *magnetic clouds* (MC), and *high speed solar wind streams* (HSSWS) from coronal holes on the Sun – have different effects on acute myocardial infarctions (AMI) morbidity and mortality. To this end, we first study the relation between AMI morbidity and mortality and the level of GMA intensity, irrespectively of which solar agent it was caused, and then we divide the geomagnetic storms into ones caused by MC and ones caused by HSSWS, and compare their effects on AMI morbidity and mortality.

## Materials and methods

Data about morbidity and mortality from AMI in Sofia region for the period 01.12.1995 - 31.12.2004 were used. Data concerned daily number of morbidity (in total 1192 cases) and mortality (175 cases) registered by the University Hospital for Active Treatment (UHAT) "St. Anna", Sofia, Bulgaria (42°43' N; 23°20' E).

The values of GMA indices were got from Internet (World Data Center for Geomagnetism, Kyoto (daily *Dst*-index): http://swdcwww.kugi.kyoto-u.ac.jp/ and Space Weather Prediction Center at the National Oceanic Atmospheric Administration (NOAA), Boulder (planetary *Ap*-index and the index *Am* derived for the middle latitudes): http://www.swpc.noaa.gov/ftpmenu/indices/old_indices.html). GMA intensity was divided into five levels according to the considered GMA indices values (Table I).

**TABLE I**
**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 |

Geomagnetic storms were divided into two types according to their solar driver: storms, driven by MC and storms, caused by HSSWS. The list of events is available online at http://evaluation.nbu.bg/stil/. The criteria for identifying them are described in [15].

Correlation coefficients were calculated and after that *ANalysis Of VAriance* (ANOVA) was applied as well to check the significance of GMF intensity level and the type of geomagnetic storms effect on AMI morbidity and mortality.

The effect of geomagnetic storms up to 3 days before and 3 days after their main phase on AMI dynamics was also investigated by ANOVA and by the method of superimposed epochs.

Post-hoc analysis (Newman-Keuls test) was used to establish statistical significance of the differences between the average values of the registered cardiac events under consideration in the separate factors levels.

Statistical package STATISTICA (StatSoft Inc., version 6, 2001) was used for data visualization and statistical analyses and the chosen level for statistical significance was $p \leq 0.05$.

## Results

*GMA intensity levels and AMI morbidity and mortality*

The number of days for the period under consideration with different GMA levels according to GMA indices (Table I) and the number of AMI morbidity and mortality are shown in Table II.

**TABLE II**
**The number of days with different GMA levels and AMI morbidity and mortality**

| | Ap | | | Am | | | Dst | | |
|---|---|---|---|---|---|---|---|---|---|
| | Days | AMI Morb. | AMI Mort. | Days | AMI Morb. | AMI Mort. | Days | AMI Morb. | AMI Mort. |
| I | 2423 | 851 | 114 | 2735 | 954 | 132 | 2177 | 766 | 105 |
| II | 686 | 236 | 44 | 504 | 201 | 37 | 952 | 337 | 58 |
| III | 155 | 78 | 12 | 59 | 24 | 4 | 152 | 65 | 6 |
| IV | 40 | 20 | 4 | 14 | 10 | 2 | 29 | 20 | 5 |
| V | 15 | 7 | 1 | 7 | 3 | 0 | 9 | 4 | 1 |

As a preliminary analysis correlation coefficients for daily, monthly and yearly averaged data were calculated. Statistically significant positive correlation coefficients (although not high by value) were established for the daily averaged data between all of the considered GMA indices and AMI morbidity and mortality.

Fig. 1 shows monthly averaged geomagnetic indices (Am, Ap and Dst) and monthly averaged AMI morbidity and mortality. Statistically significant positive correlation coefficients were established for the monthly averaged data between some of the GMA indices and AMI morbidity and mortality and they are shown in Table III.

**TABLE III**
**Significant correlation coefficients and their significance levels between monthly averaged GMA indices and AMI morbidity and mortality**

| GMA index | Morbidity | | Mortality | |
|---|---|---|---|---|
| | Corr. coeff. *r* | Signific.level *p* | Corr. coeff. *r* | Signific.level *p* |
| Am | 0.26 | 0.006 | 0.25 | 0.008 |
| Km-sum | - | Not signific. | 0.25 | 0.009 |
| Ap | 0.26 | 0.006 | 0.24 | 0.013 |
| Kp-sum | - | Not signific. | 0.26 | 0.006 |

**TABLE IV**
**Significant correlation coefficients and their significance levels between yearly averaged GMA indices and AMI morbidity and mortality**

| GMA index | Morbidity | | Mortality | |
|---|---|---|---|---|
| | Corr. coeff. *r* | Signific.level *p* | Corr. coeff. *r* | Signific.level *p* |
| Am | 0.89 | 0.001 | 0.83 | 0.006 |
| Km-sum | 0.85 | 0.004 | 0.85 | 0.004 |
| Ap | 0.74 | 0.023 | 0.69 | 0.04 |
| Kp-sum | 0.69 | 0.038 | 0.68 | 0.042 |

Yearly averaged GMA indices and yearly averaged morbidity and mortality are shown in Fig. 2. It is seen that in 2000 and especially 2003, GMA increased significantly in comparison to the other years and the number of AMI morbidity and mortality increased in these years as well. The correlation coefficients for the yearly averaged data were statistically significant, positive and high (Table IV).

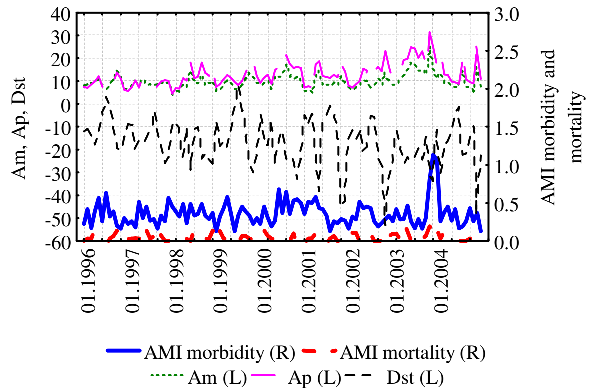


*Fig.1. Monthly averaged geomagnetic indices (Am, Ap and Dst) and monthly averaged AMI morbidity and mortality; (L) denotes Left axis while (R) – Right axis.*

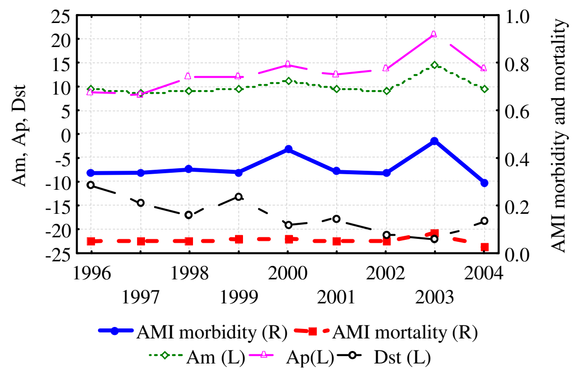


*Fig.2. Yearly averaged geomagnetic indices (Am, Ap and Dst) and yearly averaged AMI morbidity and mortality; (L) denotes Left axis while (R) – Right axis.*

After these preliminary analyses daily data were studied in more details by the help of ANOVA. Then statistically significant effect for GMA, estimated by Ap (p=0.02) and Dst-index (p=0.03), on AMI morbidity was revealed. There was an increase of AMI morbidity and mortality number (Fig. 3 and Fig. 4) on the days with high levels of GMA in comparison to days with quiet GMA and weak geomagnetic storms. Although the mortality number was not significantly affected by GMA, estimated by the different geomagnetic indices under consideration, it increased at high GMA levels as well, which is seen from Fig.3 and Fig.4. Vertical bars in the figures denote ±95% confidence intervals (CI). There is seen also some decrease during severe stormy days.

The method of superimposed epochs and ANOVA applied for a study of GMA effects (through considered indices) on AMI morbidity for the days before ("-"), during ("0") and after ("+") the main phase of geomagnetic storms with different intensities revealed statistically significant influence from $-1^{st}$ to $+1^{st}$ day for Am-, Ap- and Dst-indices on the number of AMI morbidity. Fig. 5 shows AMI morbidity dynamics for the different GMA levels regarding Ap-index from $-3^{rd}$ to $+3^{rd}$ day. It is seen that there were peak increases of AMI morbidity on the preceding days, 0 day and days after storms with high intensity.

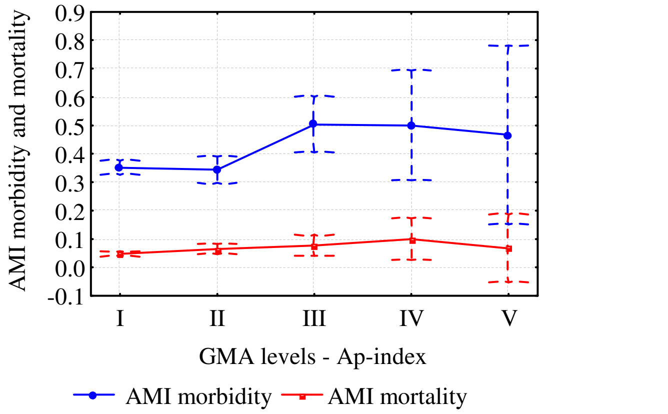


*Fig.3. GMA effect (estimated by Ap-index) on AMI morbidity and mortality (±95%CI).*

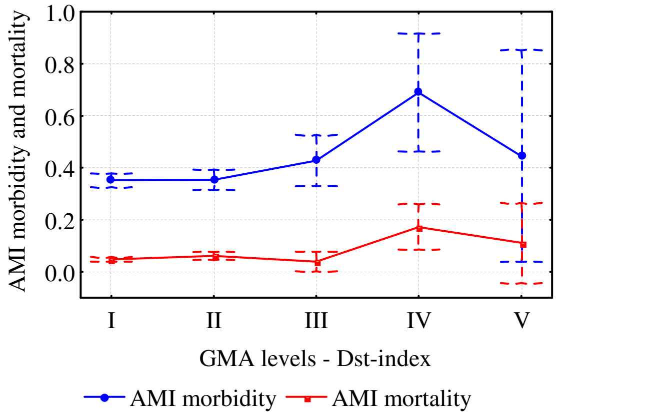


*Fig.4. GMA effect (estimated by Dst-index) on AMI morbidity and mortality (±95%CI).*

The dynamics of AMI morbidity number at different GMA intensity 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.

AMI mortality dynamic for the different GMA levels according to Ap-index from -3rd to +3rd day of GMF changes is shown in Fig. 6. The lowest number of mortality was on the days of quiet GMA. AMI mortality increased under almost all of the other considered conditions and there were peak increments on the days prior to moderate storms, +1st day of major and severe storms and +3rd day of moderate and major storms.

*Types of storms regarding their solar phenomena driver and AMI morbidity and mortality*

The number of quiet days and days with different types of geomagnetic storms and the registered AMI morbidity and mortality number are shown in Table V.

It was established that both AMI morbidity and mortality increased statistically significantly ($p$=0.05) on the days with storms caused by MC in comparison to days with quiet GMA and storms driven by HSSWS (Fig. 7). That difference was confirmed by Post-hoc analysis as well.

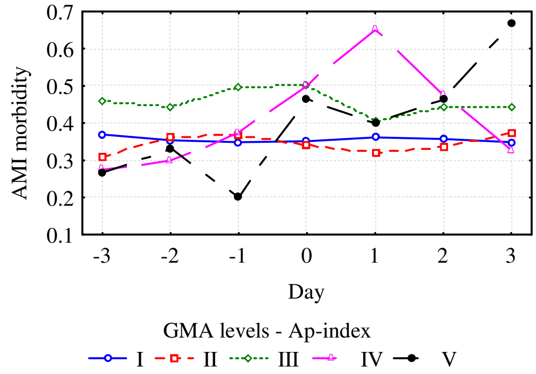


*Fig. 5. GMA effect (estimated by Ap-index) on AMI morbidity before, during and after geomagnetic storms.*

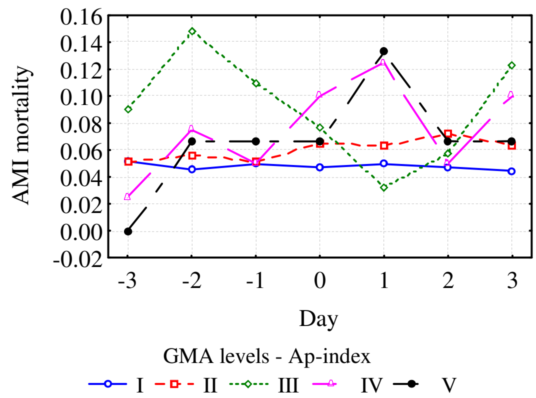


*Fig. 6. GMA effect (estimated by Ap-index) on AMI mortality before, during and after geomagnetic storms.*

**TABLE V**

**The number of quiet days and days with different types of geomagnetic storms and AMI morbidity and mortality**

| GMA-levels | Days | AMI morbidity | AMI mortality |
|---|---|---|---|
| Quiet GMA | 2927 | 1031 | 148 |
| HSSWS-caused storm | 225 | 82 | 11 |
| MC-caused storm | 167 | 79 | 16 |

The results revealed a trend for a significant increment (p<0.1) of AMI morbidity on the day before geomagnetic storms caused by MC. Post-hoc analysis showed that AMI morbidity on -1st day of MC-caused storms was significantly larger (p=0.03) than AMI morbidity on -1st day of storms caused by HSSWS. AMI morbidity remained higher even on +1st day after the storms caused by MC (Fig. 8).

Fig. 9 shows that AMI mortality increased on -2nd, -1st, 0

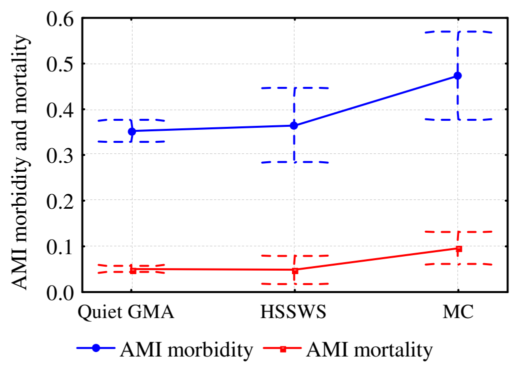


*Fig.7. GMA effect (estimated by the types of geomagnetic storms) on AMI morbidity and mortality (±95%CI).*

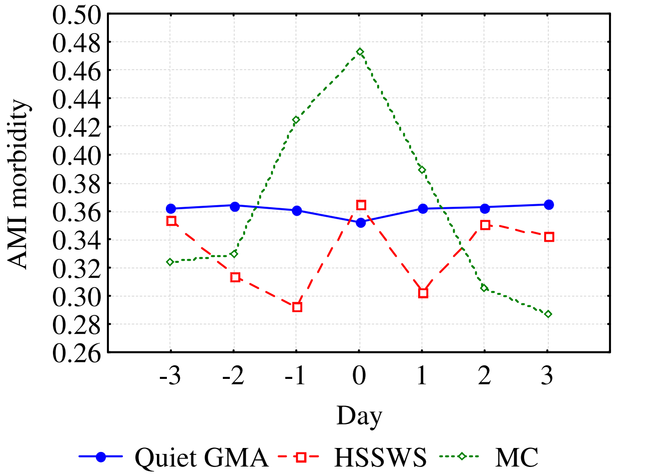


*Fig. 8. GMA effect (estimated by the types of storm) on AMI morbidity before, during and after geomagnetic storms.*

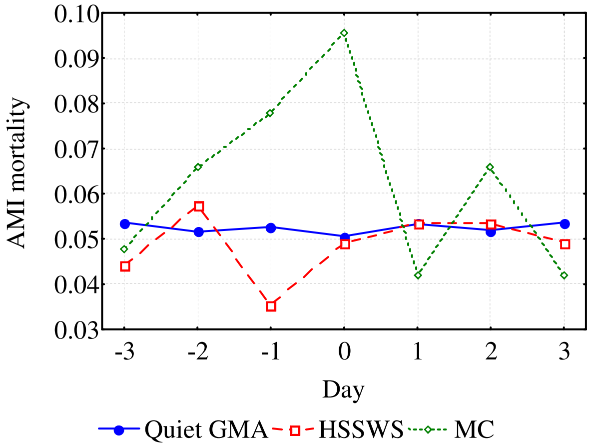


*Fig. 9. GMA effect (estimated by the type of storms) on AMI mortality before, during and after geomagnetic storms.*

and +2nd day of storms caused by MC.

## Discussion and conclusions

Results obtained in our research suggest that a correlation of different degree exists and the larger number of AMI morbidity and mortality often coincided with the most expressed geomagnetic variations. Statistically significant positive correlation was obtained between GMA indices and AMI morbidity and mortality for Sofia region for the period under consideration 1995 – 2004.

The current study revealed that AMI morbidity and mortality number were significantly increased on the days of high GMA levels and on the days before, during and after the main phase of geomagnetic storms with different intensities, estimated by GMA indices under consideration. The increased number of the considered cardiac events 1-2 days prior to GMA changes shows that probably precursors of geomagnetic storms accompanying geo-effective solar events provoke adverse cardio-vascular reactions. The increased number of AMI morbidity and mortality on the days after geomagnetic storms could be result of so called post-storm effect" [17].

There is a need of detailed and long-period investigations for establishing the reason for the decrease during severe storms (Fig. 3 and Fig. 4). This decrease is not statistically significant (see the error bars in Fig. 3 and Fig. 4), so this result may be due to the poor statistics. In our studies there were only 9 days with such high levels of GMA (according to Dst-index, see: Table II) 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. However, the result, at least regarding Dst-index, though not statistically significant, is relatively well pronounced, so it deserves further attention when a longer period with a larger number of AMI morbidity and mortality will be available. If proven real, this effect could be due to the different biophysical mechanisms “activated” by different levels of GMA, or to the different background of GMA indices.

It is seen from Fig. 5 that possibly the weaker influence (III GMA level) is like a classic “irritant”, which although weak is accompanied by 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 [18]. 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.

GMA variations mainly through their magnetic component [19] influence the central nervous system changing the frequency of spontaneous bioelectric activity of the cerebral cortex and subcortical structures [20]. Under prolonged impact of magnetic activity the functions of hypothalamus-hypophysis system, adrenal and sexual glands are changed [21], breathing frequency is suppressed, microcirculatory and blood coagulation system affected [22], arterial blood pressure is changed [23, 24, 25], informational and memory processes are influenced [20]. On a cellular level cell-division is affected, permeability of cell membranes is changed. From the cellular organelles mitochondria are especially sensitive to the impact of magnetic activity [26]. These entire fine and very sensitive and complicated processes probably participate in the transmission of GMA influence on physiological and patho-physiological processes in the human organism [27]. A positive correlation has been established between high GMA and sympatical nervous system in the process of investigation of the influence of GMA on human physiology [28]. It is possible that namely the sharp activation of the regulated processes by the vegetative nervous system set the pattern for increasing AMI number. A relation has been hypothesized between the rapid changes in the level of GMA and the cardiac arrhythmias [29].

The reaction of the human organism to the magnetic field variations in all of these references is in agreement with our finding that storms caused by MC are related to significant increase of AMI morbidity and mortality number in comparison to the storms caused by HSSWS. The main difference between the MC and HSSWS is the magnetic field. MCs by definition have high magnetic fields, and due to the magnetic field rotation often have prolonged periods of negative southward magnetic field component which leads to interaction with the Earth’s magnetic field, while their dynamic pressure can be enhanced or not, depending of the MC speed. HSSWS by definition have high dynamic pressure ($P \sim V^2$) due to their high speed, while their magnetic field is usually weak and fluctuating.

## Conclusions:

- Significant positive correlation between AMI morbidity and mortality and GMA indices was obtained for Sofia region for the period under consideration.
- There was an increment of AMI morbidity and mortality in Sofia region with GMA increase and on the days immediately before, during and after the main phase of geomagnetic storms with different intensity.
- Geomagnetic storms caused by MC were related with pronounced increase of AMI morbidity and mortality in comparison to storms driven by HSSWS and quiet GMA days for the period analyzed.
- Further studies for longer periods and medical data rows are required to confirm these results.

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